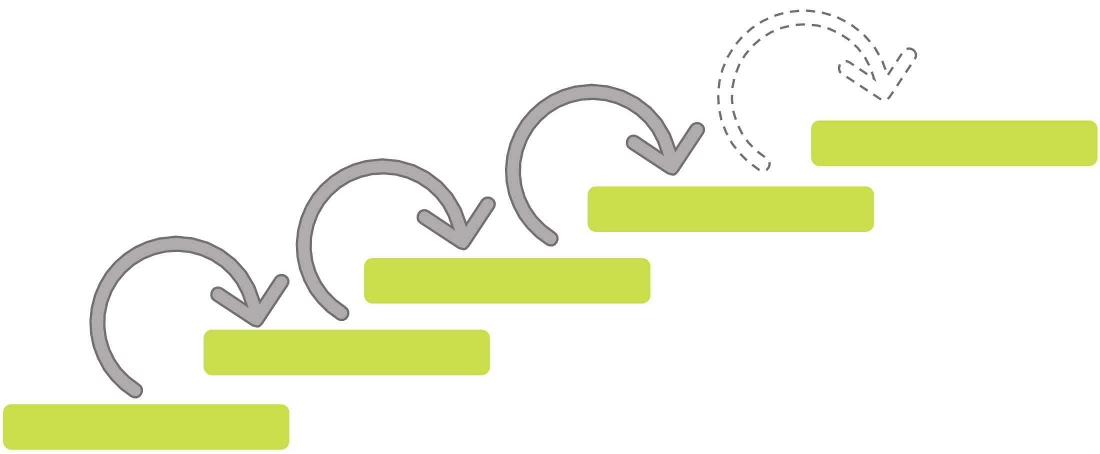
Timmerije
NEXT LEVEL IN PLASTICS

UNIVERSITY
OF TWENTE.

Transcending the Next Level in Plastics

"What improvements can be made in terms of efficiency to the lay-out of the production facility of Timmerije to transcend the next level in plastics?"

Monique Damveld
February, 2019



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Preface

Upon completion of this thesis, I am finishing the master Industrial Engineering and Management at the University of Twente, Enschede. During the last 2.5 years I have learned a lot within the Production and Logistics Management track. I have gained useful knowledge and work experience during many projects.

Here, I take the opportunity to thank those who made this thesis possible. First of all, I would like to thank dr. Peter Schuur for all the guidance and feedback directly from the start of this thesis. Our meetings are the basis for this research. Next, I would like to thank ir. Wieteke de Kogel, for the critical review of my work and the feedback with which I could improve the quality of this thesis.

I also would like to thank my colleagues from Timmerije, with which I shared the office for the last 5 months. During this research I had access to all information I needed, and I got an answer to every question I asked. I especially would like to thank my supervisor, Maarten Haagsma, for providing me with feedback on this thesis, and helping me with the formulation of this assignment.

I also might not forget to thank Bart Demkes, a fellow student who was my groupmate within every project we had to fulfill. Even during this research, we had discussions about the content of our research projects.

At last, I want to thank my friends and family for supporting me throughout the master and this research project. Without them, these 2.5 years would have felt a lot longer.

Monique Damveld,
04-02-2019

Management Summary

When the management team of Timmerije looks at the production facility and its warehouses, they have the *feeling* that the available space is limited. It is thereby wondered if they have the capabilities and space available to help customers growing. Therefore, the team is looking for ways to utilize the space more efficiently. They are hereby especially focusing on the facility lay-out, the warehouses and the internal logistics. The main research question is based on these findings:

"What improvements can be made in terms of efficiency to the lay-out of the production facility of Timmerije to transcend the next level in plastics?"

The Overall Process Efficiency (OPE) is thereby influenced by 3 process steps; the machines, the assembly, and the logistics. Before jumping to conclusions, the first task was to get an overview of all problems influencing these processes. Thereby, the research has been split into two subjects: the facility lay-out and the warehousing process. Problem clusters have been created for both subjects, from which the most important problems have been included within this research:

	Problems
Facility Lay-out	Locations of several departments.
	Non-regulated flow of materials and products.
	Forklifts and employees cross ways many times.
Warehousing Process	High number of relocations of materials, products and molds
	Non-optimal storage location of materials and products
	Limited warehousing space

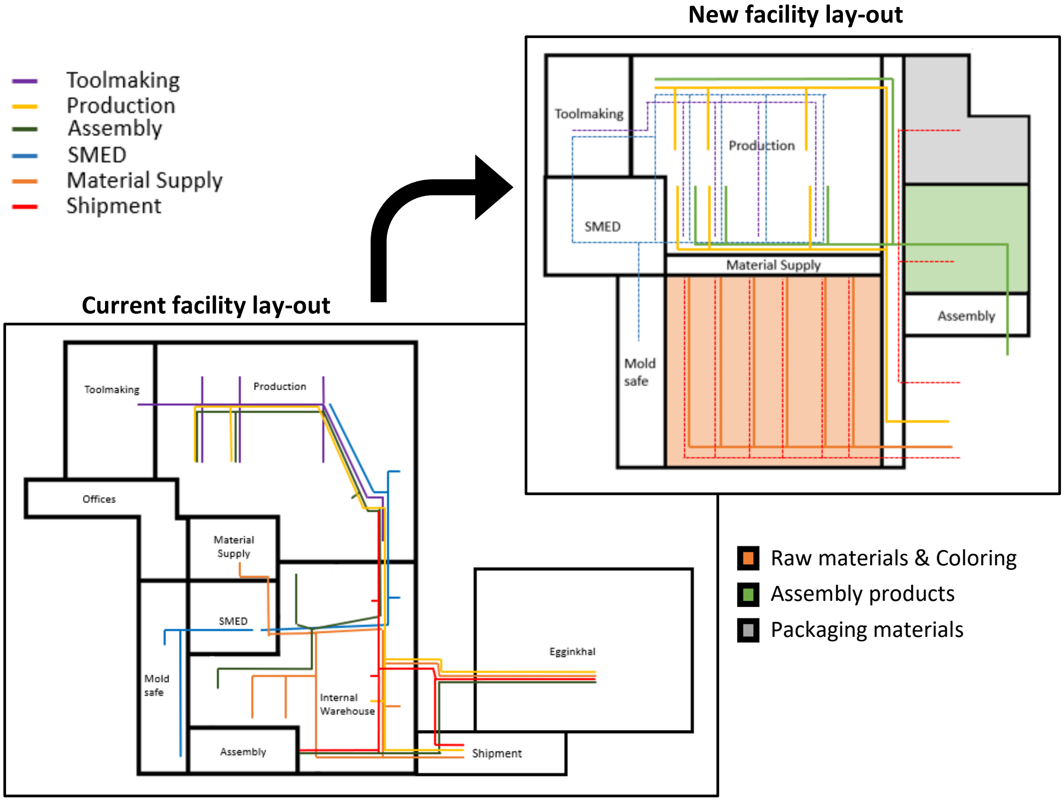
These problems have been quantified and qualified in the following way:

- By determining the transport routes of materials and products between departments, and within the warehouses.
- By determining the transportation frequency through the production department of both products and molds.
- Calculating the available workspace and the productivity level of the assembly department.

This showed that the total transportation distance per month is around 700 km. During these transportations, forklifts cross each other at many points. It was thereby also shown that the *feeling* of the management team is correct. Additional space is needed for the assembly department, and additional warehousing space is needed to store all materials and products.

During this research, 8 alternative lay-outs were developed in which it was tried to decrease the transportation distance and the number of crossings, to eventually increase the OPE. The development of these lay-outs has been done by means of the Systematic Lay-out Planning method. The space-relationship that was created as part of this method, showed that it is important to store the raw materials close to the material supply room. It thereby also showed that many relocations take place between the assembly department and various warehousing locations. The location of the assembly department therefore has a great influence on the transportation distance and the number of crossings. For every alternative, the reduction in transportation distance was determined and it showed that it is possible to reduce the transportation distance by 32% (from 700 km to 432 km per month).

Whereas the transportation distance is not the only factor to be taken into account when looking for an alternative solution, the alternatives have been compared to each other by means of the Analytic Hierarchy Process (AHP). Besides the transportation distance, the alternatives were scored on fire-safety level, the quality of products, costs, soft factors and the ability to expand in the future. It showed, that the fire-safety is the most important factor to be taken into account. From this method it was concluded that the lay-out resulting in the highest decrease in transportation time, also obtained the highest priority within the AHP method. Baring in mind the main research question, the following change in lay-out is recommended to Timmerije.



It can be seen that materials of the same type are located together, which causes the transportation distance to decrease. The new lay-out offers, next to a decrease in transportation distance, also other factors positively influencing the OPE.

1. Molds are no longer transported throughout the entire production area to get to the toolmaking department. This causes the number of crossings to decrease, thereby reducing the waiting time and increasing the safety level.
2. Workspace of assembly department is increased, which positively influences the repetitiveness of tasks and thereby the productivity of this department. It is then also possible to have every assembly employee work in-house.
3. A flow is created between the production area and the assembly department, which prevents materials, molds and products to get across each other during transport. This increases the safety level, and reduces the waiting time.

A roadmap explaining the change in lay-out is given below. The new lay-out is thereby obtained during the changes recommended for the mid-term period. The long-term focuses on an enlargement of the production area, which is not of interest for this research directly.

Short-term (1 – 2 years):

- Place the raw materials close to the material supply room.
- Store all finished products directly at an external warehouse.

In this way, the total transportation distance is reduced by 16%. Whereas there is not enough space available to store everything on-site, it is chosen to store the materials and assembly intermediate stock on-site, and the finished products at an external location. In this way all materials can be located close to the department in which they are needed, and the risk for damage is decreased.

Mid-term (3- 5 years):

- Replace the Egginkhal by a new warehouse in which the packaging materials and the assembly intermediate stock are stored.
- Create a new assembly department next to this warehouse.
- Connect the toolmaking department, SMED-department, and production area to each other.
- Replace the offices.

With these changes it is possible to reduce the total transportation distance by another 16% to 32% in total. Whereas the Egginkhal is not fire-resistant, and the fire-safety is from great importance, it is recommended to replace the Egginkhal. This also causes the flow of assembly materials to be shortened, and forklifts cross ways less. As a result of the connection between toolmaking, SMED and production area, the number of mold relocations throughout the production area is decreased. However, the offices then need to be relocated.

Long-term (>5 year):

- Expand the production area
- Create new toolmaking and SMED department.

For the long-term the production area can be expanded to the right side of the new warehouse created during the mid-term period. The assembly department will then be located in the middle of the building, so that it can be reached from both production areas, thereby limiting the number of crossings and transportation time. To avoid large transportation distances for the molds, it is recommended to also built an additional toolmaking department, and SMED to the right side of the new production area.

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Abbreviations and Definitions

<u>List of Abbreviations:</u>

AHP: Analytic Hierarchy Process
DEA: Data Envelopment Analysis
ERP: Enterprise Resource Planning
KPI: Key Performance Indicator
MAUT: Multi-Attribute-Utility-Theory
MCDM: Multi-Criteria-Decision-Making
OEE: Overall Equipment Effectiveness
OPE: Overall Process Efficiency
SMED: Single-Minute-Exchange-of-Dies

<u>List of Definitions:</u>

Overall **Process** Efficiency: the process within this research starts at the moment the raw materials are delivered to the production facility, and ends at the moment the final product leaves the production facility.

OEE: to measure the effectiveness of the machines; it thereby depends on the quality efficiency, relative performance and the machine availability.

Quality efficiency: focuses on the number of products that do not meet the requirements.
Relative performance: includes the waiting time for products and the productivity of the machine.
Machine availability: includes all events that stop planned production.

SMED-department: the employees at the SMED-department prepare the mold for production, and they gather all other materials that are needed to make a quick change of molds on the machine possible.

Toolmaking-department: is responsible for the repair, maintenance and preparation of molds.

Effectiveness: doing the right things

Efficiency: doing things right

Mold repairs: include the molds for which maintenance, repair or preparation is needed.

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1. Introduction

1.1. Introduction

This graduation thesis marks the end of the master Industrial Engineering and Management at the University of Twente, Enschede. To finalize the “Production and Logistics Management” track, research has been conducted into the internal logistics and warehousing processes at Timmerije B.V., Noordijk. To get an impression of the company itself this chapter continues with a company description, wherein the supply chain process, the production process and the warehousing process are explained.

1.2. Company introduction

Timmerije is a fast-growing injection molding specialist located in Noordijk, that was founded already in the year 1932. After a start in the agricultural sector, the business was switched into the molding of products. At first, the molds were designed externally, but from the year 1970, they have been designed in-house to create the perfect mold for the customers. In 2010, Timmerije has become part of Hydratec Industries NV, which is a worldwide specialist in industrial systems and components. Its focus lies on the agri- and food market, and the automotive- and tech markets. Their activities are thereby split into two different branches; the agri- and food systems, and the plastic components. Next to Timmerije, another company is operating in the plastic components branch, which is Helvoet. An overview of the organizational structure can be found in Figure 1.

Figure 1 Organizational structure of Timmerije

The markets in which Timmerije operates, are given to you in Figure 2. In this figure it can be seen that most of the products are made for customers’ internal transportation services. For all customers it is from great importance that their products are delivered in time, and following their set of specifications. Examples of products that are produced at Timmerije, are given in Figure 3. This figure also shows some customers of Timmerije.

A market that is not shown within Figure 2, is the market for sustainable products. Over the last years, Timmerije created a 100% biodegradable biopolymer which is strengthened by the natural fiber “Miscanthus”. In the year 2017, Timmerije was granted the “Inspiration and Innovation” award, for the development of an innovative product that was created on the basis of this biopolymer.

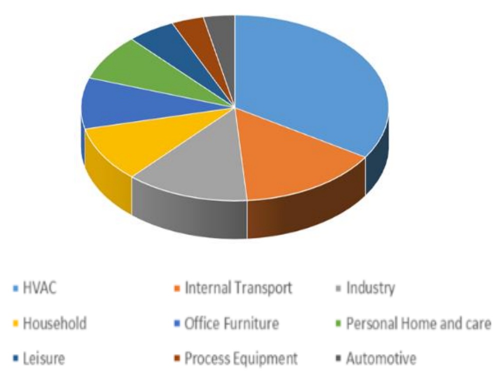

Figure 2 Market mix

Figure 3 Customers and product example

At Timmerije, everything is possible or otherwise made possible. With all the capabilities that Timmerije has in-house, the possibilities are endless. From the moment a new project starts, employees from different departments work together in cross-functional teams. The product is developed in compliance with all parties involved, to avoid late changes to the product, and to ensure that the best resources are used.

Other important key values regarding the customer can be found in Figure 4. Next to these key values, Timmerije has developed some internal Key Performance Indicators (KPIs). With regard to the customer, the KPI – Delivery Performance is from great importance. Following this KPI, Timmerije wants to deliver the product in time, at the lowest possible costs. Another important KPI that takes into account the customers, is the number of complaints received each month. Next to these KPIs, the quality standard for products within the automotive industry is high. For these customer, Timmerije is qualified with the IATF 16949 certificate.

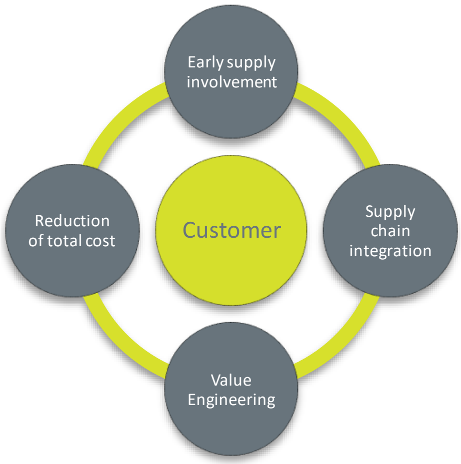

Figure 4 Customer key values

The customers can thereby choose whether they want their product to be produced made-to-stock (MTS) or made-to-order (MTO). The difference between MTS and MTO; following the MTO procedure, production does not begin until a customer order is placed, whereas in case the customer wants to have the product right away, the MTS procedure is followed. Following this last procedure, Timmerije bases the stock level on the forecasted demand (N. Zaerpour, April 2008).

Within the following sections, a more detailed description of Timmerije is provided. At first, in section 1.2.1., an insight into the entire supply chain is given. This section is added, to provide you with an overview of all the different parties involved. Later on, in sections 1.2.2. and 1.2.3., the value adding processes of Timmerije are explained in general. Section 1.2. is about the production process, and in here it is explained what steps a product follows from raw material to end-product. Thereafter, in section 1.3., it is explained what the warehousing process looks like. These last two sections are important, while they are discussed in depth within later chapters.

1.2.1. Supply Chain

The introduction at the start of this chapter showed that the customer is an important factor contributing to the success of Timmerije. Timmerije designs and improves the products they make, by working together with the customer. After the design has finished, Timmerije takes care of the entire supply chain process. The process thereby continues with the design of the mold, which is eventually manufactured in either the Netherlands, South-Europe or Asia. Even though the mold is created by Timmerije and kept in stock there, the customer will always be the owner of the mold. In case a mold breaks down, or if maintenance should be performed, Timmerije has the abilities to repair or maintain it in-house.

The mold is always designed to fit to a specific type of machine. So, after arrival of the mold at Timmerije, this type of machine is prepared for the first test run. At the time the customer has agreed on the test products, production will start. After production, the production process can be continued in two ways. In case the end-product is produced during production it is stored into one of the warehouses, or it is directly shipped towards the customer. In case further assembly is needed, the products is stored, from where it is picked in case it is needed at the assembly department. The employees working in this department all have a mental disability. To make it possible for these employees to work, they are guided by a skilled professional who lets them work individually or in small groups.

When production has finished and the end product is obtained, the product is usually placed into one of the warehouses of Timmerije. In total, there are 4 warehouses in which the product can be stored. One of them is located next to the production department (the Egginkhal), while another warehouse is rented in Neede. A third warehouse is rented in Noordijk, the so-called Henninkweg warehouse. This warehouse is used for the storage of raw materials and products that should be kept in stock for the customer for a longer period of time. The fourth warehouse is the internal warehouse, which is located inside the production facility.

Transport from the production location to the warehouse in Neede is done by the aim of trailers. When production has finished, the products (stored on pallets) are directly stored in these trailers. Once the trailer is fully packed, it will leave to the warehouse in Neede. Transportation of raw materials from the Henninkweg to the production location is done by means of a small van. This van is also used to transport small amounts of finished products from the production location to Neede, or the other way round.

Figure 5 Neede warehouse

In Figure 5 it can be seen that different packaging materials are used. Even though most of the products end up in a cardboard box, there are also products that are transported within crates or pallet boxes. These packaging materials are delivered to Timmerije by the customer itself. All other packaging material is ordered from external suppliers.

Other important parties involved within the supply chain process, are the suppliers of raw materials and coloring materials. The amount of raw materials needed, is based on the forecasted demand, whereby the inventory on-hand is monitored continuously. This is needed, while the waiting time for several materials is higher than a month.

This explains why communication, between the different parties involved, is very important. Within the next sub-section, it is explained where the customers and suppliers of raw materials and coloring materials come into the production process. Within sub-section 1.2.3. it will be seen where the suppliers of packaging materials are needed.

1.2.2. Production process

The previous sub-section explained that both the raw materials and coloring materials suppliers and the customers are important throughout the production process. In the first place, the customers are important for the planning of orders. Depending on the agreements that were made with the customer, the planning is based either on the forecasted demand or an incoming customer order. When the production run is planned, the corresponding machine is prepared for production. At first, all materials needed to adjust the machine are collected by the SMED department. In the meantime, the raw materials are collected from storage, wherefrom they are brought to the material supply room. There, they are placed into one of the drying bins that are connected to the molding machines by means of pipelines. At the moment both material and machine are ready, production starts.

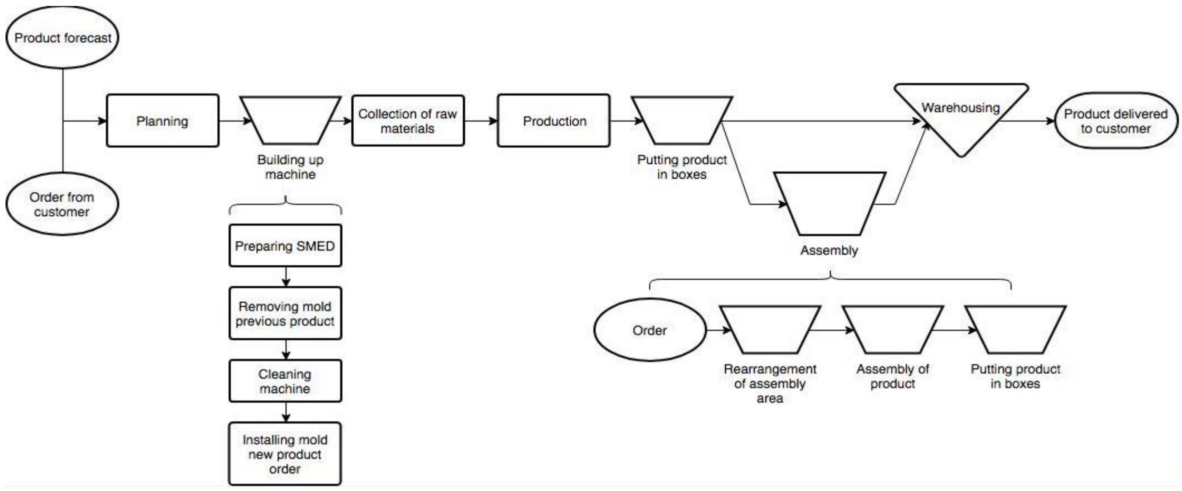

Figure 6 Process flow diagram; from raw material to product

After production, the product is placed into the packaging material that is waiting next to the machine. This operation is performed manually, so that the employee can check the quality of the product. In case a product is not conform the set of requirements, production can directly be stopped. Another reason to stop production, is when the packaging material is not available. While the packaging material is seen as part of the product quality, it is from great importance to continuously monitor the inventory levels of all packaging materials. Communication with the suppliers of these materials is thereby needed.

If all products are conform the requirements, the box of products is transported to the entrance of the production hall. There, the box is placed upon a pallet. At the moment the pallet is fully packed, it is transported to either the assembly department, or to one of the warehousing locations. In case assembly is needed, an assembly order ticket will (a week before assembly starts) be sent to the assembly department. At the end of the week, the workplaces within the assembly department are then rearranged according to the orders for the next week. When assembly has finished, the products are placed into the same packaging material as in which they entered. From the assembly department, these boxes are then transported to one of the warehouses. From there on, they will eventually be transported towards the customer. This entire warehousing process is explained with more detail within the next section.

1.2.3. Warehousing

The previous section already explained that after production, the product can follow two different paths within the warehouses. Whereas these warehouses are also used for the storage of packaging materials, coloring materials and raw materials, these materials all follow the same pathways. Within this sub-section, all the different paths are explained into depth. At the end of this section, it should be clear what path is followed by the different materials.

Within Figure 7 the raw materials, coloring materials and packaging materials are grouped under "Materials". From this figure it can be seen that these materials are stored within the Egginkhal, the internal warehouse, or at the Henninkweg warehouse. From there, they are transported towards the production area and they will end up in, or around the finished product. As mentioned before, the finished product then has two paths to follow that are explained next.

The first path for the product to follow, is the one in which further assembly of the product is needed. After production, the pallet with products is then stored at the Egginkhal, or at the internal warehouse close to the assembly department. At the moment the assembly department has an order for this product, it will be picked and brought into the assembly area. This process is represented by the green colored lines in Figure 7. At the assembly department, the products are taken from the pallet on one side, and after assembly they are placed back into the same type of box on the other side again. When the "new" pallet is fully packed, this pallet is transported towards one of the warehouses or it is directly shipped towards the customer.

The other path for the product to follow, is the one in which no assembly is needed. Then, the pallet is transported towards Neede or the Egginkhal, from where it is eventually shipped to the customer. From there the products are transported towards the customer.

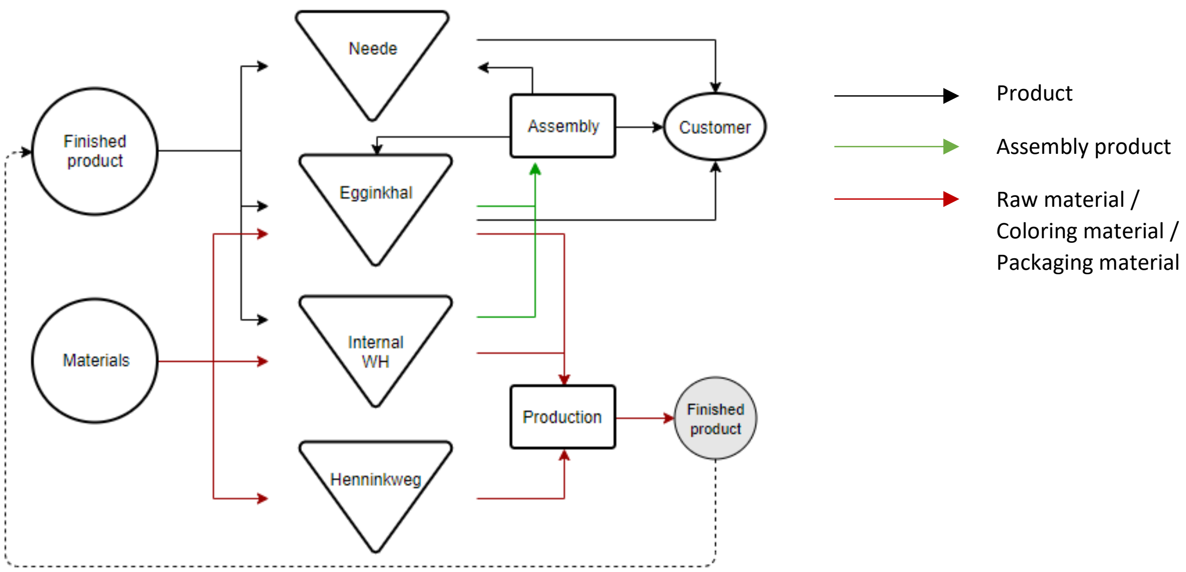

Figure 7 Process flow diagram of materials and products between warehouses

1.3. Chapter overview

This chapter started with a general introduction about Timmerije. An insight into the organizational structure, and product markets was given. Thereafter, the focus shifted towards the parties involved within the entire supply chain. These parties all contribute to the processes that were explained within sub-sections 1.2. and 1.3. From these sections it should now be clear what the production process, and the warehousing process looks like.

Now that it is clear what the company Timmerije looks like, it is time to focus on the research that has been executed; this is the subject of the next chapter. In here, it is explained what questions the management team of Timmerije had at the start of this research. This chapter also provides you with the research framework on which the remaining part of this thesis is build.

2. Research framework

The aim of this chapter is to explain the research as it has been conducted and to provide a framework for the remaining part of this thesis. Now that the production and warehousing processes from Timmerije are known, it is time to zoom in on these processes. When the management team of Timmerije thinks of the current facility lay-out and its warehousing processes, they have the *feeling* that the available space is limited. Thereby, visiting customers often ask if Timmerije has the capabilities and space available to keep delivering their products as promised. These customers hereby especially focus on future developments and growth of their own companies. They want to know if Timmerije has the possibilities and capabilities to help them growing. When taking a look at the future, Timmerije itself has put its focus on becoming the 'Next Level in Plastics'. This new level can only be reached *together* with the customer. The customer needs to trust the expertise and experience of Timmerije, before placing new orders. This trust is to be found back in the turnover forecast for the next years; stable growth of the turnover is hereby foreseen.

Recall the delivery performance, and the customer key values from the previous chapter. To keep (or improve) these values, the production process should be as efficient as possible. Limited space thereby has a negative impact on the production process, and it should be verified whether the *feeling of limited space* is actually true. Conversations with the team showed that this feeling is mostly created by a lack of knowledge regarding the internal logistics at Timmerije. The goal of this research is therefore to provide the management of Timmerije with information about their current internal logistics, and to provide them with a theoretical background and explanation about how they should handle the logistic and warehousing processes in the future. In this way, Timmerije is prepared for a growth in demand and they will be able to produce conform the customer's expectations.

This chapter continues with an explanation regarding the research framework. At first, the main research question is defined, which is followed by several sub-questions that were developed to answer the main question. Together, they form the basis for this research. After the questions, the scope of this research is explained. This explanation is followed by a sub-section explaining the deliverables. A conclusion regarding the research framework is added at the end of this chapter.

2.1. Research questions

Whereas the performance of the internal logistics are a result of the facility lay-out, the following main question has been defined:

"What improvements can be made in terms of efficiency to the lay-out of the production facility of Timmerije to transcend the next level in plastics?"

To answer this question, it should first become clear what the current situation exactly is. Thereafter, the bottlenecks rising from the current processes should be shown and explained to see where possibilities for improvements are. At the end, this question is to be answered by providing examples of improvements that could be made. These steps are best represented by the sub-questions given below. Together, these questions are the framework of this research.

1. What is the current situation?

The answer to this question can be found in chapter 3. This chapter is named “Factors of influence” while within this chapter all factors that influence the production process are given. A framework for this chapter is given by the Overall Process Efficiency (OPE). The OPE is split into 3 different process steps; machines, assembly and logistics. These steps are explained by means of 3 different measures. The Overall Equipment Effectiveness (OEE) gives an insight into the process step machines. This section is followed by the productivity of the assembly department. Whereas the focus of this thesis is on the facility lay-out, the last process step – Logistics – is explained in depth. The perceived problems regarding this process step are thereby split into the two problem clusters; one regarding the facility lay-out and one regarding the warehousing process. The chapter ends with a conclusion in which it is explained which factors are taken into account for further research, and which factors are left out of further research.

2. What influence does the current facility lay-out have on the efficiency of the production process?

Whereas the previous question shows the *perceived* problems regarding the facility lay-out and the warehousing process, this question zooms in to the facility lay-out only. Chapter 4 starts with an explanation regarding the current facility lay-out. By means of a spaghetti diagram, the transportations of all departments are explained. Thereafter, the location of the SMED & Toolmaking, production department and the material supply room are handled with separately. Within these sections it is quantified and qualified whether the *perceived* problems regarding these departments are also the actual problems.

3. What potential does the current warehousing process have?

This question is handled with in chapter 5. The problem cluster regarding the warehousing process in chapter 1, indicates that several problems are resulting from the current way of warehousing. This sub-question therefore focuses on this process, and it shows the potential that this process has. A closer look is thereby taken into the transportation distances, and the available warehousing space. This information is used as input for the Systematic Lay-out Planning method in chapter 6.

4. What alternatives can be given to improve the efficiency?

Whereas questions 2 and 3 showed that there are several problems regarding the facility lay-out and the warehousing process; this question focuses on ways to improve these processes. This chapter starts with an explanation regarding several lay-out improvement methods. It is explained here, why the Systematic Lay-out Planning (SLP) method was chosen. Within the sub-sections, the different steps of the SLP method are followed, and at the end of this method different lay-out alternatives are given.

