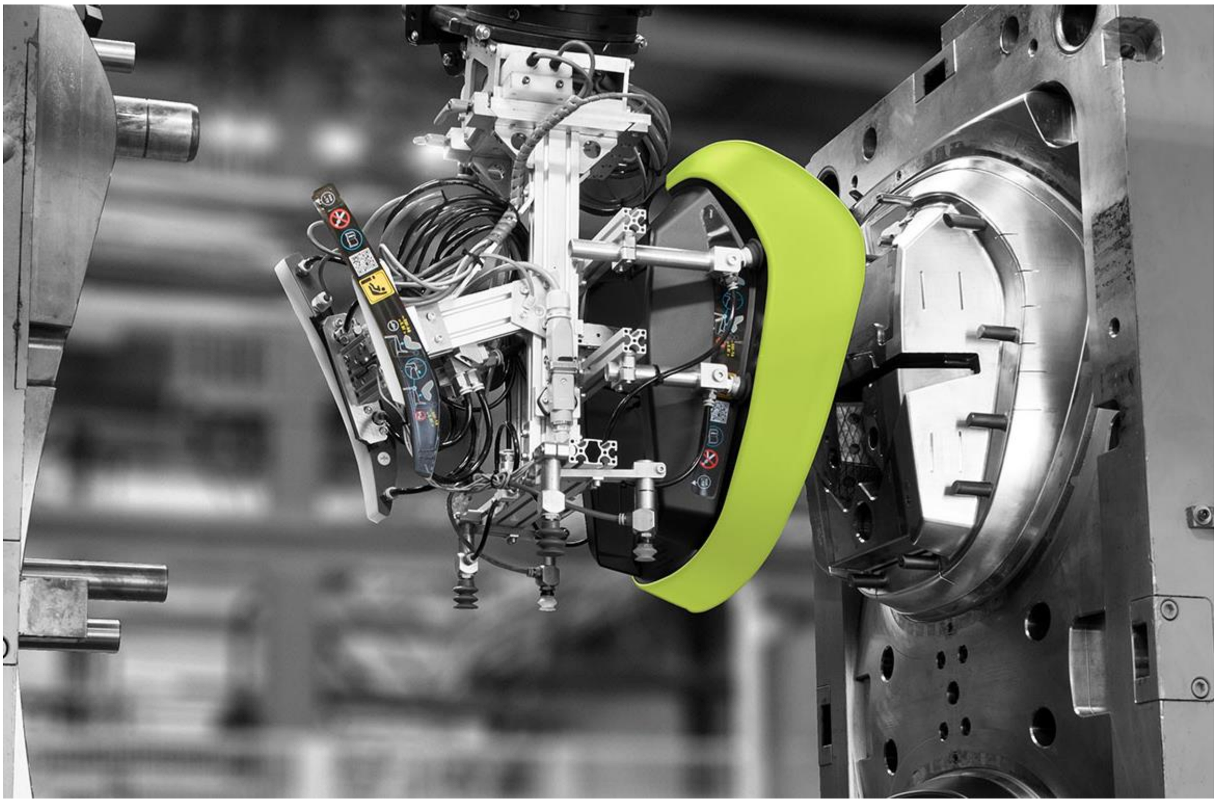
Improving the production facilities' layout to decrease the busyness at Timmerije B.V.



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02-07-2020

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Preface

This thesis concludes my Bachelor Industrial Engineering and Management at the University of Twente, Enschede. During the past months I was fortunate to work on a project which sparked my interests. I worked on a layout improvement project at Timmerije B.V. in Neede. Already thinking of the production halls, with big machines, huge output numbers and robots picking up products, makes me enthusiastic. It was an interesting and exciting assignment, for which I would like to thank Timmerije to be able to work with them and gain insight in the world of injection moulding production.

First, I would like to thank my first company supervisor Marino Sonnemans for his guidance in the beginning of the process. He always made time for me, and together we narrowed the scope and goals of the research well. I would also like to thank my second company supervisor Esther Coccoris, for helping me to finish the research well. The atmosphere at Timmerije was always very open, which made me feel welcome from the first day I walked in. During the whole research process, I have had the feeling that everyone at Timmerije was interested in my research and was willing to contribute. Unfortunately, I was not able to work on my thesis at Timmerije for most of the time due to COVID-19, but I really appreciated the employees and their mindset.

From the University of Twente, I would like to thank my first supervisor Peter Schuur, for providing me with valuable feedback, and for our open and relaxed online meetings. Also, I would like to thank Leo van der Wegen for being my second supervisor.

At last, a special thanks to my buddy and good friend Jan van Dongen, who guided and helped me well during the research process.

Jan-Hein Kloppenberg,

02-07-2020

Management summary

The production facilities at Timmerije are found to be too busy at peak times, where products cannot be transported to the checking-area across the transportation path. When this situation takes place, unsafe situations occur where forklifts have to wait on each other. Due to the busyness at the production facilities, Timmerije is (almost) at its maximum with regards to capacity and is thus not able to grow further. The goal of the research is to develop an optimal layout of the production facilities, which decreases the transportation distance and thus the busyness at Timmerije. In this way, the safety at the production facilities is also influenced positively. The main research question, which is answered in this thesis, is:

"What improvements can be made in the layout of the production facilities to decrease the busyness at Timmerije B.V.?"

The selected core problem is:

'During peak times, the bulk-products are blocking the rest-products'

Bulk-products are products with a certain physical volume which require large space (e.g. 12 products in a pallet box), whereas rest-products are products which are light and small, and which are packed in carton boxes of a hundred or a thousand pieces.

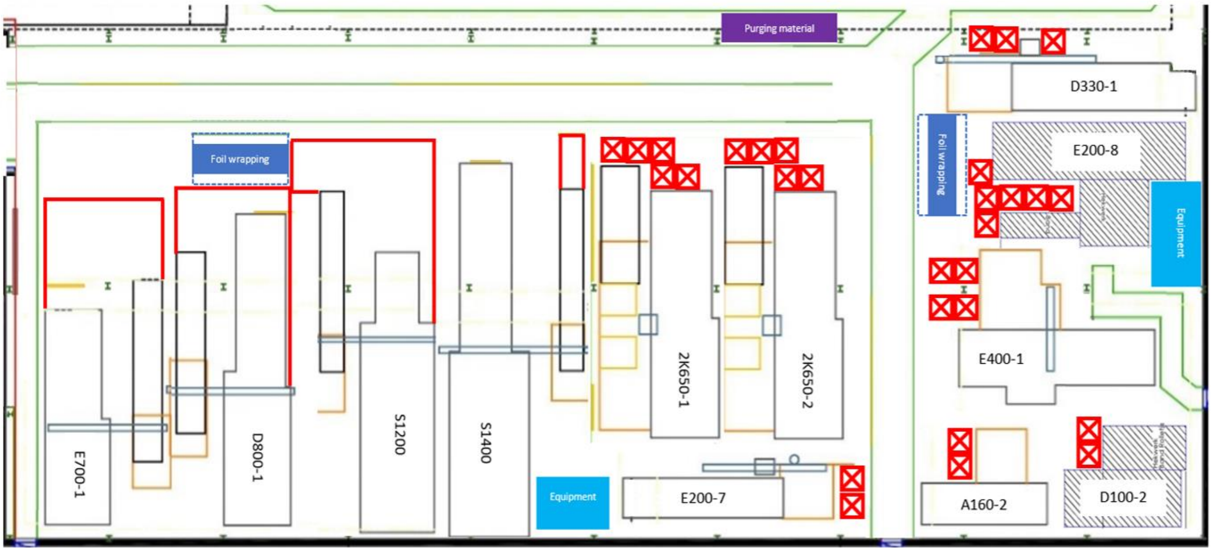
The biggest win in efficiency is accomplished by focussing on the bulk-products and leaving the rest-products out of scope. The focus is the production hall where the bulk-machines are located, which is production hall 4/5. The Systematic Layout Planning of Muther and Hales (2015) is used to guide in the layout design process. The layouts are computed with the use of photoshop and making drawings by hand.

The busyness at Timmerije is measured in the total transportation distance through the production facilities, by means of forklifts utilising the transportation path. This value consists of the distance of the movement of products and moulds. In the current situation, the total transportation distance is 30.5 km/day.

During the layout improvement process, three main layout concepts (each with sub-versions) were developed. Production hall 4/5 is filled with the principle of the machine with the highest output most to the left, closest to the checking-area. The machine with the second highest output is then placed on the location available closest to the checking-area, etc. The chosen layout, which is recommended to be implemented by Timmerije, can be found in Figure MS.1 below.

Figure MS.1 needs some clarification. The distance between pillars, which look like , horizontally is 5 metres, whereas the distance vertically is 10 metres. The white and black blocks are machines, with their machine name placed in the contours of the machines. For the four biggest machines, the space requirements have been determined, which are the red areas around the four machines on the left. Nothing is planned to be placed in these surroundings. The blocks in colours which are incorporated in Figure MS.1, are explained here. The foil wrapping blocks in dark blue are locations on which pallets with products get foil to protect the products and keep the load together. The equipment blocks in light blue represent areas in production hall 4/5 where equipment is placed, which is needed for production/assembly. The purging material block in purple represents an area with containers, filled with purging material. This material is needed to clean machines/moulds after having produced a batch. The red cube with a cross represents a pallet location. Per machine (except for the four biggest machines), the maximum amount of required pallet locations has been determined, and these pallet locations are placed around these machines.

Figure MS.1. Layout of production hall 4/5 recommended for implementation at Timmerije



The layout in Figure MS.1 is chosen based on various criteria. This layout is fire-safe, and it improves the safety because of the implemented pallet highway, which is the horizontal transportation path in Figure MS.1. The layout is future proof, because the 2K650-2 is added to the machine park to be able to cope with increasing demand. The 2K650-2 is a second 2K650-1, they are identical machines. Timmerije expects that the demand of products that have to be produced on the 2K650-x's (shorter version for 2K650-1 and 2K650-2) is going to increase massively. For that purpose, the 2K650-2 is needed. Due to the same orientation of machines, input and output flows are created, which positively influences the safety in the production facilities.

By implementing the layout in Figure MS.1, a reduction of 28.6% (from 30.5 km/day to 21.79 km/day) in the total transportation distance is realised, compared to the current situation. The estimated investment costs are €251,700.00, while the benefit per year is estimated to be €80,006.78. This means that the time for cost-recovery of the investment is approximately 3.15 years. In case there are strong expectations that the output of the 2K650-x's is going to exceed the output of the biggest machines in hall 4/5, it is recommended to implement the layout in Figure MS.2 below instead of the layout in Figure MS.1. In Figure MS.2, the 2K650-x's are placed to the left, and the other biggest machines are moved to the right.

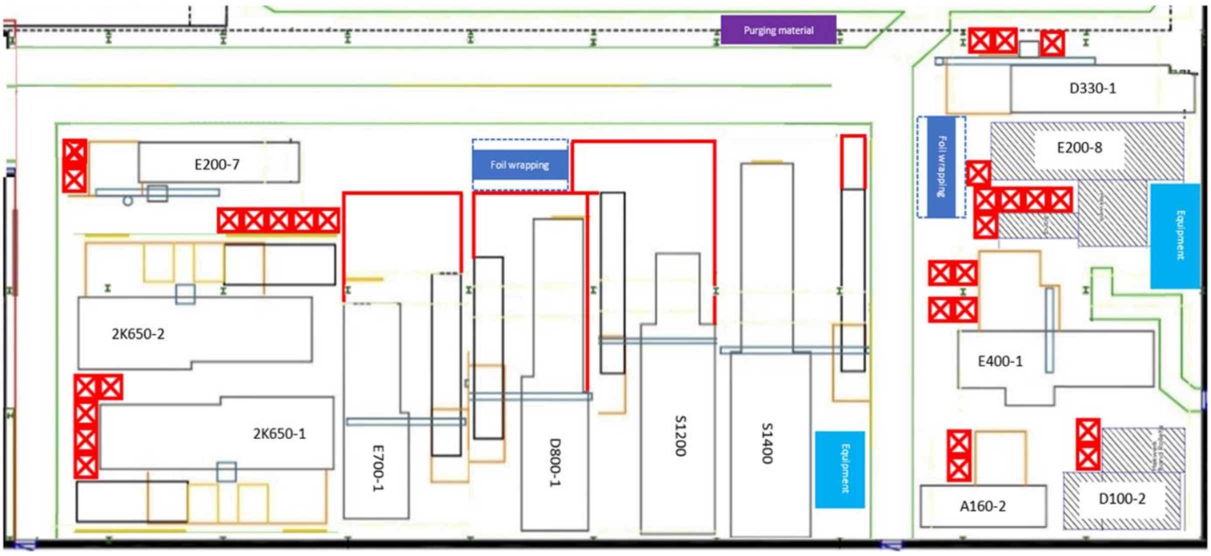


Figure MS.2. Layout in case of expectation of 2K650-x's output exceeding output biggest machines

Implementing the layout in Figure MS.1 (or the layout in Figure MS.2) means that there is going to be a standstill of machines for some period of time, because machines have to be moved, and some machines first have to be moved outside before other machines can be moved to their new location. Therefore, it is recommended to plan the implementation during a period of expected lower demand, perhaps during the holidays. It is also possible to produce batches earlier, so still some part of the to be produced batches are produced and delivered on time.

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1. Introduction

To finish my bachelor Industrial Engineering and Management at the University of Twente, research has been conducted at Timmerije B.V. in Neede to find an optimal layout of the production facilities. This chapter is an introduction to the research. Section 1.1 introduces the company and the company structure. Section 1.2 identifies the action problem, whereas section 1.3 focuses on the identification of the core problem. The research design is elaborated on in section 1.4, after which the main deliverables are described in section 1.5.

1.1. Company introduction

Timmerije is a modern plastic injection moulding plant which produces high quality plastic products, from dress guards to child seats and from seat backs to complex ventilator parts. Besides the modern plastic injection moulding plant, they also have their own engineering department, tool shop and an assembly department. Since 2010, Timmerije is an operating company of Hydratec Industries NV, a stock market listed, worldwide active specialist in industrial systems and components. Hydratec's focus is on markets in Agri & Food, Automotive and Health Tech. The company structure can be seen below in Figure 1.1.

Figure 1.1. Company structure (Timmerije B.V.)

Figure 1.2 on the right illustrates the markets in which Timmerije is active. It can be seen that the biggest market is the HVAC industry. HVAC means heating, ventilation, and air conditioning. Other big markets are the Internal Transport section and Industry.

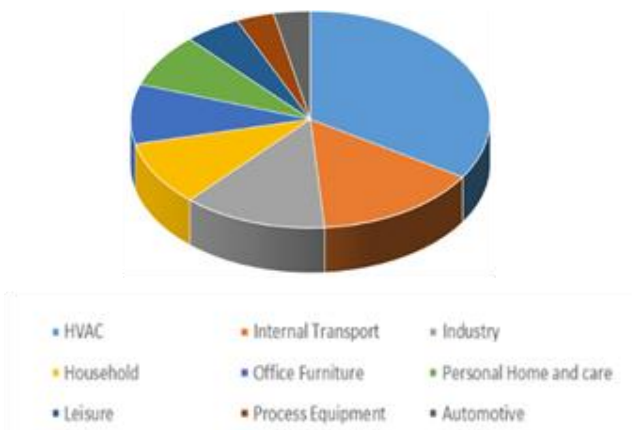

Figure 1.2. Market mix (Damveld, 2019)

Timmerije's key figures:

- 50 injection moulding machines
- 1500 different products
- 150 different raw materials
- 75 production swaps per week
- Product weights from 1 gram to 3500 grams

1.2. Problem identification

According to Timmerije, there is not enough space available in the production facilities. The reason for this, is that the company has grown historically over the past years. This means that every time they grew, an extra production hall/facility has been added to the existing layout. In this new hall, new machines were placed. After all these added production facilities, one can imagine that the existing production process layout is not optimal anymore. This non-optimal process layout results in a situation where products unnecessarily travel long distances through the production facilities. As a result, it happens that there are accumulations on and around the transportation path through the production facilities. This means that forklifts transporting pallets with products or other materials sometimes have to wait on each other in order to let the other forklift pass through. This leads to unnecessary waiting time, which is time that is being wasted. The main research question is:

"What improvements can be made in the layout of the production facilities to decrease the busyness at Timmerije B.V.?"

With the main research question, the action problem has been determined as the following:

'The saturation of the transportation path at Timmerije B.V. needs to be reduced with 50%'

With saturation of the transportation path, the congestion/busyness of the transportation path is meant. These are synonyms to describe the current problem situation.

1.3. Core problem identification

The choice of the core problem is going to be described in section 3.1. The core-problem is:

'During peak times, the bulk-products are blocking the rest-products'

The following definitions have been found in cooperation with Timmerije. They are of relevance to this core problem.

The definition of bulk-products: 'products with a certain physical volume which require large space (e.g. 12 products in a pallet box)'.

The definition of rest-products: 'products which are light and small, and which are packed in carton boxes of a hundred or a thousand pieces'.

The biggest win in efficiency can be accomplished by focussing on the bulk-products and leaving the rest-products out of the scope. The focus here is the production hall where the bulk-machines are located, which is production hall 4/5. The width of the transportation path is also considered.

To be able to improve the layout of the production facilities, knowledge questions are answered. The following knowledge questions guide through the research:

1. What does the current production process layout at Timmerije look like?
2. What are restrictions and requirements for a good production process layout at Timmerije?

3. Which optimization methods and theories are available in the scientific literature for optimizing the floor plan of a production company, such as that of Timmerije?
4. Which indicator(s) can be used to show a decrease in the saturation rate of the transportation path, and what are the norm and reality of this indicator?
5. What should the solution approach for generating the most suitable production process layout for Timmerije look like, considering the expected automation development and the strict safety and quality restrictions?
6. How can the solution be implemented at Timmerije?

1.4. Research design

The knowledge questions are more deeply elaborated on in this section. Per knowledge question, the main steps and its purpose are given.

1. What does the current production process layout at Timmerije look like?

A map of the production facilities is given, to illustrate the current production process layout, after which it is briefly explained what the activities are per production facility. The flows in the production facilities are illustrated.

2. What are requirements and restrictions for a good production process layout at Timmerije?

The requirements of the production process and the problem are explained. A problem cluster of the current situation is given, after which the restrictions are given. The problem can be justified by walking around the production facilities and talking with the people on the work floor, to hear what they experience as the main problems.

3. Which optimization methods and theories are available in the scientific literature for optimizing the floor plan of a production company, such as that of Timmerije?

A systematic literature review is conducted to find a model/theory for optimizing the floor plan of a production company, such as that as of Timmerije. The Systematic Layout Planning (SLP) of Muther and Hales (2015) has been found through a systematic literature review (SLR), which can be found in Appendix A. The steps of the SLP will be used as the main structure of the improvement process.

4. Which indicator(s) can be used to show a decrease in the saturation rate of the transportation path, and what are the norm and reality of this indicator?

An indicator that is used often in the Systematic Layout Planning (SLP) of Muther and Hales (2015), is the total transportation distance. Other indicators from the SLP can also be chosen, if they are found to be relevant to the company. These indicators can then be compared. The reality of the total transportation distance can be determined with the data that is available in the company. The data of the amount of the produced products of a specific type per machine is available in the ERP system. In the ERP system, there is also information about how many of those specific products fit into a box, and how many of those boxes fit on a pallet. With this information, the number of pallets per machine in a certain time can be determined. A map of the production facilities is available, on scale. With this map, the specific distance of a machine to the checking-area can be determined. The total transportation distance is then calculated by the sum of the multiplication of the number of pallets by this specific distance. There is also a rest-flow of pallets, on which moulds are located. This number has already been found by Damveld (2019). This value is adjusted to the production data of quarter 1 of 2020. The reality value is the total transportation distance of the products + the total transportation distance of the rest-flow. The norm value is set as half of the reality value.

5. What should the solution approach for generating the most suitable production process layout for Timmerije look like, considering the expected automation development and the strict safety and quality restrictions?

According to the SLP there are three phases in the design process. These are the analysis phase, search phase and selection phase. The analysis phase, and a part of the search phase, are already answered in the previous knowledge questions. The theoretical data is available, but the practical side is not known yet. The considerations and practical limitations are taken into account. This data is gathered by talking with the different stakeholders of the company. Then three layouts are made. After a feedback session with stakeholders and the management of Timmerije, the layouts are improved. After another session with the stakeholders and management of Timmerije, a solution is chosen, based on the various criteria. These criteria are determined in the second session as well, with the stakeholders and management of Timmerije

6. How can the solution be implemented at Timmerije?

The main implementation steps will be given. These steps are available in the SLP method by Muther and Hales (2015). The information is brief, since we assume that Timmerije is aware and capable of implementing a floor plan. Creating a roadmap, and assigning tasks to specific stakeholders, leads to stakeholders feeling more obliged to implement the solution.

1.5. Deliverables

The main deliverable is a more efficient floorplan. The focus here is the production hall where the bulk-machines are located, which is production hall 4/5. Next to that, it is known that there are two machines in hall 1 that are producing bulk-products as well. These two machines may be incorporated in the more efficient floorplan of hall 4/5. There will most likely be another layout than what the situation is now. Machines will have changed in position, and it is possible that doors have been deleted/moved/added. Perhaps all the machines have another orientation, which means that the front position is now the back position, and vice versa. This new floorplan shows the location of the machines, the orientation of the machines, the transportation path to the checking-area and the location of the doors (to go to the checking-area and/or the trucks directly). In this new floorplan, the expected future innovation in automation will be considered. This means that extra space around machines is needed, to build an automatic artificial intelligence quality check of the products, which automatically accepts or rejects products. Perhaps in the future, pallets will not be transported anymore by forklifts, but by robots. There might even be an automatic transportation lane.

This more efficient floorplan is validated. It is known what the norm is. According to the floorplan we consider to be optimal, the saturation of the transportation path during peak times should decrease to a level which is half of the original level. To validate the solution, an important deliverable is the calculation of the reality in the new solution.

Lastly, the new floorplan is to be implemented if the company chooses the new solution. For this purpose, an implementation plan will be delivered as well. In this implementation plan, the main steps become clear. Also, tips on how to implement layout changes from the literature are provided. In this way, the company is given advice on how to implement the solution.

1.6. Chapter summary

In the beginning of the chapter, the company of Timmerije is described, just like the holding structure under which Timmerije operates. The action problem and core problem have been determined, after which the knowledge questions describe the steps to solve the action problem. The research design elaborates more on the specific steps in the research. Finally, the main deliverables are given and described.

2. Current production process layout

In this chapter, the current production process layout is given. In section 2.1, a description of the production process is given. Section 2.2 illustrates the way Timmerije uses warehousing. A general overview and description of the facilities is given in section 2.3. In section 2.4, the current production facilities are shown, and what the flows of products are in the production area.

2.1. Production process

The process flow diagram of Damveld (2019) in Figure 2.1 below, illustrates the steps from raw material to the end product. The process starts with an order from a customer. This order is placed in the planning where applicable. A production batch can be started when both the machine with the required mould and the raw material are ready. Raw material is transported directly to the machines from the central raw material warehouse, with the use of a tube system. After the production, the quality of the produced product is checked manually by an employee. A machine learning algorithm is being developed in the company, in which this step is done with the self-learning algorithm. It is expected that this step eventually does not to be done manually anymore. If the quality positively exceeds a certain norm, the products are placed into carton boxes, crates or pallet boxes. These different packaging materials are then placed on pallets. Next, these pallets are moved to the checking-area, where the quality of the products is checked by picking random products. If the products are of good quality, the pallet gets marking to recognise that it has been verified. After this checking-area, pallets with products can move to the warehouse or to the assembly department. The last step of the process is the delivery of the (assembled) products to the customer.