5. What are the advantages and disadvantages related to the developed alternatives?

This question continues with the lay-out alternatives that were developed in the previous question. Within chapter 7 a look is taken into the advantages and disadvantages related to the developed alternatives. Whereas there are multiple criteria to be taken into account when choosing for the best alternative, the Analytic Hierarchy Process (AHP) is introduced here. It is a method which makes pairwise comparisons of the alternatives possible.

6. Regarding improving the process efficiency; what would be the best alternative?

Whereas the last step of the AHP method is to make a final decision, this answer is to be found at the end of chapter 7. Chapter 8 then concludes this research by providing the management team of Timmerije with an advice regarding the best alternative lay-out.

The aim of chapter 8 is to provide an answer to the main research question, and within this chapter it is explained what improvements to the current facility lay-out can be made, to eventually improve the entire production process efficiency. It thereby also shows a roadmap for the implementation of the improvements.

2.2. Scope

By looking at the way the questions are build up, it can be seen that this thesis first focuses on the current lay-out and the problems that arise from this. Next to this, the current warehousing processes are taken into account. When the current situation is known, a look at the future is taken to see where improvements are needed. Problems that do not relate to the facility lay-out, the warehousing processes or available space are outside the scope of this research.

2.3. Deliverables

This thesis has its focus on providing information about the performance of the current logistics inside the production facility and warehousing. This is done by means of the following:

1. Problem clusters; regarding the facility lay-out and the warehousing process.
2. Spaghetti diagram; to show the routes of every department.
3. Calculation; of transport distances and storage areas.
4. Systematic Lay-out Planning method; for the development of lay-out alternatives.
5. Analytic Hierarch Process; to rank the lay-out alternatives.
6. An advice; showing the possible improvements that could be made to the lay-out and to show the strengths and weaknesses of the current facility lay-out.
7. Discussion; to have a look back at the research that has been performed.

2.4. Conclusion

At the start of this chapter, the *feeling* of limited space by the management of Timmerije has been explained, and research into this subject is considered to be important by them. Their feeling has been put into a main question, which has been split into several sub-questions.

It has been shown that multiple methods are needed to:

1. Give an insight into the current situation
2. Provide an advice regarding possible improvements.

The focus in the remaining part of this thesis is on the facility lay-out and the warehousing processes. At the end of this research, it is known whether the *feeling* of limited space by the management team of Timmerije is correct. They then also know what their internal logistics are, and how the facility lay-out could be improved to eventually increase the efficiency of processing to keep fulfilling the customers' demand.

3. Factors of influence

Question 1: "What is the current situation?"

The main research question, as given in the previous chapter, showed that the efficiency at Timmerije could be improved. To eventually give an answer to this main question, it should first be clear what the current situation is. The aim of this chapter is therefore to provide an overview of the current situation. The current situation is thereby explained by means of the Overall Process Efficiency (OPE). "Process" is thereby best explained as from the entrance of raw materials at the production facility, until the moment the final product leaves the production facility. Recall the process flow diagram from chapter 1 for a description of this process. An overview of all process steps contributing to the OPE are given within Figure 8. This figure also shows how the efficiency of every process step is measured, and what factors are contributing to this measurement. The following 3 sub-sections handle with the process steps (machines, assembly, logistics) separately. Within these sections it is described what problems are influencing the efficiency of that specific step. The last sub-section of this chapter then concludes by providing an overview of all problems that are included for further research, and the problems that will be excluded from this research.

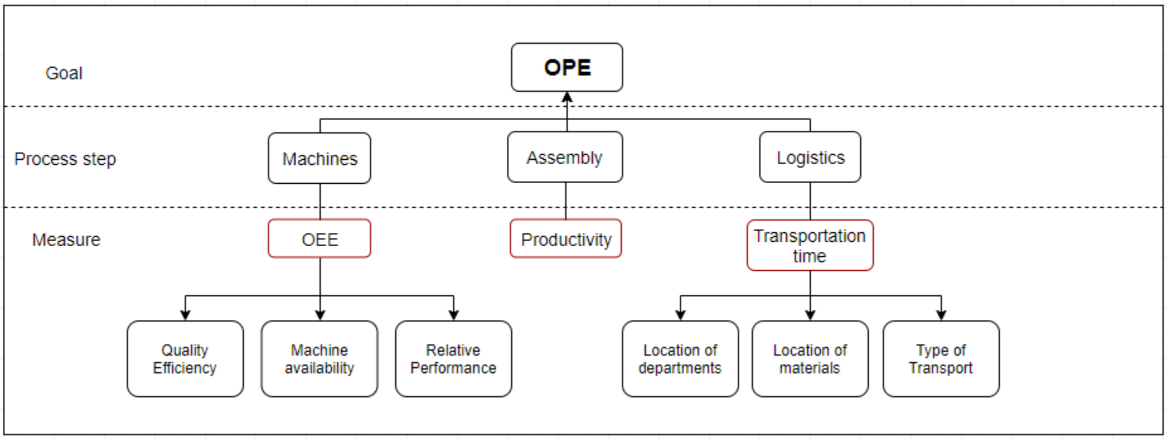

Figure 8 Overall Process Efficiency (OPE) measures and factors of influence

3.1. Machines

The machines are the first process step taken into account for the OPE. The effectiveness of the machines is usually measured by the Overall Equipment Effective (OEE). Where effectiveness focuses on doing the right things, efficiency focuses on doing things right. (Goh, 2013). Part of the factors within the OEE are however taking into account the process efficiency (like quality *efficiency* within Figure 8). These factors are important when determining the OPE. Therefore, within this sub-section it is explained how the OEE is build up, and which factors will be taken into account as a factor of influence on the OPE.

The OEE is usually build up from 3 main factors; the quality efficiency, the machine availability and the relative performance. The quality efficiency focuses on identifying the time that was wasted by producing a product that does not meet the quality standards (Vorne, 2002-2018). This includes products for which rework is needed. All events that stop planned production are combined into the machine availability. At Timmerije this factor is influenced by the time the facility is closed, the set-up time of machines, time taken for preventive maintenance and tests taking place. The last factor, the relative performance, is influenced by the waiting time for products and the productivity of the machine.

The OEE at Timmerije is calculated in the following way:

$$OEE = \frac{Net\ operating\ time}{Gross\ operating\ time}$$

The gross operating time includes all factors contributing to the **machine availability**, and is calculated as follows:

$$Gross = Total\ hours - Production\ closed - Setup\ time - Preventive\ Maintenance - Tests$$

Another way of calculating the gross operating time is by taking the sum of the following factors:

1. Production time
2. Quality issues
3. Malfunctioning
4. Waiting time

These factors all contribute to either the **relative performance** or the **quality efficiency**. The net operating time is part of the production time, and is calculated in the following way:

$$Net\ operating\ time = Production\ time - cycle\ difference - waste$$

The following sub-sections zoom in on the machine availability, the quality efficiency and the relative performance separately. Each section starts with a short explanation regarding the main factor, which is followed by an explanation regarding the influence of the current situation on the factor. Thereafter it is explained whether (parts of) the main factor is taken into account during this research.

3.1.1. Machine availability

The first factor contributing to the OEE is the machine availability. This is a factor that takes into account all events that stop planned production (Vorne, 2002-2018). As already stated before, Timmerije assigns the following parameters to this factor:

- Time production facility is closed
- Set-up time of machines
- Planned preventive maintenance
- Planned tests

At Timmerije, the machine set-up time is considered to be one of the most important parameters contributing to this factor. In case the set-up time strongly deviates from the planned set-up time, the efficiency of the process is influenced. At Timmerije, the set-up time starts at the moment the current mold is removed from the molding machine. It then stops at the moment the quality control employee states that the obtained product is conform the requirements. From all machine set-ups that take place, the set-up time is compared with the set-up time listed on the Bill of Material (BOM). Next to that, the actual start time of the set-up is compared with the planned start time. In case differences exist, this set-up is discussed during the morning meeting in which a multi-disciplinary team takes place.

Next to that the set-up time could be too long, it can also be shorter than stated in the BOM. If this time is reasonably lower, this will be discussed during the morning meeting as well. During this meeting it is tried to find out where the time difference is coming from, to make continuous improvements to this process possible. One explanation regarding the differences might be that the set-up time, as defined during the test phase, has become different over time.

Another problem regarding the set-up time is seen in the number of employees skilled to perform the set-up; this number is currently too low. New employees are trained, but it takes time for them to learn. With the training of employees for this job, new employees are needed for their jobs. Timmerije is working on this, but the demand for employees is currently high within the entire market.

The set-up times as they currently are, might be improved. To do so, a closer look should then be taken at the performance of the set-up. By recording the different steps, information about the current set-up is obtained. It is then possible to search for improvements that might decrease the set-up time. The lack of information about the set-up processes is best explained as a knowledge problem.

"A knowledge problem is a description of the research population, the variables and, if necessary, the relations that need to be investigated." (Hans Heerkens, 2017)

Research would involve gathering information about the actual set-up time and the set-up time as stated on the BOM. Next to that the set-up time is considered to be a knowledge problem, it is something that does not relate to the facility lay-out or the warehousing process. Therefore, the set-up time is considered to be out of scope for this research. The other factors that are part of the machine availability are not of interest for this research as well. The "Test" factor is not of interest, while the number of tests taking place each year is relatively low. The "Preventive Maintenance" factor is also out of scope, while it is a factor that is planned for each year. In this way, all factors contributing to the machine availability are not of interest for this research. That is why the machine availability is not taken into account in the remaining part of this research.

3.1.2. Quality efficiency

Another factor influencing the OEE is the quality efficiency. This factor takes into account manufactured parts that do not meet quality standards, including parts that need rework (Vorne, 2002-2018). Timmerije has developed a Key Performance Indicator (KPI) to measure the customer satisfaction regarding the quality. The number of complaints from customers are counted, and divided by the number of weeks within that month. The goal has been set to have a maximum of 2 complaints per week. In the year 2018, this maximum number of complaints has not been exceeded, and the quality check before transportation of the product is therefore assumed to be performed well.

However, this does not mean that the quality of all products is conform the requirements. At the moment the product quality is not met, this will result in an internal 'complaint'. These complaints are monitored, to figure out what has happened during production. When looking at the months May, June and July from the year 2018 , it can be seen that most of the internal complaints are caused by the occurrence of a burr or damage to the product (63%). In case a burr is detected, the molding machine will be stopped directly and the technical service will be called to have a look at the machine to solve this. If possible, the products with burr or damage are put for rework, where after they will be sent to the customer. In case rework is not possible, these products are considered to be waste. It is then tried to recycle these products by grinding them.

To monitor the amount of waste, the KPI waste has been developed. This parameter represents the amount of waste produced in one month. During the morning meeting, as explained in section 3.1.1., a discussion about the amount of waste produced on the previous day, is held. In this way this parameter is continuously monitored. Over the last years this parameter has decreased to 5.8% over the year 2018. This shows, that by continuously monitoring the amount of waste, great improvements could be obtained. While the amount of waste has already been improved largely, and Timmerije has a great focus on this, the quality efficiency parameter is not of further interest for this research.

3.1.3. Relative performance

Now that the machine availability and quality efficiency are both considered to fall outside the scope of this research, the relative performance is the only factor of influence left. The relative performance takes into account anything that causes the manufacturing process to run at less than the maximum possible speed (Vorne, 2002-2018). As already stated before, at Timmerije this factor is influenced by the waiting time and the productivity of the machine. The waiting time indicates a factor that could be used to improve the OPE. Sometimes the machine has to wait for raw materials or packaging materials, and the machine is stopped until these materials arrive at the machine again. While the transport of materials falls under the logistic processes, this factor is taken into account within sub-section 3.3. Logistics. The relative performance as for the machines is thereby left out of consideration.

3.1.4. Conclusion

Sub-section 3.1.1. till 3.1.3. showed that there are several problems regarding the machine availability, quality efficiency and the relative performance. However, none of these factors will be taken into account for further research. The factors contributing to the machine availability are not relevant, while they are either a knowledge problem, or it is a factor that is planned for each year. While the quality efficiency is already monitored closely, and great improvements of this factor are already made, this factor is left out of further research also. Whereas the relative performance solely focuses on the effectiveness of the machine, this factor is also taken out of the research.

3.2. Assembly

The second process step that is seen to have an influence on the OPE is the assembly of products. The measurement used to indicate the efficiency of this process, is the productivity of the assembly department. Over the last years, the number of order tickets for this department has increased from 7 to 15 per week. Due to this increase in workload, additional space has been created and part of the assembly employees are now working at the warehousing location in Neede while there is not enough space for them to work on-site. When looking at this department, it shows that around 40 pallets of one specific product are transported in- and out of this department every day. Furthermore, at the end of the week the lay-out of the assembly department needs to be changed, to create assembly lines within the assembly department. This supports the *feeling* of limited space which is felt by the management team of Timmerije. Therefore within the next sub-section (3.2.1.) a description of this department is given, which is followed by sub-section 3.3.2. in which the productivity of this department is calculated.

3.2.1. Lay-out of assembly department

The lay-out of the assembly department is given in Figure 9 and Figure 10. While some of the assembly processes are (almost) always taking place, it is tried to create a flow in these assembly steps. The tables in the middle of level 0 are normally used for these processes. At these tables, employees are working along both sides of the table. Two persons are standing at the short ends to (un)pack the products from / into the packaging box. At the long ends, it is possible to have 12 employees assembling the same product. At times these lines are not used for the assembly of 1 product, those places are used to assemble other / more products. One of the busiest places within this department, is the location of the printers. These printers are constantly in use, and they are responsible for a great part of the transportations taking place within this department. It can as well be seen that it is rather crowded in case at least 40 pallets are transported in and out of this department.

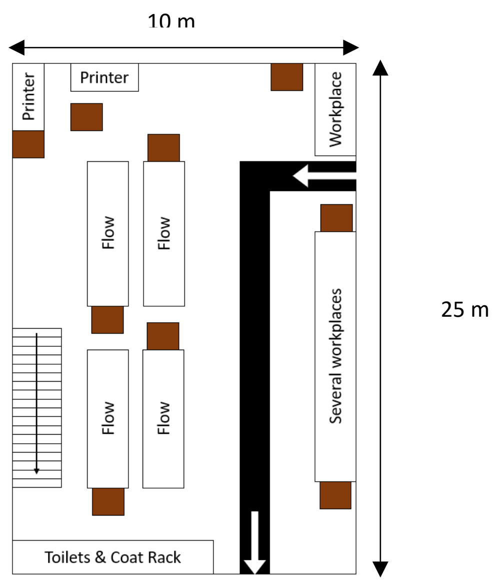

Figure 9 Lay-out Assembly Department Level 0

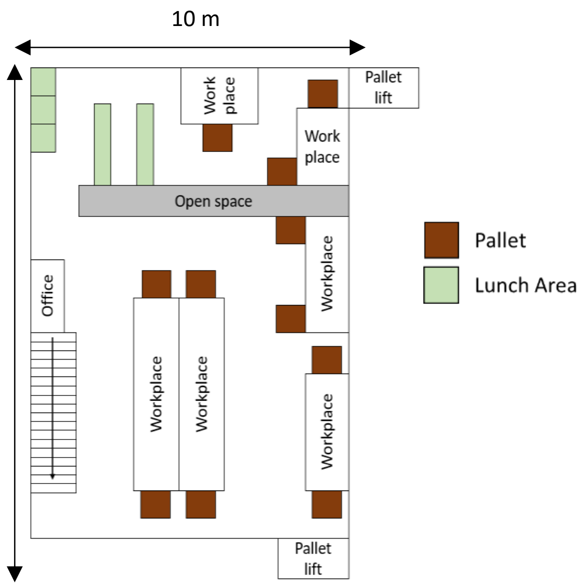

Figure 10 Lay-out Assembly Department Level 1

Pallet lifts are used to get pallets at level 1. Two of them are needed, while the first level does not cover the entire lower ground. The grey part within Figure 10 illustrates the open space. The long, small tables at the top of this figure represent the lunching area. While some of the employees are physically not capable of walking long distances and / or walking up the stairs, they have their own canteen here. Also, the other canteen does not have enough space and chairs to house all these employees at the same time. Most of the tables at level 1 are rearranged every week to accommodate for the different assembly processes.

The surface area of both levels together is equal to 460 m^2. Table 2 provides an overview of all factors to be subtracted from the available space to find the available workspace for the employees. By doing so, it is seen that there is only 287 m2 left. Currently, around 39 employees are working within this area. When looking at Table 1 it can be seen that 234 m^2 is required as surface area for this number of employees. (Winter, sd) This does not include aisles for walking and transportation of materials. The difference between available space and required space is then 50 m^2 only. This space is currently used for aisles. At this moment, 6 other assembly employees are working at the warehouse located in Neede. When adding these employees to the facility itself, around 270 m^2 is at least needed to have workspace for all employees together.

Next to that the productivity of this department is important, the number of movements in- and out of this department are considered to be important also. The number of movements are again based on the relocations data as provided by Timmerije. The results are shown in Table 3. Within this table, a difference is made between the products / materials flowing from and to this department. The flow of products out of this department only takes place during the day; between 08.00 and 16.30. This means that every hour, 13 pallets are transported out of this department. Therefore, a pallet leaves this department every 4.5 minutes (on average).

Table 1 Calculation workspace Assembly Dept.

	1 Employee (m2)	39 Employees (m2)	45 Employees (m2)
Employee	4	156	180
Working area	1	39	45
Small storage area	1	39	45
Total	6	234	270

Table 2 Current surface area Assembly Dept.

Surface area (m2)	
Area level 0	238
Area level 1	224
Total area	**462**
Palletlifts	17
Toilet & Storage	12
Passage level 1	4
Lunch: tables	4
Lunch: chairs	40
Aisle level 0	18
Aisle level 1	20
Printers	8
Pallet locations	22
Storage upstairs	10
Stairs	21
Total available	**286**

Table 3 Number of movements Assembly Department

#Movements	In	Out
Month	1321	1709
Week	330	427
Day	66	107

3.2.2. Productivity

Now that the available space within the assembly department is known, a look is taken into the productivity of this department. It is tried to see whether the productivity of this department is influenced by the available space. Within this sub-section a look is therefore taken into the productivity levels of all products that were assembled within the year 2018. The productivity level is measured on basis of the number of products assembled per hour (products/hour). Every year, this rate is based on previous experiences and at the end of the year it is decided whether this estimate still satisfies or that the value should be changed. By comparing the estimated rate, with the actual number of products assembled, it can be checked whether the assembly department is operating at the right level or not. It can also be seen which products are mostly influencing the efficiency of this department. When doing so, it is important to not only have a look at the products exceeding the estimated time, but also at the products for which less time is required than estimated. This time could possibly be used to perform assembly tasks to other products.

At the end of every day, an overview is made of all the products that have been assembled during that day. At the end of the week, this information is put into the yearly overview. This overview contains: all the products, the hours worked on these products per week, and the amount of products produced per week. The number of assembled products per hour is then calculated by the following formula.

$$Prod. = \frac{\sum x_{ij}}{\sum hr_{ij}}$$

$$x_{ij} = amount\ of\ product\ i\ assembled\ in\ week\ j$$
$$hr_{ij} = hours\ spend\ on\ product\ i\ in\ week\ j$$

The relative difference between the number of products assembled and the estimated number is then calculated by:

$$\frac{(Prod. - Goal)}{Goal} * 100\%$$

$$Goal: the\ estimated\ number\ of\ products\ assembled\ per\ hour$$

The yearly overview of 2018 showed that most of the products deviate from the estimated norm. It was therefore decided to have a look at the products deviating at least 10% from the goal (both positive and negative). In this way 44 negative results were found, against 32 positively deviating products. All products deviating more than 30% are excluded from this research, while they fall outside the scope of this research. An explanation regarding these product deviations can be found in Appendix A.

The focus of this research lies in the products deviating between 20 and 30% from the norm. Table 4 shows the *negatively* deviating products falling within this range. Products having the reason "New product" have been removed from this table, because of the learning curve which is also explained in Appendix A. From the *positively* deviating products, only 2 products (A1411 & A1264) fall within the 20-30 range. While these products are both produced in small amounts and account for only 0.1% of the total hours of 2018, these products are left out of consideration.

Table 4 Negatively deviating products: range -20% till -30%

Assembly Nr.	Prod. Diff (%)	Reason
A1352	-29	Depending on person
A1301	-29	Depending on person
A1338	-29	Usually performed by person coming back from illness
A1296	-27	AP Assembly
A1224	-27	Place left
A0073	-26	AP Assembly
A1452	-26	Other
A1385	-24	Place left
A1374	-24	Place left
A0926	-24	AP Assembly
A0050	-20	AP Assembly

The products as given in Table 4, have other reasons explaining their productivity differences. At first, the reason *"Place left"* is given to assembly processes that are simply put at places where no other assembly processes are taking place. These processes are therefore performed at a difference place every time, which makes this a non-repetitive task. Second, products are given with the reason *"Depending on person",* while the assembly process performance strongly depends on the person performing the job. As already stated before, the employees working at the assembly department all have a mental disability, and the job performance could therefore strongly differ among employees. The product that is usually assembled by a person coming back from illness, is hereby also taken into account. AP Assembly stands for: Attention Point Assembly. From these products it is known that they deviate from the standard, and that action into these assembly processes should be taken.

All products mentioned in Table 4, together add up to 5% of all assembly hours within 2018. 1.3% of these hours should actually not be spend on these products (514 hours). On average, 2 hours per day are spend on the assembly of a product, that should actually be used to assemble other products. This means that every week, 1 person is spending one day to assemble a product from which the time should actually be used for the assembly of a different product.

3.2.3. Conclusion

The first sub-section showed what space is currently available as working space for the assembly employees. It was shown there, that there is not enough space to let all assembly employees work in-house. The productivity analysis within the second sub-section showed that almost all productivity levels of the department are deviating from the standard. Multiple causes were given for this:

- New products
- Small batches
- Assembly takes place only 2 – 3 times a year
- Depending on person
- Place left
- AP Assembly

The efficiency of this department could be improved, by increasing the size of this department. The time that is now spend on the rearrangement of assembly lines and processes could then be used for the assembly of products. By increasing the space, it will as well be possible to let all assembly employees work in-house. In this way, the supervisor of this department could help all employees at the time they need his help. The processes can become more repetitive, while they can be performed in the same way every time again. This reduces the risks for making mistakes and creating waste. In this way the productivity of this department could be stabilized and the efficiency of this department could be improved.

3.3. Logistics

The last processing step that contributes to the OPE are the logistics. The efficiency of this process is measured by the transportation distance of both materials, products and molds. Figure 8 already showed that this measure is influenced by the location of departments, the location of materials inside warehouses, and the type of transport that is used. As will be explained within the next chapter, it was hard to get an overview of all movements taking place. Therefore, within this research, only the movements of forklifts have been monitored and all other transportation types are left out of consideration. Within the next two sub-sections, an overview is given of all problems related to either the location of departments (3.3.1. Facility lay-out) or the location of materials inside the warehouses (3.3.2. Warehousing process).

3.3.1. Facility lay-out

Before zooming in on the problems regarding the facility lay-out, it is important to know what the current location of the different departments is. A schematic overview of the current facility lay-out is given in Figure 11. This figure is a so-called a spaghetti diagram, that shows the movements of materials, products and molds during the day. The pink spaghetti lines have been created on the basis of the process flow diagram (Figure 6) as described and represent the perceived routes of between departments.

The numbers as written down in Figure 11 represent the following activities:

1. Collecting the product-specific mold from one of the 4 possible locations
2. Collecting the raw materials from one of the 4 possible locations. (Henninkweg is not shown in this figure)
3. Transportation of the raw materials to the material supply room.
4. Production: product quality check and product packaging performed by employees.
5. Storage space.
   5.1. Storage of to be assembled products
   5.2. Storage of finished products
   (The rented warehouses at the Henninkweg and Neede are not shown in this figure, the movements to these warehouses are represented by the lines below the Egginkhal)
6. Assembly takes place.

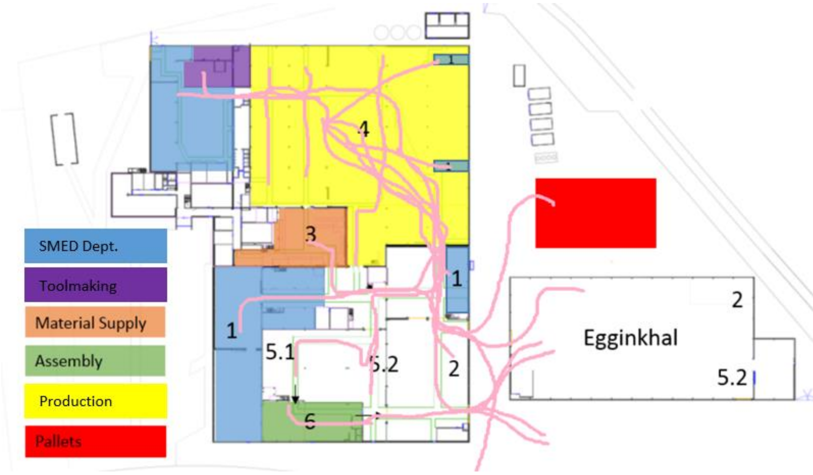

Figure 11 Spaghetti diagram showing routes based on flow diagram

Now that the current facility lay-out is known and a general overview of the transportations is given, the focus of this chapter turns to the lay-out problems influencing the OPE. The problem cluster is a frequently used method to provide an overview of all problems along with their connections. It is a method that serves to bring order to the problem context, and which makes it possible to identify the core problem (Hans Heerkens, 2017). Within the next sub-section, the problem cluster handling with the facility lay-out problems is explained. This sub-section is followed by a smaller sub-section in which the safety issues are discussed. A small conclusion regarding the facility lay-out problems can then be found at the end, before it is continued with the problems regarding the warehousing process.

Problem cluster facility lay-out

This sub-section shows the different problems regarding the facility lay-out as perceived by several employees. All problems have been bundled into a problem cluster (Figure 12). From this figure it becomes clear that problems arise from the location of certain departments. When combining the process flow information from Figure 6 with the spaghetti diagram from Figure 11 it can be seen that several departments are not directly connected to each other which causes the transportation distance to increase. Whereas the efficiency of the process step “Logistics” depends on the transportation distance, this distance should be kept at a minimum. Below Figure 12, an explanation regarding every factor of influence can be found.

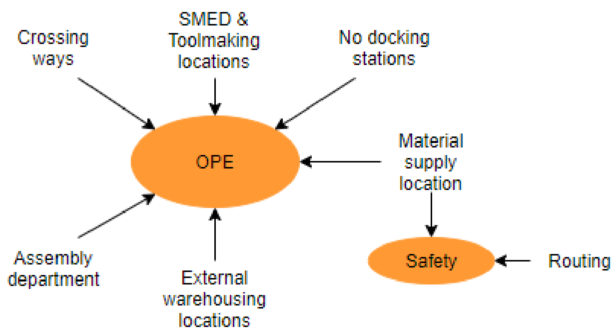

Figure 12 Problem cluster facility lay-out problems

When looking back to Figure 11, it can be seen that both the toolmaking department and SMED are located at different places at the production facility. Maintenance to molds and repairing of molds takes place in the upper left corner, whereas the molds are stored at the lower left corner and at some places inside the production hall. Therefore, in case of a machine set-up, multiple movements are necessary to get everything at the right place. The placement of finished products and raw materials at external locations also increases the number of movements. Whereas Timmerije currently has no docking stations available, the products cannot directly be stored into the trailers in which they are transported to the external locations. Therefore, it requires more time to load the products in- and out of the trailers. Something that also influences the efficiency of operations is the fact that forklifts and people cross each other many times during transportations. As a consequence of this, people have to move back- and forward when they cross ways. When looking back to the spaghetti diagram in Figure 11, these crossings occur at places where pink lines cross each other.

In section 3.2. it was already explained that the available space inside the assembly department is not enough to have all assembly employees work in-house. Another problem connected to this department, is the location of the department itself. From the spaghetti diagram it becomes directly clear that the materials needed within this department are coming from several locations. This causes the transportation distance for this department to increase.

The material supply location is the last subject directly connected to the OPE. This room is located in the center of the building, which brings advantages and disadvantages. In the middle of the building the distance to the machines is the shortest, which results in less wear of the tubes transporting the material to the machines. However, this place is not directly the closest to the machines requiring most of the raw materials. As well, the raw materials that need to be dried within this room are not located directly next to it. This influences the transportation distance for these materials. A disadvantage is also shown in the safety of this location; this is explained next.

Safety

In case the material supply room is put on fire, all raw materials located in here will melt. While this location is not entirely surrounded by fire walls or doors, the material could then easily flow into the production facility and/or the in-house warehousing area. In the event of fire, the entire archive will also be lost, while this is located directly above the material supply area. Therefore, Timmerije as a company wants to increase the fire-safety by installing a sprinkler system at places where raw materials are located. The warehousing safety parameter elaborates more on this (to be installed) sprinkler.

Another safety issue is seen in the transportations of both molds and materials that take place during the day. The entire route through the facility causes forklifts and employees to cross each other many times. While machines are placed close to each other, these can only be passed by 1 forklift or person at a time. Every employee and visitor should therefore be really careful when driving and walking around. Whereas the routing is a result of the location of the departments, this factor is taken into account here.

Conclusion facility lay-out

All problems of the problem cluster will be taken into account during further research. Most of the problems described in here relate to the facility lay-out and the route, whereby the route is a consequence of the existing facility lay-out. The *perceived* problems as described within this section, are qualified and quantified within chapter 4 to state whether they are also the *actual* problems. Even though the safety parameter does not have an influence on the transportation distance of materials, it is enclosed within the problem cluster. This has been done, while it is a factor to be taken into account when looking at the location of both the material supply room and the raw materials. The location of all other departments also influences the safety, while the routing of materials and molds depends on the location of these departments.

3.3.2. Warehousing processes

This sub-section explains the problems regarding the warehousing processes. Before looking into the problem cluster, it is important to have a clear overview of the current warehousing processes. Recall the warehousing process as it was explained within chapter 1. There it was seen that materials and products are stored at different warehouses. The different warehousing locations are shown within Figure 13.

Figure 13 Location of different materials

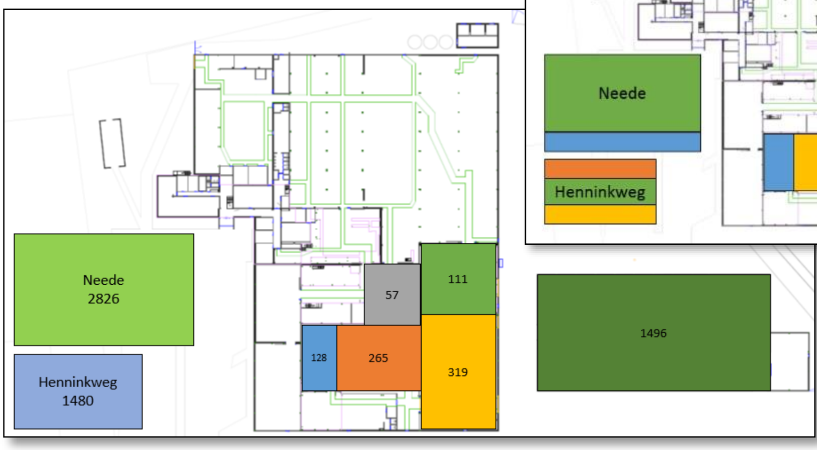

Figure 14 Number of pallet locations per area

Figure 14 was created to show the number of pallet locations per area. It shows that Timmerije has access to 6682 pallet locations from which 64% is located at external locations. Now that it is clear what materials are located where, this chapter continues on showing the problems regarding the warehouses. Within the next sub-section, a problem cluster regarding the warehousing processes can be found. Just as within the previous problem cluster, these problems are focusing on the factors influencing the OPE. At the end of this section, a conclusion about the different factors can be found. It is explained there which factors are taken into account for further research, and which problems will be left out of consideration.

Problem cluster warehousing

The problem cluster regarding the warehousing processes can be found in Figure 15. This figure shows that the different warehouses have different problems. Therefore, the problems regarding the warehousing locations are explained per location in several sub-sections. The warehousing factors that do not belong to a specific location, are explained within a separate sub-section.

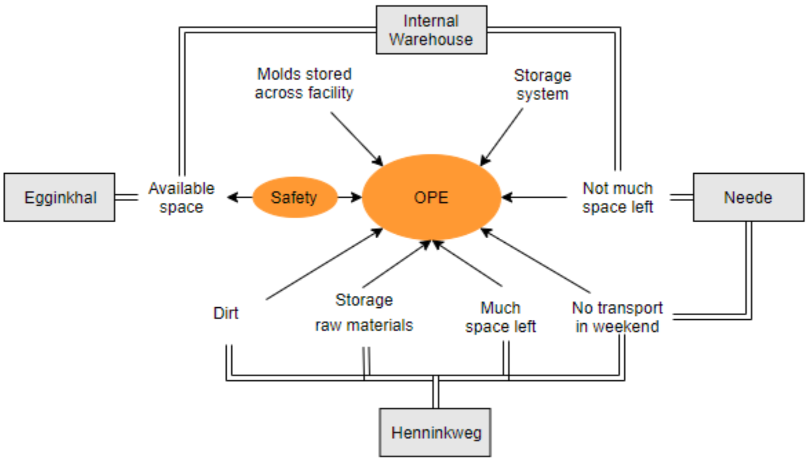

Figure 15 Problem cluster warehousing process

Henninkweg

The warehousing location at the Henninkweg is used to store raw materials and “old” products. Some of the customers require Timmerije to deliver their products till 10 years after production. It is therefore possible to find products over here that were already produced in the year 2011. Besides raw materials and finished products, empty boxes that were returned by the customer can be found here. It is however possible, that some of these boxes aren’t used within the production process any longer and they could therefore be regarded to as waste.

While the warehousing space at the production facility is limited, the Henninkweg warehouse is sometimes used for the storage of raw materials. This especially occurs at times the purchaser buys in a bulk of raw materials. At the moment this material is needed at the production facility, it will be transported there. It is however not always brought to the production facility in-time. At the moment this happens, the machine requiring the material is stopped and will only continue when the material is available again. Another factor connected to the Henninkweg warehouse, is the fact that there is still many space left within this warehouse. However, conditioning of this hall is not possible, which causes this place to be rather dirty. Therefore, Timmerije prefers to use this place only for the storage of raw materials and old products.

Neede

The Neede warehouse usually stores products that are produced in large batches. This location features 7 rolling doors that could be used for the (un)loading of products from or into trailers; currently only 4 of them are used for this purpose. Also, this location is almost always fully packed and there is almost no space left. It is therefore wondered if the current storage system over here is the optimal one. As well, there is no transport of products from this location in the weekends. Therefore, all products should be shipped during the week.

Internal Warehouse

The problem regarding the available space at the Neede warehouse is also seen at the internal warehouse on-site. In here, the storage locations from the shipping department are used for the storage of raw materials and packaging materials instead of final products. When walking around this warehouse, it can be seen that all pallet locations are fully packed, and that there is no place left for the storage of materials. While this warehouse is used to store raw materials, a sprinkler system should be installed here. Due to this sprinkler system, the number of pallet locations will even decrease within this warehouse.

Egginkhal

The Egginkhal is mainly used for the storage of raw materials and finished products. Currently, this hall is located at 10 meters from the production facility. However, to increase the fire-safety on-site, the distance should be increased to 29 meters. This causes the number of pallet locations to decrease as well. This restriction is made while the façade cladding of this hall is not fire-resistant.

Non-locational factors

Next to the problems as discussed per warehousing location, there are also other problems regarding the warehousing process. One of them is the storage of molds around the production facility. Even though there is a mold safe on-site, there are also molds that do not fit within this safe. 4 molds are located inside the production hall, whilst 18 molds are stored at the in-house warehouse. The 18 molds are stored in front of the entrance of the production area, at the side of the shipping department. These molds are all too heavy and too big in size to be transported into the mold safe. To make transport of these molds even more difficult, they are stored behind each other. In case one of the molds located at the back is needed, the other molds have to be relocated first. They are then temporarily placed onto the walkways, over which employees are walking and forklifts are transporting materials and products. These employees then have to wait until the right mold is obtained. Also, some of the molds located here, have not been used in the last 3 or even 6 years.

The placement of molds inside the production facility indicates that the technical service has to work on the molds inside the production facility. This causes them to work in between the machines and they have to bring their materials to this place to be able to perform their job. In case they did not bring the right tools, they have to walk back- and forward to the toolmaking area. Over the last year, the technicians had to work 19 times at 3 different molds inside the production facility. It is also wondered why these molds are kept in stock inside the production hall. First of all, in the event of a fire these molds are not protected and they will get lost. Without these molds, Timmerije can no longer deliver continuity to their clients. Even though the molds are owned by the customers, the value of the molds is considered to be substantial. Next to fire safety, safety issues could arise at moments the technical service is working on the molds inside the production hall.

Another factor to be considered here, is the warehousing system that is currently used. As can be seen in Figure 13, the materials and products are stored throughout each other in the warehouses. Currently, it is not known if materials and finished products are stored at the best possible place. It could be investigated whether the internal storage of raw materials, packaging materials and final products could be improved to decrease the total transportation distance. Hereby, the OPE could eventually be improved.

Conclusion warehousing process

The problems regarding the external warehousing locations (Henninkweg & Neede) will not be taken into account during future research, while no improvements to these warehouses could be made in terms of transportation distance. Another problem not taken into account during further research is the location of the molds inside the internal warehouse and the production hall. These locations are left out of consideration, while the molds that are stored there are too big and heavy to be stored somewhere else.

What will be taken into account for further research is the storage location of both materials and products. While these locations influence the transportation distance this is a factor to be taken into account when trying to improve the OPE. In case the transportation distance decreases, less amount of time is spend on these transportations. This time could then be used for other activities which add more value to the product.

3.4. Overview

The sections 3.1 till 3.3. showed that there are several factors influencing the OPE. While it will be hard to solve all problems that were described, some of them are left out of consideration. Within the figure below, the factors taken into account during this research are marked in green. It shows that the process step **“Machines”** is not taken into account during this research. Within sub-section 3.4.1. it is explained why this step is left out of consideration.

Figure 16 also shows that the process step **“Assembly”** is partly taken into account. While this process step was already explained in depth within this chapter, the problems regarding this step do not have to be researched further. The assembly information of this chapter is therefore used again within the Systematic Lay-out Process as described within chapter 6.

Whereas the problems regarding the process step **“Logistics”** have only be discussed in general within this chapter, further research into this subject is needed. Therefore, within the next two chapters, the problems regarding the facility lay-out and the warehousing process are quantified and qualified. The problems that will be included for further research can be found within sub-section 3.4.2.

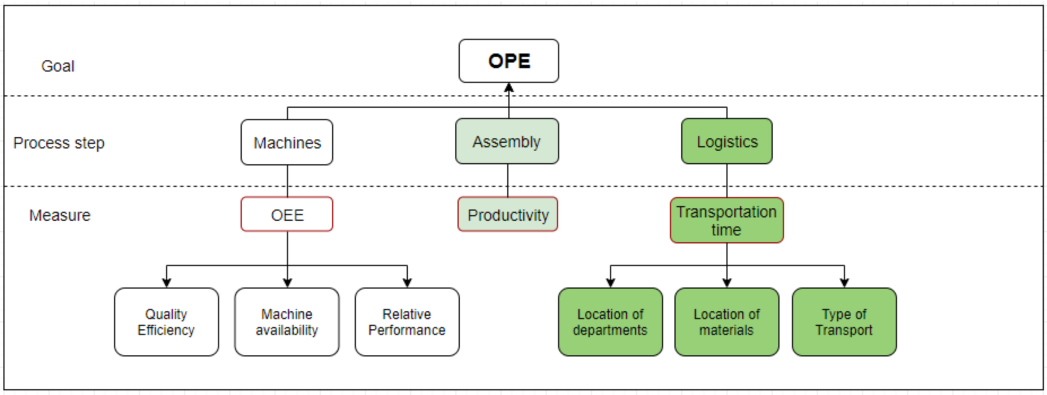

Figure 16 OPE factors taken into account during research

3.4.1. Excluded problems

The efficiency of the process step “Machines” is measured by the OEE. The OEE is thereby influenced by 3 factors; quality efficiency, machine availability and relative performance. It was explained in section 3.1.1. that the set-up time of molds is the only factor influencing the *machine availability*. Currently, the set-up times are already monitored closely and discussion about these times is held in every morning meeting. The only thing that could be researched here, is whether the set-up time as defined on the BOM is still actual. This problem is regarded to as a knowledge problem, which is not of interest for this thesis. The machine availability is therefore not taken into account during the rest of this research.

Thereafter, within section 3.1.2. it was explained that the *quality efficiency* is also not taken into account for further research, while the quality KPI has been met in all months of the year 2018. Next to this, the internal KPI regarding waste is continuously monitored as well. The production manager and quality manager are already focusing on these processes and therefore it was decided to not take the quality efficiency into account.

Sub-section 3.1.3. showed that the *relative performance* depends on the waiting time and productivity of the machine. It was already explained in here that these processes are not included for further research, while they are about the effectiveness of the machine, and not about the logistic processes.

3.4.2. Included problems

The only factor of the OPE to which further research is needed, is the process step “Logistics”. Section 3.3. showed that there are a number of factors influencing the efficiency of this process. The problems as encountered over there could be summarized as follows:

1. **Facility lay-out:**
   1.1. Locations of material supply room, assembly department, SMED department, and toolmaking department.
   1.2. Non-regulated flow resulting in many (unnecessary) movements, and forklifts and employees crossing ways.
2. **Warehousing:**
   1.1. Number of movements of materials, products and molds.
   1.2. Reduction of available storage space within Egginkhal.
   1.3. Location of materials and products.
   1.4. Available space at warehouses on-site is limited.

From this summary of problems it becomes clear that it is questioned what the internal logistics and warehousing looks like. It is not precisely known what movements with molds, materials and products take place during the day, and what space is needed for the warehousing processes. Research to these subjects is needed to improve the logistics and thereby the OPE. The parameter safety is not to be found within the list of included problems, while this factor is not directly related to the OPE. This factor should however been taken into account when looking for improvements.

This chapter is followed by chapters 4 and 5, which zoom in to the problems regarding the departmental locations and the warehousing processes separately. It is showed within these chapters how the transportation distance depends on the locations of departments and materials. It is within this chapters also shown what the current state of these factors is. Thereafter, within chapter 6, this information is used to come up with alternative facility lay-outs by means of the Systematic Lay-out Planning (SLP) method. There, it is tried to decrease the total transportation distance that was found within chapters 4 and 5.

4. Production process

Question 2: "What influence does the current facility lay-out have on the efficiency of the production process?"

After the explanation about the facility lay-out in chapter 3, this chapter deals with the problems regarding the facility lay-out which were explained in short within that chapter. There, it became clear that the facility lay-out is probably non-optimal. It was also stated that the location of the different departments influences the efficiency of the production process, whereby problems were seen in the locations of the material supply room, SMED, and toolmaking. The location of these departments influences the flow and route, which probably results in many (unnecessary) movements and forklifts and employees crossing ways. Therefore, in section 4.1., a look is taken at the facility lay-out and the route resulting from it is explained by means of a spaghetti diagram. The sub-section 4.2. till 4.4. then focus on the locations and transportations of the SMED & Toolmaking departments, the production area and the material supply room.

4.1. Spaghetti diagram

A tool frequently used for showing the internal logistic flows, is the spaghetti diagram. This tool is part of the Lean methodology which is explained by (Stoiljković, 2011):

"*Lean utilizes a unique set of tools to streamline processes and eliminate unnecessary, time-consuming steps. It seeks to enhance performance and meet customer needs by reducing complexity, improving process flow and removing unnecessary or non-value-added activities.*"

The focus of the Lean approach is on cost reduction, through the elimination of non-value-added activities via by means of a management philosophy which is focused on identifying and eliminating waste from each step in the production chain respective of energy, time, motion and resources alike throughout a product's value stream (Rahani AR, 2012). The spaghetti diagram is one of the tools used to provide an insight in the actual state of the process. The data for this diagram is obtained by drawing the movements of persons or forklift trucks as 'spaghetti' lines on a map. By following the forklift trucks for several days, an insight into their movements is created. From the created map the following information can eventually be derived:

- Route
- Crossings

The route is important for measuring the efficiency of operations, where the hotspots are important for showing the places where possibilities for delay in operations are at risk (waiting times & safety). The spaghetti diagram verifies what the route is, and where hotspots are to be found (if they exist). By following employees and forklift trucks of different departments, it will become clear over what distances materials, products and molds are transported. While the transportation distance is regarded to as one of the 7 sources of waste (Ronald G. Askin, 2002) this should be eliminated or shortened if possible. Following persons or forklift trucks for several days is however time consuming, and it is probably hard to obtain reliable data, while persons that are followed might change their behavior and route if they know they are being followed. Next to that, only one person can be followed at a time (United States Patentnr. 5465115, 1995).

The beacon technology is an interesting option to obtain more reliable data. Beacons transmit particular information in a defined radius and in regular intervals. These signals are picked up by a beacon pod from where the information is send to a server (Pavel Kriz, 2016). While it is known where the different pods are located, the route of different beacons could be analyzed. It is with this technology also possible to display the hotspots within the facility. Research into this technology however showed, that the costs related to the analysis software are substantially high. The beacon technology is therefore not a viable solution to track the employees and forklifts for this research.

Another method for obtaining data is by means of people counting. It is a method frequently used in retail establishments. It provides insight into the effectiveness of advertisements, promotions and events by monitoring the number of customers entering and exiting the retail establishment at certain times (United States Patentnr. 5465115, 1995). Simple systems only count the number of persons crossing a sensor, while more extensive systems also have the possibilities to identify different types of objects (KWBS, 2018). Further research into this subject however showed that, within the lay-out of Timmerije, this is not a viable solution. With this system it is not possible to make distinctions between forklifts and employees. Also, at the moment two persons are crossing the sensor at the same time, this will be recorded as only one person crossing the sensor. This shows, that the data obtained, might not be reliable and this system is therefore not suitable for this research.

Another option is the implementation of certain heat map cameras. By installing these cameras at several places inside the production facility and warehouses, data about the movements at those places is obtained. It is thereby possible to have a look at specific time frames and these cameras are also capable of counting the number of people within a specific area. Using a heat map camera will result in pictures showing the frequency of movements in a certain time frame. With such a system it is however hard to track the routes used by the different employees and forklifts. The costs of this system are also above the budget for this research.

While the existing technologies for the tracking of forklifts are not in reach for this research, the spaghetti diagram is used to map the current situation. The spaghetti diagram belonging to the production facility of Timmerije is shown within Figure 17. It was created by having a look inside the production facility at several moments during the day. Also, it was asked to employees what places they visit during the day. Next to that, the process flow diagram and the warehousing processes as described within chapter 1 were taken into account. The routes of the departments have been estimated based on this information. Whereas no quantitative data is used for the development of this diagram, this figure is regarded to as given a general overview of all transportations taking place. Within sub-section 4.4. and chapter 5, quantitative data from the ERP-system is used to provide an actual overview of the transportation distances of materials, products and molds.

Within this chapter, the focus is on the movements in, and around the production area. At first, it is verified whether the location of the SMED and toolmaking departments is problematic. The location of the SMED and toolmaking departments are thereby from importance while the molds have to be transported through the entire production department to get to the toolmaking area. The location of the material supply room is also taken into account within this chapter, while all raw materials needed in the production area are transported from there. Transportations taking place within expedition, assembly and the Egginkhal are handled with in chapter 5, because these mostly consist of the relocations of raw materials and finalized products and are therefore considered to belong to the current way of warehousing.

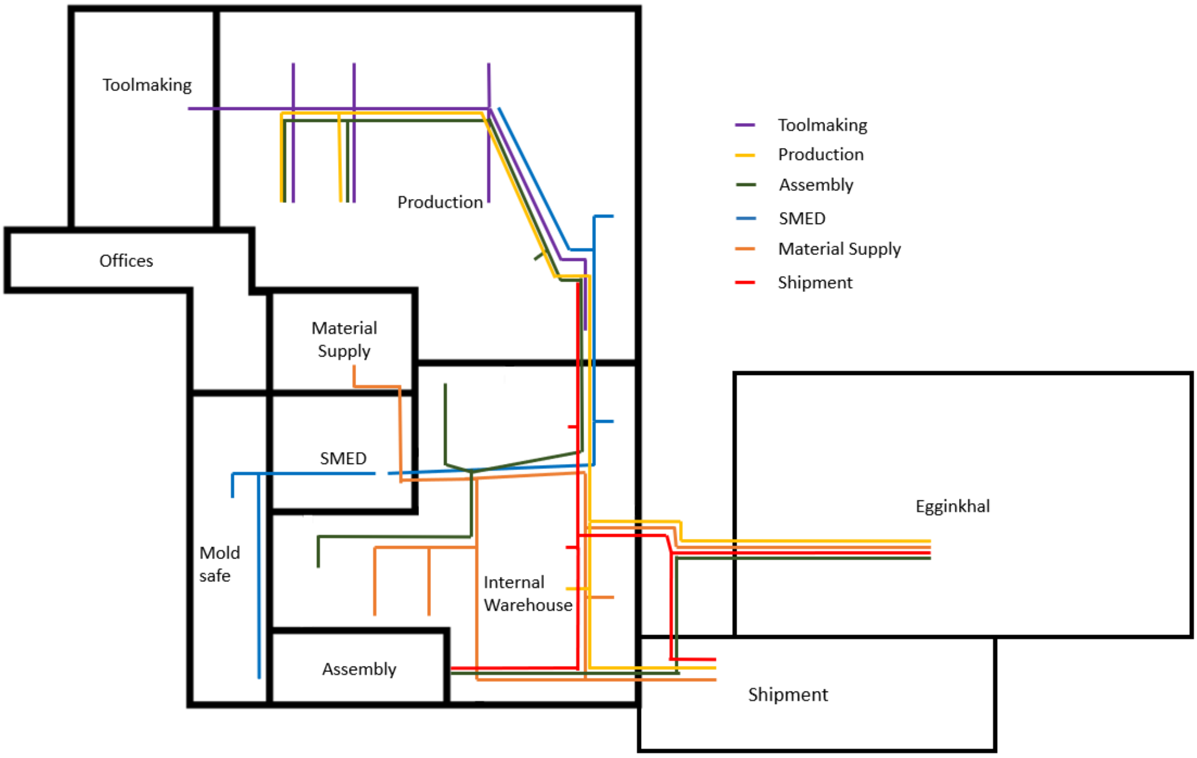

Figure 17 Spaghetti diagram showing routes per department

4.2. SMED & Toolmaking departments

This section provides more information about the relocations of molds from, and towards the toolmaking area and the production department. This information is found by having a look at the so-called number of "Mold repairs". This includes the total number of molds that have visited the toolmaking department for either repair, maintenance or preparation for production. At first, only the mold repairs of September 2018 were taken into account. Within that month, the number of mold repairs was 94. When comparing this number with the number of mold repairs from September 2017, it turned out that the number of repairs was higher then. Therefore, it was chosen to also take into account the information of other months, to come to an average mold repair value. By doing so, an average number of molds being repaired, maintained or prepared is 26 per week. This means that on average, 5 molds are repaired in the toolmaking area every day. As a consequence of this, molds are transported through the production area around 10 times a day. Based on the assumption that the toolmaking departments only works the shift from 08.00 till 16.00, it can be concluded that a mold passes the production area every 48 minutes.

Next to that molds are transported through the production department towards the toolmaking area, molds are also transported to the production department itself. Figure 18 shows the configuration of the machines within the different halls. All molds enter the production area from hall 4 / 5, from where they are transported to the right production hall. Within this figure, the blue line represents the route that is taken for the transport of a mold from production hall 2 back to the SMED department. While an employee has to travel back and forth to bring the mold to the right place, the total number of transportations is obtained by multiplying the number of mold relocations with 2.

Figure 18 Average transportation distance per production hall

The number of mold relocations of the month September 2018 were used to estimate the average relocation values. Table 5 shows the number of relocations per production area per period. The small table next to it, shows the distance to be travelled towards each production area (Distance (m)). This distance is taken as an average which is represented by the blue and red lines within Figure 18. The total distance (m) thereby also takes into account the distance between the entrance of hall 4 / 5, and the SMED department. By multiplying the "Total distance (m)" from the small table, with the number of relocations per day (#Relocations / Day) from Table 5, the total distance (Distance (km) / Day) is obtained.

The time spend on the relocations is then calculated by dividing the distance by the transportation speed of the forklifts. A speed of 1 km/hr is taken for the transport of molds, while this is a very cautious process. The total amount of time spend on the transportation of molds towards the different production areas, turns out to be almost 2 hours per day.

Table 5 Number of mold transportations per period

Location	Month	Week	Day	#Relocations / Day	Distance (km) / Day	Time (hr) / Day
Hal 1	95	24	4.8	9.6	1.03	1.03
Hal 2	49	12	2.5	5.0	0.48	0.48
Hal 4 / 5	46	12	2.3	9.2	0.47	0.47
Total	**244**	**61**	**12.2**	**23.8**	**1.98**	**1.98**

Location	Distance (m)	Total distance (m)
Hal 1	87.25	108.02
Hal 2	77.75	98.52
Hal 4 / 5	30.75	51.52

Adding these transportations to the transport of molds towards the toolmaking area, the total number of transportations throughout the production department is 34.4 per day. From this it can be concluded that a forklift with (or without) mold passes the production area every 14 minutes. This is based on the assumption that molds are only transported during the day shift from 08.00 till 16.00. Within the next sub-section, this information is extended with information about the number of products produced. In this way, it becomes clear how many times forklifts and employees could cross ways during the day.

4.3. Production Area

Next to the movements of molds throughout and within the production area, there are also other movements taking place in this area. This sub-section focuses on the transport of final products, from the different production halls towards the warehousing locations. It is shown here, what amount of time is spent on the transport of finished products, and it is also revealed how many times someone is walking through the different production areas. Hall 3 is left out of consideration, while the products produced in here are transported by the aim of a conveyor belt. These products are collected and put in boxes at the end of this hall, wherefore nobody has to walk between the different halls.

A difference in transportation method is seen between halls 1 / 2 and halls 4 / 5:

- **Halls 1 and 2;** products are placed in boxes at the machine. These boxes are collected on a cart, standing at the end of the hall (black box within Figure 18). When this cart is full, it is transported towards the entrance of hall 4 / 5. Here, the products are packed on their own pallet. If the pallet is full, it is transported towards its final warehousing location.
- **Halls 4 and 5;** products are directly packed in boxes having the size of a pallet (palletbox), or they are packed in boxes that are then directly placed on a pallet that is standing next to the machine. At the time the pallet(box) is full, it is transported towards the entrance of these halls. From there, it is transported to its final warehousing location.

Now that it is known how the products are transported through the production area, it is possible to determine the amount of time spent on these transportations. Information regarding the type and number of products produced, during September 2018 is used to determine this. This information is extracted from the ERP system, whereby the following correlated information was found:

1. Start date of production
2. Machine number (on which product is produced)
3. Runtime (in hours)
4. Quantity produced

To determine the end date, the runtime is turned into the time span in days. This time span is added to the start date, and thereby the end date is determined. Next to the end date, week numbers are added to both the start- and end date. This has been done, to determine whether the production falls within one week, or in separate weeks. This is important, while in the next calculations, the number of products produced per week are needed. Depending on the type of product, the number of products produced per week is turned into the number of boxes (halls 1/2) or pallets (halls 4/5) per week. Based on these numbers it is then possible to determine the amount of time spent on the transport of products from the production area towards the warehouse.

From the machine number, the corresponding production hall can be determined. Because of the different transportation methods for halls 1 / 2 and halls 4 /5, the calculation of the total transportation distance (km) is different for these halls.

For **halls 1 / 2**, the total transportation distance (km) per hall is calculated by the following formula:

$$D_{jk} = (\sum_{i}^{I}(B_{ijk} * X_j * 2 + B_{ijk} * \frac{1}{n} * Y_j * 2))$$

$$D_{jk} = Total\ transportation\ distance\ for\ hall\ j\ during\ week\ k\ (j = 1{,}2)$$
$$B_{ijk} = Number\ of\ boxes\ of\ product\ i\ produced\ in\ hall\ j\ during\ week\ k$$
$$X_j = average\ transport\ distance\ (km)\ within\ hall\ j$$
$$Y_j = distance\ (m)\ of\ hall\ j\ towards\ the\ entrance\ of\ hall\ 4/5$$
$$n = number\ of\ boxes\ per\ cart$$

While within these halls transport takes place by cart, the total amount of boxes coming from these halls, is to be divided by the number of boxes on this cart. The number of boxes is estimated to be 15. This number is based on the information that, within every shift, the cart is emptied 2 to 3 times on average. The number of transportations is multiplied by 2, while the employees walk back and forth between the cart and the machines.

For the calculation of the transportation distance of products coming from **halls 4 / 5**, a different equation is used. In here, the number of relocations is not calculated by the aim of the number of carts per week, but by the number of pallet relocations per week. The following formula is thereby used:

$$T_{jk} = (\sum_{i}^{I} P_{ijk} * X_j * 4) \ / \ 1000$$

$$T_{jk} = Total\ transportation\ distance\ for\ hall\ j\ during\ week\ k\ (j = 4, 5)$$
$$P_{ijk} = Number\ of\ pallets\ of\ product\ i\ produced\ in\ hall\ j\ during\ week\ k\ (j = 4, 5)$$
$$X_j = average\ transport\ distance\ (km)\ within\ hall\ j\ (j = 4, 5)$$

Within this formula, the number of relocations is multiplied by a factor 4. This is needed, while it takes 2 transportations to bring the packaging material (either a pallet box or pallet) towards the machines. Thereafter, 2 transportations are needed to bring the pallet with products towards the entrance of hall 4 / 5. Now take a look at Figure 18, in which the configuration of the production department is shown. Within this figure, the transport path of products produced in hall 2, is shown. Within this figure, X_j is represented by the red arrows, whereas the blue arrows represent Y_j. The red arrows only point to half of the aisle, while this distance is taken as the average value. The X_j and Y_j of the other halls are determined in the same way.

An overview of the results can be found in Figure 19. In here, the total transportation distance per hall per week is given. It can directly be seen that the transportation distance is mostly influenced by pallets coming from hall 4 /5. Next to the transportation distance, the average number of active machines is shown within this figure. It can be seen that there is no direct relation between the number of machines producing and the distance to be travelled. It is therefore assumed that the transportation distance depends on the production quantity and the size of the products. In case the production quantity is high, more boxes need to be transported, which causes the number of movements to increase. The same counts for the size of the products. In case the products are bigger in size, less products can be put within one box, and the number of transportations increases.

Then, the average transport time is calculated by dividing the transportation distance (of Figure 19), by a transportation speed of 3 km/hr. An overview of these results is given in Table 6. Next to the transportations of finished products, there are also other employees moving within this area. These employees are either working at the machine to perform a 100% quality check or they are packing products into boxes. Their movements cannot be tracked, and are therefore left out of this calculation.

Table 6 Transportation distance and time per week

WeekNr	Distance (km)	Time (hr)
Wk 36	127	42
Wk 37	141	47
Wk 38	134	45
Wk 39	160	53

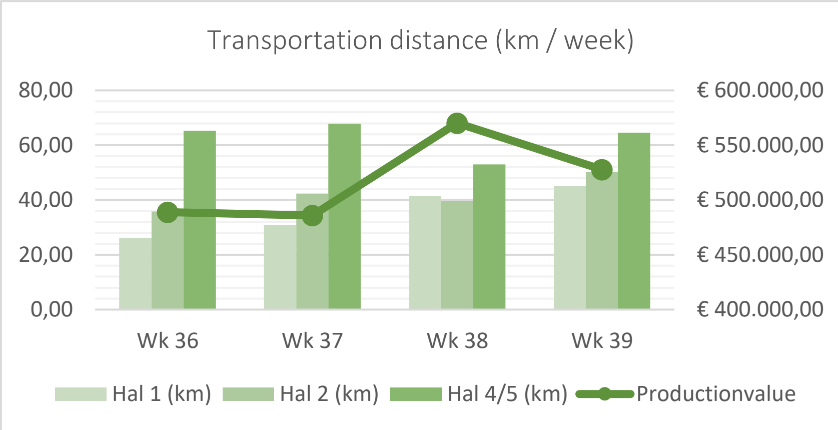

Figure 19 Transportation distances within production department per week

4.4. Material Supply Room

Now all movements throughout the production area are known, it is time to have a look at the location of the material supply room. To see whether the location of this department is problematic, data about the movements in and out of this area are needed. It was already showed in Figure 17 that the raw materials needed in this room, are coming from multiple places. Within this sub-section, the total amount of time spend on these activities is calculated. These calculations are based on the available data about the relocations of materials and goods. Currently, every time a product is transported or placed at another location, this relocation is recorded. Based on this information, it is possible to determine the number of times that transport between certain areas took place. Within this sub-section, the focus lies at the transportations from and towards the material supply room. In future chapters this data is used again, but then to provide insight into the transport of all other materials and products.

A tool used within this sub-section, is the software tool Tableau. It is a tool useful for visualizing data; it makes it possible to quickly scan data, filter on specific parts of the data and it helps to provide insights into combinations of data. (Tableau Software, sd) For this research, this software tool is helpful in the creation of maps of the facility that simultaneously show the transportations taking place. When the routes are known, it could be determined over what distance the raw materials are transported. An explanation regarding the relocation information can be found in Table 7.