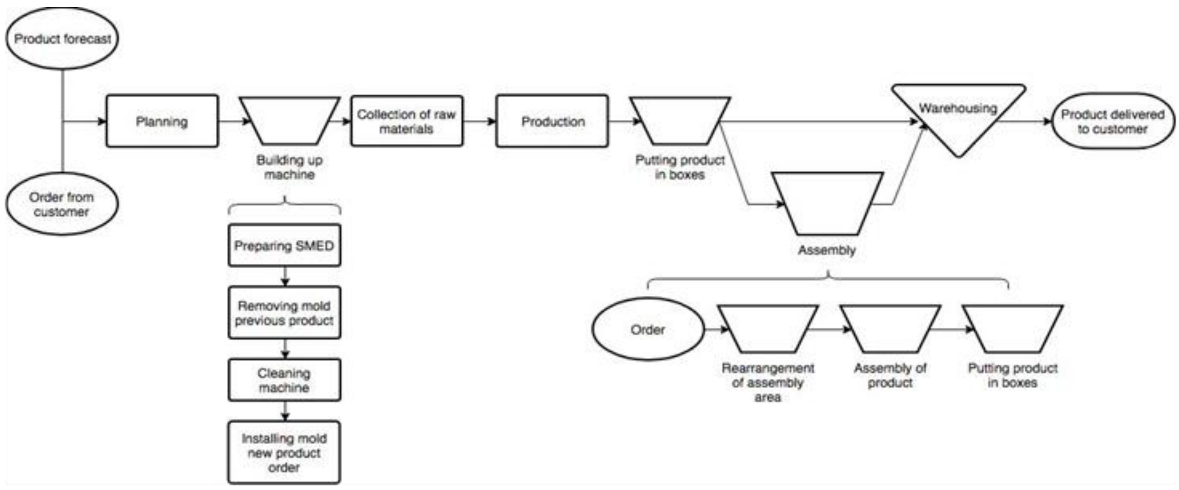

Figure 2.1. Process flow diagram (Damveld, 2019)

The previous process flow diagram holds in case the customer has placed an order of a specific product at Timmerije before, which means that the mould is already available at Timmerije. In case a customer places its first order at Timmerije, the 8-stage production development plan for a mould is executed. After every stage in this plan, the customer can agree to proceed if the executed step is conforming their wishes. An illustration of this 8-stage production development plan is given below in Figure 2.2. Every step in the process is explained briefly.

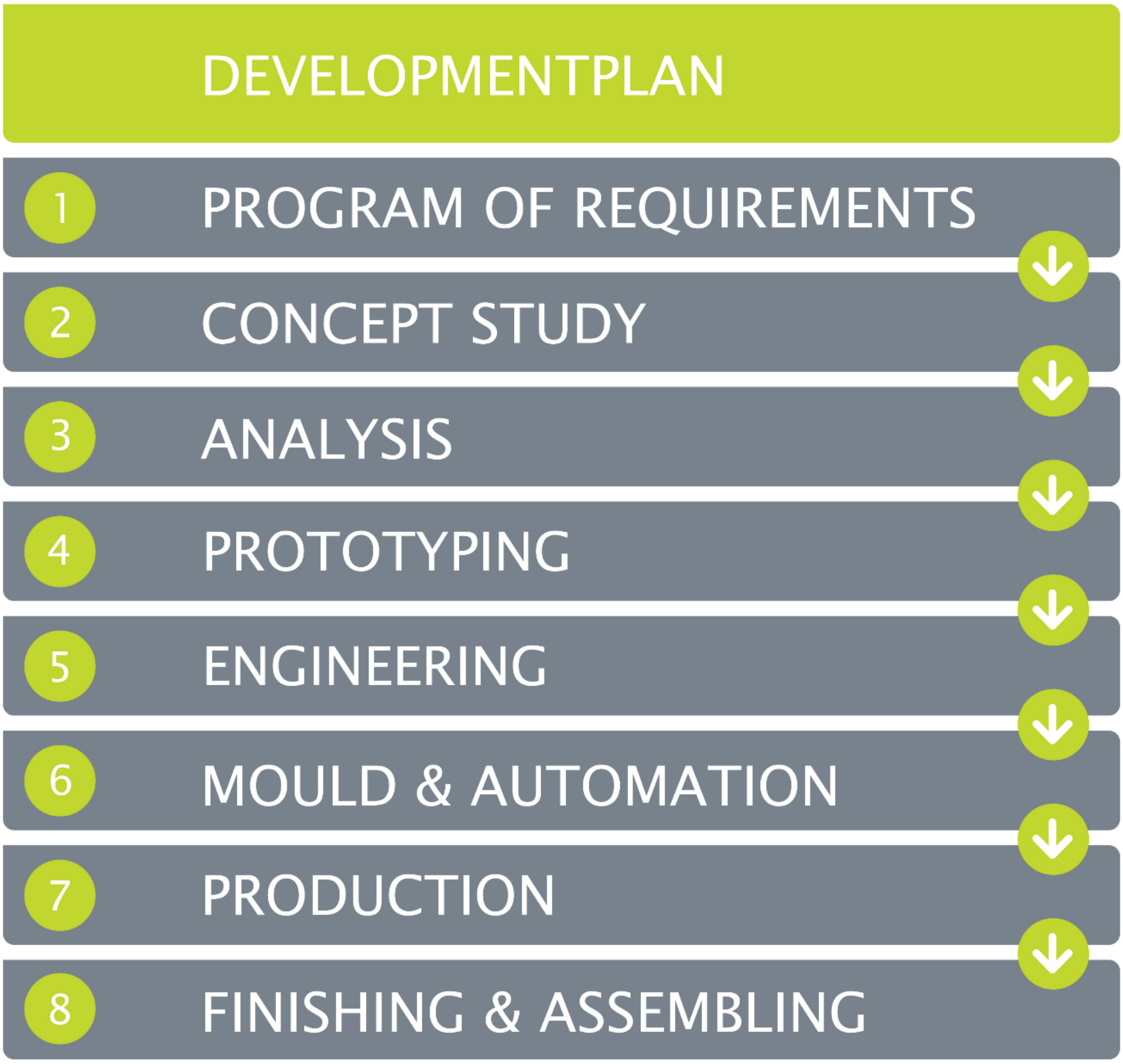

Figure 2.2. 8-stage production development plan (Timmerije B.V.)

Stage 1 concerns the program of requirements. For defining the development, it is important to set up a program of requirements to which the product should comply. In stage 2, the concept formation is given. The concept concentrates on the integration of functions and the producibility as a plastic injection moulded product. Concepts with motivations are delivered, and these concepts are tested on the requirements program. In stage 3, a risk assessment takes place in consultation with the customer. This test is performed to determine if the choice of material is suited for the set of requirements. Next to that, the purpose of the assembly of the plastic injection moulded product is analysed. Prototyping occurs in stage 4. The prototype is meant for an impression of the main dimensions, fitting and details in the product. With the use of laser-controlled techniques, Timmerije is able to quickly produce the right prototype without already having a mould.

After stage 4, detailing of the plastic injection moulded product takes place in stage 5. With the use of software (CAD for example), these moulds can be specified. With the use of CAD software, two-dimensional and three-dimensional models can be created. Timmerije starts with the development and the production of the mould in stage 6. The moulds are produced in a broad international network of mould makers, to be ensured of the right price/quality ratio and the spreading of risks. Before Timmerije starts production in stage 7, the product and the required process must be released. The main evidence that Timmerije has understood the specific customer requirements is summarized, and a product sample is provided. The same steps for the finishing and assemblage take place in stage 8. When all these steps have been executed, Timmerije can start with the production of the order, with the newly produced mould.

2.2. Warehousing

Timmerije possesses four warehouses. Inside the production facilities is one of them, which is called the internal warehouse. Another warehouse is located next to the production department, the so-called Egginkhal. The third warehouse is positioned in Neede (2.5 km distance from Timmerije), where the trucks with produced products are first transported to. Next to the Egginkhal are trucks located. When pallets with products are checked at the checking-area, and they have to be transported to the warehouse in Neede (which happens most frequently), they are placed directly in these trucks. When the truck is full of pallets, the truck departs for the warehouse in Neede. In the warehouse in Neede, the pallets are re-arranged and truckloads with pallets to the same customer are gathered. From here, the products are transported to the customer. The last warehouse is a warehouse rented in Noordijk (nearby Neede), which is the Henninkweg warehouse. Raw materials are stored here, just as products that have to be kept in stock for customers for a long time (think of spare parts).

2.3. General overview

To provide a general overview of all the facilities of Timmerije, Figure 2.3 is given below. Afterwards, it is explained what the different colours and numbers mean.

Figure 2.3. General overview of current facility layout (Adapted from Damveld (2019))

In the blue areas is the SMED department. In here, moulds are prepared for production, and all other materials are gathered that are required to be able to swap the mould efficiently and quickly. When moulds are needed for production, they are taken from one of these areas. The purple area next to the SMED department is the toolmaking area. Here, the moulds are being repaired and maintenance on the moulds is being executed. The orange area in the middle of the facility represents the material supply area. Here is the internal warehouse of the raw materials. From here, the raw material is transported to the machines with the use of a tube system. This tube system can be seen below in Figure 2.4. Raw materials are first placed in containers, after which the raw material is transported through the silo above it. The raw material then passes through the tubes to the machines. The location of the described steps is marked in red in Figure 2.4. This means that raw materials are not transported to the machines with the use of pallets.

Figure 2.4. Raw materials warehouse with tube system

The yellow area in Figure 2.3 represents the production area. This area will be more elaborated on in the next section on the current production facility flows and the flows of products in these halls. Number 1.1 in Figure 2.3 represents the storage area of to be assembled products, whereas number 1.2 in the Egginkhal is the storage area of finished products. The black star is the location of the checking-area. The green area is the assembly area. If needed, products are assembled here to form (sub-)assemblies. In the assembly department, 50 people are working who have been detached from the employment market. The warehouses in Neede and Noordijk are not shown in this figure.

2.4. Current production facility layout and flows

Figure 2.5 below shows the production halls in the current facility layout. This figure zooms in on the production department (yellow block in Figure 2.3 above). It is important to mention that the blocks are machines. The flows in these production halls are described. Another important point to mention is that there are two machines missing in production hall 4/5 in this floorplan. Since this figure solely is used to clarify which production hall is located where, and what the general flow in these halls is, it is not of importance that these two machines are missing.

The blocks and associated product flows are described briefly from top to bottom. The red block represents production hall 1. In this hall, mainly rest-products are being produced, except for two machines that are producing bulk-products. All the products are transported towards the main transportation path. In the figure, this path goes vertically through the first three production halls, after which the path goes to the left, diagonally. This main transportation path can also be recognized by the high amount (of different colours) of arrows on it. The blue block is production hall 2. Here, only rest-products are being produced. The products that are produced on the left side in this hall, are transported to the checking-area to the left, via the raw material warehouse. The other half goes right, via the main transportation path. The purple block is production hall 3. All products that are produced here, are transported to the left. These products do not use the main transportation path. The last production hall, the orange block, is production hall 4/5. Here, bulk-products are produced. The product flows of production hall 1, and (approximately) half of production hall 2, are transported to the checking-area via the main transportation path, through production hall 4/5.

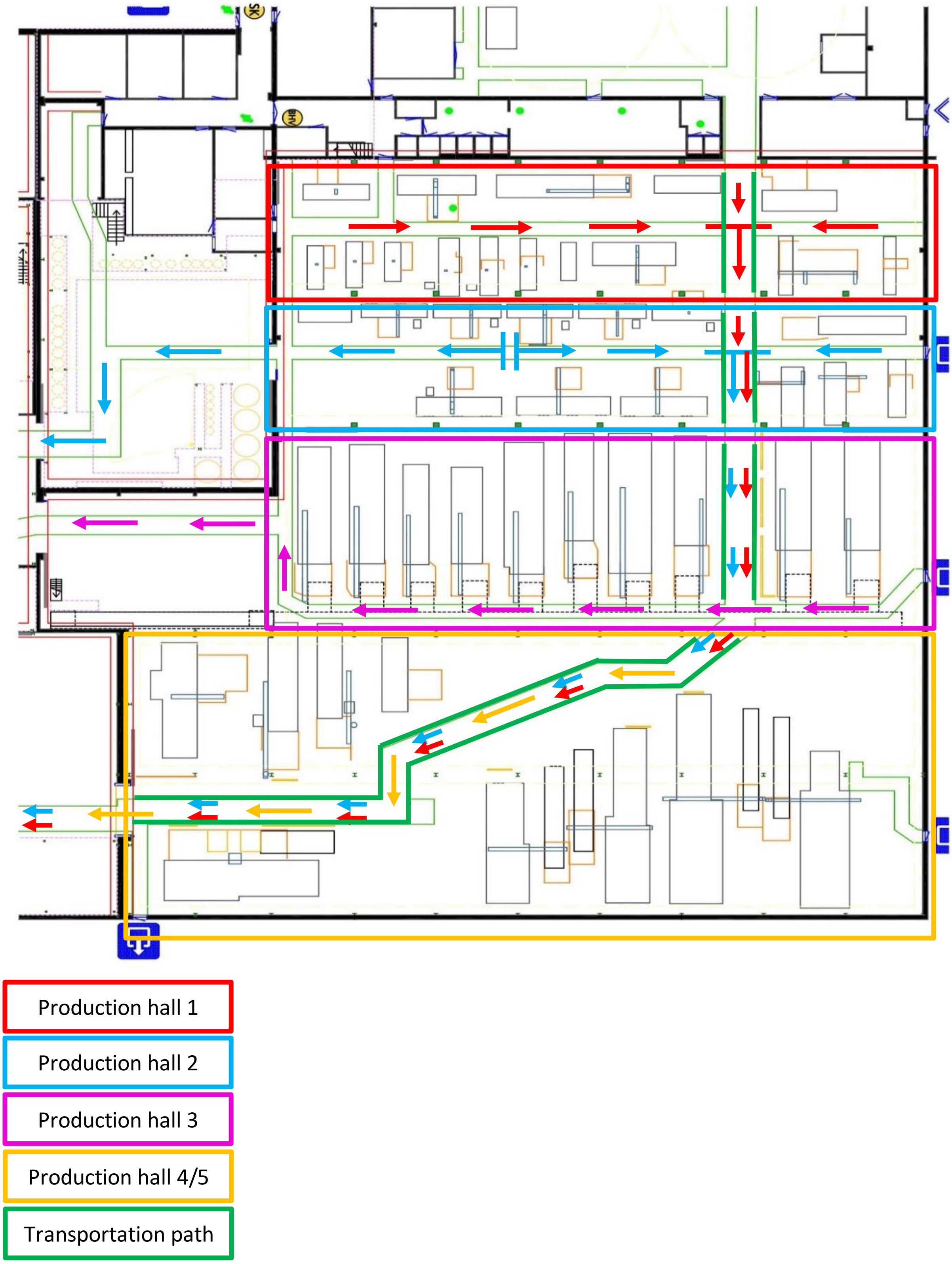

Figure 2.5. Production halls and flows in current facility layout

2.5. Chapter summary

The production process is described in this chapter, with the use of a process flow diagram. The 8-stage production development plan is given. The facility of Timmerije is described to give an overview of the company, and to supply the reader with the basis on which the research rests. To illustrate the flow in the current production halls, a map of the production facilities is given, with the flows given inside these production halls.

3. Restrictions and requirements

In this chapter, the knowledge question on the restrictions and requirements for a good production process layout at Timmerije is answered. With the use of a problem cluster in section 3.1, the restrictions at Timmerije are illustrated. This figure helps to show the core problem at Timmerije. The requirements of a good and efficient production process layout at Timmerije are given in section 3.2. The requirements for the customer are taken into account, just like the seven aspects that are of importance to Timmerije.

3.1. Restrictions

There are several reasons for the fact that the transportation path cannot handle the transportation demand. These can be found in Figure 3.1 below. A short explanation for these reasons is given, and after that the choice for the core problem is explained.

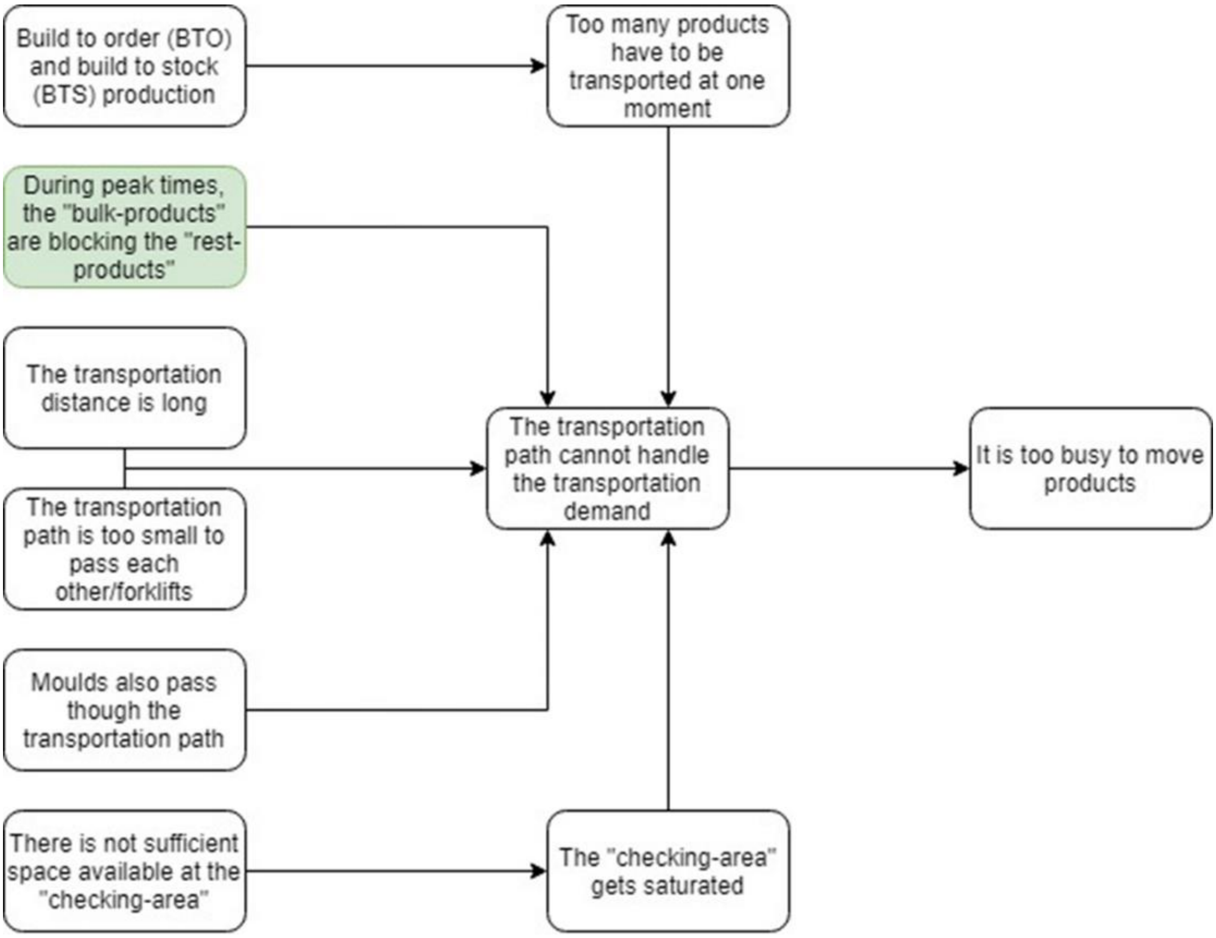

Figure 3.1. Problem cluster

Timmerije produces with a frozen period of two days, this means that they only have fixed what will be produced the coming two days. The schedule of the upcoming week is known but is not fixed. They build to order (BTO) and build to stock (BTS). Due to this, every day is different in terms of production volume and quantities, which sometimes results in peak times regarding production levels. At these moments, too many products/pallets have to be transported at a single moment in time, which in turn leads to a saturation of the transportation path.

During peak times, the bulk-products are blocking the rest-products. In principle all the machines work 24/5, which results in a lot of production output. The production output volume of the bulk-products is significantly higher than the volume of the rest-products. In Figure 2.5 in section 2.4, the layout of the production facilities was shown. The blocks in production hall 4/5 are machines that are producing the bulk-products. Next to that, there are two machines in production hall 1 that can also be considered bulk-machines. The high volume of output of bulk-machines has the result that at peak times, these products are blocking the transportation path for rest-products. Products sometimes have to wait to be able to be transported.

Pallets are transported across the transportation path in green in Figure 2.5. This path goes all the way from the top to the bottom in this figure. The transportation distance for some products from the machine to the checking-area is rather long, as can be seen in this figure. This combined with the fact that the transportation path is too small for two forklifts (or a forklift and a person) to pass each other, results in forklifts having to wait for each other.

The injection moulding machines need moulds to be able to produce products. Since there are a lot of different products to be produced, different set-ups of the machines are needed. Therefore, there are on average 75 changeovers per week on the mould of machines. The previously used mould has to be transported back to the mould warehouse by a forklift via the transportation path. Next to that, the new mould has to be transported by a forklift from the mould warehouse to the machine, via the same route. The transportation of moulds leads to a limited increase in the saturation of the transportation path.

When a machine has produced a pallet of a product, this pallet is picked up by a forklift and transported to the checking-area. This route mostly concerns the pallets from the four biggest machines, which are located in production hall 4/5. At the checking-area, the products on the pallet are checked on the quality, and the pallet gets marking to recognise that it has been verified. In addition to that, some of the pallets have to wait on the next pallet of the same product to arrive at the checking-area, because these two pallets have to be placed onto each other in the transportation truck. When a lot of products are produced, a lot of pallets are waiting on the next pallet of 'their' product to be able to move further in the process. This then leads to a saturation of the checking-area, which in turn leads to a limitation of the transportation speed near the checking-area, because products are placed inappropriately in the checking-area.

The selected core problem is:

'During peak times, the bulk-products are blocking the rest-products'

This problem results in a significant increase in the saturation of the transportation path. An example to illustrate the current situation is the following. There are four machines that are the biggest. They produce the biggest products, and therefore have most transport actions. These four machines can be found on the bottom right of the production process layout in Figure 2.5 in section 2.4. There are more bulk-machines, but these four are the biggest in the facility. Some of these machines can produce a maximum of one truckload of pallets with products on a single day (24hr). Sometimes it happens that Timmerije would like to have all four of these machines running, but they decide to have a maximum of three of these machines running. They decide so, because if they would have all four machines operational, they simply cannot cope with the massive output of these machines. The transportation path cannot handle the output of these machines at the same time, resulting in enormous blockages in the transportation path, and after that, blockages around the machines. This blockage then blocks the rest-products that have to be transported to the checking-area. In this situation, forklifts with pallets are waiting on each other. Unsafe situations originate as a result of this. The focus of Timmerije is always on employees and their safety. Since these unsafe situations exist, and Timmerije wants to grow in the future (what they cannot do now), the problem has to be solved.

3.2. Requirements

The requirements for a good production process layout at Timmerije include two main factors of influence. These are the importance of the customer to Timmerije, and the seven aspects that are the key values within Timmerije. Both these two factors are described in the following sections.

3.2.1. Customer

Timmerije's main principle is supplying quality in every step in the production process, in which the customer has a central position. The quality and delivery times are determined in cooperation with the customer, and match 1 to 1 (if possible) with the wishes of the customer.

It requires communication to order and deliver the products on the agreed upon time. For this purpose, Timmerije has an experienced sales office, which is part of the company office to keep the lines short and to be able to act adequately. Timmerije is (sometimes) able to shorten the time-to-market of the new injection moulded products, with an earlier delivery time as the result.

After the plastic injection moulding process, Timmerije ensures that the plastic injection moulded products are given added value. This includes mainly the assembly in the decoration process, in which quality is provided. The assembly activities that are provided include the following:

- Sub-assemblies
- Customer-specific packing
- Labelling
- Testing
- Digital printing

Timmerije can also comply with the increasing demand to deliver the plastic injection moulded products fully tested. The functioning of the products is optimized during the life cycle. During this process, it is determined how the function of a product or service can be fulfilled when minimizing the costs. A well-considered decision is made, after having analysed the unnecessary costs that might exist in the process.

3.2.2. Seven aspects

Timmerije has defined seven aspects of the production process that indicate the commitment and mission of Timmerije. All these key aspects are considered when decisions have to be made for the continuation of the business operations. Cases exist, where these aspects show overlap, or where there exists a correlation. The seven aspects can be found in a schematic overview in Figure 3.2 below. A brief description and examples of these individual aspects are given, to illustrate the importance of every one of them for the production process layout at Timmerije.