For this research, data from September 2018 is used. For the material supply room, only the material flows containing the Item-Code “G” are used. A path-id is created on the combinations of TFF-TFT and TFL-TTL, whereby the shipments are not of interest within this sub-section. The path-id shows the from- and to locations of the different relocations. By adding the longitude and latitude of the warehousing locations, mapping of the routes within Tableau is made possible. The length of every path is estimated by measuring the shortest possible route. The result is an estimate, while only the from- and to locations are known and it is unclear which path the employee actually took.

Table 7 Explanation regarding the relocation information from ERP

Item-Code	A: Assembly Number E: EMG; regrind raw materials G: Raw Material I: Parts used in Assembly K: Pigment M: Mixed raw materials (colors / raw materials) P: Product Number V: Packaging Material
Location	Warehousing location
Date-Activity	The date at which the relocation was recorded
Time-Created	The time at which the relocation was recorded
Adjust-Code	TFF: From (Location X) TFT: To (Location Y) TFL: Transfer From Location (X) TTL: Transfer To Location (Y) SHP: Shipment
Qty-adjust	The used quantity

Figure 20 Transportation routes raw materials

Figure 20 was created to show all relocations of raw materials and coloring materials from and towards the material supply room in September 2018. From this map it can be seen that the internal warehouse is split into several sections with different names than those seen before. This is because of the naming that is used within the ERP system. To provide a clear overview of all locations, a map was created in which all locations are shown. This map is to be found in Appendix B. The thickness of the lines within figure 20 shows the importance of the path. The thicker the line, the more important this path is. It shows that most of the raw materials are transported between Material 1 and the Material supply room. In total, 1812 pallets of raw materials have been relocated within September 2018. This results in a total transportation distance of 112 km. When dividing this distance by the average speed of a forklift (4 km/hr), and taking into mind a downtime percentage of 40, the total number of hours spend on the relocations of raw materials is around 70 hours. Both the speed of the forklift, and the downtime percentage have been estimated in accordance with the company supervisor. Next to that raw materials are stored at Material 1, they are also placed at other warehousing locations within Timmerije. When transporting materials from these locations, several ways will also be in use by employees from other departments. While these crossings mostly take place within the warehouses, this subject is discussed further in chapter 5.

4.5. Conclusion

As was already stated in the beginning of section 4.1., the transportation time is regarded to as one of the 7 sources of waste. The time spend on this activity should therefore be eliminated or shortened if possible. Problems were seen in the locations of the SMED & Toolmaking departments and the material supply room. It was stated that the location of these departments probably results in many (unnecessary) movements. Next to that, it was wondered what other relocations are taking place within the production area.

Table 8 provides an overview of the information gathered within the previous sections. To make comparisons between the different materials and departments possible, all replacement data is converted into daily information. While the toolmaking department only works a day shift from 08.00 till 16.00, one day is considered to last 8 hours.

Table 8 Conclusion 4.1. : Transport molds, raw materials, products per day

Material	From / To		#Replacements / day	Distance (km)	Time (hr)
Molds	SMED	Toolmaking	11.0	0.8	0.8
		Production	8.0	0.7	0.7
Raw materials	Warehouse	Material Supply	76.0	5.0	2.5
Finished products (boxes)	Hall 1	Entrance hall 4 / 5	34.0	1.3	0.4
	Hall 2		42.0	1.6	0.5
	Hall 4 / 5		33.0	4.1	1.4
Finished products (carts)	Hall 1	Entrance hall 4 / 5	2.0	0.3	0.1
	Hall 2		3.0	0.4	0.1
	Hall 4 / 5		0.0	0.0	0.0
Total			**209.0**	**14.2**	**6.6**

From this table it becomes clear that a forklift is used for the transport of molds towards the toolmaking area every 45 minutes (on average). Every 60 minutes, a mold is transported towards the production area. At the same moment, finished products are loaded on carts, and when the cart is full, it is transported toward the entrance of hall 4 / 5. Every relocation of finished products (boxes) means one transportation towards the cart and one transportation from the cart back to the machine (s). For the calculation of the transportation distance, the number of relocations is therefore multiplied by 2. From this table it becomes clear that every 7 minutes, 6 minutes or 3,5 minutes a box or pallet is leaving the halls 1, 2, 4 / 5 respectively. During these transportations, the products might come across the molds that are transported through this area as well. This causes the forklifts to wait for each other which increases the transportation time, and safety is put at risk. Therefore, within future alternative lay-outs, it should be tried to minimize the transportation distance of molds and decrease the number of hotspots within the production facility.

Table 8 as well shows that for the relocation of raw materials towards the material supply room, every 6 minutes a forklift is used. Within the next chapter, the information regarding the material supply room is combined with the other relocations taking place within the warehouses.

The following assumptions should be taken into account when looking at this conclusion:

1. For determining the material supply routes, only the from-to locations are known. There is no information of the movements taking place in between.
2. Calculations are based on the month September 2018.
3. Number of boxes per cart is 15. This can differ among different products.
4. Timespan of production runs does not take possible downtime into account.
5. No difference is made between certain shifts.
6. Only information regarding the relocation of boxes; other employees are left out of consideration.

5. Warehousing process

Question 3: "What potential does the current warehousing process have?"

Within chapter 3 several problems regarding the current warehousing process were mentioned. To determine the potential of the current warehousing process, a closer look should first be taken into the way of warehousing now and the problems resulting from it. From there on, it can be seen what improvements could possibly be made. As already stated within chapter 3, the following factors influence the efficiency of the warehousing process:

1. Transportation distance
2. Available storage area
3. Time the products are stored
4. Shortening of the Egginkhal

The longer the transportation distance, the higher the transportation costs. (Gallego, 1990) Also, the longer the products are stored, the higher the holding costs. It is therefore from great importance to have a look at the products or materials that have been on-site for a long period of time. Next to that, the Egginkhal should be shortened because of safety reasons. This will influence the available storage area and causes less material and/or products to be stored on-site. Within the next sub-sections, these subjects will be discussed. Sub-section 5.1. starts with an explanation regarding all transportations taking place every day. Within that section, the total transportation distance and transportation time is calculated. Sub-section 5.2. provides more insight into the available storage area and the storage area that is actually in use. In here, it will also be investigated whether the products / materials / molds in storage are still in use or not. At the end of the chapter it should be clear how much time is spend on the relocations of goods and materials and what the available storage space is.

5.1. Relocation information

To see where possibilities for improvements are, it is important to first have a look at the current warehousing processes at Timmerije. While the transport of molds and raw materials was already discussed within the previous chapter, this section solely focuses on the transportations of the other materials and the products after they have been placed at the entrance of hall 4 / 5. During the day, many different materials and products are transported throughout the warehouses on-site. Within this sub-section, it is explained what the total transportation distance is, and what time is taken for the relocations within departments. The aim of this section is to provide an insight into the hotspots seen across the warehousing locations on-site. The output of this section is used in next chapters to see where improvements to the transportation distance and time could be made. Also, this information is used to compare the current situation, with a future improved version.

The relocation information, as was explained in chapter 4, is used to calculate the transportation distance. A map showing the most frequently used routes of September 2018 is given in Figure 21. The legend thereby shows the abbreviations of the different types of materials, that were already explained within Table 7. It can be seen that the most frequently used route is the one between mattec and the docking area (see Appendix B for more information regarding the warehousing names). In the calculations that follow, an estimate of the transportation distance is taken. On average, the route from mattec to the docking area is used 300 times each week. This even excludes the weekends, while production stops at Saturday morning and starts again at Sunday evening.

The second most frequently used route again starts at the production area, but then continues to the Egginkhal. From this hall, the finished products are eventually transported to either the shipping department or the assembly department. Only a small part of the finished products is transported back to the recovery area. Another important and busy route starts at the assembly department and stops at the docking area. The products transported over this route are assembled inside the assembly department, from where they are directly shipped to an external warehouse or the customer.

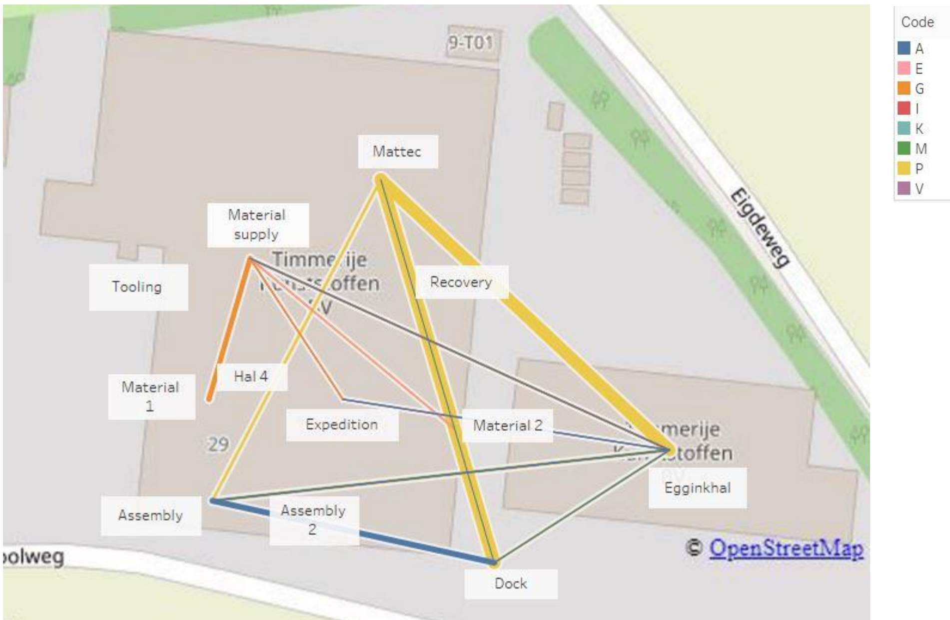

Figure 21 Most frequently used transportation routes September 2018

Now that the route frequencies are known, it is possible to calculate the total transportation distance. Figure 22 shows what the total transportation distance of the most frequently used routes is. To have a more accurate overview, only the routes with a transportation distance of 0.5 km or more are shown. The data as showed in this figure, is obtained by multiplying the distance of one route, with the number of pallets transported over that same route. From this figure it can directly be seen, that the most frequently used route also results in a high transportation distance. However, this is not valid for all routes located at the top of the frequency range. Even though the route from the assembly department to the docking area is used frequently, the total transportation distance is relatively low. When looking back to Figure 21, this could be explained by the fact that the assembly department and the docking area are located relatively close to each other. Therefore, not only the frequency of use, but also the transportation distance is important to take into account. The average time spend on the transportation of goods and materials, can eventually be calculated from these values.

The total distance of the routes showed in Figure 22 for the week weeks 36, 37, 38 and 39 is 152 km, 130 km, 150 km and 158 respectively. When taking into account all the different routes, the total distances are 170 km, 148 km, 164 km and 175 km for these weeks. The routes as showed in Figure 22, therefore account for 90%, 88%, 91% and 90% of the total transportation distance of that week. By dividing these distance by the average speed of the forklifts (4 km / hr) and a downtime percentage of 40%, the transportation time is calculated. The amount of time spend on transportation is then calculated to be 103 hours per week on average.

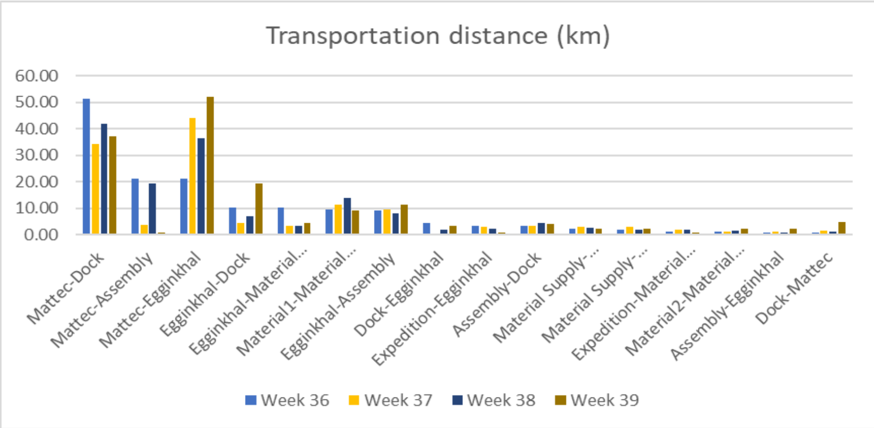

Figure 22 Transportation distance per week

However, the routes as showed in the previous figures only show the transportations between *different* warehousing areas. During the day, there are also relocations of pallets within the *same* area. Another important transportation factor is seen in the shipments taking place, while it takes time to (un)load the trucks.

Table 9 shows an overview of all factors contributing to the total transportation time per month. It thereby also includes the transport of raw material that was handled within the previous chapter. The relocation of other materials involves the relocations of packaging materials, final products and products that are kept in stock for further assembly. It shows that the monthly transportation distance is **700 km**. This transportation distance is turned into the transportation time, to see whether this is correct. The "Time 1 (hr)" represents the transport time spend on the transport of materials or products between different departments, whereas "Time 2 (hr)" represents the time needed for the (un)loading of trucks in case a material or product is shipped. The relocation time within departments is calculated by multiplying the number of pallets by an average transportation time of 2 minutes per pallet. The (un)loading time of materials and goods is calculated by multiplying the number of pallets by the average (un)loading time. For a truck filled with raw materials, the unloading time is 3 minutes per pallet on average. For a truck filled with final products the average (un)loading time is set to 2 minutes per pallet. The total amount of time spend on the relocations of all materials and products is then found by adding up Time 1 and Time 2. It turns out that the total amount transportation time for materials and products is equal to **782 hours per month**. This is justified when looking at the number of employees that are currently responsible for these transportations. At this moment, 6 employees spend 36 hours per week to the relocation of all materials and products. Together they can therefore spend 864 hours per month to the relocation of materials and products. The total transportation time that was found during the research falls within this range.

Table 9 Transportation times per relocation type per month

	#Pallets	Distance (km)	Time 1 (hr)	Time 2 (hr)
Shipments	4268	26	16	85
Relocation: Raw Materials	1812	112	70	1
Relocation: Other Materials	11980	562	351	172
Relocation: Within Department	2560	0	0	85
Total	**20619**	**700**	**437**	**344**

Table 10 % total hours spend on relocations within departments

Day Nr	Time (hr)	% Internal relocation hours
Day 3	49	52%
Day 4	39	37%
Day 5	35	53%
Day 6	36	50%
Day 7	30	40%
Average	**38**	**46%**

From Table 9 it can directly be seen, that the internal relocations and (un)loading of trucks ("Time 2") have a great influence on the total transportation time. When zooming in to week 36, it can be seen that these movements account for almost 50% of the transportation time on average (Table 10). It is shown in this table also, that the average time spend on the transport of materials and products is 38 hours per day. Weekends are excluded from this overview, while the production stops at Saturday morning and starts again in the night from Sunday to Monday.

The transportation distance not only depends on the type of materials that is relocated, but also on the forklift employee that has to transport the material. Table 11 provides an overview of the path-ID usage frequency of different scanners. Only these scanners that actually transport materials are shown within this figure. As was already explained within chapter 4, the path-ID stands for the route between two locations. From this overview it can be seen that most of the relocations between mattec and dock are executed by scanner number 4. This scanner is also used for the relocations between mattec and assembly, and the Egginkhal. A map explaining these routes can be found in Appendix C.

Table 11 Path-ID usage frequency per month

Path-ID	ID-3	ID-4	ID-5	ID-7	ID-9	ID-11	Total
Mattec-Dock	61	1777	1	0	89	33	**1961**
Mattec-Egginkhal	151	1387	1	0	34	18	**1591**
Material1-Material Supply	547	49	0	0	0	1	**597**
Assembly-Dock	0	5	237	0	76	226	**543**
Mattec-Assembly	5	480	0	0	3	43	**531**
Egginkhal-Dock	0	32	98	19	169	113	**431**
Egginkhal-Assembly	0	0	101	34	46	202	**383**
Egginkhal-Material Supply	94	120	0	0	0	3	**217**
Dock-Egginkhal	2	32	5	0	14	81	**134**
Total	**860**	**3881**	**443**	**53**	**431**	**720**	**6388**

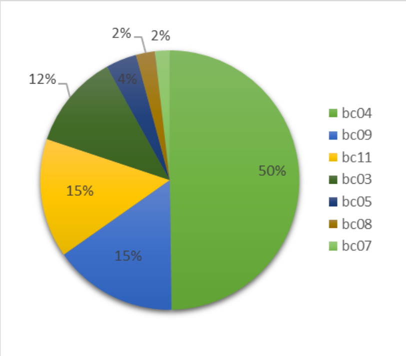

Figure 23 Scanner-ID usage frequency

While Table 11 only provides information about the path-ID usage frequency per week, another figure (Figure 23) is created to show the pallet movements per scanner. It can be seen that, next to scanner 4, there are 2 scanners that are almost equally important (scanners 9 and 11). Both scanners belong to the shipping department and together they account for 30% of all relocations within September 2018. From Table 11 it becomes clear that these relocations are split over many different paths. Another scanner that greatly influences the number of movements is scanner number 3. This scanner belongs to the material supply department, which is also seen in Table 11.

The relocations of raw materials from and to the material supply room have also been added to Table 9. In the previous chapter it was already seen that the raw materials are coming from different storage locations. When comparing the routes from material supply (showed again in Figure 25) with the other routes as showed in Figure 24, then it is seen that these routes are used by many different other departments as well. An explanation regarding the different colors can be found in Table 7. To get to material 1, the employee from material supply visits the same routes as an employee going from material 1, Hal4, tooling or assembly towards mattec or recovery (or the other way round). Next to this, raw materials being transported from the Egginkhal or material 2 towards material supply or material 1, cross ways with products coming from mattec.

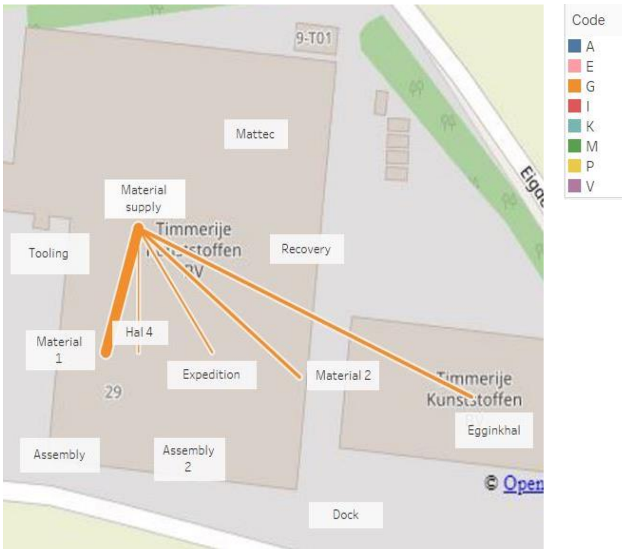

Figure 25 Routes for raw materials (Sept. 2018)

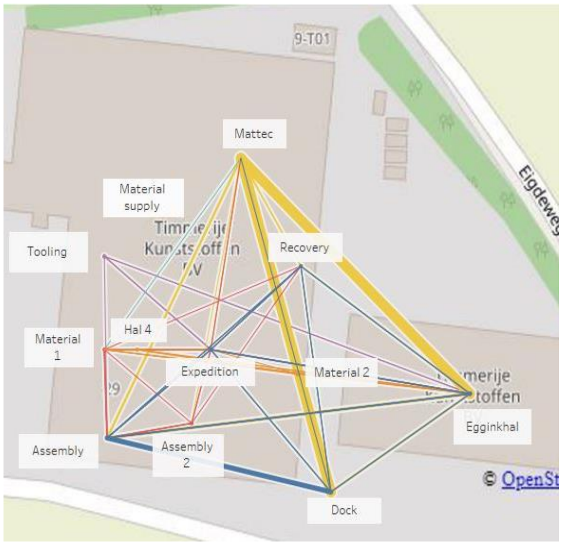

Figure 24 Most important routes of all materials (Sept. 2018)

5.2. Storage space

The previous sub-sections showed the relocations of materials and products taking place within the warehousing facilities on-site. Next to that it is important to know the relocations, it is also important to know about the available storage area. By comparing the available storage area with the required storage area it will become clear whether the available space satisfies the needs.

Within this sub-section the storage area is represented by the number of pallet locations. Section 3.3.2. Warehousing processes already showed the number of pallet locations on-site. The map as given within that section (Figure 14) shows that the number of pallet locations within the production facility is equal to 936. There, it was also showed that the Egginkhal can store up to 1496 pallets. This means that the total number of available pallet locations on-site is 2432. However, the Egginkhal currently does not satisfy to the building requirements. The distance between the production facility and the Egginkhal should therefore be increased from 10 meters to 29 meters. This causes the total number of pallet locations on-site to decrease to 1871.

In chapter 4, research was done into the number of mold relocations. For this research, a list of all mold numbers was received from the SMED department. This list shows whether the molds are still active (in use) and whether they are stored at one of the locations of Timmerije or not. It can be concluded that several molds are stored at the production facility that have not been in use for the last 2 or 3 years. 5 of these are placed at the mold storage in front of production hall 4 / 5. In the mold safe, another 1178 inactive molds and parts are stored. Next to that there are molds that have not been in use over the last couple of years, there are also materials that are no longer in use. For this research, the materials have therefore been compared with the registered list of Bill of Materials (BOM). In here, the materials were filtered on a last-used-date of before 2017, and having an inventory level above 0. Thereafter, the materials and products were filtered on the following:

1. Planned number of products 2018 = 0
2. Last sales date is before 01.01.2017
3. Produced number of products 2017 = 0
4. Forecasted number of products 2018 = 0

The results can be found in Table 12. The item-codes given within this table are the different type of materials, as was already explained within Table 7. The amount as given for item-Codes G, K, I and VB, are regarded to as the number of pallet locations. From this overview it can be concluded that 82 pallet locations are occupied by materials and products that are no longer in use.

Table 12 Inactive materials and products

Item-Code	Amount	Quantity on-hand
G	14	3564 kg
K	18	417 kg
I	16	-
VB	9	1471 pcs
P	17	21 pallets
A	2	4 pallets

5.3. Overview

This chapter has provided an insight into the current warehousing processes. At first, a closer look was taken into the transportation distance. As was already stated in the introduction of this chapter, the longer the transportation distance, the higher the transportation costs. Sub-section 5.1. showed that the total transport distance of both materials and products is equal to 700 km. All these transportations together add up to 437 hours per week. Next to the transportations between different departments, there are also relocations taking place within departments, and time is needed for the (un)loading of trucks. In total, these relocations add up to 344 hours per week. On a weekly basis, 782 hours are therefore spend to the relocations of materials and products.

Transportation of these materials and products takes place over various routes. These routes have been explained in sub-section 5.2. It showed that a frequently used place within the facility is the crossway in front of hall 4 / 5. At this point, employees have to wait for each other and safety is put at risk. Another place which is frequently visited, is the docking area. Most of the relocation time within departments is used for the (un)loading of trucks. 2 employees are currently needed to perform this task. These relocations do not add value to the production process and should therefore be eliminated. However, while these relocations do not depend on the facility lay-out, these will not be taken into account during the remaining part of this project.

When it was known what the frequently used routes were, a look was taken into the different scanner identifications. It was seen that 3 scanners are together responsible for 80% of the transportations. The transportations they perform are split over different routes that also cross ways. The last subject of this chapter was the available storage area. In here, not only the shortening of the Egginkhal was taken into account, but also the number of pallet locations occupied by materials and/or products that are no longer in use. It showed that the total number of available pallet locations on-site is equal to 1871. 82 of these locations are occupied by materials and/or products that are no longer in use. Next to that, there are also molds located on-site that are no longer in use. 5 of these molds are located in front of hall 4/5. Another 1178 inactive molds / parts are stored at the mold safe. While these also entail really small products / parts, these are not directly linked to the number of pallet locations.

6. Systematic Lay-out Planning

Question 4: "What alternatives can be given to improve the efficiency?"

The previous chapters showed several bottlenecks influencing the process efficiency. It was seen that part of these problems are resulting from the current facility lay-out. Chapter 3 already showed that the space of the assembly department is currently limited so that not all employees can work in-house. For future developments it is therefore recommended to increase the working area of this department. Chapter 4 showed that by using a different lay-out, the transportation distance of raw materials and molds might be decreased. Chapter 5 zoomed in on the warehousing processes taking place, and within this chapter it was shown that the location of materials and products greatly influences the total transportation distance. Due to the transport of both materials, molds and products the number of crossings between forklifts is high. In this case, they have to wait for each other and safety is put at risk. The aim of this chapter is therefore to come up with alternative lay-outs taking into account the information from the previous chapters. Hereby, the goal is to decrease the transportation distance (and thereby the transportation time) and to limit the number of hotspots, to eventually increase the process efficiency.

A method that is frequently used for the determination of the optimal allocation of departments is the Systematic Layout Planning (SLP) method as designed by (Muther & Hales, 1969). It is a method in which it is tried to achieve the following objectives:

1. Minimizing material handling, especially travel distance and time
2. Maintaining flexibility of arrangement and operation as needs change.
3. Promoting high turnover of work-in-process; keeping it moving.
4. Holding down investment in equipment.
5. Making economical use of floor space.
6. Promoting effective utilization of labor.
7. Providing for employees' safety, comfort and convenience.

The first objective is about minimizing the material handling processes; thereby especially focusing on minimizing the travel distance and time. SLP is not the only way to obtain this objective; another method that is frequently used is the Systematic Handling Analysis (SHA). It is an organized, systematic approach to analyze materials handling problems (Muther & Haganas, 1969). It analyzes the movements to and from the total area, taking into account external conditions. Thereafter it focuses on the type of equipment with which the materials are transported, and it takes into account the transport units/containers that could be used. It thereby first focuses on the moves between departments or buildings on a site, where after the focus turns to the moves from one specific workplace to another.

Within this research it is chosen to use the SLP method. This, while this method takes into account various objectives that are important to the management team of Timmerije, where the SHA mainly focuses on the minimization of the transportation distance only. Next, the SHA procedure takes into account the transport units and packaging materials, which are not important for this research as well, while these are determined in accordance with the customer to guarantee the quality of the products. Some customers even have their own transport unit that fits best into their own production process. Thereafter, the SHA takes into account the transportation type. Within the coming years, the forklifts at Timmerije will however not be changed, while the current facility lay-out is not suitable for the implementation of other transportation types.

The SLP method consists of 3 phases which are build up as follows:

1. Analysis phase: to acquire all information regarding the flow of materials and relationships between departments.
2. Search phase: combines the information of the first phase, where after alternative lay-outs are developed.
3. Selection phase: to determine the best lay-out alternative of those that were developed within the second phase.

The analysis phase is described within sub-section 6.1. Sub-section 6.2. then focuses on the search phase. Whereas in total 5 different lay-out alternatives were developed, it was chosen to dedicate sub-section 6.3. to these lay-out alternatives only. The selection phase of the SLP method is handled with in the next chapter. In here, the different lay-out alternatives are compared to each other by means of the Analytic Hierarchy Process. The decision regarding the best lay-out alternative is then taken at the end of chapter 7.

6.1. Analysis phase

The **analysis** phase is the first phase of the SLP methodology. The aim of this phase is to acquire all information needed to eventually create the alternative lay-outs. Information regarding the following subjects is needed in here:

1. Flow of materials
2. Activity relationships
3. Relationship diagram
4. Space requirements and available space

The following sub-sections focus on these subjects.

6.1.1. Flow of materials

Within this sub-section, the materials flow is described. This is an important step, while it provides you with an overview of the flows between departments. Recall the relocations information from chapter 5. There, it was already explained that there are many relocations between several departments. Figure 27 provides an overview of all different materials flows. This figure shows that the materials flow starts at the moment the raw materials, packaging materials and coloring materials are received at the shipping department. From there, the materials are placed into one of the warehouses. In case the material is needed, it is transported towards the material supply room, the production area or the assembly department (depending on the type of material). Currently, the finished products coming from the production area are stored in either the warehouse on-site, or in an external warehouse. Next to the products and materials flows, molds are also transported between different departments. This flow is also described in Figure 27.

6.1.2. Activity relationships

The previous sub-section showed all the material flows, whereas in this sub-section the focus is on the relationships between the different departments. They are best described by the activity relationships; an overview of these relationships is given in Figure 26. From this figure it can be seen which departments are connected to each other, and which departments have no connection at all. It shows, that almost all departments are connected with each other. The non-interrupted arrow within this figure, represents a material flow in which all the departments are visited.

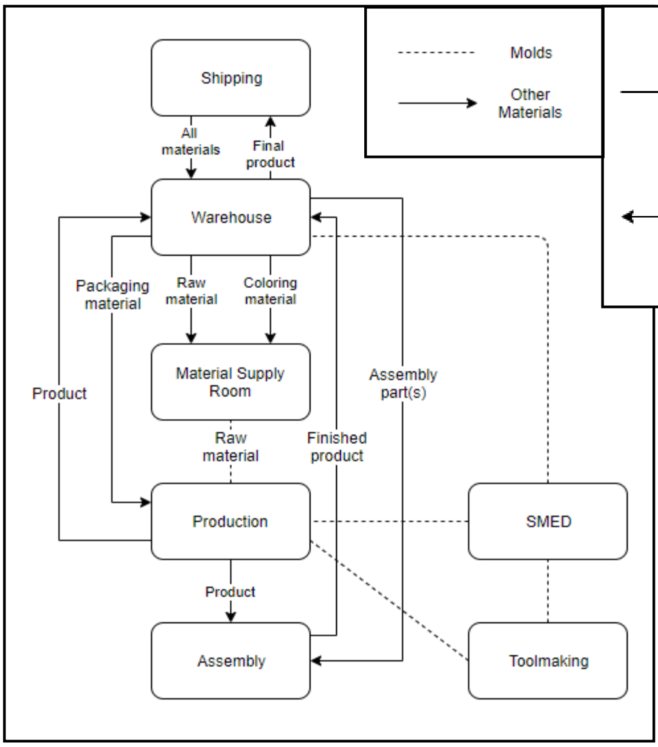

Figure 27 Flow of materials and molds

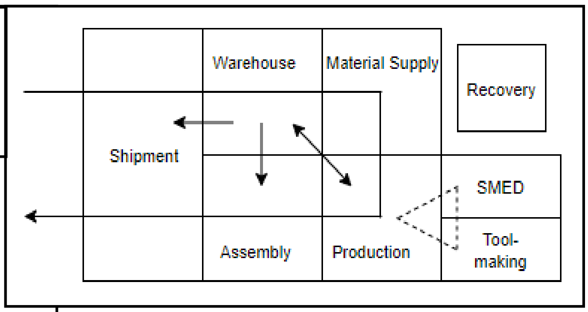

Figure 26 Relationship diagram between departments

All other relationships are explained as follows:

1. Warehouse → Shipment; in case finished products are stored before being shipped to the customer.
2. Warehouse → Assembly; in case products or parts are needed for assembly.
3. Warehouse → Production; packaging material is brought into the production department.
4. Production → Warehouse; finished products are stored in the warehouse.
5. Production – SMED; in case production is finished, the mold goes back to the SMED department.
6. Production – Toolmaking; in case a mold breaks down during a production run, someone from the toolmaking department will try to repair it.
7. SMED – Toolmaking; in case of maintenance or preparation for a production run, the mold will be brought towards the toolmaking department by the SMED department.

The recovery department is placed outside the flow, while it is not a standard procedure to let a product pass this department. Only in case a product is not produced according to the requirements, the possibility exists that this product needs to visit this department. The product will thereby only be sent to this department, if recovery of the product is possible. When in the future all products directly meet the requirements, this department is no longer needed.

6.1.3. Relationship diagram

In the previous two sub-sections, information about the material flows between departments was given. To show the importance of the relationships between different departments, a from-to chart is created (Table 13). Within this table, the number of relocations between departments is given as the percentage of all relocations taking place.

Hereby, recall the information from section 4.2. and 4.3. for the relocations of molds, and section 5.1. for the relocations of materials and products. Within Table 13 the mold relocations are shown within the yellow colored cells. It is assumed that every mold relocation is equal to one pallet relocation. Within this table, all relationships with an importance rate of more than 1%, are marked in green.

Table 13 From-To-Chart; Relationship importance (%)

From \ To	Shipment	Internal WH*	Egginkhal	External WH*	Material Supply	Production	Assembly	Recovery	SMED	Tool-making
Shipment	-	0.6%	**3.0%**	**24.4%**	0.8%	0.8%	1.2%	0.1%	0.2%	0.0%
Internal WH*	0.1%	-	0.1%	0.1%	**6.7%**	0.0%	0.7%	0.0%	0.0%	0.0%
Egginkhal	**5.6%**	0.1%	-	0.5%	1.7%	0.3%	**3.6%**	0.2%	0.1%	0.0%
External WH*	1.1%	0.0%	0.5%	-	0.1%	0.0%	0.0%	0.2%	0.0%	0.0%
Material supply	0.2%	1.5%	0.7%	0.0%	-	0.2%	0.1%	0.0%	0.1%	0.0%
Production	**15.3%**	0.0%	**11.7%**	0.0%	0.3%	-	**4.0%**	0.4%	**1.8%**	0.0%
Assembly	**4.9%**	0.3%	0.5%	0.7%	0.0%	0.1%	-	0.1%	0.0%	0.0%
Recovery	1.0%	0.0%	0.3%	0.0%	0.0%	0.2%	0.0%	-	0.0%	0.0%
SMED	0.0%	0.0%	0.0%	0.0%	0.3%	**1.8%**	0.1%	0.0%	-	0.4%
Tool-making	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	-

* *WH = Warehouse*

*** External WH = Henninkweg or Neede*

From Table 13 it follows that the most important relationships are between the following departments:

1. Shipment – External WH, Egginkhal
2. Internal WH – Material Supply
3. Egginkhal – Shipment, Assembly
4. Production – Shipment, Egginkhal, Assembly, SMED
5. Assembly – Shipment
6. SMED - Production

These relocations together account for 82.8% of all transportations taking place.

6.1.4. Space requirements and available space

Whereas the previous sub-sections focused on the relationships between the different departments, this sub-section focuses on the departments itself. In Table 14 the available space, and the required space per department are given. This information is needed to be able to create alternative lay-outs in the next phase. The surface areas of the material supply room, the production department, the recovery area, the SMED department and the toolmaking department are obtained from a facility lay-out map. For these departments it is assumed that as long as the production capacity remains the same, the required space for these departments also remains the same. The number of pallet locations of the shipping department and the warehouses were obtained by counting them. More information regarding the shipping department and the warehouses can be found in Appendix D.

.

Table 14 Overview spaces per department

Area	Available space	Required space
Shipping department *	319 PL / 575 m^2	40 pallet locations
Warehouses * - Internal Warehouse - Egginkhal - Neede - Henninkweg	6734 pallet locations - 963 PL / 543 m^2 - 1496 PL - 2826 PL - 1480 PL	7145 pallet locations
Material supply room	294 m^2	294 m^2
Production department ** - Hall 1 - Hall 2 - Hall 3 - Hall 4/5	2103 m^2 - 346.5 m^2 - 346.5 m^2 - 460 m^2 - 950 m^2	2103 m^2
Assembly department ***	287 m^2	>= 270 m^2
Recovery area	45 m^2	45 m^2
SMED department	215 m^2	215 m^2
Toolmaking department	650 m^2	650 m^2

** The area is expressed in both the number of pallet locations and the surface area, while this area in the future might be used by other departments.*

*** In case the number of machines increases in the future, the required space increases accordingly.*

**** Recall section 3.2. Assembly.*

The table shows that there is a great difference between the shipping department's available space, and the required space. By taking a look at this department, it shows that this space is currently used for the storage of raw materials and packaging materials. The table also shows that the number of required pallet locations within the warehouses, is greater than the number of available pallet locations. When designing lay-out alternatives in the next phase, this is something to be taken into account.

6.1.5. Overview

Now that the space requirements and available space for all the departments are known, the analysis phase comes to an end. From this phase, several conclusions can be drawn. Within the first two sub-sections, the flow of materials and the relations between the departments were explained. From these sections the following can be concluded:

1. There are many different flows between the departments;
2. Almost all departments are related to each other;
3. The flow of materials is different from the flow of molds.

Within the third sub-section, it was shown that there is a difference in the importance of the relationships. The importance was thereby expressed in the percentage of movements taking place between two departments over all movements taking place. It showed that the most important relationships together account for 83% of all transportations taking place. Next to an explanation regarding the relationships, sub-section 6.1.4. focused on the departments itself. In here, the required and the currently available amount of space were given per department. Within this sub-section, the conclusion was drawn that the number of available pallet locations needs to be improved. It also showed that the shipping department has many more pallet locations, than that there are currently needed by this department. Currently, these pallet locations are used as additional storage locations for raw materials and packaging materials.

6.2. Search phase

The **analysis** phase from the previous section, is followed by the **search** phase. The aim of this second phase is to create lay-out alternatives, by using the information from the first phase. Within the first step of the second phase, the space requirements information is therefore combined with the relationship diagram. This creates an overview in which the size of the different departments becomes clear, and it schematically shows which relationships are more important than others. From this overview, alternatives can be developed. The alternatives are eventually created on the basis of the current production facility lay-out of Timmerije. This has certain consequences, while not every wall or door can be removed. All modifying considerations and practical limitations are therefore described within sub-section 6.2.2. This is also conform the second step of the SLP methodology. The last step of this phase, is to develop lay-out alternatives. Those can be found within section 6.3. Results.

6.2.1. Space-relationship diagram

The space relationship diagram combines the information from sections 6.1.3. Relationship diagram and 6.1.4. Space requirements and available space (Tompkins, 2003). The purpose of this diagram is to combine spatial constraints with the activity relationship diagram. (Ajit Pall Singh, 2013) The result can be found in Figure 28. The double lines within this figure represent the most important relationships, whereas the least important relationships are represented by the dotted lines. The straight lines represent relationships that lie in the middle range of importance.

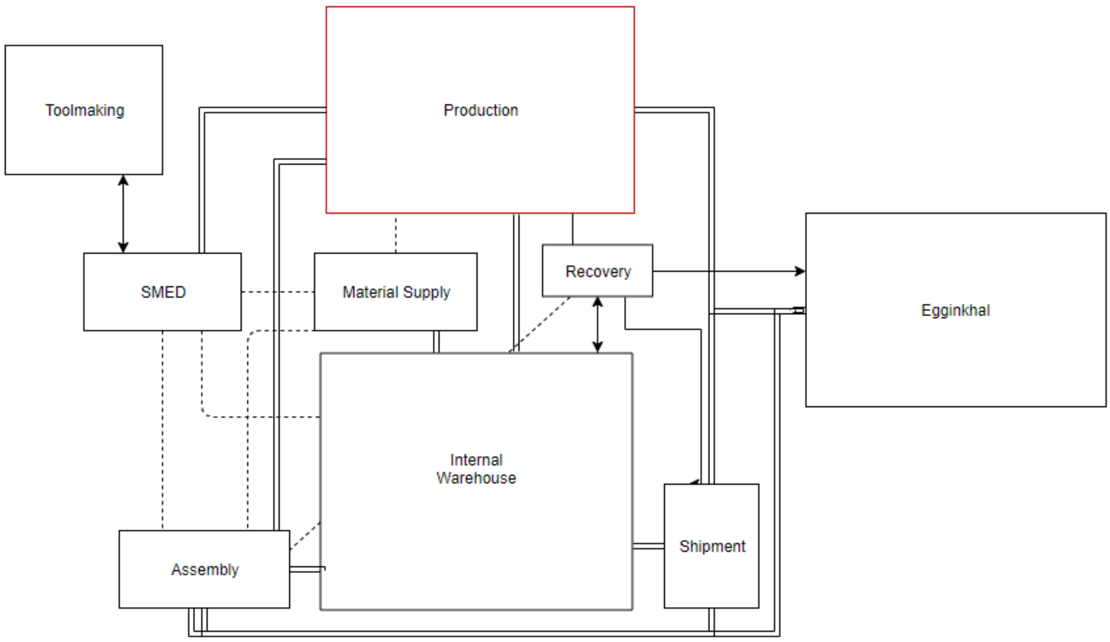

Figure 28 Space-relationship diagram current situation

6.2.2. Considerations & limitations

In the previous sub-section it was explained what the current lay-out is, and what the importance of the relationships between departments is. This sub-section focuses on the practical limitations and modifying considerations that should be taken into account when developing alternative lay-outs. These should be kept in mind to increase the feasibility of the alternative. Otherwise the possibility exists that an option is created which does not fit to the current production facility.

Practical limitations:

1. At certain locations within the production facility, there are fire-resistant doors and walls. It is preferred that these are not broken down in lay-out alternatives.
2. Not all floors are suitable for the placements of heavy machinery. Therefore, the production area cannot be relocated to another area.

Modifying considerations:

1. Section 6.1.4. showed that the number of available pallet locations on-site, is less than the number of required locations. Therefore, it is assumed that finished products are only stored on-site in case assembly is needed. Otherwise, these products are directly transported towards an external location.
2. Section 6.1.4 also showed that the assembly department needs additional space in the future.
3. The costs for replacing the material supply room are considered to be extensively high. This assumption is made on the experience and knowledge of the project manager of Timmerije. Therefore it is preferred to keep this room at its current location.
4. Timmerije also owns an additional 2 hectares on which they currently grow the “Miscanthus”. This land is located next to the production facility, and might be added to the current site.
5. Timmerije should still have the possibility to expand in the future. This is important to take into account when thinking of short-term improvements.
6. The new lay-out does not have to fit within the current building. Additional buildings may therefore be created.
7. The Egginkhal is not conform the building requirements and changes to this hall are therefore necessary.
8. Another preference of the management team of Timmerije is to decrease the number of crossings within the facility. This might lead to a decrease in waiting time, and it will improve the safety.

6.2.3. Overview

Within the first part of this section, an overview of the space requirements together with the importance of the departmental relationships was given. This overview showed that it is important to have the material supply room close to a warehouse, and to place the toolmaking, SMED and production area close together. It also showed that there are important relationships between the assembly department and other departments. However, to reach the assembly department, you first have to cross other departments.

Within the second part the practical limitations and modifying considerations were given. Part of the considerations showed there are a result of the information obtained within previous sections. Additional preferences by the management team of Timmerije were also included in this list. The next section contains the different lay-out alternatives that were created on the basis of the information from both sections 6.1. and 6.2.

6.3. Results

The previous section already showed all factors influencing the development of lay-out alternatives. This section contains and explains the lay-outs that have been created. The lay-outs have been based on 3 different scenarios, which were in turn build on different assumptions. One of the scenarios was created by the management team of Timmerije, whereas the other two were developed based on the information as obtained during this research. In the end, 8 lay-out alternatives were developed. Whereas the last 2 lay-outs focus on expanding the production capacity, these alternatives are not taken into account during the decision-making process for the best alternative lay-out, which is described within the next chapter.

Within every lay-out, the aim was to minimize the transportation distance. This distance-based objective is described by (Tompkins, 2003) in the following formula:

$$\min z = \sum_{i=1}^{m}\sum_{j=1}^{m} f_{ij}c_{ij}d_{ij}$$

$$f_{ij} = number\ of\ pallets\ moved\ per\ unit\ time$$
$$c_{ij} = the\ cost\ of\ moving\ a\ pallet\ one\ distance\ unit\ from\ department\ i\ to\ department\ j$$
$$d_{ij} = distance\ from\ department\ i\ to\ j$$

Whereas in this research all materials, molds and products are assumed to be transported on a pallet by means of forklifts, the costs are equal for every transportation. Therefore, c_{ij} is set to 1. The transportation frequencies from section "5.1. Relocation information" are used to describe f_{ij}. The distance between two departments depends on the facility lay-out, and therefore differs in every lay-out alternative. In lay-outs where no changes to departments take place, the distance is based on the currently available pathways. In lay-outs where departments change in either location or size, the distance is estimated from the middle of the department. This same procedure is followed when a new building is created. An example calculation for estimating the distance within existing locations can be found in Appendix E.

Various lay-out algorithms exist for this problem. One of them is the pairwise exchange method as explained by (Tompkins, 2003). It is an improvement-type lay-out algorithm in which all feasible exchanges in the locations of department pairs are evaluated. The pair that results in the largest reduction in total cost is selected. Within this algorithm it is assumed that all departments are of equal size. Whereas all departments at Timmerije differ in size and shape, this method is not suitable to the facility lay-out of Timmerije.

Another lay-out algorithm is the CRAFT algorithm (Computerized Relative Allocation of Facilities Techniques), which was developed by (Armour & Buffa, 1963). It uses a from-to chart as input data for the flow. Similar to the pairwise exchange method, it is an improvement-type lay-out algorithm, whereby the distance between departments is measured by taking the distance from the centroids of the departments. This distance is stored in a distance matrix. The lay-out costs are then determined by multiplying the from-chart with the corresponding entries in the unit cost matrix and the distance matrix. The method is different from the pairwise exchange method in the way that the departments are not restricted to rectangular shapes (Tompkins, 2003). Another difference is that within this method it is possible to keep certain departments at fixed locations.

A disadvantage of this method is however that it only considers the exchange of two adjacent departments or two departments that are equal in size. It then chooses for the exchange that results in the highest decrease in transportation costs. The exchanges thereby strongly depend on the initial lay-out and the optimization might end in a local optimum.

Given the strengths of the CRAFT algorithm, the development of the alternative lay-outs took place on the basis of this algorithm. Similar to CRAFT, the from-to chart of the search phase, is used to express the flow between the departments. Within this research, the distance between departments is however not only calculated by looking at the centroids, but also by looking at the original pathways in case no changes to a department are made. Different from CRAFT, alternative lay-outs have not been created by the use of pairwise exchanges of departments. This while CRAFT only considers the exchange of two adjacent departments or two departments that are equal in size. It was already seen before, that almost all departments differ in size and the currently available space is less than the required space. CRAFT can also not deal with all modifying considerations and practical limitations that were described within section 6.2. Next to the goal of minimizing the transportation distance, the lay-out alternatives will eventually also be scored on other criteria. It is therefore important to create different alternatives which might differ in transportation distance.

For every lay-out alternative, the transportation distance is calculated per material. This "scenario distance" is then compared with the "original distance" of 700 km that was found within chapter 5, whereby the difference is expressed as the improvement percentage. Next to the transportation distance, the transportation time is calculated to see what improvement could be made in terms of fte. The savings that could be made in terms of personnel costs, could eventually be used to invest in the facility lay-out. Next to the savings in personnel costs, a reduction in transportation distance will also reduce the costs for forklifts. With a new lay-out, it is also possible to reduce the number of crossings within the facility, thereby decreasing the waiting time and increasing the safety for employees.

The lay-outs (1A – 3B) have been created conform the following scenarios:

Description	**1A**	**1B**	**2A**	**2B**	**2C**	**3A**	**3B**
Raw materials & Coloring materials close to material supply room.	X			X		X	X
Assembly department kept on-site	X	X		X	X	X	X
Assembly materials close to the assembly department.		X	NA	X	X	X	X
Increase in size of assembly department			NA	X	X	X	X
Connection between toolmaking, SMED and production departments			X	X	X	X	X
New warehouse on-site.				X	X	X	X
Relocation of toolmaking, SMED and production departments						X	X
Fire-load out of facility		X			X		

It can be seen that lay-outs 1A and 1B focus on the current facility lay-out and the location of the raw materials, and the assembly materials. Lay-out 2A differs in the way that this is the only lay-out alternative in which it is assumed that assembly will no longer take place on-site, but at an external location. The difference between alternatives 2A-2B and 3A-3B can be seen in the way that within 3A and 3B several departments are relocated. Next to the scenarios, there are also assumptions that apply to all lay-out alternatives.

The following assumptions are thereby taken into account:

1. The mold relocations are not expressed in terms of transportation times, while the time spend on these relocations is relatively low (=4 hours per 24 hours). An improvement possibility is therefore seen in the number of crossings of molds with other materials. In several scenarios, it is tried to reduce the number of crossings by placing the production department, SMED and toolmaking department close to each other.
2. From section 6.1.4. Space requirements and available space, it became clear that the number of required pallet locations, is greater than the number of pallet locations on-site. It is therefore assumed that all A-products and P-products are directly shipped towards external warehouses.
3. Given the previous assumption, all A- and P-products are directly placed into a trailer. The size of the shipping department therefore only has to be the size of one entire trailer. Within the lay-out alternatives, the shipping department is therefore left out of consideration.
4. The fte is based on working 36 hours a week.
5. Installation of a sprinkler system inside the internal warehouse and the Egginkhal is possibly needed on the long-term in case raw materials are stored in there. The available space inside the internal warehouse then decreases from 963 to 617.

6.3.1. Scenario 1

This first scenario is based on the conclusions that were taken from the space-relationship diagram (Figure 28). That figure showed that there are important relationships between the warehouse / Egginkhal and the material supply room. It also showed an important relationship between the assembly department and the Egginkhal. Within this first scenario, it is assumed that the buildings remain the same. To minimize the transportation time, a solution is searched in the location of the different materials. Due to the available warehousing space, it is not possible to place both the assembly parts and the raw materials close to their departments. Therefore this scenario is split into scenario 1A and 1B, wherein either the raw materials or the assembly materials are located close to their production area. Whereas this scenario focuses on a short-term solution, the decrease in available warehousing space at the internal warehouse is left out of consideration.

Lay-out 1A

Within this scenario, the raw materials and the coloring materials are located as close as possible to the material supply room. While the required number of pallet locations for these materials (=615+90=705), is lower than the available number of pallet locations in the internal warehouse (936), there is also space left for other materials. It is decided to use this space for I-parts and assembly intermediate stock. The Egginkhal is then used to store packaging materials and the rest of the assembly intermediate stock. A schematic overview of this facility lay-out is given in Figure 29. The shipment area within this figure represents the place at which trailers are waiting for (un)loading of products. Table 15 shows the transportation distances and times per material type. Next to this table, these costs are compared with the transportation costs of the initial lay-out. From this table it becomes clear that the transportation distance can be decreased by 16%.

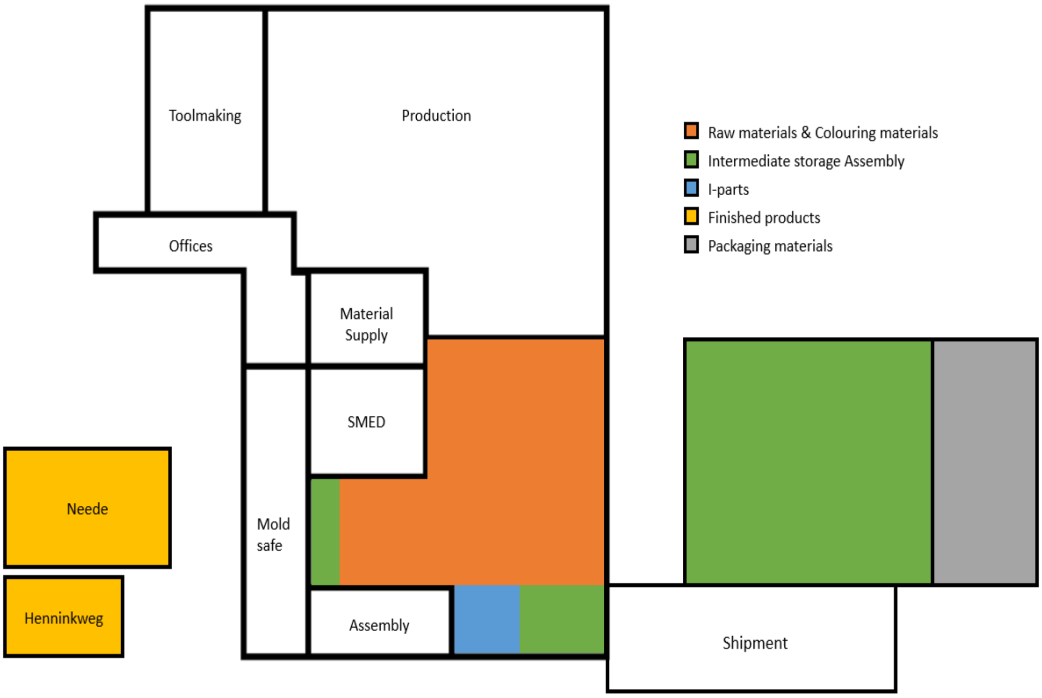

Figure 29 Lay-out 1A; Raw materials located at internal warehouse

Table 15 Lay-out 1A; transportation times per material type per month

Material type	Distance (km)	Transportation time (hr)	Relocation Time (hr)
Raw materials	86	53	8
I-parts	10	6	3
Assembly	205	128	73
Packaging	23	14	4
Products	264	165	198
Total	**588**	**366**	**286**

Original distance (km)	700
Scenario distance (km)	588
Improvement (%)	**16**

Lay-out 1B

In contrast to scenario 1A, the internal warehouse within this scenario is used to store the assembly intermediate stock. While the number of required pallet locations (1138) is greater than the available number of pallet locations inside the internal warehouse (936), part of the assembly intermediate stock still needs to be placed inside the Egginkhal. A schematic overview of this lay-out can be found in Figure 30. This figure shows that the internal warehouse also stores the I-parts (60 pallet locations). This room is reserved for these materials, while calculations showed that this results in a higher reduction of the total transportation time. The results of this scenario are shown in Table 16. It shows that, when putting all assembly materials close to the assembly departments, the total transportation distance decreases by 9%.

Table 16 Lay-out 1B; transportation times per material type per month

Material flow	Distance (km)	Transportation time (hr)	Relocation Time (hr)
Raw materials	145	94	8
I-parts	15	9	3
Assembly	190	119	71
Packaging	24	15	4
Products	264	165	198
Total	**638**	**402**	**284**

Original distance (km)	700
Scenario distance (km)	638
Improvement (%)	**9**

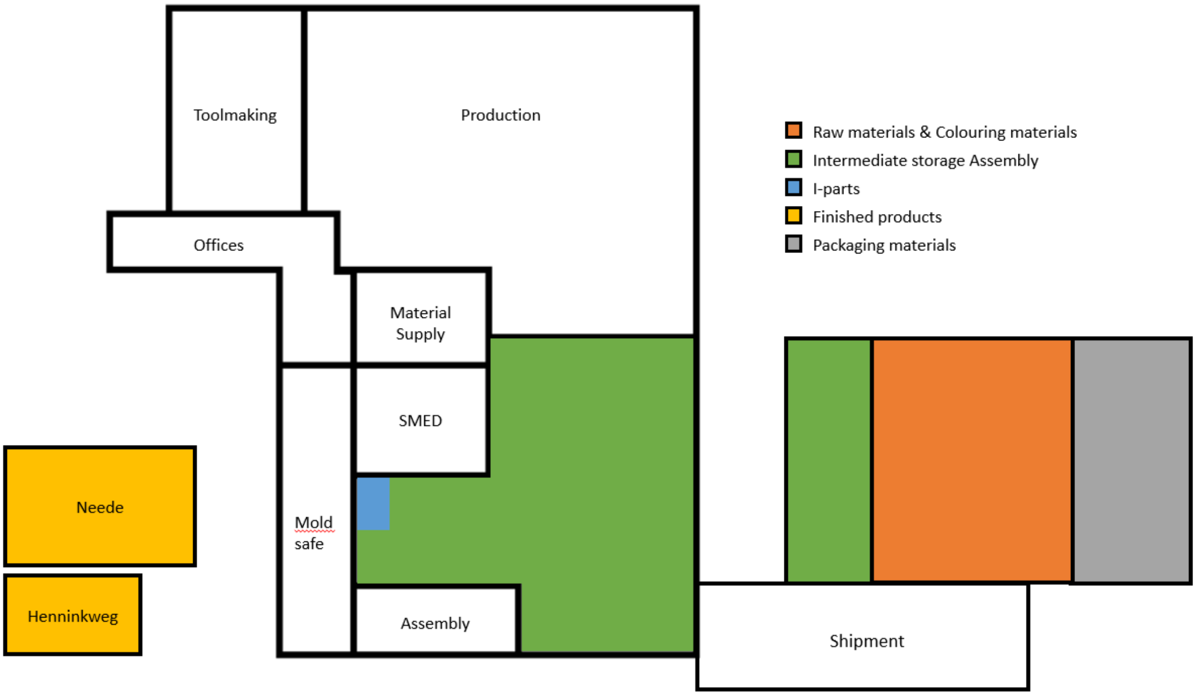

Figure 30 Lay-out 1B; Assembly materials located at internal warehouse

6.3.2. Scenario 2

The second scenario is based on the input of the management team of Timmerije. The meetings with the insurance company in November 2018 revealed that it will be hard to insure the Egginkhal as it is now. The team is therefore looking for alternative solutions in which the Egginkhal is removed or replaced. The three options explained within this scenario are all options that could be implemented on the short-term. The following 3 lay-outs are based on the following assumptions:

Assumption	**2A**	**2B**	**2C**
Assembly department at external location.	X		
Assembly department kept on-site.		X	X
Fire-load out of production facility.			X

In the previous scenario, no changes were made to the lay-out of the production facility. In the coming lay-outs a difference will be seen. Within these lay-outs a connection is created between the SMED, toolmaking and the production area. This, to prevent the molds from being transported throughout the entire production area, as was seen in section 4.1.

Lay-out 2A

The first scenario as created by the management team is based on the assumption that the assembly department is transferred to an external location. Recall from the analysis phase that the required space for the assembly department is less than the currently available space. The team therefore thought of placing the entire assembly department at an external location. In this way, the assembly intermediate stock will also be removed from the production facility location. The resulting facility lay-out is shown in Figure 31.

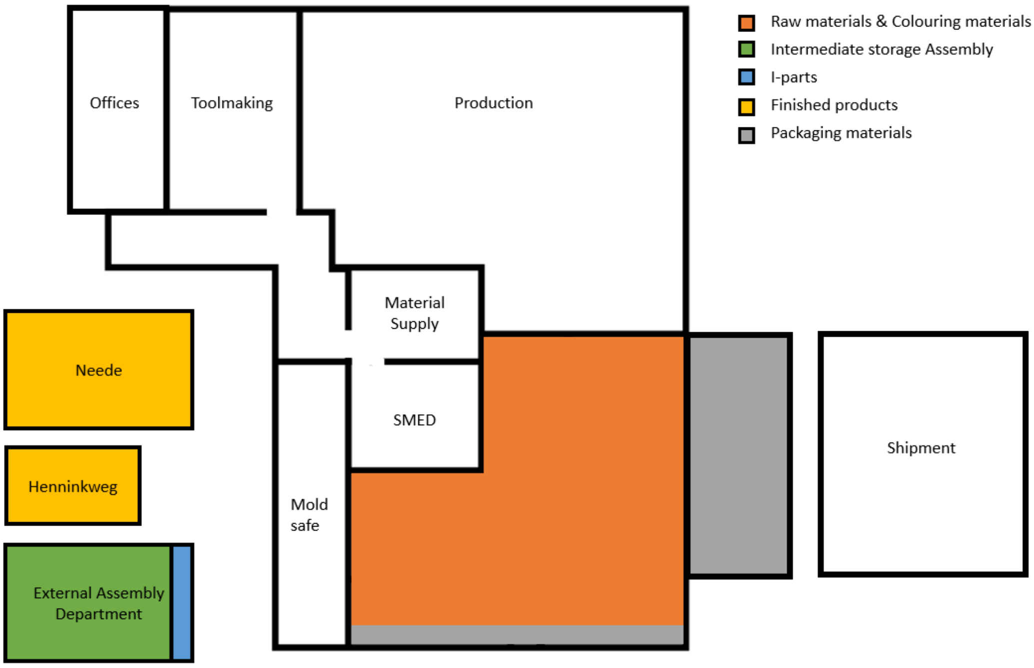

Figure 31 Lay-out 2A; Assembly department and products at external location

A new space-relationship diagram was created for this scenario, which is shown in Appendix F.1. Relationship diagram 2. By removing the assembly department from the production facility, 150 additional pallet locations can be created within the internal warehouse. The total amount of pallet locations inside this warehouse then increases to 1086. Following the new space-relationship diagram, the raw materials and the coloring materials are both placed inside the internal warehouse to keep them close to the material supply room. Following the assumption that a sprinkler system needs to be installed in case the raw materials are placed at the internal warehouse, the number of pallet locations inside the internal warehouse decreases by 315 from 1086 to 771. Whereas the raw materials and the coloring materials take up 705 pallet locations, there are 66 pallet locations left that could be used for the storage of packaging materials. The required number of pallet locations for the packaging materials is however higher (=812). Given the assumption that the Egginkhal is removed, a new warehouse should be created to store all packaging materials on-site.

The corresponding transportation distances and times are shown in Table 17. From this table it can be seen that the transportation- and relocation time of both the I-parts and the assembly materials decreases within this scenario. By doing so, the total transportation distance decreases by 32%.

Table 17 Lay-out 2A; transportation times per material type per month

Materials Flow	Distance (km)	Transportation time (hr)	Relocation Time (hr)
Raw materials	86	54	8
I-parts	7	5	6
Assembly	111	70	69
Packaging	9	6	4
Products	264	165	198
Total	**477**	**300**	**285**

Original distance (km)	700
Scenario distance (km)	477
Improvement (%)	**32**

Lay-out 2B

This lay-out differs from the previous one, in the way that it is assumed that the assembly department is kept on-site. In this scenario, the raw materials, coloring materials, packaging materials and the assembly intermediate stock then have to be stored on-site. In total, 2945 pallet locations should then be available inside the warehouses. Based on the space requirements from the analysis phase, additional space should be created for the assembly department. One of the possibilities is, to expand the assembly department within the current production facility, thereby decreasing the number of pallet locations of the internal warehouse. However, when keeping in mind the space-relationship diagram (Figure 28) and the information from lay-out 1A, it is more important to store the raw materials close to the material supply room. This means that a sprinkler system needs to be installed in here.