Figure 3.2. Key aspects of Timmerije

Social & Health

Timmerije expresses its social function in the neighbourhood by sponsoring of the local sport clubs, participation in festivities and organising company visits. They make themselves available as a learning company in the neighbourhood for traineeships and apprenticeships. Safety always comes first in the production process. When the company cannot guarantee the safety of the employees, they will not start or continue with the production batch. There are strict rules in the company, related to health and safety policies. An example is that one has to stay within the lines of the transportation path that runs through the production halls. When you have to go outside these lines, you need safety shoes. Another example is that employees who work longer than a certain time frame in the production facilities, have to use ear plugs. The machines all together produce an enormous amount of noise, and this noise is not healthy. Timmerije follows these rules well, and these rules are required for a safe production process.

Zero Waste

One of the key performance indicators (KPI) is the amount of waste. Less raw material and energy waste is the durable thought of Timmerije. For this purpose, they have started an internal project *'Don't waste it'*, to reduce waste in the production process. By investing in a Manufacturing Execution System (MES), they are able to execute this reduction in a controlled manner, and they can therefore ensure the reduction.

This MES leads to efficient inventory management. By ordering what is needed, and not having too much material in stock, waste can be reduced due to changing customer demand. Getting deliveries of raw materials in bulk, and delivering products to the customers in bulk, leads to less packaging waste. The packaging material can even be returned to Timmerije, so the material can be used again. By using the preventative maintenance schedule on the moulds, a lot of waste of time and money is prevented, and also waste of material is prevented. Wear and tear in the moulds can occur, that is a normal occurrence in any manufacturing process. Batches can be produced wrongly if the mould would contain an error. It is more beneficial to control the costs to prevent a breakdown instead of reacting to a breakdown later, which results in unnecessary overtime and increased shipping costs to expedite delivery. This zero-waste policy is an extremely important requirement for a good and efficient production process, because waste costs money and time, and is not beneficial to the environment.

Innovation

Timmerije has the mentality and the knowhow to continuously take a step further to develop new injection moulding techniques. Timmerije wants to reach a “Next Level in Plastics” consistently by doing this. By integral thinking the processing becomes increasingly smarter and over the years many different injection moulding processes have been created at Timmerije. Most processes are run completely automatic and are set customer-specifically. These processes include the following:

- 2k, 3k injection moulding
- Co-injection moulding
- Gas & water injection moulding
- Compression moulding
- In-mould labelling
- In & outsert moulding
- Multicomponent injection moulding

Being able to innovate is essential to Timmerije, since the plastic market is a rapidly changing and demanding market. To be able to keep meeting (and exceeding) customer requirements, innovation in the production process is crucial (The Rapidly Changing Polymers Industry, 2018).

Digital

Timmerije has an efficient planning of internal and external processes to ensure a high delivery reliability. For this purpose, Timmerije uses an ERP package that is specifically developed for plastic injection moulding. This ERP package is a niche product for the discrete plastics industry like injection moulding. Due to this, Timmerije is able to plan the injection moulding process to the finest detail and the company is able to handle the complexity of the high number of products, moulds and raw materials. With this ERP package, customers can order in various ways, ranging from build-to-order to Kanban. The planning module in the ERP system enables Timmerije to efficiently produce comparable products with (almost) the same moulds and materials. The ERP controlled warehouse management is completely digital and is essential for on time (FIFO) delivery.

For sustainable and controllable plastic injection moulding, Timmerije has invested in the most extensive and advanced type of process and control monitoring. For this purpose, Timmerije has connected its machine park to a Manufacturing Execution System (MES). This is an interlayer, which links the logistical and administrative systems in the organisation with the production. This system continuously provides up to date order information from the ERP package, and the performance on the production floor. The performance on the production floor includes the machine parameters, the possible downtime, the product quality and the operator work activities. This information is transferred in such a way that employees only see the specific information that is of interest to them. Employees can respond quicker and more adequate to developments, by combining this data with tolerances.

Having these digital systems, like the ERP package and MES, enables Timmerije to produce more efficient with less waste produced. Also, they can provide a high delivery reliability. That is why these digital systems are a requirement for the production process of Timmerije.

Flexibility

Timmerije is flexible in various ways. There are 50 employees who work daily in the assembly area. The assembly lines are shifted in such a way that the assembly is done optimally for this specific product. The company arranges warehousing and the logistics during the design and production processes. As Timmerije performs these activities in house, short lines are used so high quality and flexibility are offered. They are also flexible regarding production. There are 50 injection moulding machines, 150 different raw materials, and as a result 1500 different products can be produced. To accomplish the production of all these different products, there are on average 75 production swaps per week. Most moulds fit on a couple of machines. This means that Timmerije can be even more flexible with producing a certain product. If needed, they can change or start a batch relatively fast. With all these different combinations of machines, raw materials and products, Timmerije can thus quickly adjust the production to customer requirements. To meet the customer demand, it is very important for Timmerije to be able to produce and assemble in a flexible way.

Green & Sustainable

Important environmental aspects with the injection moulding activities of Timmerije are noise, waste materials, energy consumption and water. Noise has already been discussed in the part on Social & Health. Waste materials have been discussed in the section on Zero Waste. The energy and water consumption will be discussed below.

Timmerije also uses biopolymers besides recyclates. These biopolymers are bioplastics that are made from polymers with a biologic origin. They are a sustainable alternative for the plastics that are produced based on petroleum. These biopolymers can produce almost anything that is being produced from synthetic plastics. Bioplastics are applied in a closed cycle, in this case cradle-to-cradle (C2). In this way, the use of fossil fuels is reduced to a low minimum, and the emission of CO2 is limited. Next to that, the production and processing of bioplastics requires less energy than the production and processing of synthetic plastics. As these biopolymers are still in the development stage regarding the options of application, Timmerije provides its own moulds to accelerate the improvements made in these processes. In cooperation with raw material suppliers, it is researched how this sustainable solution in plastic injection moulded products can best be processed.

To reduce the energy consumption for the production, the company has tightened their specifications and method of work. Significant investments have been made to focus on this point. For that purpose, all the new machines are more energy efficient, and the machine park is disconnected when there is no production. Lastly, the warehouse at Timmerije is equipped with solar panels. This green energy is used for the production processes at the company. The energy consumption of fossil fuels is reduced too in this way.

Water is used in the production process to cool the produced products and the mould. Since large amounts of products are produced, and the temperature in the production process can reach very high temperatures, a significant amount of water is needed. The newly acquired machines are already more efficient in water consumption. A small percentage increase in efficiency already means that huge amounts of water are saved. These environmental aspects are very important to Timmerije, and therefore it is required that the environmental aspect is taken into account well.

Logistics

Besides the modern plastic injection mould plant that Timmerije possesses, they also have their own engineering department, tool shop and an assembly department. Having all these departments directly available ensures that the communication lines within the departments are short, which means that they are very flexible and that they can fix certain aspects quickly and efficiently. The logistics within Timmerije include the following:

- Automated order processing and invoicing
- Barcode system
- Warehousing
- Customer-specific packing
- Returnable packaging
- Transport

The automated order processing and invoicing makes sure that (unnecessary) work is taken from the employees. Also, no human-made errors are made, because the system does the work in a concise manner. Timmerije uses a barcode system to verify if a pallet with products is conform the requirements. This barcode system is also used to track the other materials that have to be transported through the production facilities, like raw materials and moulds. It has already been explained in section 2.2 what the warehousing logistics at Timmerije looks like. Timmerije uses customer-specific packaging. This is a requirement or wish from the customer, which Timmerije fulfils. Next to that, returnable packaging is used, in order to decrease the packaging waste. Timmerije takes care of the transportation within the logistics process. When integrating all these functions and departments in the logistics department, the processes can be aligned on each other extremely well. No time is being wasted because of unclarities or unreliable partners in between.

There is a large flow of products, packaging material and other material through the production facilities. In order to let this flow go through the facility layout smoothly, it is required that the transportation path through the facility can handle the transportation demand. By this, it is meant that if a pallet needs to be transported, the pallet should be able to be picked up immediately and be able to move to the checking-area. If this is not possible, pallets start to accumulate around the output positions of machines. Especially in the case of the big bulk-machines, this is of utmost importance. Since these machines can produce a truckload full of pallets on a single day, one can imagine the speed with which products are being produced, and how fast accumulations can occur.

A requirement for a good and efficient production process of Timmerije, therefore is that the logistics are well aligned, and that these aspects preferably are performed in house. Next to that, it is required that the transportation flow through the facility layout runs smoothly and that there are no accumulations. This can be achieved by optimizing the logistics at Timmerije.

3.3. Chapter summary

The theoretical basis for a good and efficient production process layout is laid in this chapter. With the use of a problem cluster, the restrictions that Timmerije currently faces, are illustrated. The requirements for Timmerije include two main factors, which are the customer and the seven key aspects within the company. These two factors are elaborated, and their essence to the future layout is given.

4. Optimization method and theories

In this chapter, the chosen optimisation method for optimizing the floor plan of a production company like Timmerije, is given. The method is found by executing a systematic literature review, which can be found in Appendix A. The main findings are given in section 4.1. A description of the method is given in section 4.2.

4.1. Systematic Literature Review

After analysing the different articles in the systematic literature review, it turns out that there are quite some different layout improvement methods. An optimisation method is needed to establish structure in the layout improvement process. Just to name a few methods; Dynamic Facility Layout Problem (DFLP), Stochastic Dynamic Facility Layout Problem (SDFLP), Facility Layout Planning (FLP), Systematic Layout Planning (SLP) and Job Shop Scheduling Problem (JSSP). These methods/theories all have a different scope, take different parameters into account, and have different aims.

Some of these methods, like SDFLP, require higher mathematics, algorithms, and computer software to get results. This by far exceeds the scope of the research. Timmerije does not require these kind of models, they want something that already is an improvement, but it does not necessarily need to be an optimal solution.

What is needed is a simple, but effective method to improve the efficiency and productivity of a production facility by changing the layout. A universal approach and a specific set of steps to reach the end goal, is required. These steps are needed to provide extra insights on the topic. After the systematic literature review, it turned out that Systematic Layout Planning (SLP) fits the research most.

This is the case, because no higher mathematics, algorithms or computer software are needed to get results. Rather it applies common-sense in an orderly way. Math is limited to arithmetic and software use is largely limited to spreadsheets and visualization. Minimizing material handling, especially travel distance and time are key indicators to decrease the busyness at Timmerije. The examples provided in the articles are almost 1 to 1, compared to the research. Next to that, SLP provides for employees' safety, comfort, and convenience, which are the key principles of Timmerije. The employee and their safety always come first.

4.2. Systematic Layout Planning (SLP)

The SLP model of Muther and Hales (2015) uses a step-by-step approach to solve the layout problem. The optimisation that is central in the SLP (the optimisation mindset) is applied to the research. One could say that mostly the spirit of the model is used. The first version of the SLP was published in the 1950s, this means that the book and theory is more than 50 years old and is still in daily use throughout the world. There have been some updates in the versions over the years, the SLP model that we use is the fourth version.

The main objectives are the following;

- minimizing material handling especially travel distance,
- maintaining flexibility of arrangement and operation as needs change,
- promoting high turnover of work-in-process,
- holding down investment in equipment,
- making economical use of floor space,
- promoting effective utilization of labour,
- providing for employees' safety, comfort and convenience.

There are three phases in the design. These are the analysis phase, search phase and selection phase. All these phases will be described briefly. The phases are also illustrated in Figure 4.1 below. The main activities and deliverables per phase are visualised.

Analysis phase

In this phase, all information is acquired regarding the flow of materials and relationships between departments. There are four main subjects in here:

- Flow of materials, which gives an overview of the flows between departments.
- Activity relationships, which shows the relationships between the different departments.
- Relationship diagram, to show the importance of the relationships between different departments.
- Space requirements and available space, to be able to create alternative layouts which fit in the existing setting.

Search phase

In this phase, the information of the first phase is combined, after which alternative layouts are developed. The following three components are part of this phase.

- Overview of size of different departments, to show which relationships are more important than others.
- Modifying considerations and practical limitations, to know what all the possibilities are.
- Develop layout alternatives.

Selection phase

In this phase, it is determined what the best layout alternative is of those that were developed within the second phase.

- Select one layout, based on different criteria with weights.

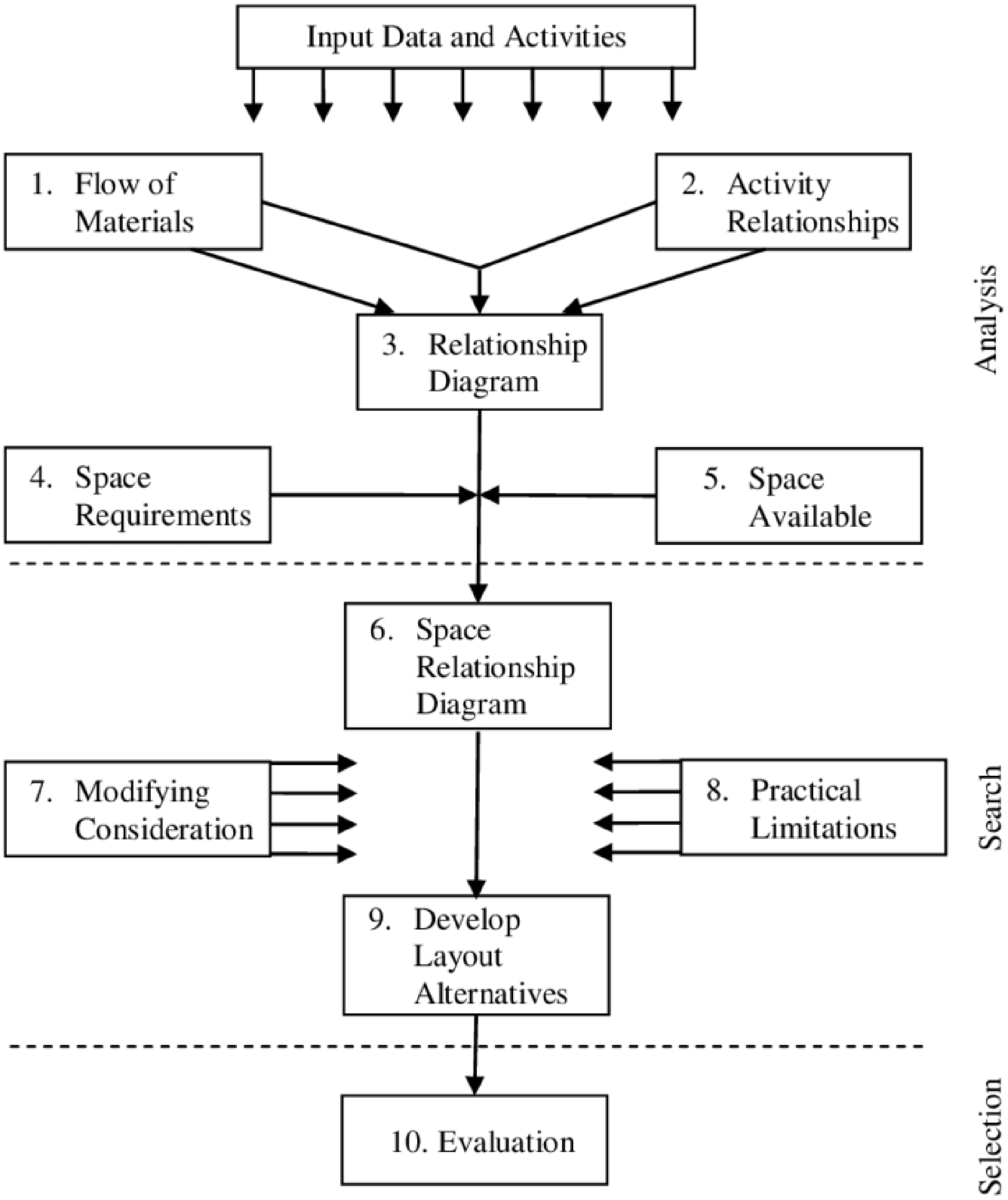

Figure 4.1. Systematic Layout Planning procedure (Suhardini et al, 2017)

4.3. Chapter summary

After having executed the systematic literature review, the Systematic Layout Planning method of Muther (2015) is found as the method to optimize the layout of the production facilities at Timmerije. The method is described in section 4.1, where its main objectives are given. Next, the three phases of the SLP are described. To visualize the different steps and deliverables of the SLP, a schematic overview of the SLP procedure is given. This method forms the theoretical basis on which the research rests.

5. Indicator of saturation rate of transportation path

The executed SLR of the previous research question resulted in an indicator which can be used to measure the decrease in the saturation rate of the transportation path. Section 5.1 elaborates on which indicator is used, why this indicator is used, and how the value of this indicator can be calculated. The current value of this indicator is calculated in section 5.2, after which the norm of this indicator is given in section 5.3.

5.1. Total transportation distance

The Systematic Layout Planning of Muther and Hales (2015) is often used to solve layout problems. During and after executing the systematic literature review, it turned out that a frequently used indicator with this method, is the total transportation distance. In the articles that were found during the SLR, similar problems with similar companies to Timmerije popped up. The total transportation distance was often used to quantify a decrease in busyness in the production facilities, or more applicable to my research, the saturation rate of the transportation path. According to Muther and Hales (2015), the saturation rate of the transportation path decreases if the total transportation distance decreases.

The reality of the total transportation distance can be calculated with data that is available at Timmerije. Pallets with different units on it have to be transported across the transportation path through the production facilities. These are pallets with produced products, packaging material and moulds. The total transportation distance per time unit of pallets with moulds has already been found in the research of Damveld (2019). This distance has been determined on a basis of 12.2 mould relocations per day. The number of relocations in Q1 of 2020 is 15. The number found in the research of Damveld (2019) is therefore adjusted to the reality value, because the calculation method for the transportation distance used in the research is valid. This final value will be elaborated on in section 5.2. This distance is about movements through the production facilities, back and forth across the transportation path. This part of the total transportation distance will be referred to as the *basis flow*, since this flow will remain (approximately) the same before and after the implementation of a more efficient layout. Also, this number is rather small compared to the transportation distance of produced products. This will be illustrated after the calculation of the reality value of the indicator.

The two remaining transportation distances are the transportation distance of the bulk-products, and of the rest-products. In section 3.1 it is determined that the bulk-products are blocking the rest-products. Since the improved layout only focusses on the bulk-products, the total transportation distance of the bulk-products is determined per individual machine. This is the case, because these bulk-machines are moved in the new setting, and thus get another transportation distance. For the rest-products, an approximation per production hall is made, because this flow stays constant.

The output in terms of produced products per machine is available in the ERP system. In here, there is also data available on how many of those products fit into a specific box, and how many of those boxes fit on a pallet. With this data, the total output in terms of pallets is calculated. Since pallets that are half full for example still have to be transported through the production facilities, the number of pallets per machine is rounded up. The production data of the first quarter of 2020, so the production in January, February and March in 2020, is taken for the calculation of this output. Timmerije recognizes seasonal influences, which tend to be comparable year on year. In this pattern, there is a peak in May and September. Since quartile 1 does not include these months, it can be concluded that the data is representative for an average quarter. Due to the appearance of COVID-19, there are some minor changes in the production levels, but these are found to be minimal. One could state that COVID-19 influences the improved layout, since more space between machines/the transportation path is needed to fulfil the 1.5-metre distance rule. Since the machines are big, and the distances are already large, there is no need to incorporate the COVID-19 rules for the layout. For this reason, the data can be taken as an accurate representative of a 'normal' first quarter.

For the calculation of the total transportation distance of the bulk-products, the distance from the specific machine to the checking-area is needed. This data can be computed with the use of a map of the production facilities, with a scale. The transportation distance per machine is the output of the machine, times the transportation distance of that machine to the checking-area. The total transportation distance of the bulk-products is the sum of the transportation distance of the individual machines.

For the distance of the total transportation distance of the rest-products, the distance from the middle of the production hall to the checking-area is needed. This information is available in the map of the production facilities, with a scale. The number of pallets of rest-products is calculated in the same way as the number of bulk-products. The number of pallets is then clustered and multiplied by the average transportation distance from that production hall to the checking-area. The total transportation distance of the rest-products does not change, since the improved layout does not take the rest-products into account. This number will however keep existing in the new layout and should thus be taken into account.

The reality value of the total transportation distance can then be calculated by the sum of the basis flow + the total transportation distance of the rest-products + the total transportation distance of the bulk-products.

To verify that the bulk-products are indeed significantly larger in numbers than the rest-products, the number of pallets with produced products, per production hall is given below in Table 5.1. Hall 4/5 contains the bulk-machines, this can be seen in the table due to the high number of pallets. The output of hall 4/5 is much higher than the output of hall 1 and hall 2. Approximately half of the production of hall 2 moves left (404 pallets) and does not use the transportation path. Production hall 3 does not use the same transportation path as the other production halls either. Thus, expressed in percentage of the total that is transported across the transportation path, this percentage is even higher (87.75%).

Table 5.1. Pallet output in Q1 2020

Production hall	Number of pallets rounded off	% of total output	% of output across transportation path
Hall 1	683	4.78	7.43
Hall 2	847 (of which 404 go left)	5.92	4.82
Hall 3	4701	32.88	-
Hall 4/5	8067	56.42	87.75

5.2. Reality value of indicator

The reality values of the transportation distance of the basis flow, rest-products and bulk-products are calculated in this section. The process and calculations per aspect of the total transportation distance are given.

5.2.1. Basis flow

The calculation of the transportation distance of the basis flow in the research of Damveld (2019) consists of two types of mould relocations. These are the mould relocations within the production facilities, and the mould relocations to/from the toolmaking area for maintenance and repair. The data is related to September 2018. Since Timmerije experiences a seasonal pattern year on year, with peaks in May and September, this data needs to be adjusted to the data of Q1 of 2020.

Table 5.2. Relocation information September 2018 (Adapted from Damveld (2019))

Kind of relocation	# relocations / day	Transportation distance / day (km)	% of total # relocations	Reality # relocations	Reality transportation distance / day (km)
Production	12.20	2.09	72.19	10.91	1.87
Toolmaking	4.70	0.69	27.81	4.20	0.62
Total	**16.90**	**2.78**	**100**	**15.1167**	**2.49**

Table 5.2 shows that there were on average 16.9 mould relocations per day during September 2018. During Q1 of 2020, there were 907 mould relocations (including both relocations for production and toolmaking). That means that there were on average 15.1667 mould relocations per day during Q1 2020. During Q1 of 2019, there were also 907 mould relocations. Since the values of Q1 2019 and Q1 2020 are the same, and since the data of September 2018 and Q1 2020 differs significantly, the calculated transportation distance for the basis flow of Damveld (2019) will be adjusted to the reality values. The distribution of production and toolmaking of the total number of relocations is used as the basis for determining the up to date basis flow. The value of the basis flow is 2.49 km per day. This value will stay approximately the same after improving the layout, since moulds still have to be transported through the production facilities.

5.2.2. Rest-products

These products are produced by rest-machines, which are located in production hall 1 and 2. Two machines in production hall 1 are not grouped under the rest-machines, but under the bulk-machines. That is why these two machines are not mentioned in Table 5.3. The output of the five machines in production hall 2 that are located on the left-hand side of the production, moves to the left and does not utilise the transportation path. That is why the output of these five machines is not mentioned in Table 5.4. The output per production batch per machine is rounded up, since a pallet that is half full still needs to be transported across the transportation path. The output of the rest-machines is given in Table 5.3 and Table 5.4.

Table 5.3. Output hall 1 for rest-products in Q1 2020

Hall 1 (Rest-products)	
Machine name	**Number of pallets rounded off**
E120-5	46
E120-2	103
2K110-1	11
A050-2	37
A025-1	38
D025-3	30
D025-4	18
A080-1	24
A050-1	40
A035-3	40
E025-2	25

Table 5.4. Output hall 2 in Q1 2020

Hall 2 (output to right)	
Machine name	**Number of pallets rounded off**
A085-1	26
A100-1	142
2K200-1	10
A200-3	71
A200-4	52
2K100-2	31
2K080-1	11
D080-2	100
Total	**443**

A100-4	61
A160-4	58
A050-3	39
Total	**570**

A map of the production facilities is given below in Figure 5.1. This map includes a scale. The blocks in the halls are the pillars in the halls. The distance between the pillars is five metres vertically, and 10 metres horizontally. This map provides the basis for the distance determination. Since there are no indications of the machines, nor the transportation path, in this figure, the detailed map of the production facilities (Figure 2.5 in section 2.4) is used to determine the distance from A to B. The distances have been measured on a printed version of the map in Figure 2.5, to determine the values in an accurate way. Since the output of the rest-machines is clustered per production hall, an average distance is found from production hall 1 and 2 to the checking-area. Since these halls have machines on the left side of the transportation path, as well as on the right side of the transportation path, an average distance from these both sides is determined. The conclusion of these average distances can be found in Table 5.5 below.

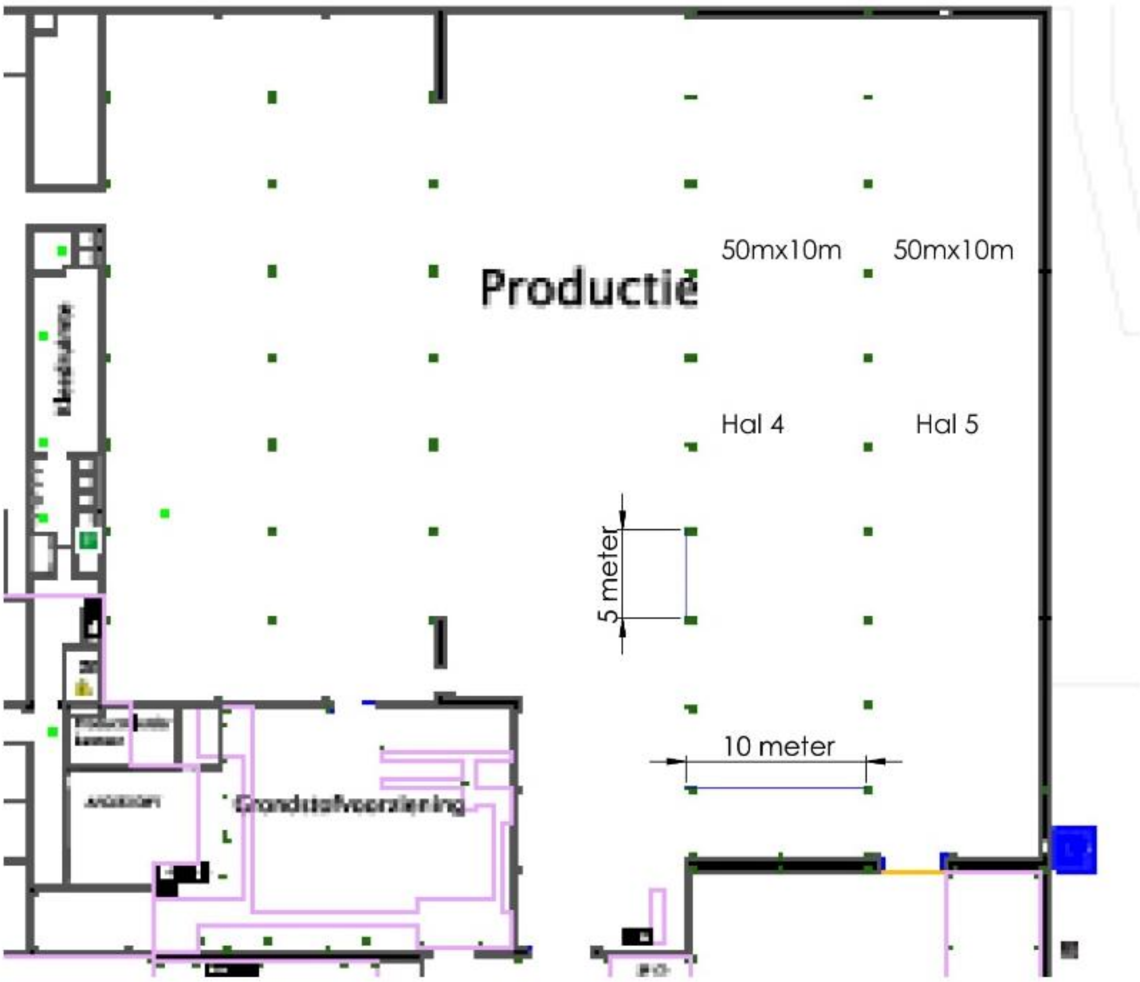

Figure 5.1. Map of the production facilities with scale (Internal source Timmerije B.V.)

Table 5.5. Distances for rest-products (numbers in brackets link to various paths)

Path	Distance (m)
Middle hall 1 to right (1)	14
Right side hall 1 to left (2)	5
Transportation path between hall 1 and 2 (3)	9
Middle hall 2 (of part that goes right) to right (4)	8
Right side hall 2 to left (5)	5
Transportation path between hall 2 and 4/5 (6)	20
Transportation path through hall 4/5 (7)	44.5
Transportation path between hall 4/5 and checking-area (8)	10

For halls 1 / 2, the total transportation distance (km) for Q1 2020 is calculated with the use of the following formula:

$$D = \sum_{j}^{2} ((P_j * X_j * 2) / 1000)$$

$$D = Total\ transportation\ distance\ of\ rest - products$$
$$P_j = Number\ of\ pallets\ produced\ in\ hall\ j\ (j = 1,2)$$
$$X_j = Average\ transportation\ distance\ (m)\ from\ hall\ j\ to\ checking - area$$

The transportation distance is multiplied by 2, since employees have to transport the pallets with products to the checking-area, and they have to return to the machine where the pallet with output was produced. Products that are produced in hall 1 use the paths (1), (2), (3), (6), (7) and (8) in Table 5.5. Products that are produced in hall 2 use the paths (4), (5), (6), (7) and (8) in Table 5.5. Filling in the formula, leads to the value of the total transportation distance of the rest-products in Table 5.6 below.

Table 5.6. Calculation total transportation distance of rest-products in Q1 2020

Route	Distance (km)
Hall 1 - checking-area	116.85
Hall 2 - checking-area	77.53
Total	**194.38**

5.2.3. Bulk-products

Bulk-products are produced by machines in hall 4/5, and by two machines in hall 1. Again, the output in pallets per production batch, per machine, is rounded up. Since the output per bulk-machine differs massively, and the optimized layout incorporates different locations/orientations of the bulk-machines, the transportation distance of output of these machines is computed individually. With the use of Figure 2.5 and 5.1, these individual distances have been determined. First, the distance from the output position of a machine to the middle of the transportation path has been found. Then, the distance from that point to the checking-area has been determined. Since two machines in hall 4/5 (E200-8 and D100-2) are not in the map of Figure 2.5, these distances have been computed on approximate values. The sizes of these machines are known, so an approximate value can be determined. Also, the orientation of these machines is known. This orientation can be seen in Figure 5.2 below.

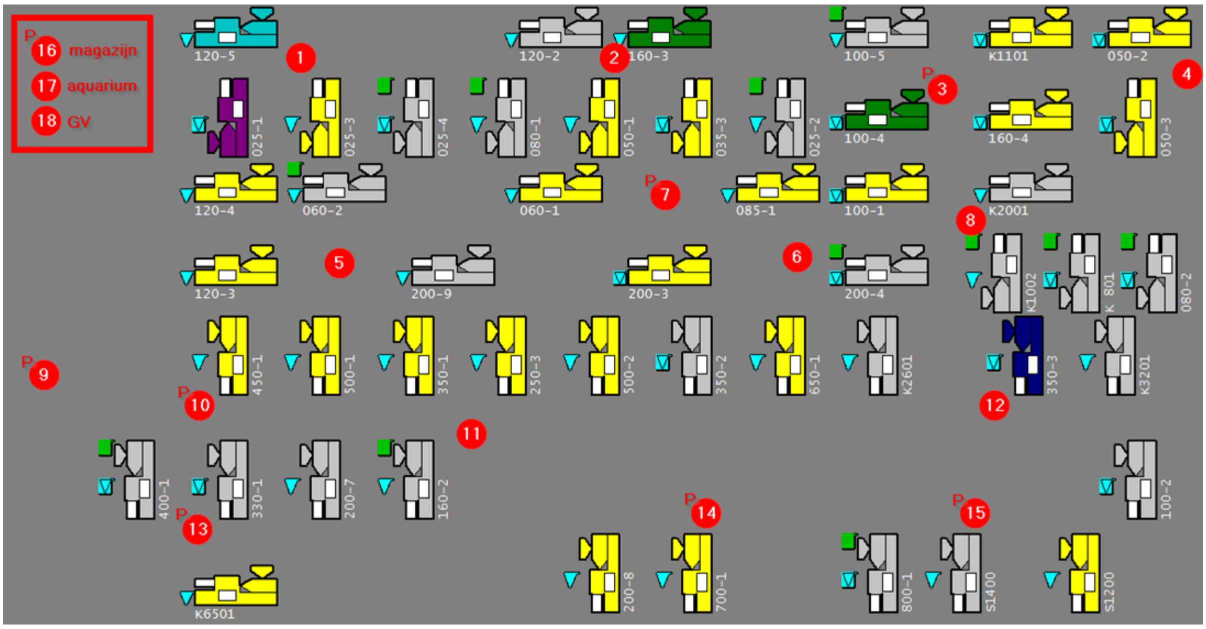
Figure 5.2. Orientation of machines (Internal source Timmerije B.V.)

The total transportation distance of the bulk-products in hall 1 is calculated with the use of the same formula as for the rest-products in hall 1. This formula can be found above and will therefore not be given again. The conclusion of the transportation distance of the output of these machines can be found in Table 5.7 below.

Table 5.7. Bulk-products hall 1

Machine name	Number of pallets rounded off	Transportation distance (km)
A160-3	78	15.99
A100-5	35	7.18
Total	**113**	**23.17**

The computation of the total transportation distance of the output of the bulk-machines in hall 4/5 during Q1 2020 requires a different formula, which is given below.

$$T = \sum_{i}^{11} (P_i * (X_i + Y_i) * 4) \;/\; 1000$$

$$T = Total\ transportation\ distance\ of\ bulk - products\ in\ hall\ 4/5$$
$$P_i = Number\ of\ pallets\ produced\ by\ machine\ i\ (i = 1\ to\ 11)$$
$$X_i = Transportation\ distance\ from\ machine\ i\ to\ transportation\ path$$
$$Y_j = Transportation\ distance\ from\ point\ j\ on\ transportation\ path\ to\ checking - area$$

The transportation distance is multiplied by a factor 4, and not a factor 2 as was previously done, because packaging material (a pallet or pallet box) is brought to the machine by means of a forklift transportation. This forklift then returns to the warehouse. When the pallet is full, the pallet is picked up and moved to the checking-area. This means a total of 4 transportations through the production facilities. The results of P_i, X_i and Y_j, together with the value of the total transportation distance of bulk-products during Q1 2020, can be found below in Table 5.8.

Table 5.8. Bulk-products hall 4/5 in Q1 2020

Machine name	Number of pallets	Distance machine to path (m)	Distance path to checking-area (m)	Distance output (km)
E400-1	90	8	15.5	8.46
D330-1	308	5.5	17.5	28.34
2K650-1	424	2	22.5	41.55
E200-7	199	4	22.5	21.09
A160-2	74	3	33	10.66
E200-8	239	4	28	30.59
E700-1	2170	4.5	38.5	373.24
D800-1	1669	4.5	40.5	300.42
S1400	1383	5	49.5	301.49
S1200	1470	6.5	51	338.10
D100-2	41	10	48	9.51
Total	**8067**	**-**	**-**	**1463.46**

Table 5.7 and Table 5.8 combined, lead to Table 5.9 below in which is the value of the total transportation distance of bulk-products through the production facilities, during Q1 2020.

Table 5.9. Total of bulk-products in Q1 2020

Route	Distance (km)
Hall 1 - checking-area	23.17
Hall 4/5 - checking-area	1463.46
Total	**1486.62**

5.2.4. Conclusion

The information combined from the previous sections leads to the computation of the reality value of the total transportation distance through the production facilities during Q1 2020. The reality value per day consists of the total distance of all produced products per day, added to the basis flow per day. As can be seen in Table 5.10 below, the reality value of the indicator total transportation distance through the production facilities is *30,50 km per day* during Q1 2020.

Table 5.10. Conclusion on reality value of indicator

Kind of movement / time unit	Distance (km)
Total distance all produced products / Q1 2020	1681.00
Total distance all produced products / month	560.33
Total distance all produced products / week	140.08
Total distance all produced products / day	**28.02**
Basis flow / day	**2.49**
Reality value / day	**30.50**

5.3. Norm value of indicator

To achieve a significant impact on the busyness of the transportation path at Timmerije, it is determined that the total transportation distance through the production facilities should decrease with at least 50%. By focussing on the bulk-products, the transportation distance of the rest-products and the basis flow will keep constant. This constant flow accounts for 5.73 km per day, which means 18.79% of the total transportation distance. As a result, the total transportation distance of the bulk-products should decrease with a percentage larger than 50. To accomplish the norm, the total transportation distance of the bulk-products should decrease with at least 68.79%, because the constant flow will remain the same in the new layout. The norm of the total transportation distance is 50% of the reality value and is thus *15.25 km per day* during Q1 2020.

5.4. Chapter summary

The total transportation distance is used as the indicator to measure the saturation of the transportation path at Timmerije. The total transportation distance consists of three separate parts, which are the basis flow of mould through the production facilities, the transportation distance of rest-products and the transportation distance of bulk-products. The reality value of the total transportation distance during Q1 2020 is calculated, which is *30.50 km/day* during Q1 2020. We determined that the norm value is half of the reality value, so *15.25* km/day. It is now possible to quantify (possible) solutions, and to prove if solutions reach the norm or not, because the calculation method of the transportation method is determined.

6. Solution approach

This chapter focusses on the creation of the various layout options. First, the considerations are named in section 6.1, and the practical limitations are named in section 6.2. After that, all information is available to make layout concepts, which are described in section 6.3. Since layouts are not perfect immediately, feedback sessions guide towards an optimal layout. This process is also described in section 6.4. Section 6.5 names the different criteria on which to evaluate layouts, after which the chosen optimized layout (based on the criteria and marks given) is given in section 6.6.

6.1. Considerations

There is one main consideration, which takes the flow in the production facilities into account. This flow is very important to the management and other stakeholders in Timmerije. A smooth flow means that the input/entrance is always on one side, while the output/exit is always on the other side. Flows of products and moulds do not interrupt each other in this way.

Timmerije has started a trajectory to realise further automation (vision with regards to quality control, automatic packaging, and removal of products). A machine learning algorithm is being developed in the company, in which the quality checking step is done with the self-learning algorithm. If the quality positively exceeds a certain norm, the products are placed into carton boxes, crates or pallet boxes by this robot/machine. For this purpose, it is expected that more space around the output position of machines is needed. An approximation has been made that around 1 squared metre is needed per machine. This space should be incorporated in the improved layout(s).

6.2. Practical limitations

All machines in the production facilities produce heat, with the two biggest machines in hall 4/5 (S1200 and S1400) producing an immense amount of heat. This is not a problem when it is not that hot outside, however in the summer with high temperatures outside, this problem pops up. These two machines are now located in the corner of hall 4/5, where the heat cannot escape easily. This factor can be taken into account when making new layouts.

The machines weigh a lot, especially the biggest machines have a heavy weight. Research has been done on the weight capacity of the production floors. It has been determined that there are no restrictions with regards to the weight capacity. Practically, all the machines can be moved to the place where desired.

The walls that are present in the production facilities will remain on their location, because the structure of the facility in terms of the walls is conform the requirements. However, there is the possibility to move/add/remove doors where desired. This holds if it is practically possible. With this it is meant, that no rules/requirements are violated when moving/adding doors.

The large machines in hall 4/5 need large moulds for production. These moulds cannot be transported to the machine via the regular transportation path, because they are simply too heavy and big. These moulds are located in hall 4/5 itself and are transported to the machines with the use of overhead cranes. The south side of hall 4/5 (where the S1200 and S1400 are located in Figure 5.2) contains a crane that is able to carry all kinds of moulds horizontally, and to the middle of hall 4/5 vertically. The capacity of this crane is 15 tons. The north side of hall 4/5 also contains an overhead crane, however the capacity of this crane is 5 tons. Together with Timmerije, it has been determined that these cranes will not move positions. Practically, this means that all machines can move to the south side of hall 4/5, but not all machines can move to the north side of hall 4/5.

Four emergency exits are present in the production halls. These are the blue blocks in Figure 2.5 in section 2.4. Three of them exist on the right-hand side of this figure, and one exists on the bottom side of the figure. We determined that these exits cannot be used as new transportation paths, because of the need of these emergency exits on those specific spots, and because of practical limitations. Between the two lowest exits on the right of Figure 2.5, storage silos are located. These silos have to be located in that specific spot and cannot be moved as a result of that.

As stated in section 2.3, Timmerije uses a tube system for the transportation of raw material to the machines. This tube system already exists and can easily be modified to a new setting. As a result, there are no restrictions in terms of the supply of raw material.

Since the production processes in Timmerije produce a lot of heat, there is the danger of fire, and the consequences that come as a result of that. An advanced sprinkler system is present in the production facility, in which there is a sprinkler on every couple of squared metres. These sprinklers are also present on places where there are no machines located. This means that there are no restrictions with regards to the solution being fire-proof, because all the machines can be moved or oriented in the way that is required.

There are two places in hall 4/5 where the pallet with produced products can get a foil wrapping to keep all the products/boxes together, and to protect them. One of these foil wrapping machines has a fixed position, but if needed this piece of equipment can get another location. The location of these two machines is not that strict to approve/disapprove of layouts. They are incorporated in the improved layout(s). This means that there is no restriction with regards to these foil wrapping machines.

6.3. Layouts of first improvement cycle

There are three main concepts for the layouts. The main points per layout are elaborated on below. After that, the map of that layout is given. To illustrate easily which machine is located where, the machine name is placed in the image of that specific machine. The reality value of the total transportation distance of the new layouts has been calculated, with the use of the same method as for the calculation of the real-life reality value. These layouts have been presented to the stakeholders and management of Timmerije, after which feedback was given to improve the layout concepts. First, the layout of the current situation is given below in Figure 6.1, in order to notice differences between layouts clearly. The A160-3 and A100-5 are still located in hall 1 and are therefore not in the current layout of hall 4/5.

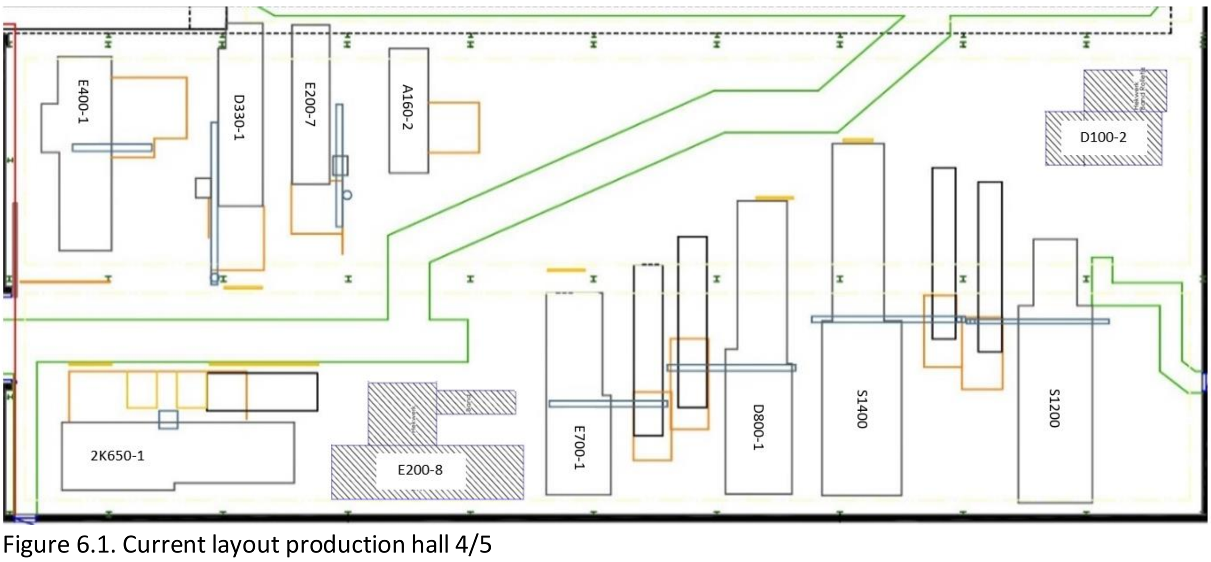

Figure 6.1. Current layout production hall 4/5

Layout 1

In this layout, the doors and the transportation path maintain the same location as in the original situation. This layout functions as an improved layout of the current situation, without making radical changes. The checking-area is located on the left side of hall 4/5, at the ending of the transportation path. For this reason, the machines with the highest output in terms of pallets are placed on the location closest to the checking-area, where possible. The E700-1 for example has the most output in terms of pallets and is thus placed most to the left as possible. The D800-1 has the second largest output and is thus placed on the second-left position. The capacity of the cranes is taken into account here. The lower half of production hall 4/5 has the 15 tons crane capacity, whereas the upper half has the 5 tons crane capacity. The four biggest machines need the 15 tons crane and are therefore located for more than 50% in the lower half of hall 4/5. We determined that the location of the moulds in the biggest machines, is below half of the length of the machines. This means that at least half of the length of those machines is located in the lower half of production hall 4/5. Layout 1 is given in Figure 6.2 below. The calculated reality value of this layout is 23.52 km/day. The previously determined norm is 15.25 km/day, which means that this layout does not meet the requirements of the norm.

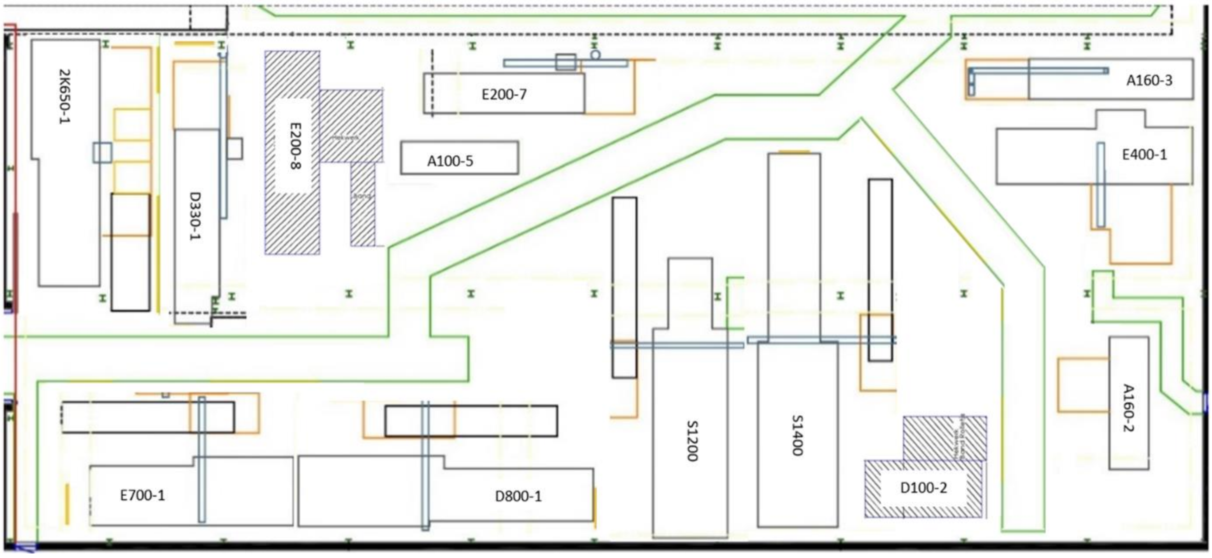

Figure 6.2. Layout 1

Layout 2

Layout 2 contains a pallet highway. This is the horizontal transportation path through production hall 4/5. The horizontal part contains two separate transportation paths, so double the width of the transportation path is now available for the movement of products/moulds. The door to the checking-area is moved in the direction of hall 1 and 2. This is possible, since there is only a warehouse behind the wall where the new door should be located. The warehouse is the location of the checking-area. The location where the new door should be located is illustrated by the red arrow in Figure 6.3 below.