It is therefore chosen to relocate the assembly department, and to add the current assembly area to the internal warehouse. Just as in the previous lay-out, this additional space will then be used to store packaging materials. The assembly department is given a new building, in which the assembly intermediate stock will also be held. As a result, the assembly materials do no longer cross ways with other materials. Within this new building, room is also reserved for the storage of packaging materials, while the internal warehouse does not have enough pallet locations to store all packaging materials. A new space-relationship diagram is developed for this situation; this diagram can be found in Appendix F.2. Relationship diagram 2B. The corresponding facility lay-out is given in Figure 32. It is, within this lay-out, also possible to display the flow as described within the relationship diagram in Figure 26.

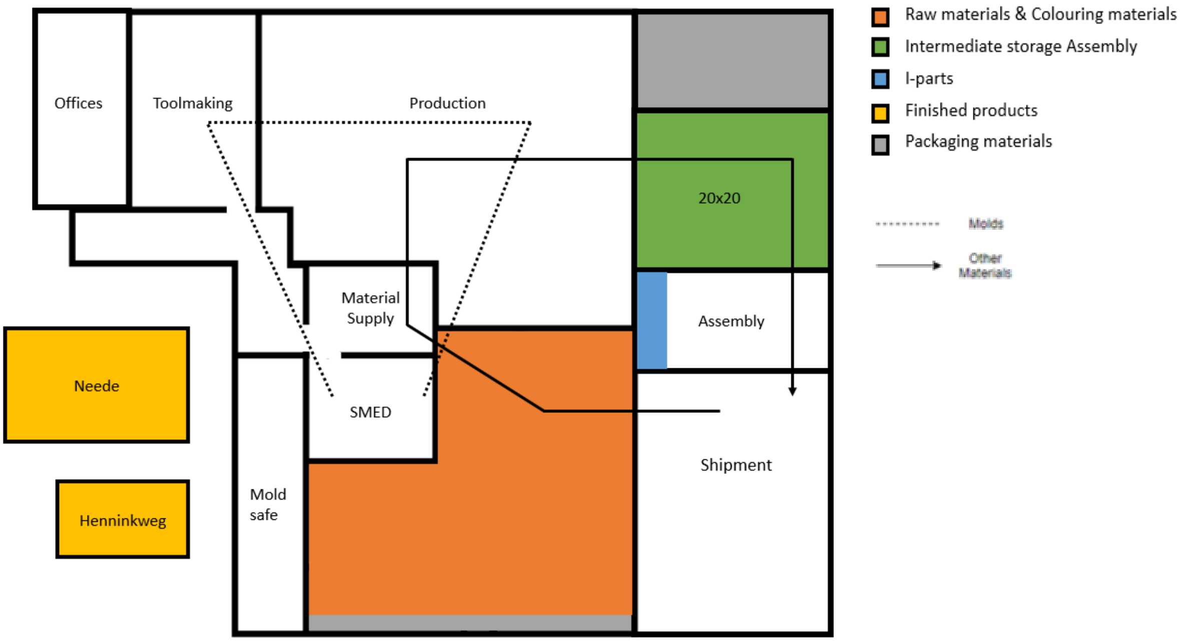

Figure 32 Lay-out 2B; new assembly department and additional warehouse

The size of the assembly intermediate stock warehouse is determined as follows. The number of required pallet locations is set to 1368. With an optimal utilization rate of 85% (Richards, 2011) and an assumed pallet size of 1 m^2, the required space becomes 1600 m^2. The currently available forklifts can reach over a pallet stack size of 4. Therefore, it is decided to split the 1600 m^2 over 4 layers. Then, the surface of the assembly area becomes 400 m^2. To cover this surface, both the length and the width of the (to be developed) assembly warehouse are set to 20 meters.

The additional warehousing space covering the packaging materials is calculated in a similar way. With the storage of 69 pallets inside the internal warehouse, additional space should be created for 812 pallets. By again assuming an optimal utilization rate of 85%, the required space is 955 m^2. When dividing this over 4 layers, an additional surface of 240 m^2 is needed. Therefore, 11 meters are in the length added to the assembly warehouse, to create the space needed for the pallets with packaging materials.

The transportation distances and times resulting from this lay-out, are given in Table 18. A comparison with the original transportation distance is made in the table next to it. This table shows that, when placing both the assembly department, and the assembly intermediate stock next to the production department, the total transportation distance decreases by 25%.

Table 18 Lay-out 2B; transportation times per material type per month

Materials Flow	Distance (km)	Transportation time (hr)	Relocation Time (hr)
Raw materials	86	54	8
I-parts	8	5	3
Assembly	152	95	73
Packaging	12	7	4
Products	264	165	198
Total	**522**	**326**	**286**

Original distance (km)	700
Scenario distance (km)	522
Improvement (%)	**25**

Lay-out 2C

The previous scenario is based on the assumption that it is best to place the raw materials close to the material supply room. These two areas are however the two most flammable places. Whereas the management team of Timmerije wants to remove all fire-load out of the production facility, it is best to place both the raw- and coloring materials and the material supply room elsewhere. Unfortunately, the management team states that relocation of the material supply room is a very costly operation, due to the infrastructure between the material supply room and the production department. Within this lay-out it is therefore chosen to describe a short-term solution in which the material supply room is kept inside the production facility. All raw materials and coloring materials are stored outside the production facility. The corresponding lay-out can be found within Figure 33.

Whereas the available space for the assembly department is currently limited, it is decided to extend the assembly department at its current location. This decreases the number of pallet locations of the internal warehouse, but this is taken into account when creating a new warehouse. Next to the raw materials that are stored inside the new warehouse, this warehouse is also used to store the packaging materials and part of the assembly intermediate stock.

Next to this new warehouse, a transportation area is created between the new warehouse and the already existing production facility. This area is placed here to control the movements that are now taking place within the production facility. In this way, the transport of finished products towards the shipping department, is separated from the transport of finished products towards the assembly department. The raw materials being transported to the material supply room will still cross ways with products from production.

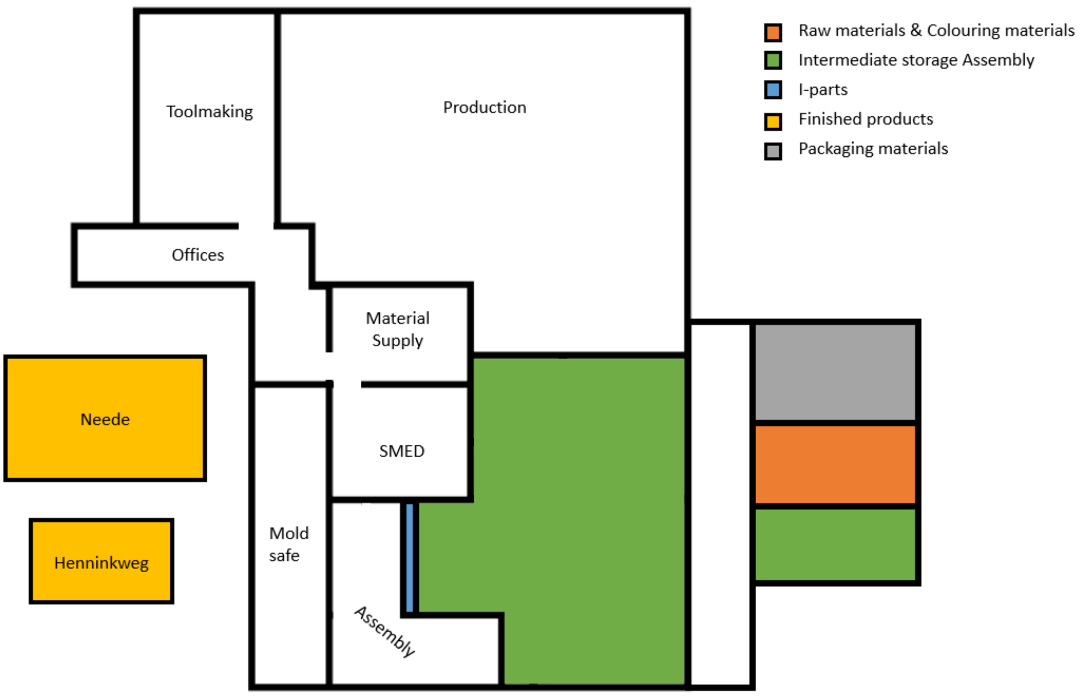

Figure 33 Lay-out 2C; extended assembly department and new warehouse

The warehousing space is calculated the same as before. By keeping an utilization rate of 85%, and a pallet size of 1 m^2, a warehouse of 2443 m^2 should be realized. This surface area is rounded to 2500 m^2, where after it is divided by a stacking height of 4 pallets. The required surface area then becomes 625 m^2. Based on the currently available space, it is decided to create a warehouse with a length of 42 meters and a width of 15 meters.

Material	Warehouse space (pl)	Warehousing space (m²)	Warehouse (%)
Assembly	500	588	24
Raw & Coloring	705	829	33
I-parts	60	71	3
Packaging	812	955	39
Total	*2077*	*2443*	*100*

The results, in terms of transportation distances and times, are shown in Table 19. It can be seen that this lay-out results in the same reduction in transportation distance as within lay-out 1B.

Table 19 Lay-out 2C; transportation times per material type per month

Material flow	Distance (km)	Transportation time (hr)	Relocation Time (hr)
Raw materials	119	74	8
I-parts	17	10	3
Assembly	225	141	74
Packaging	14	8	4
Products	264	165	198
Total	**639**	**397**	**287**

Original distance (km)	700
Scenario distance (km)	639
Improvement (%)	**9**

Overview Scenario 2

All 3 lay-outs described under this scenario, show that it is possible to reduce the transportation distance by at least 9%. When changing the location of the assembly department, it is even possible to decrease the transportation distance by 25 to 32%. The lay-outs that were developed under this scenario, are all alternatives that could be implemented on the short-term. The lay-out alternatives developed under the next scenario, also take into account possibilities for the future on the long-term.

6.3.3. Scenario 3

Whereas the scenarios under *Scenario 2* describe the short-term possibilities for improvement, this sub-section shows an option taking into account the long-term. The most important factors of influence here, are the fire-load and the location of the storage areas for the assembly department and the material supply room. While this option is looking at the long-term, the Miscanthus area is added to the facility area. Currently, this space is used for the growing of Miscanthus, but it might in the future be used to expand the production facility. This area is separated from the current site by a road. In case this area is used to expand the production facility, the road should be relocated so that the traffic flows around the facility. Timmerije already has a permit from the local government to do so. The costs for this operation are however high, while there is a water pipeline located below this road, which should then be relocated also.

This scenario is split into scenarios 3A and 3B, whereby 3A shows a lay-out option that fits within the current available area. Then, in scenario 3B, it is showed how the lay-out from scenario 3A can be expanded in the very long future. Other scenarios regarding future improvements were also created. In accordance with the supervisors of this research, it was however decided to exclude them from further research. These scenarios can be found in Appendix G.

In contrast to the previous two scenarios, the time spend on transportations and relocations is only given for scenario 3A. While scenario 3B shows a future production facility lay-out, it is unknown what the routing and frequency of movements will be. Therefore, the hours spend on transport and relocation are not given for this scenario.

Lay-out 3A

This scenario shows a lay-out option in which the production facility fits within the currently available space (Figure 34). In this option, the raw materials are kept at their current location. The material supply room is placed in between the raw materials warehouse and the production area. In this way, the SMED department can be extended and connected to the mold safe, and the drying machines are located closer to the right production area. The raw materials are then also kept closer to the material supply room. Even though a sprinkler system should then be installed, all materials still fit in the internal warehouse. New storage areas are created for the packaging materials, and the assembly intermediate stock. These warehouses are placed at the right side of the current production facility. A hall way is placed in between, to take transportations out of the production area. This hall way makes it also possible to transport the packaging materials from the shipment area towards the warehouse. Due to the expansion of the SMED department, part of the offices are no longer available. Those should therefore be created elsewhere. Within Figure 34, 3 possible locations are shown. In case the toolmaking or SMED departments needs to expand more, it is best to place the offices at location 2 or 3. When expansion of the mold safe is necessary, the offices can be placed at location 1 or 3. Location 3 is added as an option, while the offices have (in terms of transportations) no direct connection with the other departments.

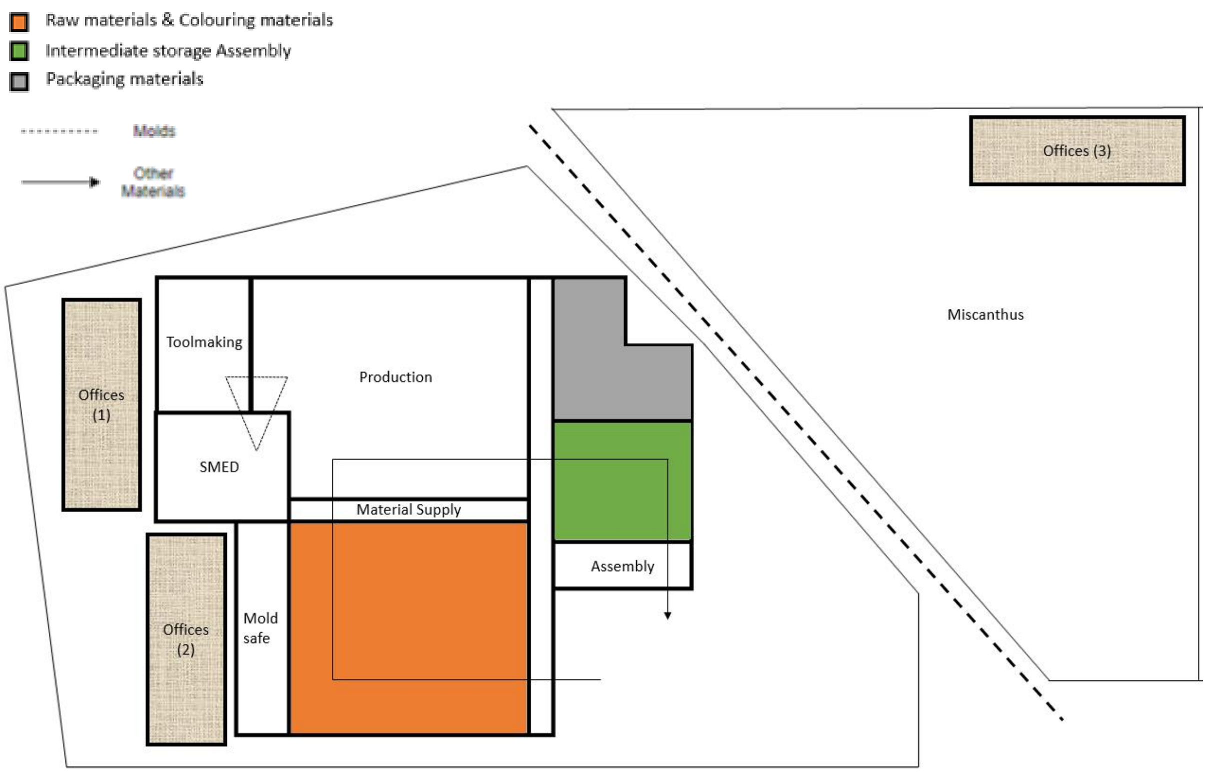

Figure 34 Lay-out 3A; Relocation of toolmaking, SMED and material supply departments

The relationship diagram is also added to Figure 34. It can be seen that the relationships, as described within Figure 26 are obtained for both molds and materials. The corresponding results with regard to the transportation distance and time are given within Table 20. It shows that the same decrease in transportation distance is obtained as in Lay-out 2A. Within that lay-out the assembly department is however no longer placed on-site.

Table 20 Lay-out 3A; transportation times per material type per month

Material Flow	Distance (km)	Transportation time (hr)	Relocation Time (hr)
Raw materials	36	23	8
I-parts	8	5	3
Assembly	152	95	74
Packaging	15	9	4
Products	264	165	198
Total	**475**	**297**	**287**

Original distance (km)	700
Scenario distance (km)	475
Improvement (%)	**32**

The following two lay-outs (3B-1, 3B-2) were developed on the basis of lay-out 3A, whereby in both lay-outs possibilities for expansion of the production facility are shown. Within both lay-outs, a new production area is placed to the right side of the assembly warehouse and assembly department. The difference between B-1 and B-2 are the locations of the toolmaking, SMED, and assembly department (and assembly intermediate stock).

Lay-out 3B-1

This lay-out shows how the production facility from scenario 3A can be expanded in the long future. Figure 35 shows that the warehouses for packaging materials and intermediate stock are kept at the same location. A new production area is added to the right side of these warehouses. A new material supply room and small warehouse for the raw materials are added here also. In this way, the assembly department and the packaging materials can be reached from both sides. However, the distance between the production area and the toolmaking and SMED departments increases. It might then be necessary to create a toolmaking and SMED department at the right side of the production facility also. In this way the molds and materials are not transported via the same ways.

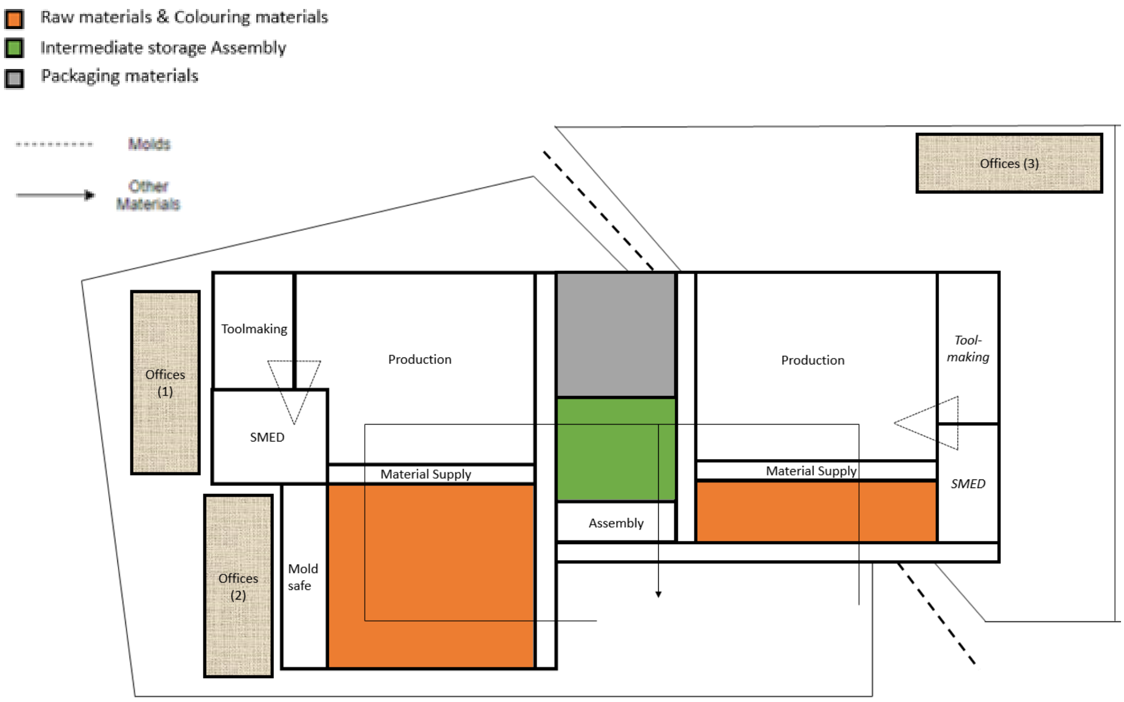

Figure 35 Lay-out 3B-1; expanded production area

Lay-out 3B-2

This lay-out shows how the distance between the toolmaking and SMED department and the new production area is decreased in a different way. Within this scenario, these departments are located in the middle of the building, whereas the assembly department is now split into two separate locations. Both are connected to one of the two production areas. The mold safe is relocated also, so that it can easily be reached by the SMED, toolmaking department and the production department. The original location of the mold safe can then be used to create additional offices, or it can be used to store raw materials.

However, when looking at the relationships between the different departments, it can be seen that the number of crossings increases. Also, while there are no docking stations on the left side of the production facility, all products from the left production area still need to be transported throughout the entire production facility. They thereby cross ways with the molds that are being transported. The same counts for the products coming from the production area on the right, for which no assembly is needed. Therefore, when looking at the long-term solution, it is recommended to look at scenario 3B-1.

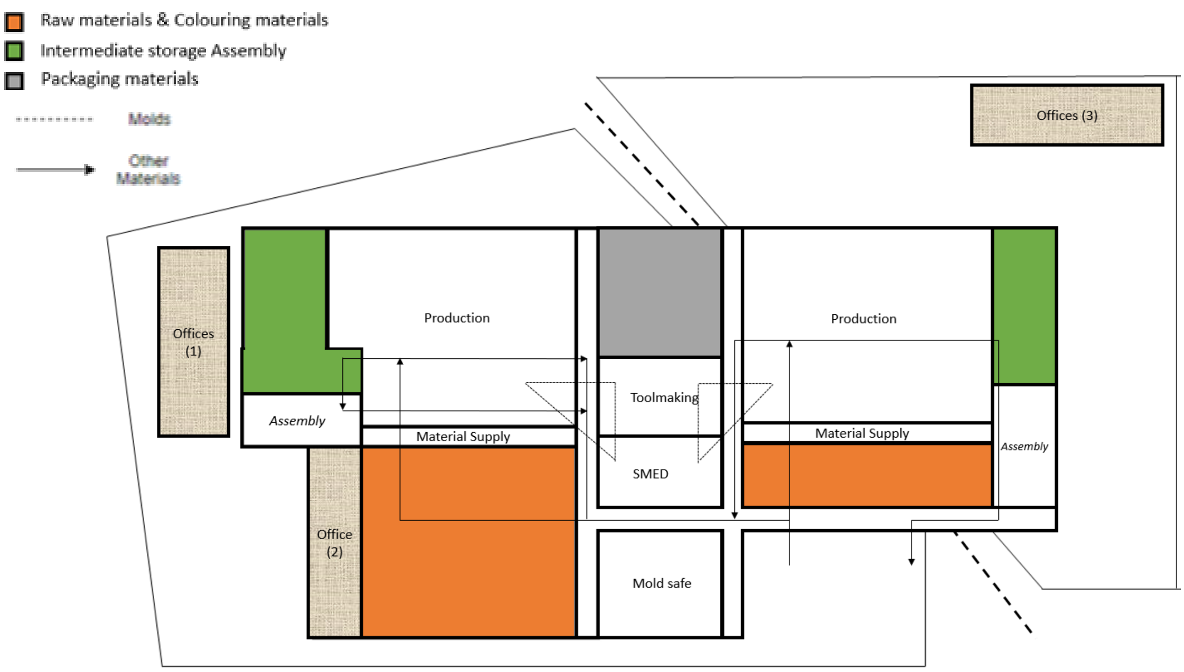

Figure 36 Lay-out 3B-2; location change of SMED, toolmaking and mold safe

Overview Scenario 3

Under scenario 3, a look on the long-term was taken. At first, a lay-out alternative was given that fits within the current available space. The decrease in transportation distance of this lay-out was thereby the same as within lay-out alternative 2A (=32%). The other 2 lay-outs, 3B-1 and 3B-2, were developed as further developments of lay-out 3A. Transportation distances and times were not calculated for these lay-outs, while they contain new production areas from which it is unknown what the influence on the number of transportations is.

6.4. Conclusion

From the previous chapter it followed that multiple bottlenecks are influencing the process efficiency of Timmerije. It was seen in there that part of the problems are a result of the current facility lay-out. Within this chapter, the focus therefore was on the development of alternative lay-outs, to eventually improve the process efficiency. The Systematic Lay-out Planning (SLP) was chosen as a method to develop these lay-outs.

At the beginning of this chapter, an explanation regarding this method can be found. There, it is explained that this method consists of 3 phases. The first phase (the analysis phase) was handled with in sub-section 6.1. Within this phase, all information regarding material flows, departmental relationships and the required and available space of the departments is collected.

This information is used in the second phase (the search phase) that was explained in sub-section 6.2. The aim of this phase is to combine all information from the first phase. Next to that, the practical limitations and modifying considerations are listed in here, to keep an overview of all other factors that have to be taken into account when designing a new / improved facility lay-out.

Within the last phase of the SLP method, development of the alternative lay-outs took place. The result of this phase was given in sub-section 6.3. There, 8 different lay-out options were shown. Those lay-outs were developed on the basis of 3 different scenarios. From 6 of these lay-outs the transportation distances and times were calculated. An overview of the results can be found in Table 21.

Table 21 Overview of improvement (%) per month per lay-out alternative

Lay-out alternative	Transportation Distance (km)	Improvement (%)	Total Time (hr.)	Difference (hr.)	Difference (ft)
1A	588	16	652	130	0.9
1B	638	9	686	96	0.7
2A	477	32	585	197	1.4
2B	522	25	612	170	1.2
2C	639	9	684	98	0.7
3A	475	32	584	198	1.4

Based on Table 21, it would be best to implement scenario 2A or 3A, while this would result in the highest decrease in transportation distance with regard to the initial (current) lay-out. This table thereby also shows that the amount of time spend on the transportations is then decreased by 198 hours. This is equal to a reduction of 1.4 fte in personnel.

However, when investing in a new (or change in) facility lay-out, there are other factors to be taken into account also. Therefore, before choosing the best lay-out alternative, the alternatives are compared to each other on other factors first. This step is performed by the Analytic Hierarchy Process which is described within the next chapter.

7. Analytic Hierarchy Process

Question 5: "What are the advantages and disadvantages related to the developed alternatives?"

Within the previous chapter many different lay-out alternatives were mentioned, and ranked based on the improvement regarding the transportation distance. Within this chapter, the focus turns to other factors that influence the decision regarding the best alternative lay-out. The aim of this chapter is to provide an overview of all the advantages and disadvantages related to the alternatives to rank them accordingly.

A choice can be made between various Multi-Criteria Decision-Making (MCDM) techniques. Within the paper of (Velasquez & Hester, 2013) a literature review of common MCDM methods is found. It describes the advantages and disadvantages of the identified methods, and it is explained how the common applications relate to their relative strengths and weaknesses. One of the methods described in here, is the Multi-Attribute Utility Theory (MAUT), which is a very popular MCDM approach. It is an utility theory that can decide the best course of action in a given problem by assigning a utility to every possible consequence and calculating the best possible utility. Its major advantage is that it takes uncertainty into account. This however makes this method extremely data intensive.

Another also frequently used method, is the Analytic Hierarchy Process (AHP). It is "a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales" (Saaty, 2012). Its main advantage is its ease of use, which allows the decision makers to weight coefficients and compare alternatives with relative ease. It is thereby less data intensive as MAUT. Regarding the focus on efficiency, the Data Envelopment Analysis (DEA) method would be another great method to compare the alternatives. However, the efficiency is not the only important factor and therefore it was chosen not to use this method within this research. Other MCDM methods were not taken into account either, while they are less common in use and not relevant to the subject of this research.

The AHP method fits best to this research, while it makes it possible to rank the alternatives on different criteria, whereby the weight of the criteria is taken into account as well. The method consists of 6 steps (E. Mu, 2017) which are the basis for the sub-sections within this chapter. At the end of this chapter an overview can be found that shows a ranking of the previously explained lay-out alternatives. The conclusion and recommendation regarding the best alternative are explained within the next chapter.

7.1. Developing a model

Within the first step of the AHP method a model is developed that contains the hierarchy for the decision. The decision is thereby broken down into:

1. Goal
2. Criteria
3. Alternatives

The developed model is given in Figure 37. The criteria given within this model have been developed in accordance with the management team of Timmerije.

It can be seen that some of the factors have already been discussed before, whereas others are derived from the key factors contributing to the vision of Timmerije. These key factors were developed several years before, by a multi-disciplinary team. An overview of all the key factors can be found in Appendix H. The criteria as mentioned within Figure 37 contribute to the following key points; zero waste, logistics and social & healthy.

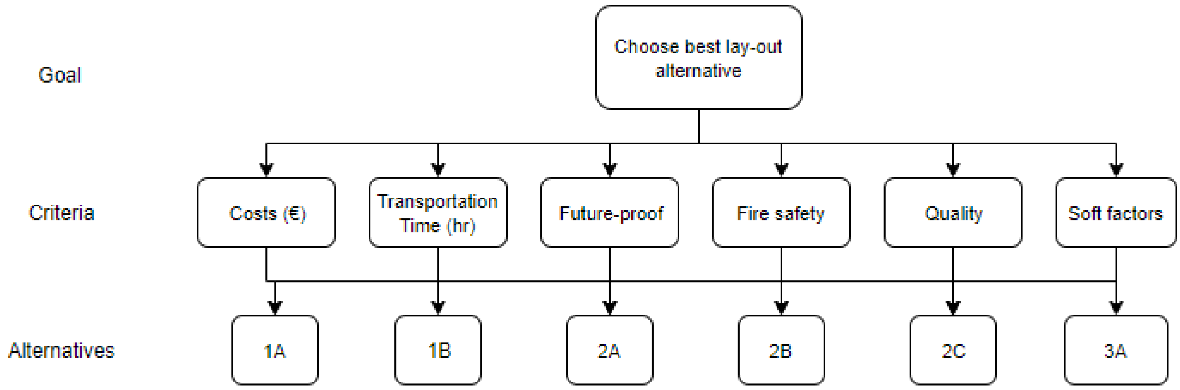

Figure 37 AHP Model

The criteria are explained as follows:
- Costs (€): building costs new warehouse, removing warehouse
- Transportation time (hr): for the relocations of pallets
- Future-proof: are there still possibilities to expand in the future?
- Fire-safety: is the fire-load removed from the main facility?
- Quality: is the quality of products guaranteed?
- Soft factors: working environment, conditioning of products

From this model it can be seen that lay-outs 3B-1 and 3B-2 are left out of consideration. As was already stated within the previous chapter; these are lay-outs developed as extensions to lay-out 3A. They are therefore not taken into account within the decision-making process.

7.2. Criteria weights

The second step of the AHP method is to derive priorities for the criteria. To obtain the relative importance of each criterium, they are compared pairwise. Every comparison is thereby given a score; the scoring range is given in Table 22. These scores are based on the pairwise comparison scale of (Saaty, 2012). In there, a scoring range of 1-9 is used, but within this research the scoring range is decreased to a range of 1-5. The range is limited, while several employees of the management team of Timmerije were asked to perform this step. From their scores, the average is taken for each pair. By limiting the scoring range, the employees are forced to make a distinction between the criteria. Eventually, this makes the average score more reliable.

Table 22 Judgment scores for criteria and scenarios

Verbal judgment	Score
Strongly more important	5
	4
Moderately more important	3
	2
Equally important	1

The results of the pairwise comparisons are presented in Table 23. This table is to be read from left to right. As an example: the cost factor is considered to be moderately (=2.40) more important than the transportation time. The importance of the transportation time over the costs then becomes 1/2.40 =0.42. An explanation on the calculation of the priorities can be found in appendix H.2. Normalized matrix. From Table 23 it becomes clear that the fire safety is considered to be the most important factor.