Figure 6.3. Location of to be placed door

Practically, this means that the flow of products and moulds, to and from production halls 1 and 2, can now be transported directly to the checking-area and the mould warehouse (with the upper transportation path of the two). In this way, this flow does not interfere with the flow of products from production hall 4/5. Significant less unsafe situations occur in this way, because forklifts with different flows (mostly) do not interfere anymore. The most important point to Timmerije always is safety, and this layout contributes a lot to the safety of the employees. The machines are placed in the same way as in the previous layout, so the largest output to the left, and the second largest on the second left place where possible, considering the crane capacity restrictions. Layout 2 is illustrated in Figure 6.4 below. The calculated reality value of this layout is 20.86 km/day, which means that the reality value gets closer to the norm value, but the norm is not reached yet.

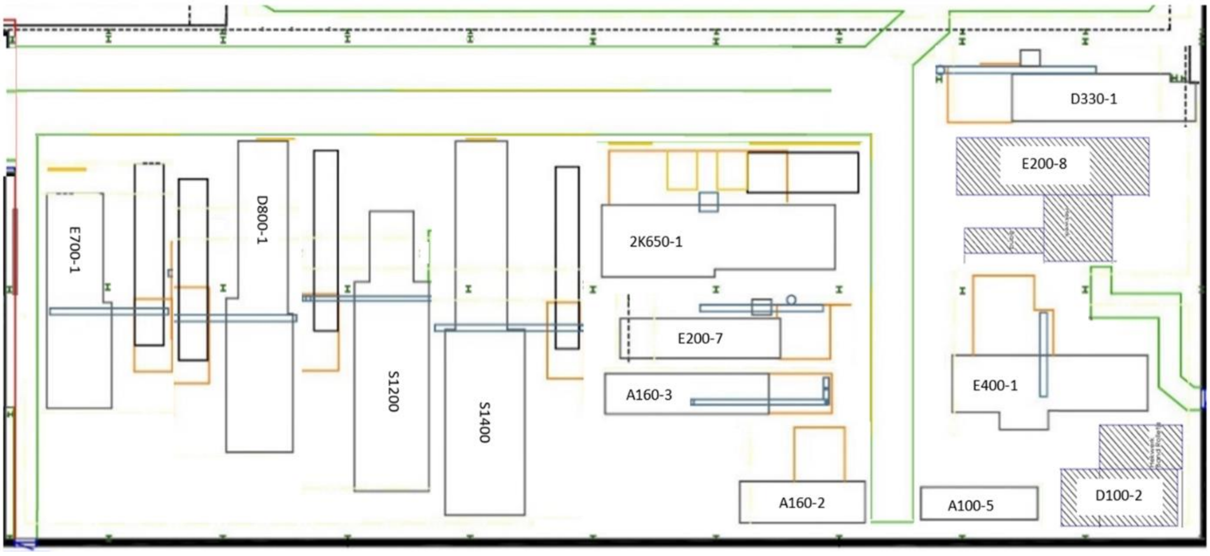

Figure 6.4. Layout 2

Layout 3

The main principle in layout 3 is the addition of doors on the bottom side of production hall 4/5. In this way, the output of the biggest machines can immediately go outside, where it is checked and placed in the transportation truck. There is enough space available for these trucks on the bottom side of hall 4/5. This means that the output of these machines does not interfere with the output/moulds of the other machines. The four biggest machines are turned 180 degrees, and the output points to the new doors. One door is added for the E700-1, one for the D800-1 and one for the S1200 and S1400 together. The remaining places in the hall are filled in the same way as before. The machine with the most output is placed most to the left, which is nearest to the checking-area. The safety of the employees also increases in this layout, because originally interfering flows are now separated, and thus the occurrence of dangerous situations decreases. Layout 3 can be found below in Figure 6.5. The reality value of this layout is 9.06 km/day. Since it should be a maximum of 15.25 km/day, the norm has been reached. Even, the transportation distance may increase a little. For this purpose, previously added doors have been deleted again, and the reality is calculated again. Two sub-versions of layout 3 are given below, with the calculated reality value.

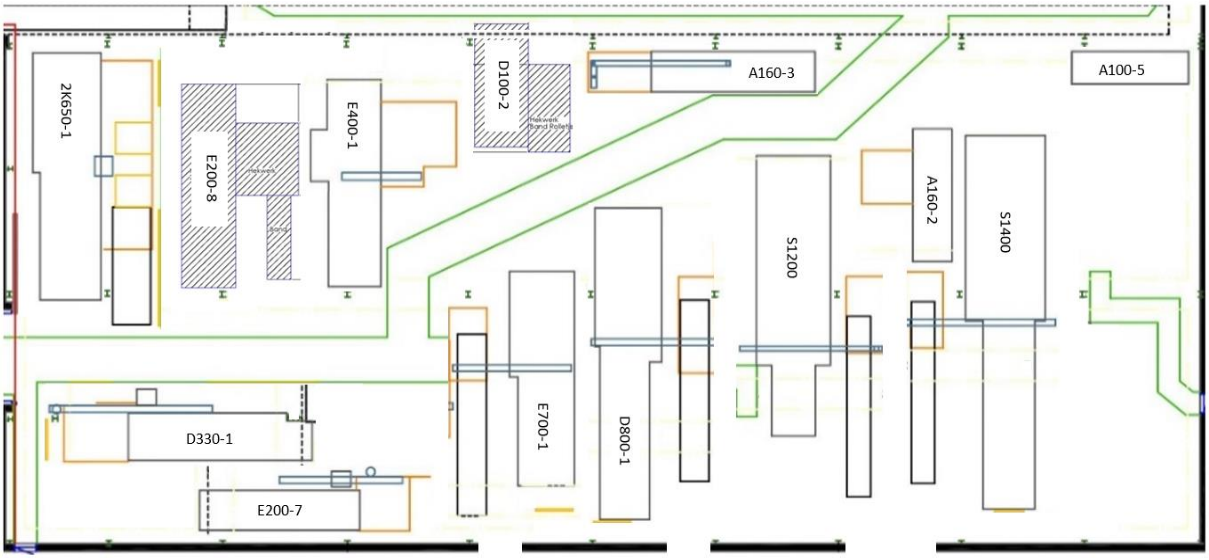

Figure 6.5. Layout 3

Layout 3.1

The doors for the E700-1 and D800-1 have been removed again in this layout. These two machines are turned 180 degrees, back to the original situation. The calculated reality value is 18.52 km/day. This means that the norm has not been reached in this layout. Layout 3.1 is illustrated in Figure 6.6 below.

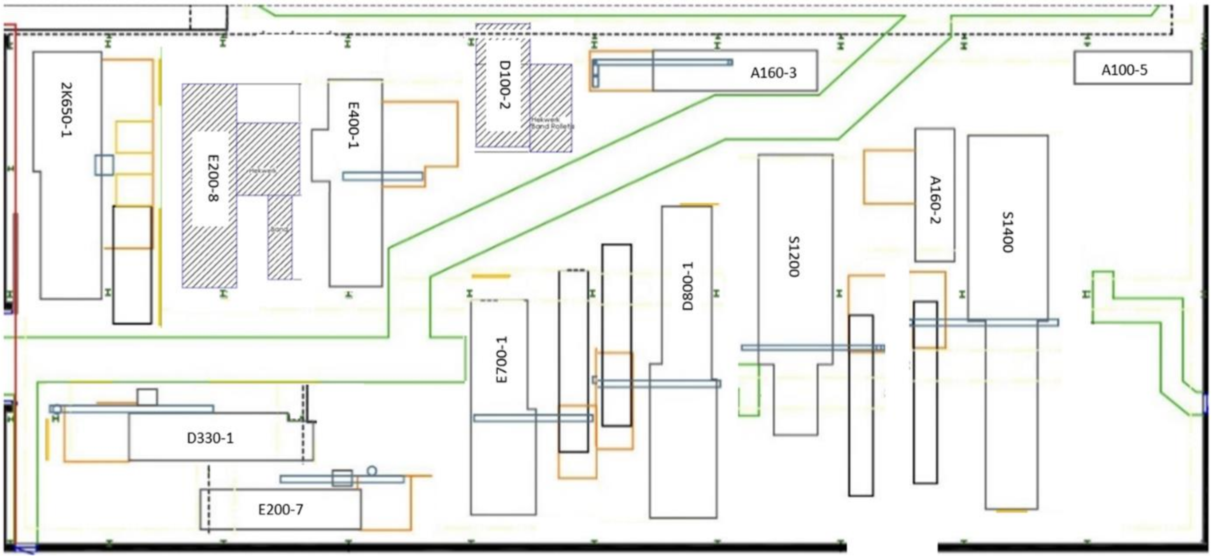

Figure 6.6. Layout 3.1

Layout 3.2

The door of the S1200 and S1400 is removed again in this layout. These machines are turned 180 degrees, back to the original situation. The other machines/doors are unchanged compared to layout 3 in Figure 6.5. The calculated reality of this layout is 18.34 km/day. This means that this layout functions slightly better than sub-version 3.1, but still the norm is not reached. Layout 3.2 can be found below in Figure 6.7.

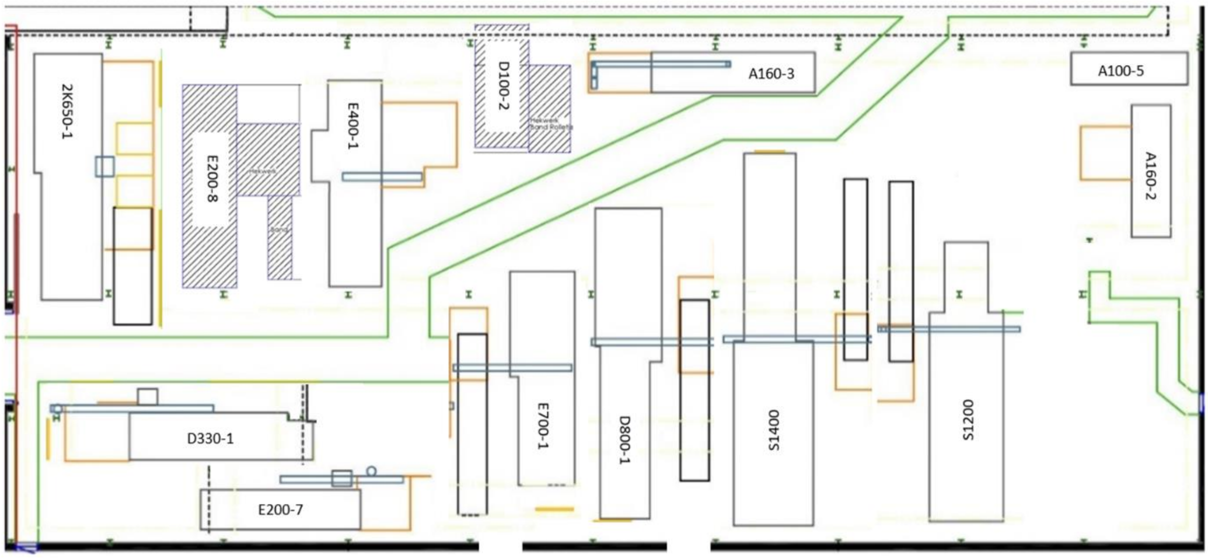

Figure 6.7. Layout 3.2

Main feedback given by the stakeholders at Timmerije

The main point of feedback is that there are more pallet place locations required around machines, for the storage of output, packaging material, waste material, etc. This required number of pallet place locations per machine is determined after the presentation of the layout concepts for the stakeholders and management of Timmerije. Next to that, in the layout concepts we did not incorporate the pallet foil wrapping locations. When a pallet with products is full, it is placed on this foil wrapping location, and foil is wrapped around the pallet to keep the load together. Two of these locations exist in hall 4/5, of which the dimensions are determined as well. Also, containers for purging material (to clean the machine/mould after production) are missing in the layouts. Again, the dimensions have been determined after the feedback session. Lastly, two production equipment locations are not incorporated in the layout concepts. In these locations, equipment is located which is sometimes needed during production in hall 4/5. That is why this material should be incorporated in the layouts of hall 4/5. The dimensions of these two areas are determined as well.

We previously determined that only the four biggest machines need the 15 tons crane. During the feedback session with the shift manager, it turned out that the mould needed for the 2K650-1 weighs 12 tons and also has to be transported with the 15 tons crane. This means that the previously described main layout concepts are practically not even possible, since the 2K650-1 is always placed in the upper half of hall 4/5. For this reason, the 2K650-1 is always placed in the lower half of hall 4/5 of the layouts in the second improvement cycle.

In the beginning of the process, we determined that there are two bulk-machines in hall 1, which are the A160-3 and the A100-5. After having calculated how much these two machines from hall 1 contribute to the output of the bulk-machines, and thus the total transportation distance, it turned out that these two machines have only minor influences on the total transportation distance, due to a relatively low output in terms of pallets. During the feedback session, the management of Timmerije described the expectation to further grow the coming years, and for that growth another 2K650-1 is needed. The other 2K650-1 gets the number 2K650-2 from now on. They asked to try to incorporate the 2K650-2 in hall 4/5, and if needed due to limited space, move the A160-3 and A100-5 back to hall 1.

The layout concepts of layout 3 show the biggest blocks of the four biggest machines in the upper half of hall 4/5, and this is practically not possible, because of the mould location being in those bigger blocks of the machines. As a result, the 15 tons crane cannot reach these locations. For this reason, the bigger blocks of the four biggest machines should be located in the lower half of hall 4/5.

Since layout concepts 3.1 and 3.2 do not meet the norm, and because the stakeholders and management of Timmerije do not see the potential of these layouts, these sub-versions of layout 3 are not updated according to the gathered feedback.

During the feedback session, we determined that for the total surface of the A100-5, the original figure of the machine should be doubled and mirrored along the long side of the machine.

6.4. Layouts of second improvement cycle

The required number of pallet locations for the two machines in hall 1 and the machines in hall 4/5, except for the four biggest machines in hall 4/5, is given below in Table 6.1. For these machines, the number of pallet locations is sufficient to know how many separate squared metres should be available around the machine. One pallet location accounts for one squared metre. For example, for these machines, it does not matter if a pallet with waste material is located immediately at the output location of the machine, or at two metres distance from the output position. If space is available for the required number of pallets, it is already sufficient.

For the bigger machines, the number of pallet locations is not given, since several squared metres next to each other is needed. One can think of a large packing table of several squared metres next to each other, combined with a long conveyer belt for example. We made schematic drawings to determine the required squared metres precisely. Since such a schematic drawing tells much more than just a number of squared metres (due to machines having odd shapes), this number is not given, but the space requirements are given in Figure 6.8 below, in which the extra required spaces have a red outline.

Table 6.1. Pallet locations per machine in hall 4/5

Machines in hall 4/5	Required # of pallet locations
A160-2	3
E200-8	6
E200-7	2
2K650-1	5
D330-1	3
E400-1	4
D100-2	2
A160-3	2
A100-5	2

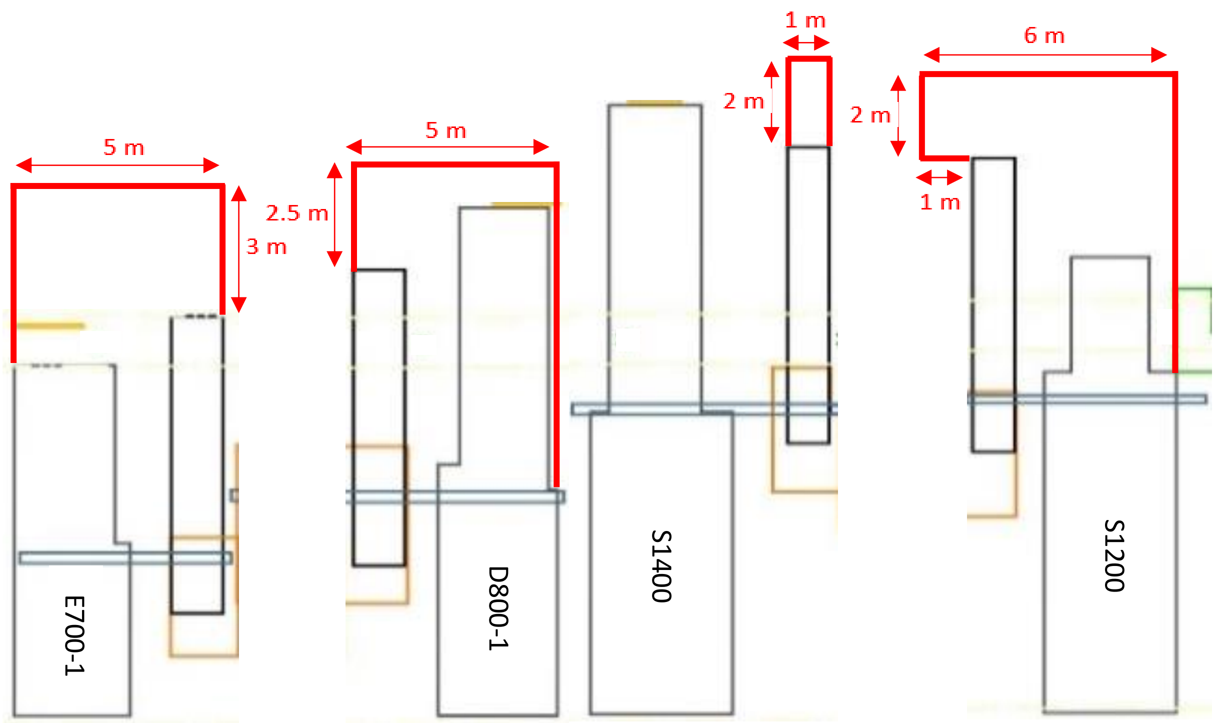

Figure 6.8. Space requirements four biggest machines

There are two pallet foil wrapping places, one of them is (mostly) fixed on one location, whereas the other one has a flexible location. This means that the second foil wrapping place is moved to wherever is desired. To illustrate what such a pallet foil wrapping place looks like, pictures from the fixed and flexible location are added below. Figure 6.9 shows the fixed pallet foil wrapping place, and Figure 6.10 shows the flexible pallet foil wrapping place. We measured that the dimensions of these pallet foil wrapping places are 4 metres by 1 metre, with a width of 0.5 metres needed along both long sides to be able to walk around the place. These dimensions may seem odd when looking at Figure 6.9, because of a kind of L-shape. This L-shape can be transformed into an I-shape, which is more practical. For this reason, the dimensions are determined in the way as described in this paragraph. Two of these pallet foil wrapping places are placed in the layout concepts.

Figure 6.9. Fixed pallet foil wrapping place

Figure 6.10. Flexible pallet foil wrapping

In section 6.2 we determined that there are containers with purging material missing in the layout concepts. The dimensions are found to be 5 metres by 1 metre. These containers with material are incorporated in the new layout concepts. The containers should be located in a central place in the production facilities, since this cleaning material is needed to clean the machine/mould after every batch has been produced. To give an illustration of these containers, a picture of the containers with material is given below in Figure 6.11.

Figure 6.11. Containers with purging material

Lastly, in section 6.2 it was mentioned that there are two locations in production hall 4/5 in which equipment for the production runs is stored temporarily. To give an impression of these locations and the equipment that is stored there, pictures of these locations can be found in Figure 6.12 and Figure 6.13 below. The dimensions of the first equipment storage area are 2 metres by 3 metres, whereas the dimensions of the second equipment storage area are 2 metres by 4 metres. These two locations are incorporated in the improved layout concepts of this improvement cycle.

Figure 6.13. Equipment location 1

Figure 6.14. Equipment location 2

Figure 6.9 to, and including, 6.14, all showed locations that have to be added in the new layouts. The space requirements for the biggest machines, as shown in Figure 6.8, are also added in the new layouts. Table 6.1 informs about the required number of pallet locations per machine. Per pallet location, a red cube with a cross is placed in the layouts. To illustrate the locations that are added in the updated layouts, Figure 6.15 is given below with the schematic figures which are placed in these updated layouts.

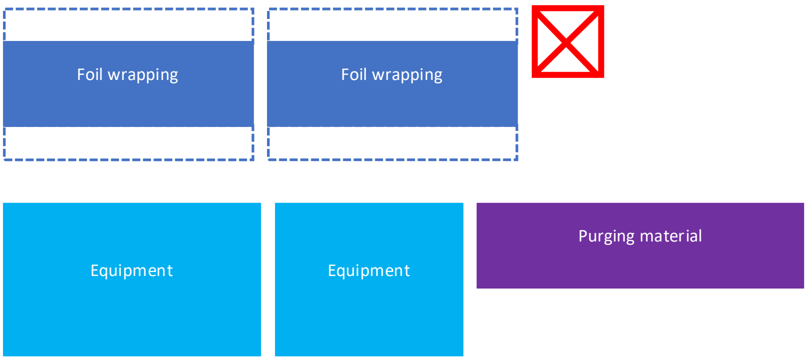

Figure 6.15. To be placed locations in the improved layouts

Below, the updated improved layouts and the calculated reality value of the total transportation distance per layout, can be found. In the main feedback part in section 6.2, Timmerije's wish to see the 2K650-2 in hall 4/5 instead of the two machines of hall 1, was described. For this reason, there are two sub-versions of layout 1 and 2. The first sub-version of these layouts includes the machines of hall 1 (and not the 2K650-2), whereas the second sub-version of these layouts includes the 2K650-2 (and not the machines of hall 1). Layout 3 has one version, since the 2K650-2 simply would not fit when taking the restrictions of layout 3 into account. Layout 3 in the first improvement cycle had two sub-versions, but these sub-versions lacked the potential. As a result, these two sub-versions are not taken into account anymore.

Updated layouts

Layout 1

The first sub-version of the improved version of layout 1 can be found below in Figure 6.16. The main principle of layout 1 is keeping the transportation path and the doors on the original location. Next, machines with the most output get a location closest to the left, where the checking-area is located. In this layout, and the other layouts, additional locations in the production facilities are incorporated. These are the purging material in purple, the foil wrapping locations in dark blue, the equipment locations in light blue, the required additional space for the biggest machines contoured in red, and the required pallet locations with a red cube, containing a red cross. The two machines of hall 1 are placed in hall 4/5, and there is no 2K650-2 in this sub-version. The calculated reality value of the transportation distance is 25.03 km/day. In the first version of layout 1, the reality value was 23.52 km/day. The difference in reality values is only caused by changed locations of machines, due to the requirements and restrictions that became clear during the feedback session.

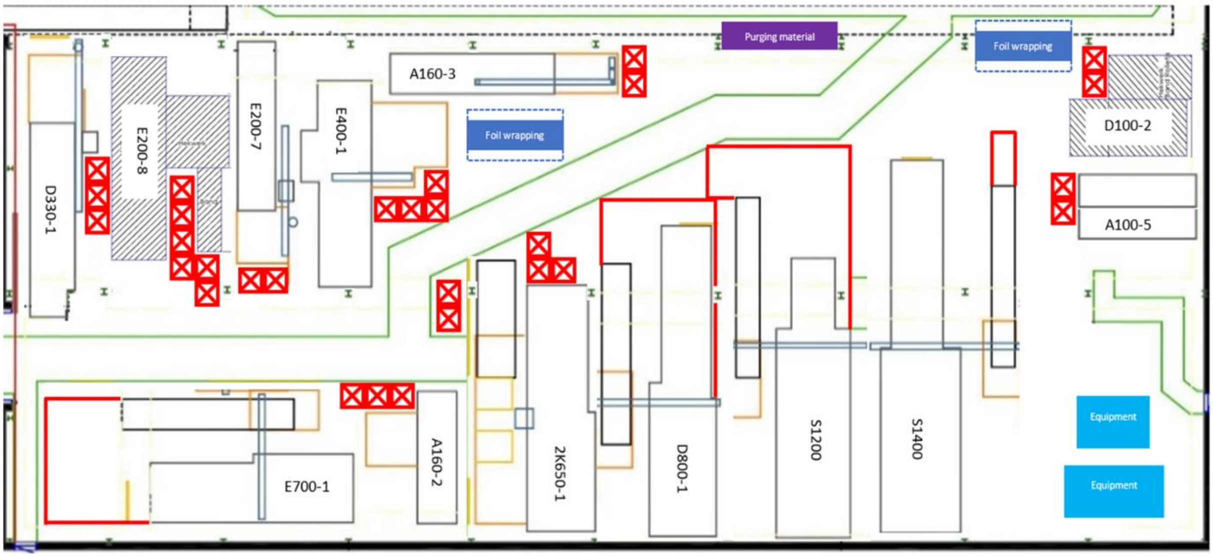

Figure 6.16. Layout 1.1

The second sub-version of the improved version of layout 1 can be found below in Figure 6.17. The main difference compared to the first sub-version, is the 2K650-2 instead of the two machines from hall 1. Next to that, only the D100-2 has another location. The reality value of the total transportation distance is 26.50 km/day. Since the output in terms of pallets of the 2K650-2 is much higher than the two machines from hall 1 combined, it is difficult to compare the values of the two sub-versions. By subtracting the transportation distance of the two machines from hall 1, and by adding the additional transportation distance from the 2K650-2, it is determined that 1.5 km/day is added because of the swap of the machines (addition of 2K650-2, and removal of two machines from hall 1). For this reason, the value of the transportation distance is already higher than the previous sub-version. The 2K650-2 is placed on the existing emergency path, but the emergency exit is still well accessible. It is determined that this is no problem.

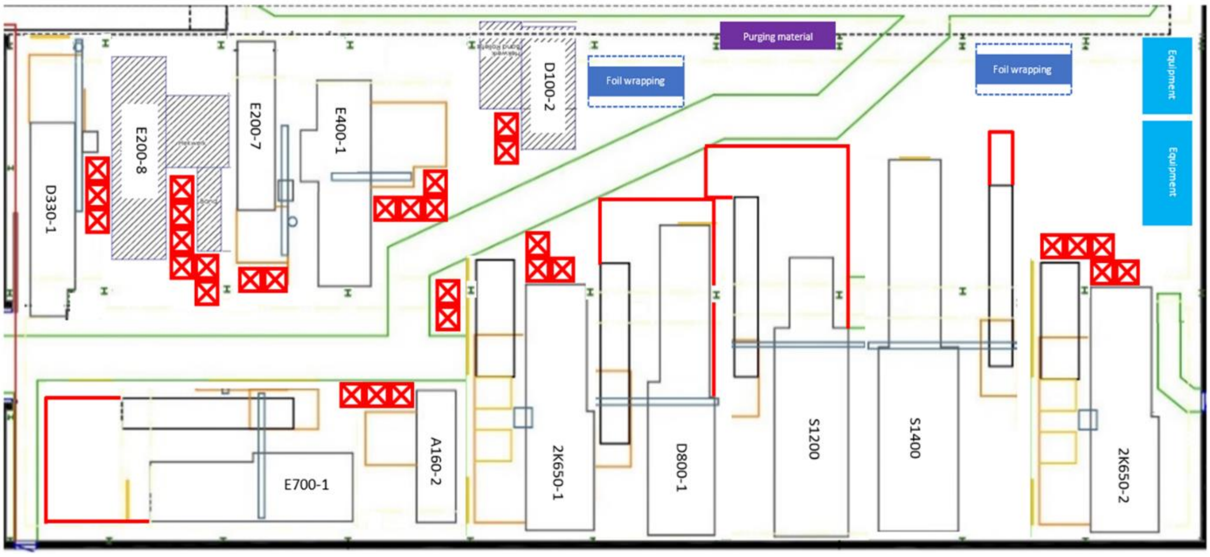

Figure 6.17. Layout 1.2

Layout 2

The first sub-version of layout 2 can be found below in Figure 6.18. In layout 2, a double pallet highway is created to make sure that flows of moulds/products between the production halls would interfere less. The door to the checking-area is moved in the direction of production hall 1. Again, machines with the most output are placed most to the left where possible. The machines from hall 1 are incorporated in this sub-version, whereas the 2K650-2 is left out of this layout. The calculated reality value of the transportation distance is 22.44 km/day. The reality value of the transportation distance of the first version of layout 2 was 20.86 km/day. This value increased due to the restrictions and requirements that became clear during the feedback session.

Figure 6.18. Layout 2.1

The second sub-version of layout 2 can be found below in Figure 6.19. Again, the main difference compared to the first sub-version, is the 2K650-2 instead of the two machines from hall 1. The 2K650-1 and 2K650-2 perfectly fit in the space between the S1400 and the transportation path. More machines have changed location as a result of that. The reality value of the transportation path is 22.76 km/day. This is only slightly more than the reality value in the first sub-version of layout 2. Again, the output of the 2K650-2 is much larger than the output of the two machines from hall 1 combined. The addition of the 2K650-2 accounts for 0.97 km/day, but because of the optimal location of the 2K650-2, the difference between sub-version 1 and 2 is not that large as 0.97 km/day.

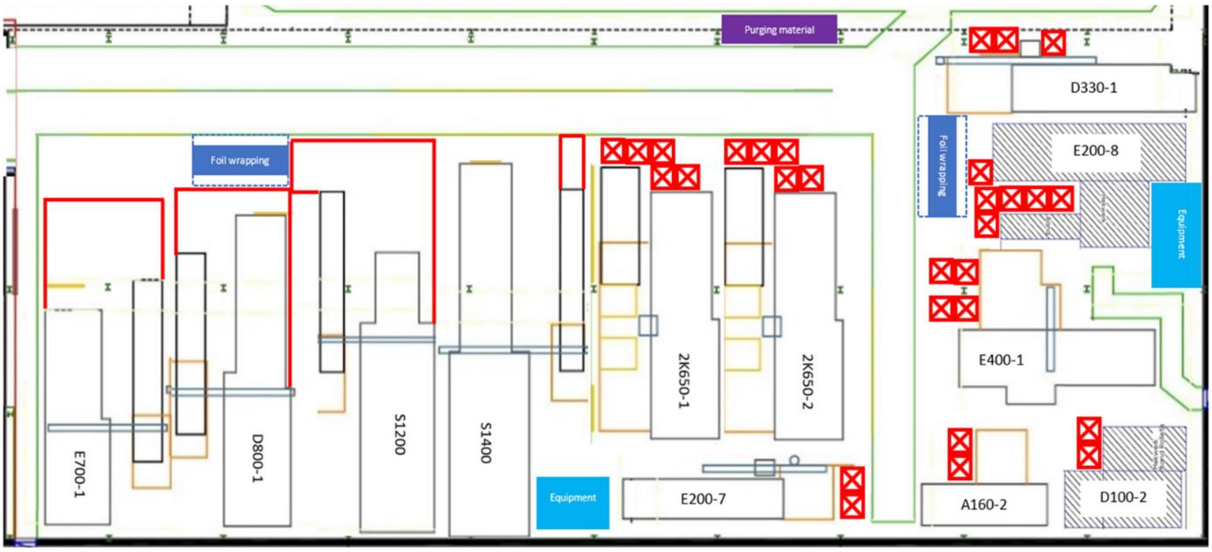

Figure 6.19. Layout 2.2

Layout 3

Layout 3 has one improved version compared to the first improvement cycle, which can be found in Figure 6.20 below. In layout 3, doors are added on the south side of production hall 4/5, so the output from the four biggest machines can immediately be transported outside. This means that this output does not need to be transported along the transportation path anymore, which results in much less interference of flows of products and moulds. The 2K650-2 simply would not fit in this layout, even when the A160-3 and A100-5 are placed back to hall 1. Due to the orientation of the four biggest machines, this is not possible. The conveyer belt of the S1200 and S1400 is mirrored and points to the bottom of hall 4/5, while the biggest blocks of the S1200 and S1400 are in the lower half of hall 4/5. Mirroring the conveyer belts, and thus leaving the biggest blocks of the S1200 and S1400 in the lower half of hall 4/5 is possible according to the shift manager. The reality value of the transportation distance is 10.56 km/day. This means that this is the only layout which reaches the norm.

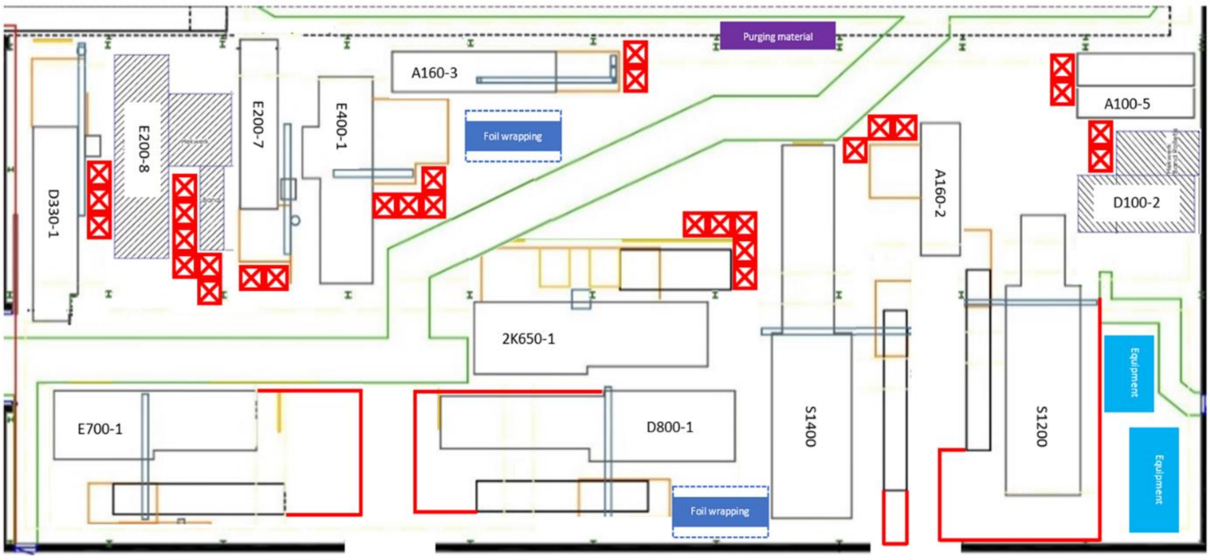

Figure 6.20. Layout 3

6.5. Criteria

The layouts are assessed on various criteria, which are given below. After that, the criteria are elaborated on in more detail.

- Safety
- Layout being future proof
- Reaching the norm of the total transportation distance
- Estimated investment cost
- Creation of flow

Safety has always been the most important factor for Timmerije. There are two aspects of safety that the company focuses at. These are safety for the employees on the work floor, and fire safety. Safety for employees on the work floor means that unsafe situations do not occur (or occur less). One can think of unsafe crossings of forklifts and of people. Fire safety takes the possibility of a quick spreading of fire across the production facilities into account. Since these two described aspects of safety are of utmost importance, the criterion safety is considered as a binary criterion. When at least one of the described aspects of safety is found to be insufficient, the layout is rejected.

The next criterion is the layout being future proof. It has already been described that Timmerije expects to grow, and therefore needs the 2K650-2 to be able to cope with the increasing demand of products that have to be produced on a 2K650-x. The machine name is written in this way, since it does not matter if products are produced on the first or second version of this machine, because the machines are identical. This concrete expectation did not exist yet in the beginning of the research process, but it has become very concrete towards the end of the research process. For a layout to be future proof, it is required that the 2K650-2 is incorporated in the layout solution. It is determined that this criterion is also binary. This means that if the 2K650-2 is not incorporated in a layout, this layout is rejected.

Reaching the norm of the total transportation distance is a wish of Timmerije. In the beginning of the process, a 50% reduction of the total transportation distance was given as wish to see the required decrease in saturation of the transportation path. This 50% reduction has been determined as a very rough estimate of the required decrease. Since it is such a rough estimate, a decrease to a lesser extent than the 50% would also be acceptable for Timmerije. For this reason, this criterion is more described as a wish to see a 50% reduction in the total transportation distance, however it is not required.

The fourth criterion is the estimated investment cost. The estimated investment cost is a rough estimate and is expressed relative to the other layouts. This is done, since this comparison gives a more reliable indication between layouts, instead of just an estimated number of the total costs. The costs are taken into account when choosing a layout, but it is not a binary criterion. Timmerije is willing to invest in a solution if it solves the space problem, and therefore money does not play the biggest role.

The creation of a flow is something that has already been described in this thesis. With the creation of flow, it is meant that machines have the same orientation and in this way input and output positions are separated. It is important as this aspect takes both the safety and layout being future proof into account. The separation of flows leads to less crossings and makes sure that the transportation path is utilized more efficiently and is thus more future proof. This criterion can also be seen as a wish of the company. However, it is a relevant wish that has to be incorporated.

6.6. Chosen layout

The evaluation of the layouts, based on the criteria given in section 6.5, is given below in Table 6.2. After that, the evaluations are elaborated on, and the chosen layout is given. It is explained why specifically this layout is chosen.

Table 6.2. Evaluation layouts based on criteria

Criterion ↓ / Layout →	Layout 1.1	Layout 1.2	Layout 2.1	Layout 2.2	Layout 3
Safety	Yes	Yes	Yes	Yes	No
Layout being future proof	No	Yes	No	Yes	No
Reaching the norm	No	No	No	No	Yes
Estimated investment costs	Low	Low	Average	Average	High
Creation of flow	No	No	Yes	Yes	Yes

Layout 3 scores a 'No' on safety, and then specifically on fire safety. In layout 3, checking-areas outside the existing production facilities have to be built to check the products that are produced by the four biggest machines, and which are transported outside directly. Next to these checking-areas outside, trucks have to park parallel to the south wall of hall 4/5. These checking-areas, combined with the trucks, increase the width of hall 4/5. As a result, the bottom side of hall 4/5 gets too close to the Egginkhal, with regards to fire safety. When there is a fire in one of these facilities, the distance between them makes sure that the fire does not spread to the other facility. Implementing layout 3 cannot guarantee the distance to be large enough to prevent fire from spreading between the two facilities.

In layout 1.1, 2.1 and 3, the 2K650-2 is not incorporated. For this reason, these layouts score a 'No' on the layout being future proof and are therefore rejected. As a result, the final layout is 1.2 or 2.2. The reality value of the total transportation distance in layout 1.2 is 26.50 km/day, and for layout 2.2 it is 22.76 km/day. The transportation distance for layout 2.2 is thus much lower. The estimated investment costs for layout 2.2 are expected to be (slightly) higher than the costs for layout 1.2. Lastly, a flow is created in layout 2.2, whereas this is not the case in layout 1.2. To summarize the information given above, layout 2.2 scores equal or better than layout 1.2 on every criteria, except for the investment costs. As described previously, Timmerije is willing to invest, and therefore there is no big difference between an average and a low investment cost. The lower investment cost does not compensate a difference of the total transportation distance of approximately 4 km/day, and the lack of the creation of a flow. For this reason, layout 2.2 is chosen as the final layout.

Timmerije expects that the output of the 2K650-x's can exceed the output of the E700-1 and D800-1. For this reason, they asked if the 2K650-x's can take the leftmost position in hall 4/5, and that the E700-1, D800-1, S1200 and S1400 move to the right. It is investigated and is determined that this is possible. For this purpose, layout 2.3 has been made as a replacement of the 2.2, in case Timmerije wants the 2K650-x's most to the left. Layout 2.3 is a possible layout if it turns out that the output of the 2K650-x's will be enormous compared to the other big machines. Layout 2.2 will remain the final chosen layout, with layout 2.3 as being a potential in case the previously described situation is going to occur. An important point to mention is that the expected automation development is incorporated in layout 2.2 (and layout 2.3). Enough space around machines is left for robots and/or automatic quality control. Also, the pallet highway enables the possibility of transforming the transportation path into a robot transportation lane. There is enough space available, and the flows to and from the production facilities are separated.

During the second feedback session, layout 2.2 was chosen. Some final points of improvement popped up. The first one concerns the width of the individual transportation paths in the pallet highway. The original width of these transportation paths is 1.9 metres, in which a buffer is incorporated. Since two of these transportation paths run parallel next to each other, twice the buffer is not needed. It is determined that a width of 1.5 metres of an individual transportation path in the pallet highway is sufficient. The next point of improvement is the addition of an emergency exit at the end of the vertical transportation path to the bottom of hall 4/5. Both layout 2.2 and 2.3 are updated according to the given feedback. The final version of layout 2.2 is given below in Figure 6.21.

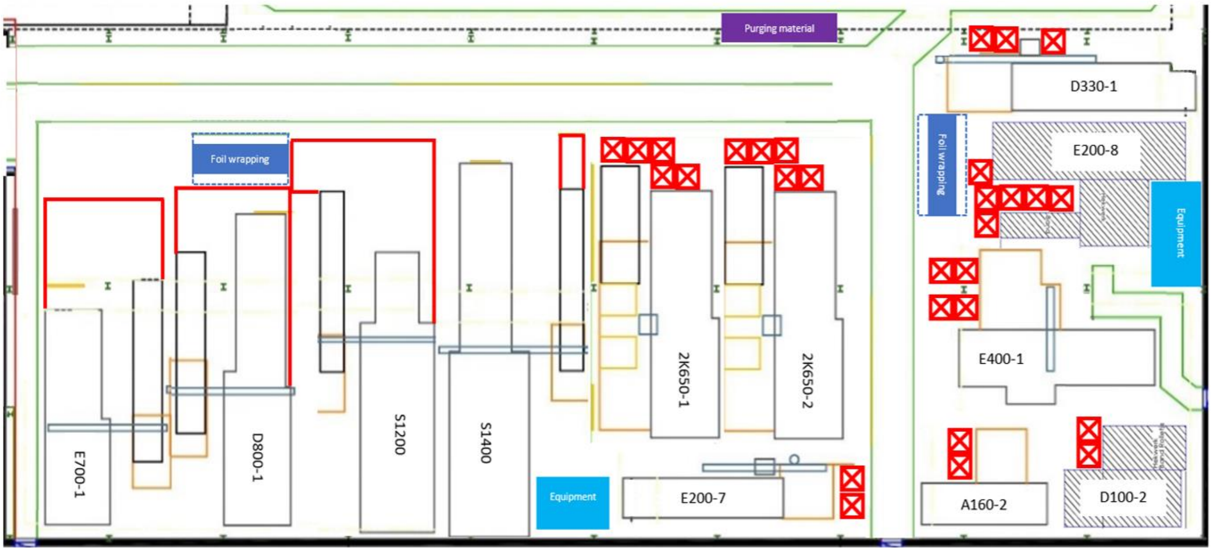

Figure 6.21. Final version layout 2.2

Layout 2.3 can be implemented in case of enormous output figures of the 2K650-x's. This layout can be found below in Figure 6.22. The vertical transportation path on the left of the 2K650-x's is extended to a width of 1.9 metres.

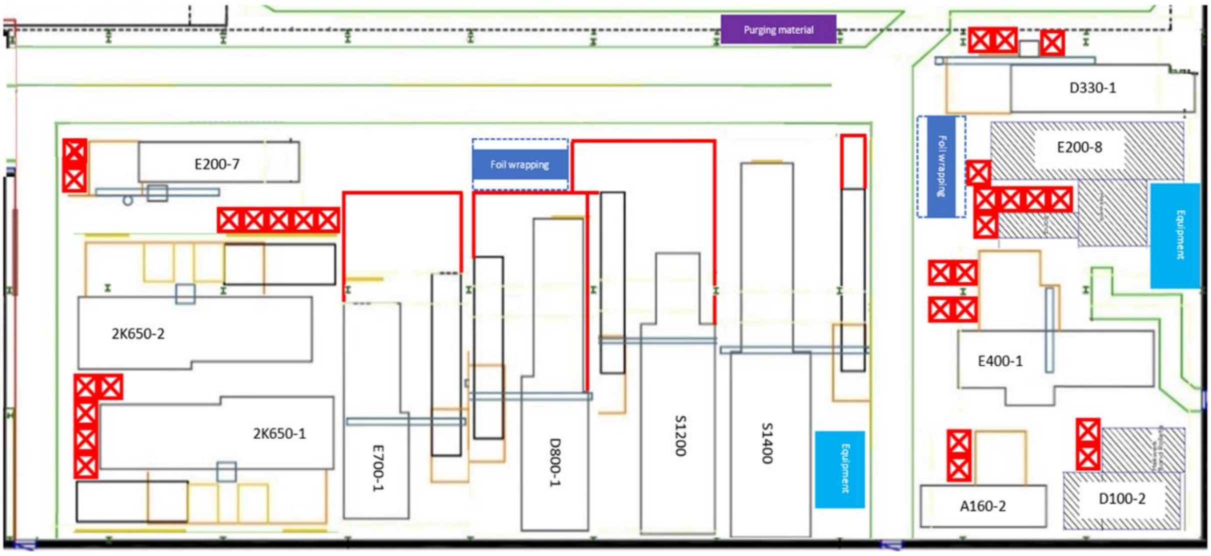

Figure 6.22. Layout 2.3 in case of enormous output 2K650-x's

6.7. Chapter summary

The design process of the layouts took place in this chapter. First the considerations and practical limitations were described. The aspects that were described had to be taken into account when designing the different versions of the layouts. With the use of two improvement cycles, in which feedback was given on the layouts by the stakeholders at Timmerije, several layouts were developed.

The criteria on which to choose/reject layouts were described, after which the final layout was chosen. Since Timmerije expects to grow in the future (but it is unknown with what numbers), an adaption of the final layout is given. This version of the final layout can be implemented if the output of the two 2K650-x's is expected to raise beyond the output numbers of the biggest machines. A rough implementation plan and a cost/benefit analysis are given in the next chapter.

7. Implementation of the solution

In section 7.1, the steps for implementing layout 2.2 are described, after which a cost/benefit analysis is made in section 7.2. In this section, it becomes clear what the time for cost-recovery for implementing layout 2.2 is. Tips for implementing layout changes of the Systematic Layout Planning from Muther and Hales (2015) are given in section 7.3.

7.1. Practical steps of implementation

The practical steps of implementing layout 2.2, which are determined by the technical service department at Timmerije, are given below in Table 7.1. Per machine, the costs for moving the machine, adjusting the electricity supply, adjusting the raw material supply and adjusting the railing around the machine, are determined as an estimated value by the technical service department of Timmerije. Next to that, other tasks are found, which also need to be executed when realising the improvement of the layout. The costs of those activities are also estimated. The technical service department at Timmerije also determined the estimated values of the implementation steps. Since this department is specialised in realising layout plans, the estimation of the costs is to be found reliable.

Table 7.1. Estimated costs implementation layout 2.2

Activity	Estimated costs per activity	
Moving of machines		
E400-1		
Move machine (approximately 40 metres directly, not across transportation path)	€	3,000.00
Adjust electricity supply	€	5,000.00
Adjust raw material supply	€	1,000.00
Adjust railing around machine	€	500.00
D330-1		
Move machine (approximately 32 metres directly, not across transportation path)	€	3,000.00
Adjust electricity supply	€	5,000.00
Adjust raw material supply	€	1,000.00
Adjust railing around machine	€	500.00
2K650-1		
Move machine (approximately 14 metres directly, not across transportation path)	€	3,000.00
Adjust electricity supply	€	9,000.00
Adjust raw material supply	€	2,000.00
Adjust railing around machine	€	1,500.00
E200-7		
Move machine (approximately 24 metres directly, not across transportation path)	€	1,000.00
Adjust electricity supply	€	5,000.00
Adjust raw material supply	€	1,500.00
Adjust railing around machine	€	500.00
A160-2		
Move machine (approximately 30 metres directly, not across transportation path)	€	1,000.00
Adjust electricity supply	€	6,000.00

Adjust raw material supply	€	1,500.00
Adjust railing around machine	€	500.00
E200-8		
Move machine (approximately 37 metres directly, not across transportation path)	€	1,000.00
Adjust electricity supply	€	6,000.00
Adjust raw material supply	€	1,500.00
Adjust railing around machine	€	500.00
E700-1		
Move machine (approximately 20 metres directly, not across transportation path)	€	3,000.00
Adjust electricity supply	€	12,000.00
Adjust raw material supply	€	1,500.00
Adjust railing around machine	€	500.00
D800-1		
Move machine (approximately 20 metres directly, not across transportation path)	€	3,000.00
Adjust electricity supply	€	15,000.00
Adjust raw material supply	€	1,500.00
Adjust railing around machine	€	500.00
S1400		
Move machine (approximately 15 metres directly, not across transportation path)	€	5,000.00
Adjust electricity supply	€	15,000.00
Adjust raw material supply	€	1,500.00
Adjust railing around machine	€	500.00
S1200		
Move machine (approximately 26 metres directly, not across transportation path)	€	5,000.00
Adjust electricity supply	€	22,000.00
Adjust raw material supply	€	1,500.00
Adjust railing around machine	€	500.00
D100-2		
Move machine (approximately 14 metres directly, not across transportation path)	€	1,000.00
Adjust electricity supply	€	2,000.00
Adjust raw material supply	€	1,500.00
Adjust railing around machine	€	200.00
2K650-2		
Add 2K650-2 (approximately 36 metres from the new door)	€	5,000.00
Make electricity supply	€	25,000.00
Make raw material supply	€	3,000.00
Make railing around machine	€	500.00
External additions around machines		
Adjust extraction in production hall 4/5	€	10,000.00

Adjust fan shafts	€	10,000.00
Other activities		
Change the coating of the floor	€	5,000.00
Move the door (the door to the checking-area)	€	30,000.00
Move storage with shelves (what is behind the location of the new door)	€	2,000.00
Move fire extinguishing hoses + reel extinguishers	€	2,000.00
Make additional emergency exit between the E200-7 and A160-2	€	3,000.00
Move three consoles of MES system	€	3,000.00
Total costs	**€**	**251,700.00**

7.2. Cost/benefit analysis

As can be seen in Table 7.1 above, the total estimated costs of implementing layout 2.2 are €251,700.00. Only manhour costs and equipment costs are considered, not the costs of the production facilities not being able to produce products. Since the layout has to be implemented, it is not possible to produce (all) products during that period, because machines are disconnected and have to be moved. Furthermore, since the improvement is made in hall 4/5, and machines have to be moved across hall 4/5, it is most likely not possible to move (all) products from the other production halls across the transportation path to the checking-area. The time needed to implement the solution, and the costs of machines not being able to produce, are extremely rough estimates compared to the estimation of the costs of the activities in Table 7.1. Therefore, these standstill costs are not incorporated.