Table 23 Pairwise comparison of criteria

	Cost	Transportation Time	Future-Proof	Fire Safety	Quality	Soft factors	**Priority**
Cost	1.00	2.40	0.40	0.25	1.96	0.88	**0.112**
Transportation Time	0.46	1.00	0.74	0.90	1.50	1.46	**0.127**
Future-Proof	2.75	2.88	1.00	0.67	2.13	2.80	**0.212**
Fire Safety	4.00	3.83	2.00	1.00	3.25	3.25	**0.309**
Quality	1.40	1.31	0.93	0.36	1.00	1.63	**0.119**
Soft factors	1.25	1.56	1.49	0.34	0.88	1.00	**0.122**

7.3. Local priorities

Within the previous sub-section the priority of each criterion was determined. This sub-section focuses on the priority of each lay-out alternative. These are so-called local priorities that show the comparison score of one lay-out with regard to another for every criterion separately. These local priorities are also based on the comparison scale from Table 22. The end result of this section is given within Table 24, whereas the intermediate matrices are shown in appendix H.3. Local priorities matrices. It shows that lay-out alternative 3A obtains the highest score on almost all criteria.

Table 24 Local priorities for every criterium per alternative lay-out option

Alternative	**Cost**	**Transportation Time**	**Future-proof**	**Fire Safety**	**Quality**	**Soft Factors**
1A	**0.282**	0.071	0.051	0.060	0.073	0.057
1B	0.263	0.047	0.091	0.113	0.093	0.057
2A	0.097	**0.295**	0.066	0.091	0.043	0.093
2B	0.132	0.180	0.271	0.151	0.309	**0.313**
2C	0.187	0.112	0.176	**0.385**	0.161	0.167
3A	0.038	**0.295**	**0.345**	0.235	**0.320**	**0.313**

7.4. Model synthesis

The aim of this step is to obtain the overall priority of each alternative. Therefore, the local priorities from the previous step are multiplied by the weight of the criteria that was obtained within sub-section 7.2. Then, a weighted value per criterion per lay-out alternative is obtained. The priority of each alternative is then taken as the average of all criteria scores belonging to that alternative. The result of this step can be found in Table 25. From this table it can be concluded that lay-out 3A is the best alternative solution, while it obtains the highest overall priority score.

Table 25 Overall priorities given per alternative lay-out option

Alternative	Cost	Transportation Time	Future-proof	Fire Safety	Quality	Soft Factors	**Overall Priority**
Criteria Weight	*0.112*	*0.127*	*0.212*	*0.309*	*0.119*	*0.122*	-
1A	0.282	0.071	0.051	0.060	0.073	0.057	**0.086**
1B	0.263	0.047	0.091	0.113	0.093	0.057	**0.108**
2A	0.097	0.295	0.066	0.091	0.043	0.093	**0.107**
2B	0.132	0.180	0.271	0.151	0.309	0.313	**0.217**
2C	0.187	0.112	0.176	0.385	0.161	0.167	**0.231**
3A	0.038	0.295	0.345	0.235	0.320	0.313	**0.263**

7.5. Sensitivity analysis

In the previous sub-section, it was concluded that lay-out alternative 3A would be the best way to improve the production facility lay-out. This outcome however depends on the weights of the criteria, which were determined on the basis of the opinion from members of the management team. Therefore, a sensitivity analysis is part of the AHP method. Within this analysis it is seen how changes in the criteria weights could affect the end result. In this way, the rationale behind the obtained results can be understood (Saaty, 2012). The following cases have been tested:

1. What if all criteria are equally important?
2. For all lay-outs to be equally important, what should the weights be?

The answer to the first question is that even if all criteria are equally important, lay-out alternative 3A is still the best option for implementation (Table 26). Only if the importance of the fire-safety criterium is decreased to less than 0.167, alternative 2B would become the best option for implementation. When looking at the results for question 2 it shows that, to have all lay-outs within the same priorities range, the cost criterium has to become 4 times as important (Table 27). Next to the cost criterium, the transportation time also needs to become 3 times as important as it is now. The importance of the quality, soft factors and the future-proof criterium decrease to a minimum. The importance of the current most important criterium - Fire Safety - is decreased by 67%.

Table 26 Case 1; Priorities based on the criteria having equal weights

Alternative	Original Priorities	Equal Weights Priorities
1A	0.086	0.099
1B	0.108	0.111
2A	0.107	0.114
2B	0.217	0.226
2C	0.231	0.198
3A	**0.263**	**0.258**

Table 27 Case 2; Weight of criteria for obtaining equal priorities for all lay-out alternatives

Alternative	Cost	Transportation Time	Future-proof	Fire Safety	Quality	Soft Factors
Original	0.112	0.127	0.212	**0.309**	0.119	0.122
Equal Alternatives	**0.457**	0.390	0.048	0.101	0.002	0.002

7.6 Making a Final Decision

The last step of both the SLP and the AHP is to make a decision on the best lay-out alternative. This step thereby provides an answer to sub-research question 6:

"Regarding improving the process efficiency, what would be the best alternative?"

Based on the information from both chapters 6 and 7, it can be concluded that lay-out alternative 3A would be the best option to be implemented at Timmerije. First of all, when comparing the transportation distance of this lay-out alternative with the current situation, it is seen that the transportation distance can be reduced by 25% when implementing this lay-out. When also taking into account other factors, it showed that lay-out alternative 3A also obtains the highest score. Whereas the importance of the other criteria were determined together with the management team of Timmerije, it is recommended to implement lay-out alternative 3A.

7.7. Overview

Whereas the focus of the previous chapter was on the development of different lay-out alternatives, this chapter created a ranking of these alternatives. This has been done by the aim of the Analytic Hierarchy Process.

The method starts with the development of a model, which serves as a framework for the rest of the method. In here, the goal, criteria and alternatives are presented together. From there, the importance of each of the criteria is calculated. While this research is important for the management team of Timmerije, they were involved within this process. They have been asked to make pairwise comparisons between the criteria. It showed that the fire-safety criterium is seen as the most important criterium.

Thereafter, the lay-out alternatives from the previous chapter were compared with each other, taking into mind each criterium separately. This resulted in a priority ranking of all lay-out alternatives. Within sub-section 7.4., the criteria weights and the priority ranking were combined into one overview. From this overview it could then be concluded that lay-out alternative 3A is the best lay-out option for implementation. The next chapter continues on this conclusion.

8. Conclusion

The aim of this chapter is to answer the main research question that was stated within chapter 2.

"What improvements can be made in terms of efficiency to the lay-out of the production facility of Timmerije to transcend the next level in plastics?"

Within that chapter it was described that the management team of Timmerije has the *feeling* that the available space is limited. To see whether this feeling is correct, a look was taken at the Overall Process Efficiency (OPE). It was seen that 3 process steps contribute to this factor; machines, assembly and logistics. The process step "Machines" was left out of consideration during this research, while this factor does not directly contribute to the feeling of limited space.

It showed that it is important to take into account the process step "Assembly". Within chapter 3 it was shown that *the available space for this department is less than the required space*. In here, the productivity level of this department has been researched as well. It showed that, to keep the productivity level constant, additional space is needed. There will then be room for all assembly employees to work in-house, and the employees will be distracted less, while they have more working space. By increasing the size of this department, it will also no longer be necessary to change the lay-out of this department at the end of every week. Within the lay-out that was eventually chosen, it can be seen that the working space of the assembly department is increased.

Conversations with the management team of Timmerije showed that the feeling of limited space is mostly created by a lack of knowledge regarding the internal logistics. This process step was therefore measured by calculating the total transportation distance. The total transportation distance thereby depends on the locations of materials and departments, and the type of transport that is used. Within this research it is assumed that forklifts are the only way of transport, while the current buildings are not suitable for another type of transportation. Within the developed lay-out alternative, the total transportation distance decreases by 32%.

A closer look has been taken into the locations of departments and materials in chapters 4 and 5. The spaghetti diagram at the beginning of chapter 4 showed that many departments make use of the same routes. The forklifts transporting the molds and materials thereby cross ways at several places inside the production facility. Next to that this causes the waiting time to increase, the safety is also put at risk. Whereas the toolmaking department, SMED department and the production area are not directly connected to each other, the molds from the mold safe have to be transported throughout the entire production area to get them at the toolmaking department. Within chapter 4 it was also shown that the raw materials are located at many different locations. This causes the transportation distance to increase. In the final lay-out alternative, the SMED department, toolmaking department and the production area are directly connected to each other. It can be seen that the number of crossings between molds, and materials and products is kept at a minimum. In this way, the safety of employees also increases.

Chapter 5 then focused on the warehousing processes, and it was seen that the total transportation distance of materials and products currently is 700 km per month. This distance was then also expressed in the number of hours (=782 hours per month), to see whether this outcome comes across the expectations of the management team of Timmerije. While there are currently 6 employees working for 36 hours per week each to the relocation of all materials and products, this number of transportation hours is reasonable. To increase the OPE, the transportation distance (and thereby the transportation time) should be decreased. Therefore, alternative lay-outs were created by means of the Systematic Lay-out Process (SLP) within chapter 6.

The SLP method starts with an explanation regarding the different flows of materials and molds. It showed that there is an important relationship between the material supply room and the location of the raw materials. It was concluded that it is more important to store the raw materials close to the material supply room, than storing the assembly products close to the assembly department. This method also takes into account the *available space and the required space* of departments. Conform the feeling of the management team of Timmerije, it showed that next to the assembly department, additional space is also needed for the storage of products and materials on-site. Within the development of lay-out alternatives it was therefore assumed that all final products are directly transported towards the customer.

In total, 6 different lay-out alternatives were created that have been compared to each other in chapter 7 by means of the Analytic Hierarchy Process (AHP). The alternatives have thereby been scored on the basis of several criteria. It turned out that lay-out alternative 3A is the best option to be implemented at Timmerije. This lay-out is shown again within Figure 38.

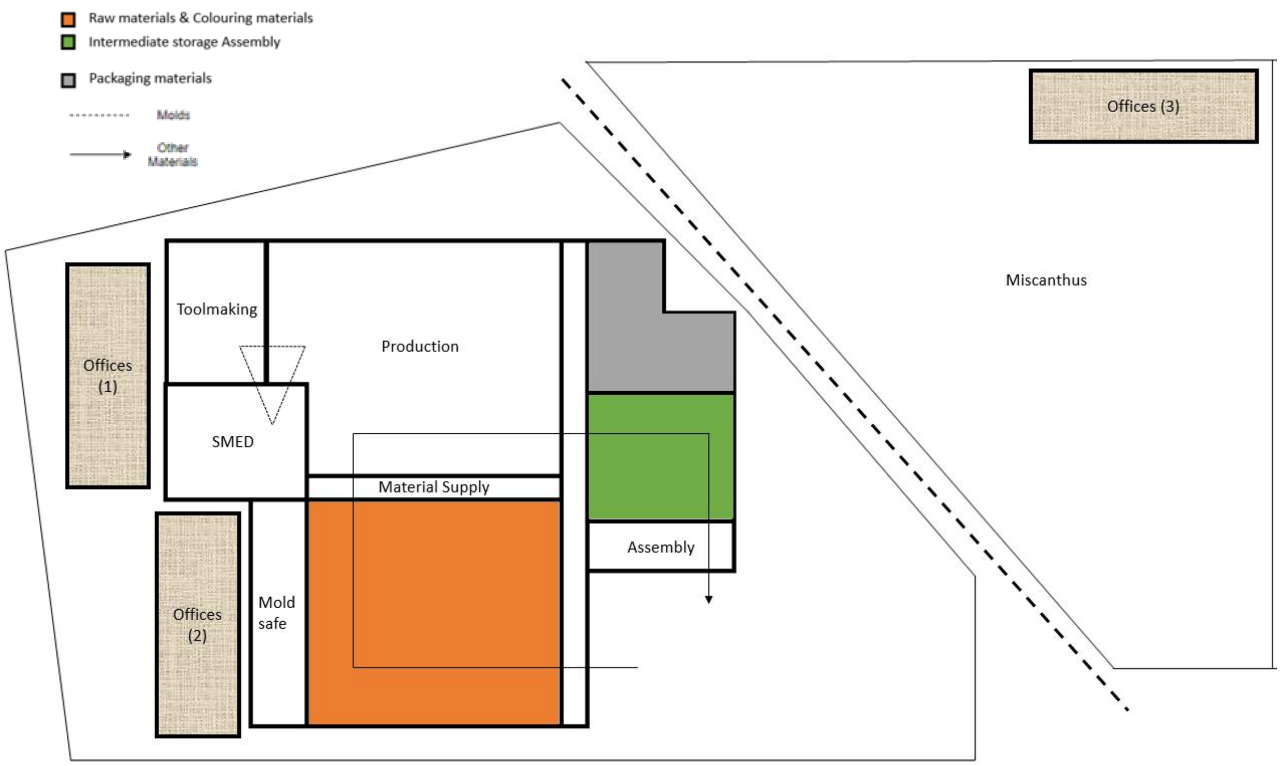

Figure 38 Lay-out 3A; including flow of materials and molds

With regard to the current facility lay-out, the following changes are recommended:

1. Connect SMED department directly to the toolmaking department, production area and the mold safe.
2. Spread the material supply room over the length of the production area.
3. Remove the Egginkhal and create a new warehouse to the right of the production area for the storage of packaging materials and assembly materials.
4. Connect a new assembly department to this warehouse and create additional warehousing space at the internal warehouse.
5. Use the internal warehouse for the storage of raw materials.
6. Build new offices at one of the 3 possible locations.

When implementing this lay-out, the transportation distance is decreased by 32% (from 700 km to 475 km). The amount of time spend on the transportations of molds, materials and products is thereby decreased from 782 hours to 584 hours. This is equal to a reduction of 1.4 fte in personnel. The personnel costs that could be saved by this alternative lay-out, could be used to create the new warehouse that is needed to store the materials and products on-site, and to provide additional workspace for the assembly department.

Throughout this research, it showed that the **fire-safety** is also an important parameter to be taken into account. Within this lay-out alternative, the fire-safety is increased by the relocation of the Egginkhal by a new warehouse, which could be build conform the requirements of the insurance company. Still, the fire-load is not removed out of the entire facility, while the material supply room and the raw materials are placed within the facility. However, the material supply room is no longer in the center of the building and the fire-safety of these departments could be increased further by the installation of a sprinkler system.

Next to the transportation distance, the **waiting time** of forklifts is also decreased, while products and molds cross ways less (Figure 39). Raw materials can flow directly from shipment towards the storage area, from where they can directly be transported towards the material supply room, without coming across other materials or products. Products coming from production can directly be brought into the assembly intermediate stock area, or shipped towards external locations. They thereby only cross ways with packaging materials, in case these materials are coming from the shipping department. Unfortunately, molds will still cross ways with employees and products within the production area. The number of crossings is however reduced to a minimum, while the molds do no longer have to be transported throughout the entire production area when being brought to the toolmaking area for repair or maintenance.

The **productivity** of the assembly department can be kept at the same level, while additional space for this department is created. In this way it is possible to create assembly lines, which do not have to be rearranged every week as is the case now. This will also positively influence the quality of products, while the lines and way of working will then be the same every time a product is produced. The additional space also makes it possible to have all assembly employees working on-site. While the assembly intermediate stock is located next to the assembly department, the products can be brought in just-in-time, and less time is spend on the transport of materials towards this department.

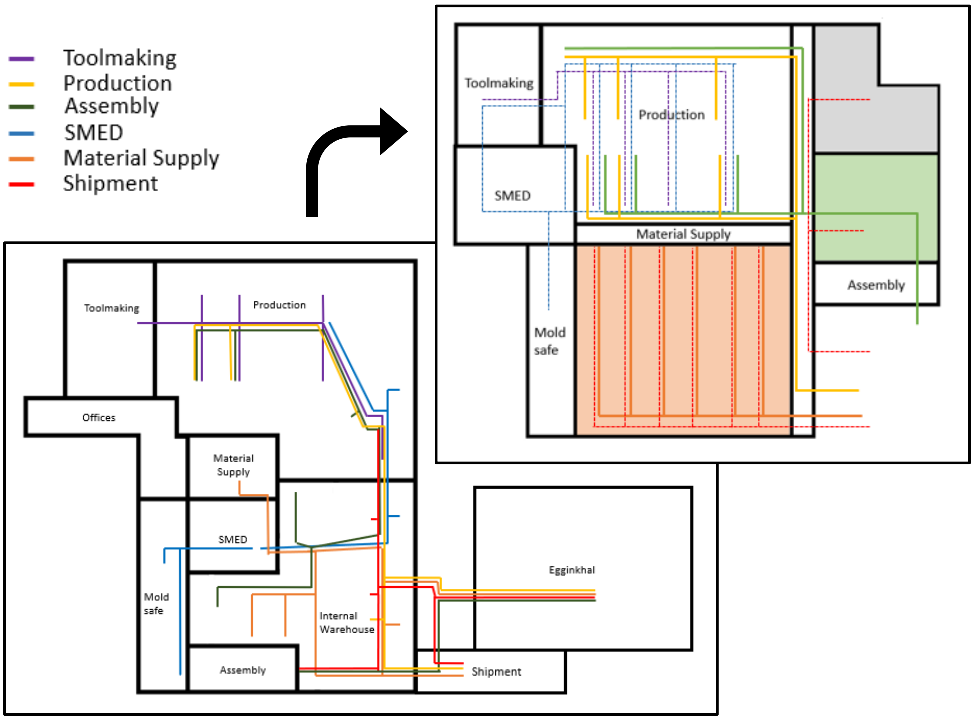

Figure 39 Departmental flows per facility lay-out

This lay-out also differs from the current facility lay-out, in the way that finished products are no longer stored on-site. At the moment the products are finished at either the production area, or at the assembly department, they will be transported towards an external location directly. It is decided to do so, while this is the fastest way to create additional warehousing space on-site for the materials and the assembly intermediate stock. Next to a change of facility lay-out, it was also found that there are other ways to improve the process efficiency. From importance here, was the conclusion that there are many molds stored on-site, which have not been used over the last years. There are thereby also products and materials kept in stock, that have not been sold over the last years. It showed that in total 80 pallet locations are in use by these products. The process efficiency could therefore be improved in terms of the storage of materials and products. A look could thereby be taken at the times the products, materials and molds need to be stored by Timmerije.

The implementation of lay-out alternative 3A can be spread over several years. A roadmap is therefore given for the short-, mid- and long-term. The lay-outs corresponding to the different terms are shown in Figure 40.

<u>Short-term (1 – 2 years):</u>

1. Place the raw materials, and the coloring materials close to the material supply room.
2. Store all finished products directly at an external warehouse.

Research showed that it is most important to have the raw materials close to the material supply room. While there is not enough space available on-site, it is chosen to store all finished products directly at an external warehouse. These improvement possibilities only require changes to the internal logistics and routing, and the buildings are remained the same as before.

Mid-term (3- 5 years):

1. Replace the Egginkhal by a new warehouse in which the packaging materials and the assembly intermediate stock are stored.
2. Create a new assembly department next to this warehouse.
3. Connect the toolmaking department, SMED, and production area to each other.
4. Replace the offices.

Implementation of all these steps results into facility lay-out alternative 3A. These steps require changes to the production facility and the warehouses.

Long-term (>5 year):

1. Expand the production area
2. Create new toolmaking and SMED department.

In case additional space is needed for the production department, it is recommended to build this area to the right of the new assembly warehouse. Thereby, it is also recommended to create a toolmaking department and SMED at this side of the facility, to prevent the mold, products and materials flow from interrupting each other. This lay-out is shown within Figure 40.

Figure 40 Roadmap explained by lay-out figures

9. Discussion

Chapter 7 showed that the management team of Timmerije sees the fire-safety as the most important criterium. However, to realize the suggested lay-out, an investment in new buildings is needed. The sensitivity analysis in chapter 7 already showed that in case the cost criterium becomes 4 times more important, all developed lay-outs have the same priority. Then, it does not matter which of the developed alternatives is implemented.

Within the development of the alternative lay-outs it was assumed that all finished products are directly transported towards an external location. Additional warehousing space should then be rented, while the current warehousing space is less than required. The costs related to this are not taken into account here, while this is assumed to be the same within all scenarios. This will however be from importance in case the cost criterium becomes an important aspect.

It is assumed within the recommended lay-out alternative, that a sprinkler only needs to be installed inside the internal warehouse. Currently, it is however not entirely clear if a sprinkler system is to be installed, and at what places it should then be installed. At the moment this is known, the costs might differ.

The transportation distances and times have in this research been estimated on the basis of the scanner information. From this information, it is only possible to create paths between the from- and to location of a material. The route is thereby taken as the shortest path possible. It is however not clear, if this is the same route as was taken by the forklift employee. Next to this, an average speed of 4 km/hr was taken as the speed of the forklifts. This is an average value which might differ among the types of materials being transported. The decrease in transportation distance will only be achieved in case every employee follows the suggested routes. Thereby, it can take some time before the transportation distance is actually reduced, while the employees have to get familiar to the change in lay-out.

Within the lay-out alternatives it is assumed that the internal relocations within certain departments are no longer necessary. These relocations have therefore not been taken into account during the calculation of the transportation time. In case no improvements are made on these relocations, those still have to be taken into account. Also, the transportation time is calculated by multiplying the distance with the number of pallets being transported. In reality however, there are also cases in which two pallets are transported at the same time. This might have a positive influence on the amount of time spend on the transportations.

A department that is also not taken into account is the recovery department. In the future it is assumed that the quality check at the machines is performed well such that recovery of the products is no longer needed. Also, the amount of relocations towards this department is relatively small, which makes the location of this department less important.

10. Recommendations for further research

At the beginning of this research, it was tried to determine the transportation distances of forklifts by the aim of beacons. The costs for such a system were however found to be relatively high. In case it is possible to implement this system in the future, the transportation routes per forklift can be determined. It will then also be known where a forklift is in case it is not transporting any material, product or mold. The transportation distance and time can then be monitored continuously, which increases the accuracy of the measurement. It can then be stated with more confidence what change in transport time could be obtained by the suggested lay-out.

It was recommended to build a new warehouse and assembly department to the right of the production area. To further increase the efficiency of operations, it is important to have a look at the at the placement of materials inside this warehouse. A difference could thereby been made between slow- and quick movers, and made-to-stock and made-to-order products.

The storage systems have not been taken into account during this research also. Several warehousing systems are currently in use:
- Push-back
- Block-stacking
- Pallet racks

Further research into these types of storage systems could be done to improve the warehousing process further.

Within this research the focus has been on the internal logistics and the warehousing process. Chapter 3 also showed another process step “Machines” that contributes to the OPE. This process step is measured by the Overall Equipment Effectives (OEE) which depends on the quality efficiency, machine availability and relative performance of the machines. Even though this measure focuses on the effectiveness of the machines, it also contains factors that influence the OPE. It was discussed within chapter 3 that the set-up time of the molds on the machines is a factor that might be improved. In case it is possible to reduce this time, the number of actual production hours increases. This time could then be used for the production of products.
Another factor that might not only influence the OEE, but also the OPE is the quality efficiency. The quality efficiency focuses on the products that do not meet the requirements as set by the customer. This factor influences the OPE in the way that time is spend on the recovery of products for which this time could better be used for other processes.

11. Reflection

At the start of this research, I did not know what I had to expect. Even though I had visited many companies during my bachelor and master, it is always different when you are spending 40 hours a week in the same office. In September 2018, I set the goal to finish the research project within 5 months. By that time, I had already spent some days at the production facility itself to get a feeling of everything that happens during the day. This also gave me the opportunity to get familiar with the subject and to formulate the plan of approach. After approval of the 1st supervisor, I started to work on the actual research.

Thereby I have spent the first month writing the company description, interviewing employees regarding to what they perceive to be problems regarding the available space, and I have looked for methods to obtain the logistics information. It turned out that the hardware for the tracking of people or machines is available for a reasonable price. However, there is no software available that can extract the information from the hardware. When you want to obtain this data, you have to involve a company to develop the software for you. I got the chance to invite several companies to have a look at the facility, and inform me about the possibilities. Eventually it was however concluded that the prices for such systems are outside the range of this research. Therefore, it was decided to "track" the movements of forklifts by looking at the information from the ERP system.

After this decision was made, I had to "create" the data myself. I have thereby spent several hours into the processing of the data from the scanners. Eventually, I made it possible to show the different pathways by means of the Tableau software, which made me feel very proud because now I could obtain value from the work I had done. Later on, I also used this data to obtain the transportation distances of the lay-out alternatives.

At the beginning I sometimes struggled with the research framework and the different types of problems that exist. There were many paths I could follow and I found it difficult to chose a certain path. With the guidance of the supervisors I decided to focus on the internal logistics and the warehousing processes, and I am very proud of the thesis that I have created. I had a lot of fun working on it, and I enjoyed the conversations I had during the afternoon walk. Then, it was time to chat about everything that is not directly related to work. During the last 6 months I have thereby not only gained work experience, but I have also learned some other life lessons which I could use within the coming years

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Appendix A

Within chapter 4 a look is taken into the productivity level of the assembly department. It was already stated in there that almost all productivity levels deviate from the estimated level. Within this appendix the products can be found from which the productivity level deviates more than 30% in both the positive and negative way. An overview of these products can be found within Table 29 and Table 28. The last table shows that that the products having the highest positive productivity difference, are all products that are produced in small amounts. These are not of interest for this research, while products that are produced in small amounts only take a few product hours each year (0,10% of all hours).

Table 29 Negative deviations (>30%)

Assembly Nr	Prod. Diff	Reason
A1397	-0,84	New product
A1437	-0,71	New product
A1440 t/m A1447	-0,56	1 person assembly
A1439	-0,55	
A1389	-0,55	Small amount, 1x year
A1391	-0,52	New product
A1426	-0,51	New product
A1343	-0,44	Small amount
A1165	-0,43	Small amount
A1388	-0,43	Small amount
A1327	-0,35	Small amount
A1390	-0,33	New product
A1418	-0,31	New product
A1418	-0,31	New product

Table 28 Positive deviations (>30%)

Assembly Nr	Prod. Diff	Reason
A1179	0,32	3x per year
A1369	0,33	-
A1420	0,33	Small amount
A1421	0,37	1x per year
A1455	0,38	2x per year
A1396	0,39	2x per year
A1454	0,48	1x per year
A1456	0,58	1x per year
A1392	0,67	1x per year
A1377	0,70	-
A1412	0,73	1x per year
A1382	0,80	1x per year
A1314	0,81	Small amount
A1259	1,00	Small amount
A1333	1,00	Small amount
A1311	1,18	Small amount
A1332	1,40	Small amount
A1309	1,67	Small amount
A1414	1,92	Small amount

The products having the reason "*New product*" as explanation for their productivity difference, are also not of interest for this research, while the employees first have to get familiar with the product and the handlings they have to perform. It takes time for them to learn and eventually reach the required productivity level. This learning curve is best explained by (Kolb A.Y., 2012) within (Figure 41).

From this figure it can be seen that data is best remembered from the fifth repetition. Next to that, learning is most effective and efficient around meaningful activities. Employees are then engaged with the learning process and after a certain time they will perform their handlings faster and better (Naidu S., 2012). The products described as *"New product"* should therefore be checked in the next year to see whether improvements to the assembly time have been made. It should then be decided whether the estimated assembly rate is correct or that it should be changed.

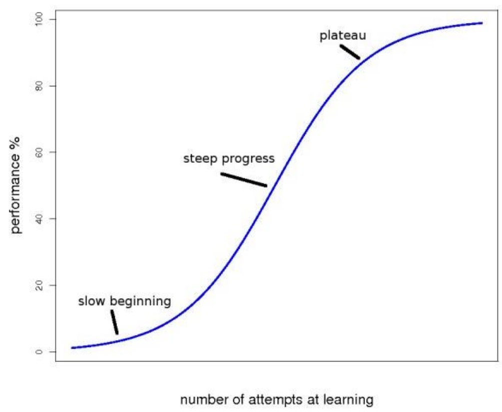
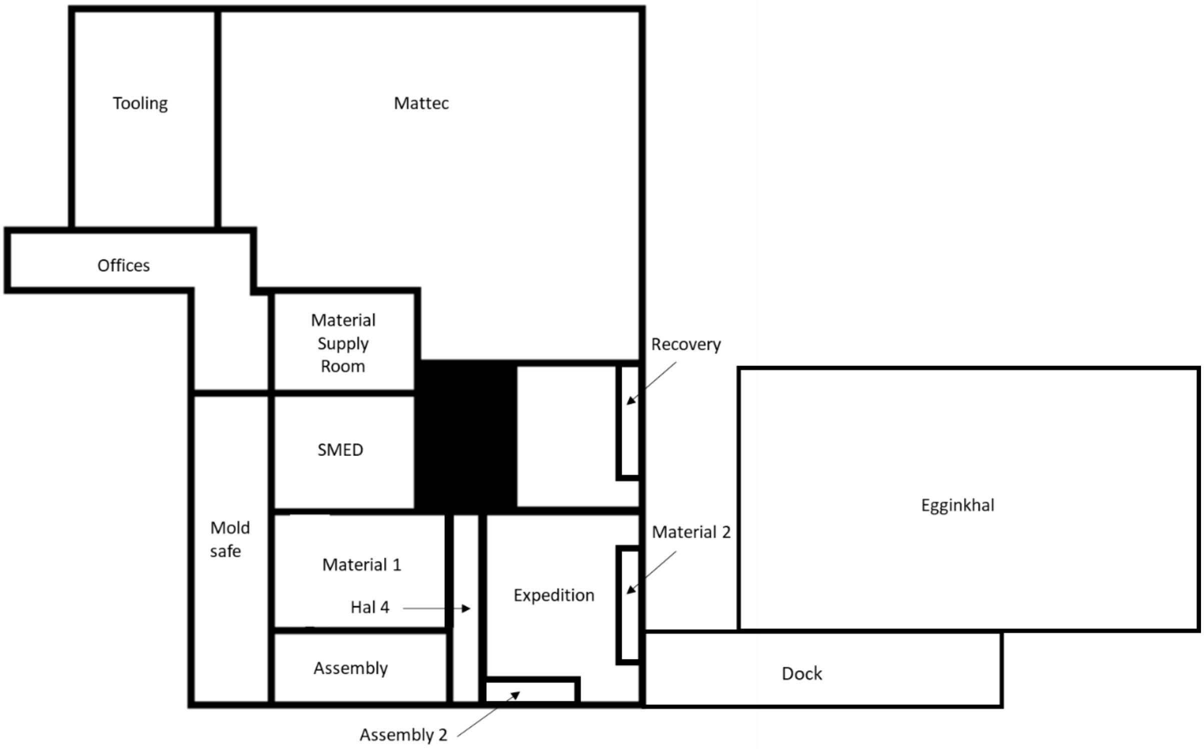


Figure 41 Learning curve

Another reason for the productivity difference is shown in the number of times a product has been assembled over the last year. It is showed that some of the products are only produced once or twice a year. Improving the assembly process of these products will not result in high savings, while these products only capture 0,67% of the assembly hours of the year 2018. Therefore, these products are excluded from this research also.