The benefit of implementing the layout is a decrease in the total transportation distance. Since layout 2.2 consists of the 2K650-2 instead of the A160-3 and A100-5, the to be transported output is much higher, and therefore the total transportation distance is higher. To be able to compare the total transportation distance with the reality value of the current situation, the reality value of layout 2.2 is corrected for the higher output of the 2K650-2. In the paragraph above Figure 6.19 it was described that the 2K650-2 instead of the A160-3 and A100-5 accounts for 0.97 km/day in addition to the reality value. The calculated reality value of the total transportation distance for layout 2.2 is 22.76 km/day. The corrected reality value of layout 2.2 therefore is *21.79 km/day*. The reality value of the total transportation distance of the current situation is *30.50 km/day*. This means that the total transportation distance decreases with *28.6%*, when implementing layout 2.2.

The decrease of the total transportation distance has to be expressed in costs. Since the total transportation distance decreases, operators have to walk less and products have to be transported fewer metres. The benefit of implementing the improved layout is thus expressed in the decrease in wage costs of an operator. The benefit per year therefore is:

$$248\ days \times 24\ hours \times €47 \times 0.286 = €80{,}006.78$$

On average, Timmerije is operational 248 days per year. On those days, production is running 24 hours per day. The wage per hour of an operator is €47. The multiplication of all these numbers with the reduction in total transportation distance leads to a benefit of €80,006.78 per year. There are more factors in which the benefit could be expressed. The most straightforward one would be safety, since less transportation distance leads to less crossings. Also, the pallet highway of layout 2.2 leads to even less crossings. However, it would be a very rough estimate to give a cost reduction in terms of safety. This is the same case with the standstill of machines in the cost estimation. For this reason, the increase of safety in the production facilities is not considered as a benefit in terms of money values.

By dividing the total costs by the total benefits, the time for cost-recovery of implementing layout 2.2 can be calculated. Roughly, the investment is earned back in 3.15 years. We consider this approximation to be in line with the wishes of Timmerije.

7.3. Tips for implementation

Muther and Hales (2015) provide tips for implementing layout changes. Useful tips and figures from the theory are given in this section. All information is taken from the Chapters 15 and 16 of Systematic Layout Planning of Muther and Hales (2015), therefore no individual references are made. Since we assume that Timmerije is already able to implement layout changes, only relevant information for Timmerije is provided.

In the SLP, an Installation Coordination Worksheet has been created. It is developed as a checklist of tasks that are likely to be overlooked. In this way, it functions as a guide in the installation planning, with a status check. An example of a filled-in Installation Coordination Worksheet can be found below in Figure 7.1. In here, it can be seen that is written down what needs to be done, who is responsible and when it should be finished. Each task is divided in sub-tasks, which makes it easier to finish tasks and see the progress made. Periodic status checks and managing the tasks enable the installation progressing on time as scheduled.

INSTALLATION COORDINATION WORKSHEET

Plant (Company) *Sturdy, Ltd.* Project *A 965-3*
By *T. Lynch* With *G.C.*
Date Originated *8/2* Sheet *1* of *1*
Date of this review *10/6*

		WHAT	WHO	WHEN	STATUS	As of (date)
MAKE READY	PLAN	1. Start planning the installation	J. Heller	8/20	Complete	10/2
		2. Establish sequence and timing of moves	J. Heller	8/20	Complete	10/2
		3. Inventory materials and equipment to move	H. Dunlap	8/20	Complete	10/2
		4. Get disposition of non-moving material and equipment	V. Daniel	8/26	Complete	10/6
		5. Schedule moves in detail	J. Heller	9/10	Complete	10/2
		6. Assign move numbers; check vs inventory & equipment (tag) number	J. Heller	9/20	Complete	10/2
		7. Verify procedural changes and timing (a)	na	na		
		8.				
	PROVIDE	1. Decide who will make moves	C. Jacks	10/5	Complete	10/2
		2. Secure bids as necessary	A. Printz	8/20	Complete	10/2
		3. Determine and reserve moving equipment required	A. Printz	9/10	Complete	10/6
		4. Set up communications for both ends of move	J. Heller	11/2		
		5. Appoint key person for each area	D. Bell	10/10	Complete	10/6
		6. Get work order(s) for moves	C. Jacks	10/10	By 10/20	
		7. Verify delivery for any new equipment (b)	na	na		
		8.				
	PREPARE	1. Prepare new locations -- physical area, conditions, auxiliaries	C. Jacks	10/20		
		2. Broadcast plans	Z. White	10/10	Briefing 10/26	
		3. Brief personnel specifically involved	Z. White	10/10	Briefing 10/26	
		4. Mark everything to move; identification, move no., destination	J. Heller	10/15	Resched 11/3	
		5. Disconnect or ready equipment	C. Jacks	10/27		
		6. Check out equipment and release to movers	J. Heller	10/27		
		7. Complete required training (c)	V. Daniel	10/30		
		8.				
DO	INSTALL	1. Move equipment intact to reduce re-assembly time	C. Jacks	11/10		
		2. Move close to spot to reduce line-up and hook-up time	C. Jacks	11/10		
		3. Post move performance as accomplished	C. Jacks	11/10		
		4. Keep moving crew informed, coordinated	C. Jacks	11/10		
		5. Be on hand -- layout interpretation	J. Heller	11/10		
		6. Be on hand -- auxiliaries interpretation	J. Heller	11/10		
		7. Be on hand -- procedures interpretation (a)	na	na		
		8				
PUT AWAY	HOOK-UP	1. Spot equipment; check location	J.Heller	11/10		
		2. Temporary hook-ups where needed	J.Heller	11/10		
		3. Check and release for permanent connections	C. Jacks	11/10		
		4. Inspect the installation & release for tryout	C. Jacks	11/12		
		5. Maintenance tryout	C. Jacks	11/13		
		6. Release to operating group; secure acceptance	J.Heller	11/14		
		7.				
		8.				
	CLEAN-UP	1. Survey-inspect old and new areas	C. Jacks	11/15		
		2. Schedule & assign clean-up -- old and new areas	C. Jacks	11/18		
		3. Verify layout as installed	J. Heller	11/18		
		4. Verify auxiliary service as installed	J. Heller	11/18		
		5. Verify or adjust layout & service-specification records	J. Heller	11/20		
		6. Recap installation costs and performance	J. Heller	11/25		
		7. Final sign-off by operating group	V. Daniel	11/25		
		8.				

Reference Notes:
a. *No changes in operating procedures or work instructions*
b. *No new machinery; just rearrangement*
c. *Walk operators through mock-up of planned new layout.*
d.

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Figure 15-3. Installation Coordination Worksheet is used to assign responsibilities and check status of installation planning. This sheet shows the timing established for each step in coordinating a move. Along with the due times go assignments to specific individuals for the completion of each step. A status report is issued periodically (information on the right side of the form) to prevent detail "fall downs" from affecting the completion date scheduled for the entire project.

Figure 7.1. Installation Coordination Worksheet (Muther & Hales, 2015, pp. 287)

The steps in the Installation Coordination Worksheet can still be considered ‘large’ steps. “Move equipment” is still broad, since 12 machines have to be moved in hall 4/5 at Timmerije’s production facilities. In here, also the sequence of moving the machines matters. This is the case, since some machines are very large and first have to be transported outside, so the location of other machines can be changed. For the purpose of establishing 'smaller' steps in the implementation process, an example of a filled-in form of the Installation Instructions Summary is provided below in Figure 7.2. In here, utility changes are placed, just as electrical requirements. Even more structure is established in this way.

Figure 15-6. The Installation Instructions Summary is a condensed way of issuing instructions. The item number is keyed to the layout plan for easy reference. Description refers to the equipment being moved. A check or an X in the columns under Utilities indicates services that must be provided or removed. The Electrical column calls out the electrical requirements. The columns labeled Millwrights-Mechanical and Electricians will hold a brief description of the work each trade is to perform. The remainder of the form allows room for instructions or special assignments for other people involved with the installation.

15-8

INSTALLATION INSTRUCTIONS SUMMARY

Description *Relayout of Kitchen*

Plant *Nortot* | By *O.M. Cramer* | Date *11/10*

Project *343* | With *D.F. Addis* | Sheet *2* of *2*

ITEM No.	DESCRIPTION	MACH./EQPT. No.	MOVE	UTILITIES: Air	Water	Gas	Drain	Vent	Steam	MILLWRIGHTS-MECHANICAL	ELECTRICAL: Volts	Phase	KVA	Amps	H.P.		ELECTRICIANS	OTHER WORK -- (Code who and describe) C - Carpenters M - Methods S - Safety Engr. F - Fire Marshall P - Plant Engrg. * - Outside Contractor: WHO	WHAT
1	Sink	D-1	-- --	--	✓	--	✓	--	--	Reorient									
2	Food Prep. Table	D-2	A-5 B-10	--	--	--	--	--	--	Relocate	110			15			Install	C	Revise table per drawing T6538
3	Steamer (Stag)	D-3	A-5 B-10	--	✓	✓	✓	✓	✓	Relocate	110			15			Hook up		
4	Proof Box	D-4	A-7 B-10	--	--	--	--	--	--	Relocate after repairs	110			15			Install		
5	Bake Oven	D-5	A-7 B-10	--	--	✓	--	✓	--	Relocate								F	Check for fire regulations
6	Portable Mixer	D-6	A-7 B-10	--	--	--	--	--	--	Relocate	110			15			Install		
7	Range	F-7	C-5 B-12	--	✓	✓	--	✓	--	Relocate								F	Check for fire regulations
8	Range	F-8	C-5 B-12	--	✓	✓	--	✓	--	Relocate								F	Check for fire regulations
9	Portable Slicer	F-10	C-5 B-12	--	--	--	--	--	--	Relocate	110			15			Install	S	Certify present guards
10	Exhaust Hood		-- --					✓		Rearrange and tie-in with 3,5,7,8									
11	Partition		A-5 76															C	Disassemble and salvage

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Figure 7.2. Installation Instructions Summary (Muther & Hales, 2015, pp. 291)

The sheets in Figure 7.1 and Figure 7.2 provide a clear structure, in order to break the process of implementing layout 2.2 into manageable separate parts. Below, practical tips for implementation are given and elaborated on.

When the installation work is divided among two or more groups, it should clearly be defined what the work of each group is. Next to that, it should be clear for all of the groups what the other group is supposed to do. In this way, all tasks are being executed and the division between the tasks is clear.

The timing of implementing the layout is important. It should be scheduled during periods of low production or changes in process, equipment or products. Losses in production time, disrupting effects on employees, and interruptions in shipping schedules are (partly) avoided in scheduling the change in this manner. It is practically impossible to find a period for the implementation where all parties are satisfied. If it is possible, an attempt can be made to maintain production schedules during the change in layout. Also, the change can be made during seasonal lower levels of production. It is often advisable to suspend operations and make the move all at one time, rather than tangle with everyone during the move.

Before the move, supporting-service and operating supervisors should be briefed. By having photos, prints and a 3D physical model available to them, the supervisors can explain to the executing teams and employees what is going to happen, and who is responsible for what. It is important to keep employees 'in the know', to improve morale. This is extremely important when there is a certain amount of disruption.

After having completed the layout project, it is wise to make a post-installation audit of the savings and costs that were estimated. This increases the accuracy for estimating the costs of installation and makes it easier to realise such projects in the future.

The operators are going to work most in the new setting. For this reason, it is important that these people keep believing in the new layout. Therefore, it is best to involve the operating people in the development (which has been done) and evaluation of the plans. For the evaluation period, enough time should be allowed to let operating people become convinced of the benefits of the new layout. After that, they will support it as a 'good layout' for Timmerije.

Figure 7.3 below sums up when greatest production results. This is the case when each person is given a definite task to be done in a definite time and in a definite manner. Muther and Hales (2015) states: "By clearly specifying what is to be done, who is to do it, when it is to be done, by getting acceptance of the program for accomplishment, and by following an organized, systematic method of planning layouts, productivity of planning must improve" (pp. 309). This is the key tip to a successful implementation of layout 2.2.

"Greatest production results when…	Key Word	Application to Layout Planning Project
"each PERSON is given a	Who	Layout Planner
definite TASK to be done in a	What	Specific Project at Hand
definite TIME and in a	When	Project Schedule
definite MANNER." *	How	Systematic Layout Planning
*Frederick W. Taylor		

Figure 16-9. Effective performance in executing of layout projects reduced to fundamentals of production output.

Figure 7.3. Fundamentals of production output (Muther & Hales, 2015, pp. 309)

7.4. Chapter summary

The implementation of layout 2.2 has been described in this chapter. The steps for implementing the layout have been given, with an estimate of their associated costs. The total costs of implementing layout 2.2 are estimated to be €251,700.00. The benefits of implementing layout 2.2 are expressed in the hours worked by operators, multiplied by the wage per hour of an operator. Per year, the benefit is estimated to be €80,006.78. Dividing the total costs by the benefits leads to an approximate time of 3.15 years for the investment to be cost-recovered. Figures like the Installation Coordination Worksheet and Installation Instructions Summary provide structure in implementing the layout. Next to that, useful tips from the literature have been given. The main tip is that greatest production results when each person is given a definite task to be done in a definite time and in a definite manner.

8. Discussion, conclusion & recommendation

In this thesis, a layout improvement process has been executed at Timmerije, to decrease the busyness in the production facilities. The production facilities at Timmerije are found to be too busy at peak times, where products cannot be transported to the checking-area across the transportation path. The previous chapters guided to the final layout, which is chosen by the stakeholders and management of Timmerije, based on various criteria. By answering knowledge questions in every chapter, the following main research question can be answered:

"What improvements can be made in the layout of the production facilities to decrease the busyness at Timmerije B.V.?"

The main research question will be answered in section 8.3. A discussion of the results is given in section 8.1, whereas possibilities for future research are given in section 8.2. Section 8.4 concludes with the recommendations for Timmerije.

8.1. Discussion

By implementing layout 2.2, the 50% reduction in total transportation distance compared to the reality value of the current situation, is not being reached. Timmerije describes the reduction as a wish, and not as a requirement. Therefore, it is not a problem that the 50% reduction is not being reached.

In this research, it is shown that the current layout of production hall 4/5 at Timmerije is not optimal. By implementing the principle of placing machines with the biggest output closest to the exit, an optimal layout of production hall 4/5 can be found. The creation of a pallet highway stimulates the flow of products in the production facilities, and it improves the safety in the production halls.

The production data on which the research is based, is from Q1 2020. In this time period, COVID-19 hit the Netherlands. Even in this uncertain time period, the production levels were found to be approximately representative for a regular Q1. Therefore, the data is valid and represents an average Q1. Timmerije experiences a seasonal peak in production during May and September. The data is thus representative for all months in a year, except for May and September. For these months, it still has to be proven to be representative for the seasonal peak months.

COVID-19 did have a negative effect on the research. For a long time, most people were not welcome at Timmerije, because of the restrictions of the government. For this reason, I (almost) have not been at Timmerije during the layout design process. As a result, several practical limitations only popped up in a later phase of the process. When it would have been possible to walk in the production halls and ask employees about these limitations, these limitations would have popped up in an earlier stadium. It was not possible to get instant feedback on the layouts. An example here is including the pallet locations around machines in the layout. This only became clear after the first improvement cycle, whereas it would have been clear early in the process if it would have been possible to visit Timmerije. Fortunately, it was possible to visit Timmerije a couple of times, to finish the design process in a good manner.

When layout 2.2 is going to be implemented, it means that the employees have to be able to cope with the change in layout. When they see the benefit of implementing the layout, it is believed that they are able to cope with the change in layout well. Also, it means that investments are to be made to realise the change in layout. As a result, it is expected that all large machines are able to produce products simultaneously after the implementation of layout 2.2, so it is easier to cope with production demand. In case Timmerije chooses not to implement the improved layout, it can be expected that they are not able to cope with the increasing demand and busyness. This is stated, because Timmerije has already accepted a production project in which a lot of products have to be produced on a 2K650-x. The expected demand simply would not be coped with when only one 2K650-x exists in the machine park.

The reality value of the total transportation distance is not calculated for layout 2.3. This is the case, since the production output of the 2K650-x's is not known yet, and giving a rough estimate of the production output of these machines would not give a representative outcome of the total transportation distance. Next to that, by moving the four biggest machines to the right in layout 2.3, the total transportation distance already increases. This results in an even higher total transportation distance.

By implementing layout 2.2 (or layout 2.3), flows are created, which results in less interference between input and output. Due to the pallet highway, pallets with products can be transported to the checking-area much quicker and more efficiently. In the beginning of the thesis, a practical disadvantage of the current situation was given. It was described that Timmerije chooses to not have all four of the biggest machines operational at the same time, because the transportation path simply could not cope with the massive output of these machines. When layout 2.2 (or layout 2.3) is implemented, it means that all four of the biggest machines can be operational at the same time. As a result, the implementation of one of these layouts is even more beneficial than previously has been described, because at the same time, more products can be produced.

8.2. Future research

For further research, it is recommended to research the effectiveness of using the same principle of optimising production hall 4/5 for the other production halls at Timmerije. With the same principle, the principle of placing machines with the highest output closest to the exit, is meant. In this way, it becomes clear if other production halls can be optimised with the same method.

Next to that, it can be researched if the location of machines can be considered when planning the production of batches. Sometimes, products can be produced on multiple machines, and therefore the optimal machine (with regards to total transportation distance and busyness) for a production batch can be determined. For example, when a product can be produced on machines X-1 and X-2, and

Also, the seasonal peaks in production levels during May and September can be researched, to see if other products are produced more during these periods, or that the overall production is higher. This might result in other production output values, and thus possibly machines getting different priorities when designing the production facilities' layout.

Lastly, the scope of the research can be extended from thinking in restrictions of existing walls, to determining an optimal layout with no restrictions at all (as if the layout with all production facilities would be made from the very beginning). Perhaps production halls would be designed differently (and filled differently with machines) when using this way of thinking.

8.3. Conclusion

The main problem at Timmerije was that it can be too busy to move products during peak times, which resulted in a saturation of the transportation path. Products and moulds have to be transported from the machine to the checking-area/mould warehouse. This transportation takes place across the transportation path. Since this problem occurs, it sometimes happens that Timmerije chooses to not have some machines operational, while they would have liked to see them operational and producing products. The transportation path simply would not be able to cope with the output of the machines.

By improving the layout of the production facilities, the transportation path is able to cope better with the transportation of the production output. The focus of the layout improvement research is laid on production hall 4/5, because bulk-products are produced in that hall, and products from other production halls also have to be transported via production hall 4/5.

The Systematic Layout Planning of Muther and Hales (2015) is used to provide structure in the process of improving the layout. This method guides through the different steps in the layout improvement process.

To measure a decrease in the busyness of the transportation path, the total transportation distance in the production facilities is calculated. A decrease in the total transportation distance leads to a decrease in the busyness of the transportation path. The total transportation distance consists of the transportation distance of pallets with produced products, and of moulds. The data from Q1 2020 is used to calculate the current value of the total transportation distance per day. On average, 30.5 km/day was being travelled in the production facilities during Q1 2020.

After having gathered considerations and limitations, the first versions of layout concepts have been built. After a feedback session at Timmerije, feedback was gathered and the layouts were improved. During a second feedback session, the final layout was chosen. This chosen layout, which is also referred to as layout 2.2, can be found below again in Figure 8.1.

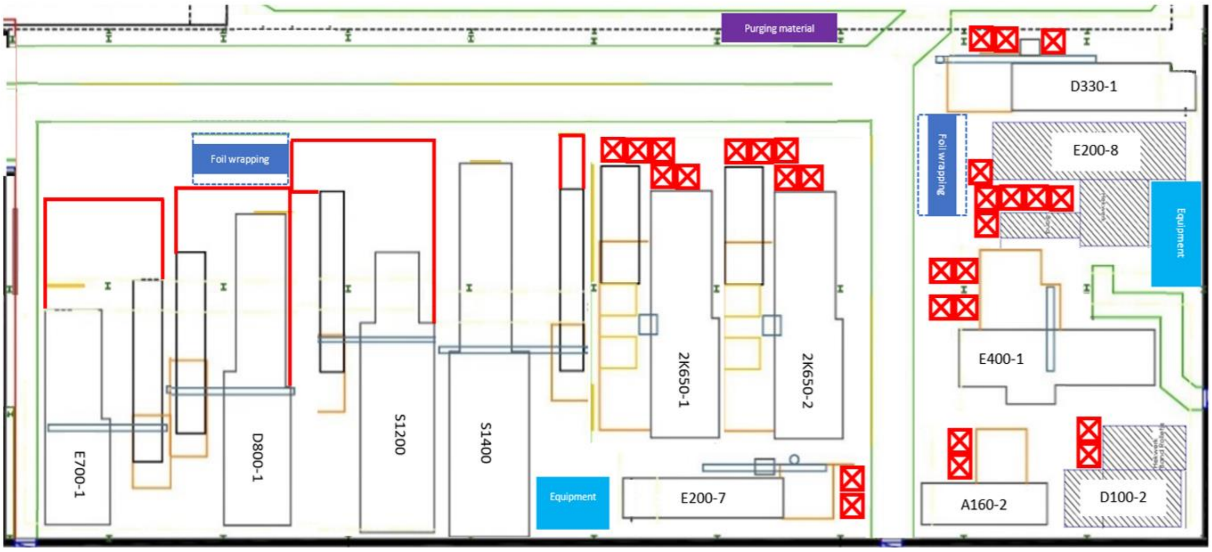
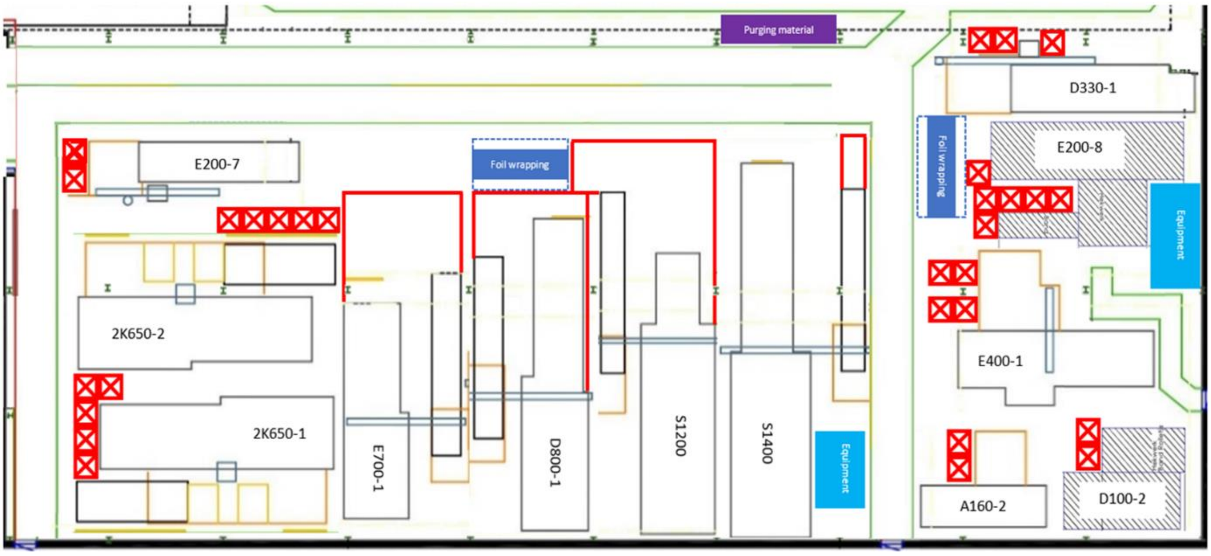


Figure 8.1. Final improved layout

The layout is chosen based on various criteria. Layout 2.2 improves the safety, because there are less crossings due to the pallet highway that is created in this layout. Flows are separated with this pallet highway. The improved layout is also found to be safe with regards to fire-safety. The 2K650-2 is incorporated in the new layout, instead of the A160-3 and A100-5 from production hall 1. By adding the 2K650-2 to the machine park, Timmerije is able to cope well with an expected increase in demand of products that have to be produced on the 2K650-1 or 2K650-2 (these machines are referred to as 2K650-x's from now on, since they are identical). This layout does not reach the norm of a 50% reduction in transportation distance that was determined in the beginning of the process. Timmerije sees the 50% reduction as a wish, and not as a factor that is as important as the layout being safe and/or future proof. The investment costs are found to be on average, relative to the other layouts. Lastly, a flow is created in layout 2.2. This is the case, because all machines have the same orientation and there is a clear input flow to machines, and a clear output flow from machines to the checking-area.

The presence of the 2K650-2 instead of the A160-3 and A100-5 accounts for 0.97 km/day in addition to the reality value, because of a larger output of the 2K650-2. The calculated reality value of the total transportation distance for layout 2.2 is 22.76 km/day. The corrected reality value of layout 2.2 therefore is *21.79 km/day*. The reality value of the total transportation distance of the current situation is *30.50 km/day*. This means that the total transportation distance decreases with *28.6%*, when implementing layout 2.2.

In case it is expected that the output of the 2K650-x's exceeds the output of the biggest machines in hall 4/5, it is recommended to implement layout 2.3 instead of layout 2.2. In here, the 2K650-x's are placed to the left, and the other biggest machines are moved to the right. This layout is given below in Figure 8.2.



Layout 8.2. Layout in case of expectation of 2K650-x's output exceeding output biggest machines

The costs of implementing layout 2.2 are estimated to be €251,700.00. The benefit of implementing layout 2.2 is found to be €80,006.78 per year. This means that the time for cost-recovery of the investment is 3.15 years. The steps for implementing layout 2.2 are given in Chapter 7. Tips from the Systematic Layout Planning are also provided here.

8.4. Recommendation

The main recommendation to the management team of Timmerije is to implement layout 2.2. In this way, Timmerije can solve the problem that currently is the bottleneck in the production facilities, which is that it can be too busy to move products during production times. By implementing layout 2.2, the total transportation distance decreases. Due to that, the busyness in the production facilities decreases, and the safety is being influenced positively. A reduction of 28.6% of the total transportation distance in the production facilities is realised with this implementation. It is estimated that the time for cost-recovery of the implementation is 3.15 years.

In case the expected output of products that have to be produced on the 2K650-x's, exceeds the output of the biggest machines in hall 4/5, it is recommended to implement layout 2.3 instead of layout 2.2. In this layout, the 2K650-x's are located on the position most left to the checking-area, and the other biggest machines are placed two machine positions to the right.

To be able to cope with the increasing demand of products that have to be produced on a 2K650-x, it is recommended to purchase the 2K650-2. It is important to be able to keep growing, and this is possible by investing in another machine of the 2K650-x. Since a production project with products to be produced on a 2K650-x is already accepted, the 2K650-2 is needed to cope with the expected increasing demand.

Implementing layout 2.2 (or layout 2.3) means that there is going to be a standstill of machines for some period of time, because machines have to be moved, and some machines first have to be moved outside before other machines can be moved to their new location. Therefore, it is recommended to plan the implementation during a period of expected lower demand, perhaps during the holidays. It is also possible to produce batches earlier, so still some part of the to be produced batches are produced on time.

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Appendix A. Systematic Literature Review (SLR)

1. Definition of the knowledge problem/research question

Which optimization methods and theories are available in the scientific literature for optimizing the floor plan of a production company, such as that of Timmerije?

2. Defining the inclusion and exclusion criteria

The inclusion and exclusion criteria have been determined with the help of two academic sources, to get an idea of the possibilities. (Systematic Reviews, 2020), (Robergs, 2010)

Table A1. Exclusion criteria

Number	Criteria	Reason for exclusion
1	Pre-1980 articles	The way of manufacturing should be up-to-date
2	“layout” OR “lay-out” OR “floorplan” AND “facility” not mentioned in abstract	This is the core of the research and should be included in the research. It is assumed not relevant if it is not mentioned in the abstract.
3	Medical topics	Not relevant for companies
4	Educational topics	Not relevant for companies
5	Virtual reality	My company is not into VR
6	Artificial intelligence	My company is not into AI
7	Simulation models/programming	A method needs to be found, not a simulation model
8	Survey	Not needed, a model needs to be found
9	Cellular manufacturing systems	Not relevant for the layout in my company
10	Single row layout problem	Not relevant for the layout in my company
11	Other location than Western countries	Layout and economic situation have to be comparable to a Western facility layout

Table A2. Inclusion criteria

Number	Criteria	Reason for inclusion
1	“Efficiency” is mentioned in abstract	This is the main improvement point
2	“Manufacturing” OR “production” in any field	The article should be about these kind of processes

3. Defining the databases used

First Scopus has been used to find the relevant search strings, after that these search strings have been used in Web of Science. I did not use Google Scholar as my first database on purpose. My expectation was that there would be extensive amounts of literature available on my topic. Therefore, I wanted to go into depth in Scopus immediately. My expectation proved to be true during the systematic literature review, which is why the review has been conducted further in the way that was being worked with.

4. Describing the search terms and the used strategy

First a search matrix has been set up with the main constructs, and the terms related to these constructs. The search matrix can be found below in Table A

3.

Table A3. Search matrix

Constructs	Related terms	Broader terms	Narrower terms
Optimization		Improvement	Efficiency
Floor plan	Layout	Design, arrangement	
Production	Manufacturing	Making	Injection moulding
Company	Firm, facility, plant	Organization, business, enterprise, operation, concern	

With trial and error, it has been determined what the relevant words are to find the articles that were looked for. It first started with only searching for two constructs, and it turned out that there were far too many entries. After some time, it became clear what combinations of search words had the required effect. To give an illustration of these steps, Table A4 below gives some insights in the strategy to come to the right terms. Eventually, five search strings were found in Scopus that had the right amount of entries, and which were relevant. These search strings were then used in Web of Science. After each of these five searches in Scopus and Web of Science, the results were exported to EndNote. In EndNote was the collection of all the articles.

Table A4. Start of search strategy

Date	Search string	Scope	Date range	Number of entries
6-4-2020	optimization AND "floor plan"	All fields	1980-present	1110
6-4-2020	optimization AND "floor plan"	Article title, abstract, keywords	1980-present	202
6-4-2020	optimization AND "floor plan" AND produc*	Article title, abstract, keywords	1980-present	32 (too few and not my topic)
6-4-2020	(Optimization OR Improvement) AND (Floorplan OR Lay-out OR design) AND (Production OR Manufacturing) AND (Company OR Organization)	Article title, abstract, keywords	1980-present	6519
6-4-2020	optimization AND (floorplan OR lay-out) AND (production OR manufacturing) AND (company OR firm)	Article title, abstract, keywords	1980-present	110
6-4-2020	theory AND optimization AND (floorplan OR lay-out) AND (production OR manufacturing) AND (company OR firm)	Article title, abstract, keywords	1980-present	69
6-4-2020	Optimization AND (floorplan OR layout) AND efficiency AND (company OR plant OR facility)	Article title, abstract, keywords	1980-present	649
6-4-2020	(Optimization OR Improvement OR Efficiency) AND (Floorplan OR Lay-out OR Design) AND (Production OR Manufacturing) AND (Company OR Organization OR Firm OR Operation OR Business)	Article title, abstract, keywords	1980-present	25686
6-4-2020	(Optimization OR improvement) AND (floorplan or lay-out OR design) AND (production OR	Article title, abstract, keywords	1980-present	2908

	manufacturing) AND (company OR plant OR facility) AND efficiency			
6-4-2020	(Optimization OR improvement) AND (floorplan or lay-out OR design) AND (production OR manufacturing) AND (company OR plant OR facility)	Article title, abstract, keywords	1980-present	14225

The final search strings that have been used can be found below in Table A5.

Table A5. Final search strings

Date	Search string	Scope	Date range	Number of entries
Search protocol for Scopus				
6-4-2020	(Optimization OR Improvement) AND (Floorplan OR Lay-out OR design) AND (Production OR Manufacturing OR industr*) AND (Company OR Organization) AND "plastics industry"	Article title, abstract, keywords	1980-present	16
6-4-2020	(Optimization OR improvement) AND (floorplan OR design) AND (production OR manufacturing) AND ("plant layout" OR "facility layout") AND efficiency	Article title, abstract, keywords	1980-present	89
6-4-2020	(Optimization OR improvement) AND (production OR manufacturing) AND ("plant layout" OR "facility layout" OR floorplan) AND efficiency	Article title, abstract, keywords	1980-present	163
6-4-2020	(Optimization OR improvement) AND (floorplan or lay-out OR design) AND (production OR manufacturing) AND (company OR plant OR facility) AND "plastics industry"	Article title, abstract, keywords	1980-present	19
6-4-2020	(Optimization OR Improvement) AND (Floorplan OR Lay-out) AND (Production OR Manufacturing) AND (Company OR Organization)	Article title, abstract, keywords	1980-present	20
Search protocol for Web of Science				
6-4-2020	(Optimization OR Improvement) AND (Floorplan OR Lay-out OR design) AND (Production OR Manufacturing OR industr*) AND (Company OR Organization) AND "plastics industry"	Title or topic	1980-present	4
6-4-2020	(Optimization OR improvement) AND (floorplan OR design) AND (production OR manufacturing) AND ("plant layout" OR "facility layout") AND efficiency	Title or topic	1980-present	73
6-4-2020	(Optimization OR improvement) AND (production OR manufacturing) AND ("plant layout" OR "facility layout" OR floorplan) AND efficiency	Title or topic	1980-present	103
6-4-2020	(Optimization OR improvement) AND (floorplan or lay-out OR design) AND (production OR	Title or topic	1980-present	5

	manufacturing) AND (company OR plant OR facility) AND “plastics industry”			
6-4-2020	(Optimization OR Improvement) AND (Floorplan OR Lay-out) AND (Production OR Manufacturing) AND (Company OR Organization)	Title or topic	1980-present	8
Total in Endnote				**500**
Removing duplicates				-206
Exclusion criteria				-261
Removed after complete reading				-16
Total selected for review				**17**

5. Listing the number of articles found, the number of duplicates, the final set of articles

The number of articles found, and the number of duplicates can be found above in Table A5. The final set of articles is:

Cao, Y. H., & Kang, X. C. (2014) Improving workshop’s production efficiency by applying industrial engineering methods. In & C. Beijing Gireida Education Research, S. International, C. Education Researcher Association, & C. Vip-Information Conference Center (Vol. Ed.)*: Vol. 685. 2014 4th International Conference on Mechanical Engineering, Industry and Manufacturing Engineering, MEIME 2014* (pp. 693-696): Trans Tech Publications Ltd.

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Kovacs, G., & Kot, S. (2017). FACILITY LAYOUT REDESIGN FOR EFFICIENCY IMPROVEMENT AND COST REDUCTION. *Journal of Applied Mathematics and Computational Mechanics, 16*(1), 63-74. doi:10.17512/jamcm.2017.1.06

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Li, Z., Cao, J., & Xiao, J. (2012) Optimization design for production logistics system of corrugated box. In & E. Singapore Institute of, Science, & I. Engineering (Vol. Ed.)*: Vol. 463-464. 2012 2nd International Conference on Advanced Material Research, ICAMR 2012* (pp. 962-966). Chengdu.

Moatari-Kazerouni, A., Chinniah, Y., & Agard, B. (2015). Integrating occupational health and safety in facility layout planning, part I: methodology. *International Journal of Production Research, 53*(11), 3243-3259. doi:10.1080/00207543.2014.970712

Morinaga, E., Iwasaki, K., Wakamatsu, H., & Arai, E. (2017) A robust facility layout planning method considering temporal efficiency. In*: Vol. 514. IFIP WG 5.7 International Conference on Advances in Production Management Systems, APMS 2017* (pp. 168-175): Springer New York LLC.

Morinaga, E., Iwasaki, K., Wakamatsu, H., & Arai, E. (2019) Reduction of Computational Load in Robust Facility Layout Planning Considering Temporal Production Efficiency. In*: Vol. 567. IFIP WG 5.7 International Conference on Advances in Production Management Systems, APMS 2019* (pp. 189-195): Springer New York LLC.

Naqvi, S. A. A., Fahad, M., Atir, M., Zubair, M., & Shehzad, M. M. (2016). Productivity improvement of a manufacturing facility using systematic layout planning. *Cogent Engineering, 3*(1), 12. doi:10.1080/23311916.2016.1207296

Radhwan, H., Shayfull, Z., Farizuan, M. R., Effendi, M. S. M., & Irfan, A. R. (2019). *Redesign of bahulu production layout to improve the efficiency of process flow.* Paper presented at the 5th International Conference on Green Design and Manufacture 2019, IConGDM 2019.

Ripon, K. S. N., & Torresen, J. (2014). Integrated job shop scheduling and layout planning: A hybrid evolutionary method for optimizing multiple objectives. *Evolving Systems, 5*(2), 121-132. doi:10.1007/s12530-013-9092-7

Tayal, A., & Singh, S. P. (2019). Analysis of simulated annealing cooling schemas for design of optimal flexible layout under uncertain dynamic product demand. *International Journal of Operational Research, 34*(1), 85-103. doi:10.1504/IJOR.2019.096941

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6. Conceptual matrix

Table A6. Conceptual matrix

Journal	Authors (Year)	Methodology	Main aim/goal	Main theory or model used	Applicability theory to research
	Cao & Kang (2014)	One workshop's production efficiency was evaluated and improved according to the evaluation results.	Reduce the waiting time and handling waste	Systematic Layout Planning (SLP)	The waiting time at my company has to be decreased. SLP seems to be a good method for this purpose.
International Journal of Production Research	Kovacs	Integrating the different advantages of Lean methods and facility layout design (FLD)	The elaboration of the methodology and procedure of a new combined efficiency improvement method which basically applies Lean methods and also uses the facility layout design (FLD) method simultaneously	Lean methods and facility layout design (FLD)	After the research, it was shown that several KPIs had been improved, such as travel distance of materials and material workflow. These KPIs are relevant for the research, but it seems that the scope of the methods used is too broad.
Journal of Applied Mathematics and Computational Mechanics	Kovacs (2017)	Case study to show how the efficiency and reduced manufacturing cost can be improved.	To show the reasons, objectives and steps of a layout redesign process.	Facility Layout Problem (FLP)	The model is relating to location of objects, and the workflow between them. In my case this is the workflow of the machines to the warehouse. This model therefore seems to be relevant
Engineering Optimization	Kumar & Singh (2017)	To show the efficiency of the two-phase heuristic approach, 21 instances are generated and solved using the optimization software package LINGO.	To propose a novel similarity score-based two-phase heuristic approach to solve the DCFLP optimally, instead of	Dynamic cellular facility layout problem (DCFLP)	It is very difficult to solve the DCFLP in reasonable time. The heuristic clusters machines, based on similarity criteria. This is not applicable to my research, since

			solving it NP hard		every machine produces on itself and should not be clustered
Computers & Operations Research	Li & Rong (2009)	Three approaches are applied to achieve the goal. Then a multi-objective design model is proposed. FACO is also presented.	Ensuring just-in-time production	Fuzzy ant colony optimization (FACO)	The method to determine the shortest path is too complex for the research. Next, it is also not relevant because it exceeds the scope of the research.
Journal of Shanghai Jiaotong University	Li, Wu & Pang (2003)	Use the algorithm, then a machine layout is found and then the HGA is applied with various criteria.	To show that the algorithm is a good way to improve the searching algorithm	Hybrid genetic algorithm (HGA)	The main aim is not linked with my research. With this algorithm, a machine layout is found as an intermediate step, while a method for determining the optimal layout is needed
	Li, Cao & Xiao (2012)	Various factors are considered, such as analysing the processes and the parameters. A from-to table is included. The optimal solution is evaluated by using weighted checklist approach.	To optimize the facility layout, production logistics system and working procedures	Systematic Layout Planning (SLP)	The method and various steps, also with the weighted checklist approach, seem what is expected of me at the company. This method looks very reasonable for conducting my research.
International Journal of Production Research	Moatari-Kazerouni, Chinniah & Agard (2015)	By integrating occupational health and safety (OHS) features in the early design of a facility layout, the OHS issues are reflected prior to the construction of a facility.	To propose a facility layout planning methodology which integrates the occupational health and safety (OHS) features in the early design of a facility layout	Integration of occupational health and safety (OHS) features	It is about a facility design, not a redesign. My company has its primary focus on health and safety of its employees. The focus can therefore only lay on an optimal layout, which is not proposed by this paper.

	Morinaga, Iwasaki, Wakamatsu & Arai (2017)	To define an evaluation index based on distance and find a layout which minimizes it. Temporal efficiency is not considered in this stage but in later stages.	To consider the robustness against the changes in production scenarios	Facility layout planning (FLP)	This method provides the optimal layout plan for a fixed production scenario. My company has provided me with the information that I can use a more or less fixed production scenario. Next to that, this model focusses on the transportation distance, which can be determined with information that is already available in the company
	Morinaga, Iwasaki, Wakamatsu & Arai (2019)	The authors have developed an FLP method considering temporal efficiency, in which facility layout is optimized using genetic algorithm (GA), and have enhanced it so that robustness against changes in production environment can be taken into consideration.	To provide a method for reducing computational load in the robust FLP based on the sampling approach where each layout plan is evaluated with only a limited number of production scenarios in the optimization process by GA	Facility layout planning (FLP), genetic algorithm (GA)	Robustness against changes in production environment are outside the scope of my research.
Cogent Engineering	Naqvi, Fahad, Atir, Zubair & Shehzad	This paper provides a comprehensive comparison of different approaches used in layout design. The study also simplifies the application of systematic layout planning (SLP) in the development of new	To simplify SLP and show how SLP can be implemented, and how a solution can be chosen.	Systematic layout planning (SLP)	My company also has products with high varieties. The steps described require information that I already have or can acquire. SLP has the goals that I also have been

		layout. The company produces products with high varieties.			given by the company.
	Radhwan, Shayfull, Farizuan, Effendi & Irfan (2019)	There are several layouts generated using Systematic Layout Planning (SLP) and Graph-Based Theory (GBT) and the Efficiency Rate (ER) of each layout was calculated. The layout with the highest rate was then selected and validated by using WITNESS software	To improve the current plant layout by redesigned it with increasing the production efficiency and productivity of the company.	Systematic Layout Planning (SLP) and Graph-Based Theory (GBT)	The methods described look applicable to my research. They had the wished effects (Efficiency Rate). The efficiency and productivity of a real manufacturing system have been improved by a redesign layout, and that is exactly what has to happen in my research.
Evolving Systems	Ripon & Torresen (2014)	In this research, a hybrid genetic algorithm by incorporating variable neighbourhood search is applied to simultaneously optimize make span and mean flow time for JSSPs, as well as total material handling cost and closeness rating scores for FLPs.	To present a multi-objective evolutionary method for solving JSSP that considers transportation delays and FLP as an integrated problem, which presents the final solutions as a Pareto-optimal set.	Facility layout planning (FLP) and job shop scheduling problem (JSSP)	The production planning of machines is also considered, and it is described that the used algorithms are quite time consuming. That is why I cannot use this paper for this purpose
International Journal of Operational Research	Tayal & Singh (2019)	Various SA cooling schemas are discussed, computed and evaluated for generating the optimal flexible layout. A computer-based tool was developed and analysis was conducted on small to large size problem set.	To explore the way uncertainties are addressed in designing of flexible optimal layout	Stochastic dynamic facility layout problem (SDFLP), with an adaptation of simulated annealing (SA) meta-heuristic	It is an NP-hard combinatorial optimization problem, which means the time taken to solve increases exponentially with problem size. The problem size is rather large in my company, which means that this method would exceed the scope of the research.

Institute of Industrial Engineers	Venkatasamy & Krishnan (2010)	The paper first describes the optimization-based approach for cell formation. A modified grouping efficiency measure is developed to determine the best cell configuration. The result from the cell formation is then fed into a genetic algorithm.	To determine the best layout to reduce the material handling cost	Cellular Manufacturing	The focus area for my research are several machines in a production hall. These cannot be clustered in a cells, because they are not that similar. This method therefore will not be used.
Journal of Jilin University (Engineering and Technology Edition)	Zha, Guo, Huang & Fang (2017)	A method of dynamic facility layout combined with fuzzy-random theory is proposed considering the deficiency of the description of uncertain demands. Then, the main factors causing uncertain demands are analysed and the uncertain demand are presented by fuzzy random variables. Finally, combining with system layout planning, the optimization method of the position-based colonial competitive algorithm is proposed to obtain feasible optimal solutions for the proposed problem.	To demonstrate the effectiveness of the algorithm.	Dynamic Facility Layout Problem (DFLP)	The DFLP takes a dynamic production demand into account, which makes the model much more complicated and time-consuming. This model exceeds the scope of my research.
	Zulkifli, bin Md Yasir & Abd Aziz (2017)	Steps of the SLP are used. The current situation is analysed, after which various diagrams are set up. Next, several layouts were found of which one was evaluated and chosen.	To be able to make recommendations to improve the plant layout in order to provide a better performance in production activity and	Systematic Layout Planning (SLP) and Line Balancing	Five criteria for the SLP method were discussed (space utilization, flow of material, traffic flow, preferred closeness and safety and working

			product quality.		

7. Integration of the theory, organized around concepts

After analysing the different articles, it turns out that there are quite some different layout improvement methods. Just to name a few; Dynamic Facility Layout Problem (DFLP), Stochastic Dynamic Facility Layout Problem (SDFLP), Facility Layout Planning (FLP), Systematic Layout Planning (SLP) and Job Shop Scheduling Problem (JSSP). These methods/theories all have a different scope, take different parameters into account and have different aims.

Some of these methods, like SDFLP, require higher mathematics, algorithms and computer software to get results. This by far exceeds the scope of the research. My company does not require these kind of models, they want something that already is an improvement, but it does not necessarily need to be an optimal solution.

What is needed is a simple, but effective method to improve the efficiency and productivity of a production facility by changing the layout. A universal approach and a specific set of steps to reach the end goal, is required. These steps are needed to provide extra insights on the topic. Personally, I know some of these steps and I can use common-sense, but I might forget certain aspects. After the systematic literature review, it turned out that Systematic Layout Planning (SLP) fits my research most.

This is the case, because no higher mathematics, algorithms or computer software are needed to get results. Rather it applies common-sense in an orderly way. Math is limited to arithmetic and software use is largely limited to spreadsheets and visualization. Minimizing material handling, especially travel distance and time are key indicators to decrease the busyness at Timmerije. The examples provided in the articles are almost 1 to 1, compared to my research. Next to that, SLP provides for employees' safety, comfort and convenience, which are the key principles of my company. The employee and the associated safety always come first.