Appendix B



Tooling
Mattec
Offices
Material Supply Room
Recovery
SMED
Eggingkhal
Mold safe
Material 2
Material 1
Expedition
Hal 4
Assembly
Dock
Assembly 2

Appendix C

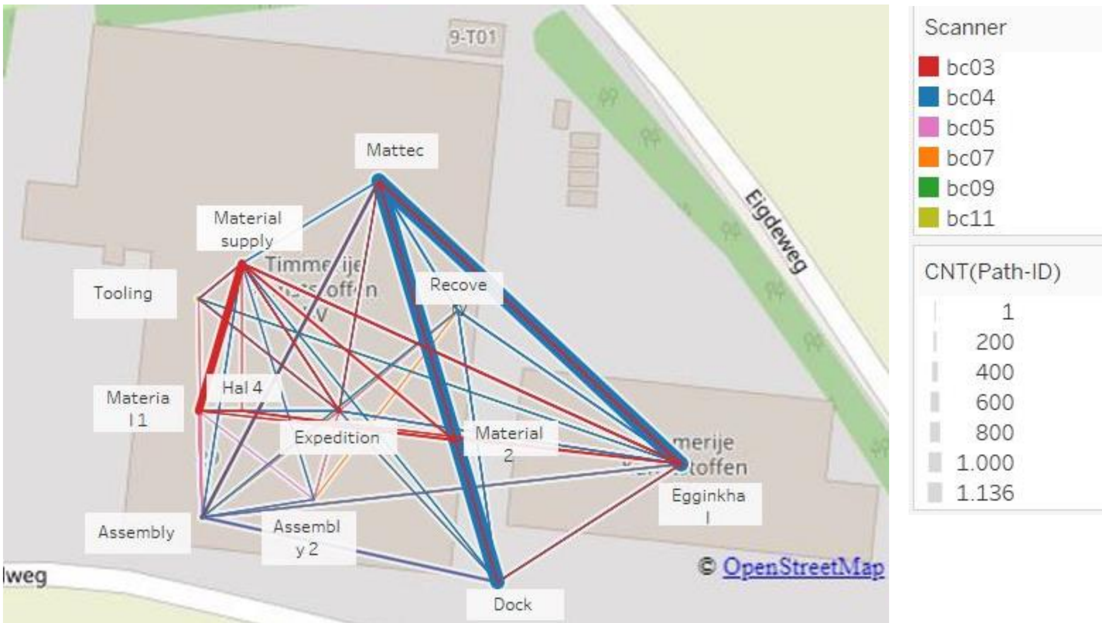


Figure 42 Frequent routes per scanner-ID

Appendix D

D.1. Warehouses

The available number of pallet locations was found by counting the number of pallet locations. The *required* number of pallet locations is however based on the average number of pallets locations as were needed for the different type of materials in the year 2018. The following numbers are then obtained:

- Raw materials	615
- Coloring materials	90
- Packaging materials	812
- A-products	3529
- P-products	671
- Intermediate storage Assembly	1368
- I-parts	60 +
Total	7145 pp

D.2. Shipment

The *available* space for the shipping department currently is 958,92 m2. In reality however, this space is also used for the storage of raw materials and packaging materials. This entire space is therefore considered to be warehousing space. The *required* space for the shipping department depends on the number of trucks to be loaded every day. A difference is thereby made between the place needed for the (un)loading of trucks to/from customers and the loading of trucks towards the external warehousing locations. Whereas there is always at least one truck available for the transport of materials towards the external warehousing locations, space should already be reserved for 1 truck. Next to that, additional space is needed to dock the products that are shipped to the customer. These products are picked one day in advance. To determine the amount of space needed for this, a look is taken at the products that were shipped during September 2018. The following is found:

1. 40% of the shipped products is picked at the day it is shipped.
2. Number of products shipped on Mondays is almost always twice as large as on the other days of the week.
3. On Fridays, only the products from customers having orders every day, are shipped.

For the products that are picked and shipped on the same day, no additional space is needed. For the other products it is from great importance to know from where they are shipped to the customer. If these products are transported from the external warehouses, these should not be taken into account at the production facility location. The list of shipped products is compared with the list of transfers towards the external warehouse located in Neede. It is seen that on average 40% of the products is shipped from the external warehouse in Neede (Table 30).

Figure 43 provides an overview of the number of pallets that are picked at the production facility one day in advance. While the number of pallets is highly fluctuating in September, data from the month October is added to provide a more accurate overview. From this figure it is assumed that the number of pallet locations, needed for the shipping department, is around 40. All other products are shipped from the warehouse in Neede, or they are picked on the day they are shipped.

Table 30 Shipping from locations (%)

Week Nr	Noordijk	Neede	% Neede
Week 36	394	378	49%
Week 37	380	236	38%
Week 38	550	324	37%
Week 39	579	298	34%
Average	**476**	**309**	**40%**

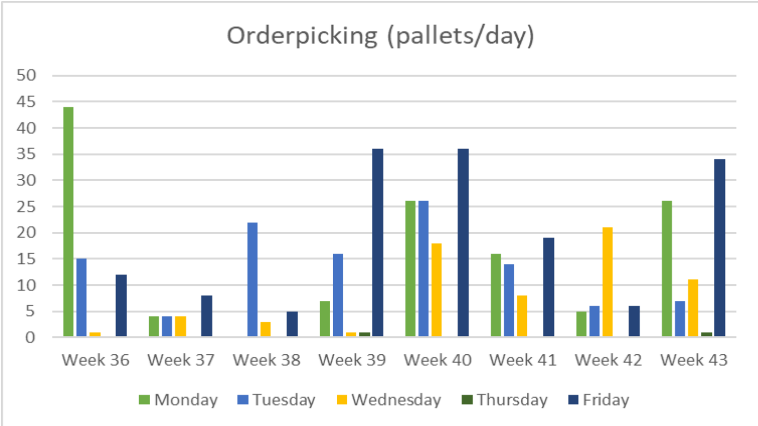


Figure 43 Order picking September / October 2018

Appendix E

Within this appendix, an example calculation regarding the distance measurement can be found. Table 31 shows an example for scenario 1A. In this scenario, the raw materials and the coloring materials have been placed inside the production facility warehouse. An overview of the different areas within this warehouse can be found in Figure 44.

Table 31 Scenario 1A example calculation

	PalletLocations	Percentage RM	to MSR	MSR
Assembly WH	0	0%	63,06	0,00
WH	265	38%	55,34	20,80
Between	57	8%	24,955	2,02
Entrance 4/5	111	16%	38,26	6,02
Expedition	272	39%	58,646	22,63
	705	1		51,47

The estimated distance from the warehousing location towards the material supply room is calculated based on the information in Table 31. The first column shows the different warehousing areas. The second column shows the number of pallet locations that is used from this area. The percentage of pallets possibly coming from this area is calculated in the 3rd column by dividing the number of pallet locations of a certain area by the total number of pallet locations needed. This percentage is then multiplied by the distance as expressed within the 4th column. The estimated distance in case the material is transported from the warehouse to the material supply room (MSR) is 51,47 meters.

Figure 44 Warehousing lay-out

Appendix F

F.1. Relationship diagram 2A

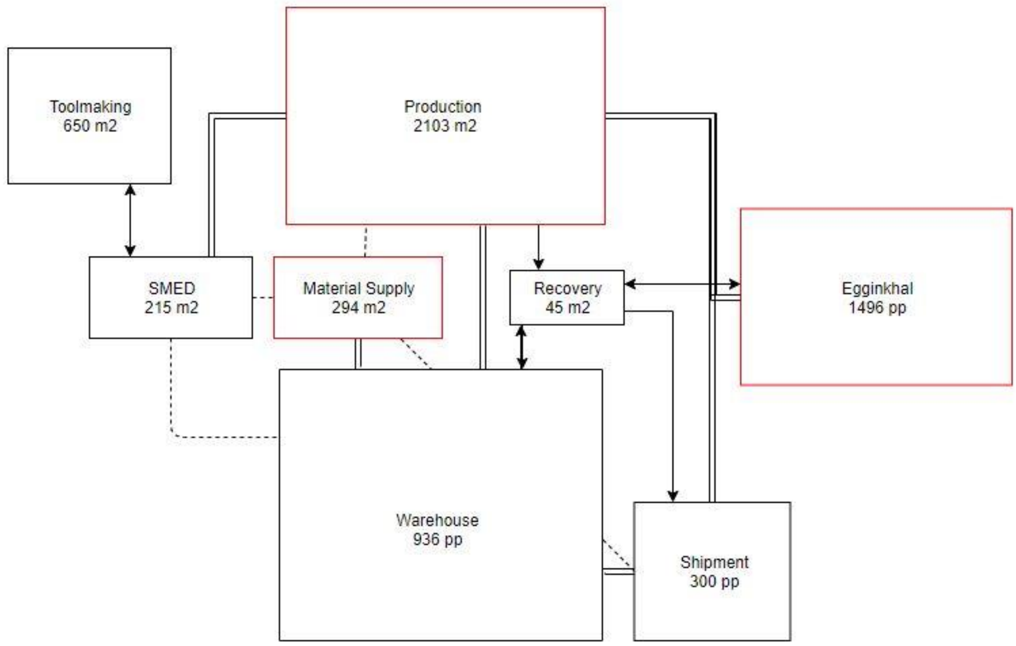


Figure 45 Space-Relationship diagram scenario 3

F.2. Relationship diagram 2B

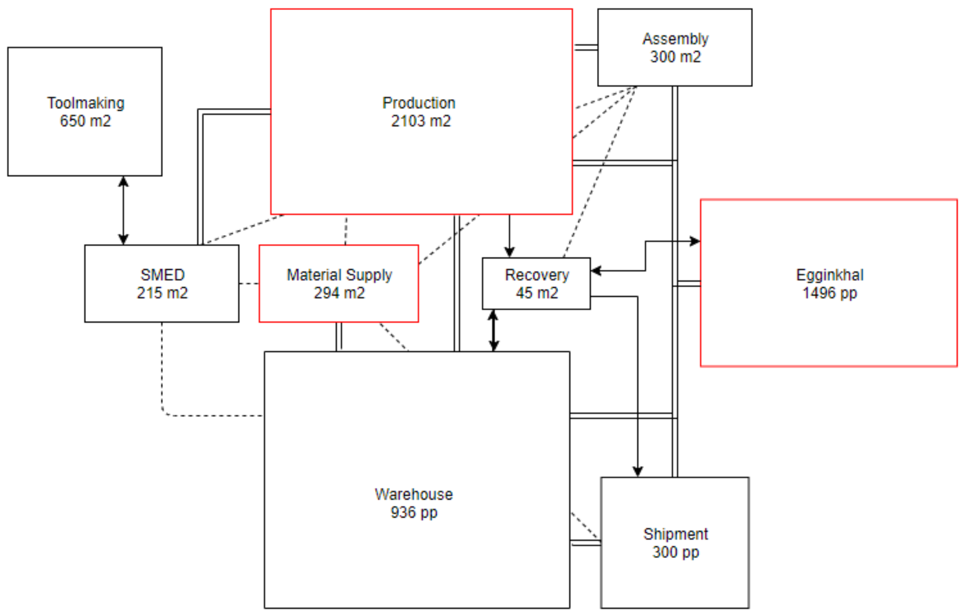


Figure 46 Space-Relationship diagram scenario 2

Appendix G

Within chapter 6, several lay-out options have been discussed. It was already mentioned there that several other scenarios were created also. However, these are not discussed when choosing an alternative solution. In consultation with the supervisors, it was decided to place these scenarios in the appendices. While the scenarios were created as an addition to scenario 3, the sub-sections are build up the same as within scenario 3 of chapter 6:

1. Scenarios I, II, III; all describe a new lay-out that fits within the current site.
2. Scenarios I, II, III – Expanded; all describe what the new lay-out looks like, when the production facility is expanded.

G.1. Scenario I

Recall the production facility lay-out created for scenario 3 (Figure 47). Within that section, it was decided to expand the facility to the right of the new assembly and packaging warehouse by placing a new production area and material supply warehouse over there.

Next to this lay-out, another future lay-out possibility was created. This option is explained within the next sub-section.

Figure 47 Scenario 3A

G.2. Scenario I - Expanded

In contrast to the future lay-out option as given within 6.3.3. Scenario 3, this lay-out does not create a new production area to the right side of the packaging and assembly warehouse. Instead, this warehousing space is used to create a new production area, and the packaging and warehousing materials warehouse is shifted to the right. An explanation regarding this change can be found in Figure 47. Also as in the expanded version of scenario 3, the material supply room is expanded.

Figure 47 Scenario I - Expanded

To keep the raw materials close, it might be useful to create a small storage area next to it also. With this new lay-out it is also possible to keep the flow, as described within the relationship diagram (Figure 26), intact.

Also, the toolmaking area and the SMED are expanded. Therefore, some offices need to be relocated. The different options, that were already explained within scenario 3, are therefore also shown within this figure.

The distance between the new production area and the toolmaking and SMED department is in this option smaller than in the expanded versions of scenario 3. However, the assembly department is located further away. While many relocations are taking place between the production area and the assembly department, it was decided to not use this version (Scenario I – expanded) for further research.

G.3. Scenario II

Whereas in scenario I the raw materials are kept at the same location, within this scenario this warehouse is used to store the assembly materials. While there is not enough space to store all materials, it should be expanded. Also, the assembly department is relocated and enlarged to keep the flow as shown within the relationship diagram.

Then, additional warehousing space is needed to store the raw materials. The material supply room is then relocated as well, to get the fire load at the side of the production facility and to keep it close to the raw materials. By placing both departments on the right side of the current facility, the flow as described within the relationship diagram is still kept.

Next to this relocation, a hall way is created in between the production area and the assembly department. It is then possible to transport the products from the different production areas towards the docking area, without crossing the other production areas. Also, this hall way could be used for the transport of molds, final products and packaging materials. It can be seen that everything still fits within the current site. The next sub-section shows how the production facility could be expanded, based on this scenario II.

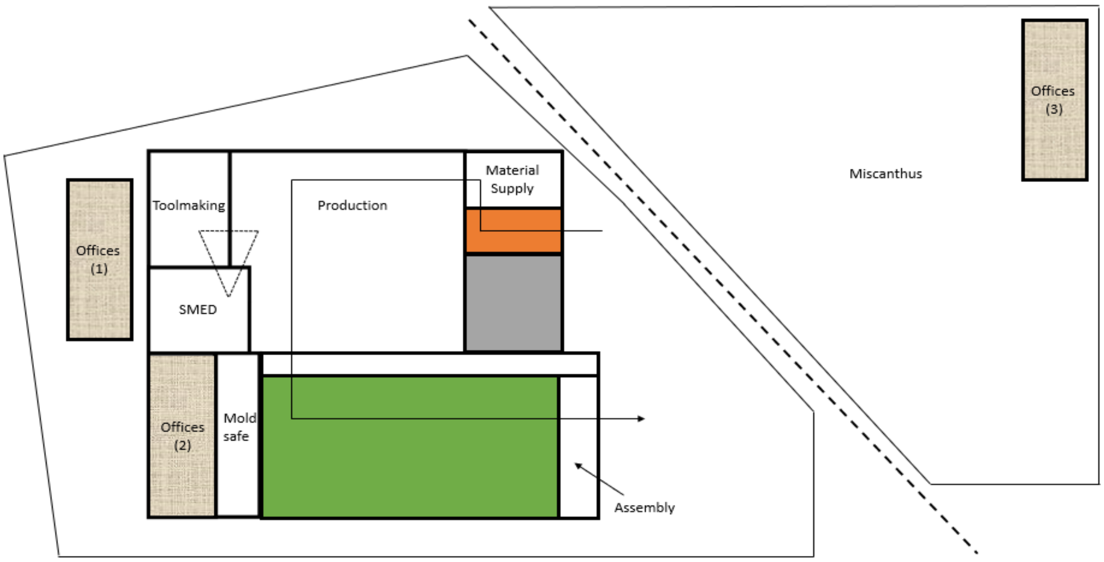


Figure 48 Scenario II

G.4. Scenario II – Expanded

Within the previous sub-section, it was showed how the existing lay-out could be improved within the currently available space. In this sub-section, the production facility is expanded. A description of this lay-out is given in Figure 49. In this figure it can be seen that a production area is added to the right side of the production facility. To make transport of raw materials towards the storage area possible, a small hall way is added here also. While the material supply room is placed in between both production areas, it can be connected to the new production area easily. It is within this lay-out also possible, to transport the packaging materials to the different production areas in a direct way. The assembly department is kept at the same location, so the products coming from the new production area have to be transported to here via de hall way.

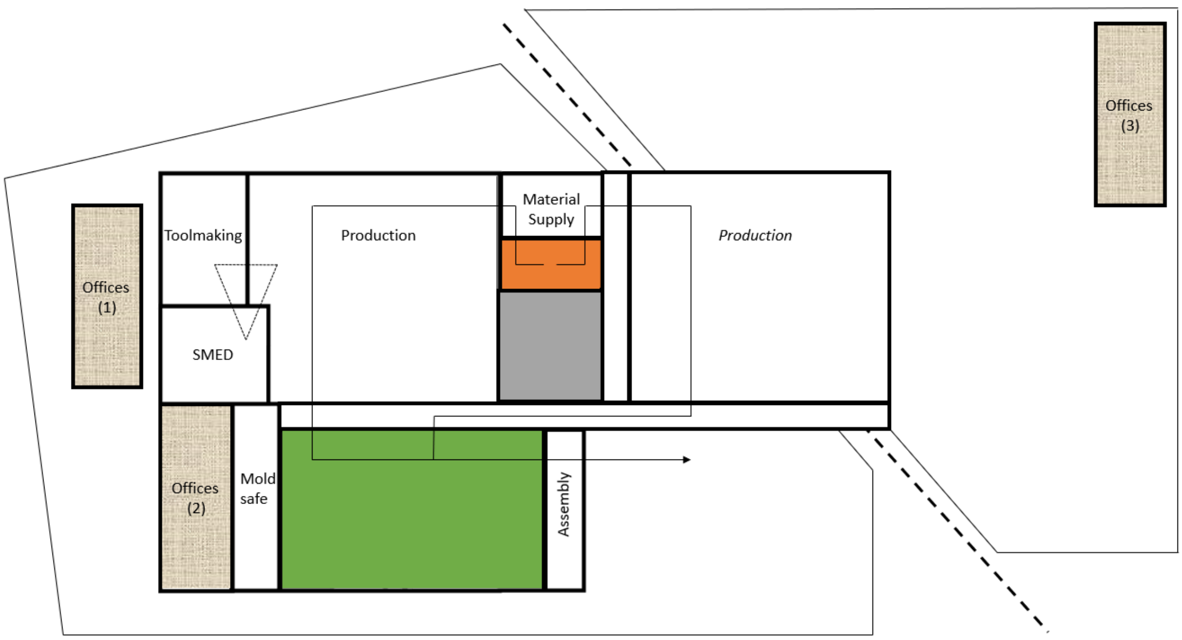


Figure 49 Scenario II - Expanded

This scenario is excluded from further research, while both the material supply room and the raw materials are located in between the production areas. This means that the fire load is again placed in the middle of the building. This is something that should be prevented when creating new lay-out options. Next to this, by increasing the production area, it is also likely that the material supply room needs to expand. Following this, both the raw materials warehouse and the packaging department need to be enlarged.

G.5. Scenario III

Figure 50 shows that this last scenario is quite similar to the one given in scenario II, while the assembly department is kept at the same location. A difference is made with the location of the material supply room. This room is relocated to the back of the production area. A new warehouse is build next to the production area to create space for the raw materials and the packaging materials. A hall way is created in between the production area and the assembly intermediate storage, to take the transportations out of the production area. An explanation regarding the different office locations can be found in chapter 6 – scenario 3. In here, an explanation regarding the changed SMED and toolmaking departments can be found also. The flow as described within the relationship diagram is also added to this lay-out. It can be seen that within this option, it is possible to create this flow without interrupting it. The scenario as described within the next sub-section is based on the lay-out option as given in Figure 50.

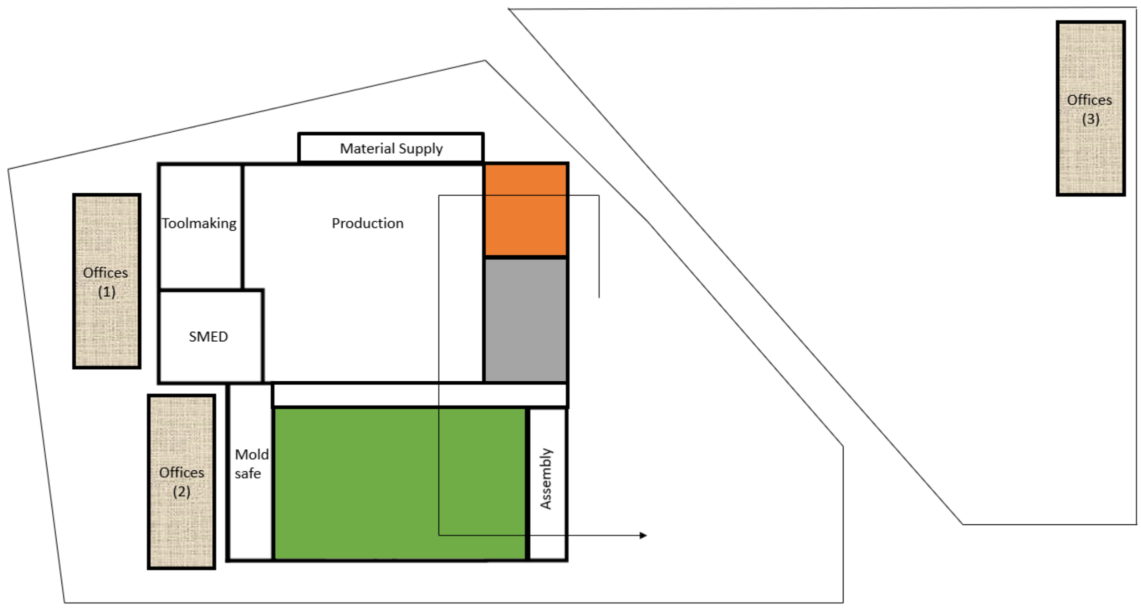


Figure 50 Scenario III

G.6. Scenario III – Expanded

Within this scenario, the production facility is extended towards the miscanthus area. To create additional space for both the packaging materials and the raw materials, an additional warehouse is build on this land. The raw materials are stored in here, to get the fire load out of the production facility. The storage area that becomes available then, can be used for the storage of packaging materials. Next to this change in warehousing locations, the material supply room is extended towards the miscanthus area. This is done, to cover the newly created production area on the right. The hall way in between the production area and the assembly intermediate stock is also extended, to create a connection between the new production area and the assembly department. This way can also be used for the transportation of molds.

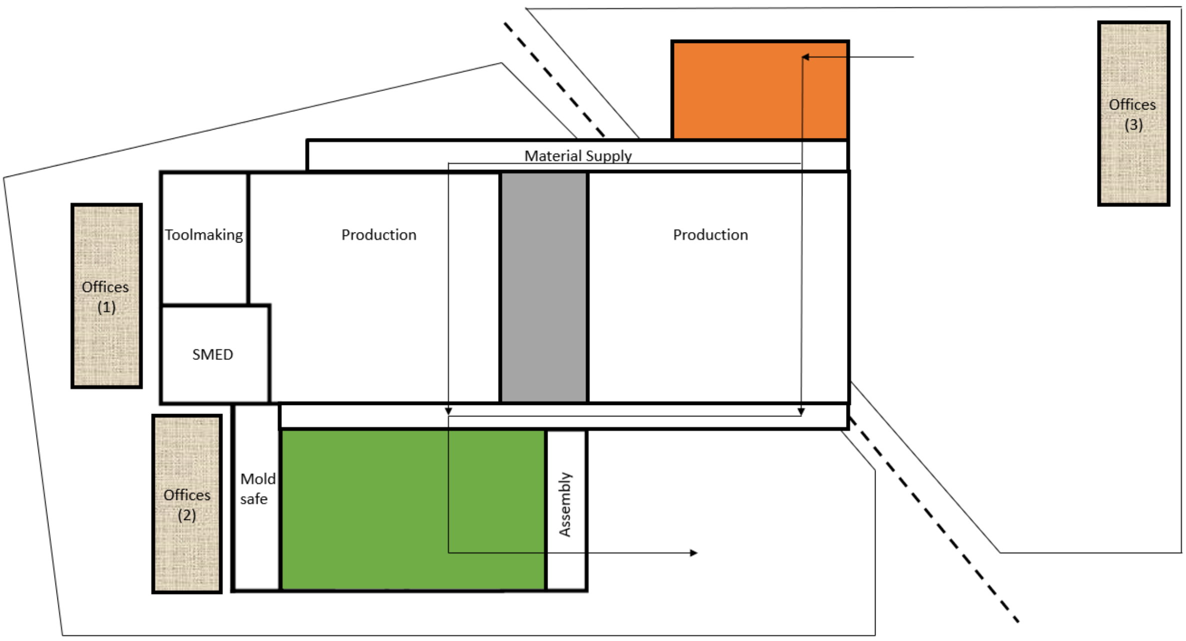


Figure 51 Scenario III - Expanded

This scenario is excluded from the research, while many changes to the current facility need to be made. Also, many crossings will possible occur when transporting molds and final products over the hall way between the production areas and the assembly department. Also, the raw materials warehouse needs to be covered by a sprinkler system. When replacing this department from inside the production facility, towards the miscanthus area, this system also needs to be placed in here. It was therefore decided to exclude this scenario from the research options.

Appendix H

H.1. Key Points Timmerije

The table below describes the key points that have been developed by a multi-disciplinary team of Timmerije.

Table 32 Key Points Timmerije

Key points	Example
Social & Healthy	The integration of sheltered employment for the assembly of products.
Zero waste	This has become one of the key performance indicators (KPIs).
Innovative	Developing new products together with customers.
Digital	The introduction of a manufacturing execution system (MES) to control the waste levels and continuously monitor the machines.
Flexible	Timmerije has a flat organization which makes it possible to react to changes and developments quickly.
Green & Sustainable	Developing biodegradable products with the use of biopolymers and recycling of products. Next to this, Timmerije has invested in energy efficient machines and solar panels.
Logistics	Timmerije takes its CO2 footprint into account by making agreements with customers about delivering fully packed trailers only. Materials are taken with the trailers on the way back to Noordijk.

H.2. Normalized matrix

Table 33 shows the normalized matrix of the values from the pairwise comparison. These are calculated in the following way:

1. Take the sum of every column
2. Divide each importance criterion by the sum of the column

The priorities are then calculated by taking the average of each row.

Table 33 Normalized matrix

Choosing best alternative	Cost	Transportation Time	Future-Proof	Fire Safety	Quality	Soft factors	**Priority**
Cost	0.092	0.185	0.060	0.071	0.183	0.079	**0.112**
Transportation Time	0.042	0.077	0.113	0.256	0.140	0.132	**0.127**
Future-Proof	0.253	0.221	0.153	0.189	0.198	0.254	**0.212**
Fire Safety	0.369	0.295	0.306	0.284	0.304	0.295	**0.309**
Quality	0.129	0.101	0.141	0.103	0.093	0.148	**0.119**
Soft factors	0.115	0.120	0.227	0.097	0.082	0.091	**0.122**

H.3. Local priorities matrices

Costs	1A	1B	2A	2B	2C	3A	Priority
1A	1.000	1.000	3.000	3.000	2.000	5.000	**0.282**
1B	1.000	1.000	3.000	2.000	2.000	5.000	**0.263**
2A	0.333	0.333	1.000	0.500	0.333	5.000	**0.097**
2B	0.333	0.500	2.000	1.000	0.500	5.000	**0.132**
2C	0.500	0.500	3.000	2.000	1.000	5.000	**0.187**
3A	0.200	0.200	0.200	0.200	0.200	1.000	**0.038**

Future-Proof	1A	1B	2A	2B	2C	3A	Priority
1A	1.000	0.500	0.333	0.250	0.250	0.250	**0.051**
1B	2.000	1.000	3.000	0.250	0.333	0.250	**0.091**
2A	3.000	0.333	1.000	0.200	0.200	0.200	**0.066**
2B	4.000	4.000	5.000	1.000	3.000	0.500	**0.271**
2C	4.000	3.000	5.000	0.333	1.000	0.333	**0.176**
3A	4.000	4.000	5.000	2.000	3.000	1.000	**0.345**

Fire Safety	1A	1B	2A	2B	2C	3A	Priority
1A	1.000	0.500	0.500	0.333	0.250	0.333	**0.060**
1B	2.000	1.000	2.000	1.000	0.250	0.333	**0.113**
2A	2.000	0.500	1.000	1.000	0.250	0.333	**0.091**
2B	3.000	1.000	1.000	1.000	0.333	0.333	**0.151**
2C	4.000	4.000	4.000	3.000	1.000	3.000	**0.385**
3A	3.000	3.000	3.000	3.000	0.333	1.000	**0.235**

Quality	1A	1B	2A	2B	2C	3A	Priority
1A	1.000	0.500	3.000	0.250	0.333	0.200	**0.073**
1B	2.000	1.000	3.000	0.250	0.333	0.250	**0.093**
2A	0.333	0.333	1.000	0.200	0.250	0.200	**0.043**
2B	4.000	4.000	5.000	1.000	3.000	1.000	**0.309**
2C	3.000	3.000	4.000	0.333	1.000	0.333	**0.161**
3A	5.000	4.000	5.000	1.000	3.000	1.000	**0.320**

Soft factors	1A	1B	2A	2B	2C	3A	Priority
1A	1.000	1.000	0.500	0.200	0.333	0.200	**0.057**
1B	1.000	1.000	0.500	0.200	0.333	0.200	**0.057**
2A	2.000	2.000	1.000	0.250	0.500	0.250	**0.093**
2B	5.000	5.000	4.000	1.000	2.000	1.000	**0.313**
2C	3.000	3.000	2.000	0.500	1.000	0.500	**0.167**
3A	5.000	5.000	4.000	1.000	2.000	1.000	**0.313**

Transportation Time	1A	1B	2A	2B	2C	3A	**Priority**
1A	1.000	2.000	0.250	0.333	0.500	0.250	**0.071**
1B	0.500	1.000	0.200	0.250	0.333	0.200	**0.047**
2A	4.000	5.000	1.000	2.000	3.000	1.000	**0.295**
2B	3.000	4.000	0.500	1.000	2.000	0.500	**0.180**
2C	2.000	3.000	0.333	0.500	1.000	0.333	**0.112**
3A	4.000	5.000	1.000	2.000	3.000	1.000	**0.295**