Increasing the capacity in the current building of Niverplast

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Important: This is a public version of the report, which means that some parts are adjusted or removed to ensure the confidentiality.

Foreword

In front of you lies my report "Increasing the capacity in the current building of Niverplast", which is the result of the research I conducted at Niverplast Engineering B.V. This thesis is written to conclude my bachelor, Industrial Engineering and Management, at the University of Twente.

Hereby I want to thank all people who have supported me in the past month while I was conducting this research. First, I want to thank Rutger Grootewal, my external supervisor from Niverplast. Rutger helped me a lot by answering questions, providing me information, giving me feedback, and come up with good ideas for my research. Further, I want to thank all other people from Niverplast who helped me in any form during my research.

Next to the people of Niverplast, I want to thank Marco Schutten, my supervisor from the University of Twente. He gave me valuable feedback, advice, and tips during this research. At last, I want to thank Peter Schuur for being the second supervisor.

I hope you enjoy reading this report.

Jorieke Havinga
Wierden, August 2020

Summary

The summary describes the research motivation, the research method, the results and the conclusion and recommendations we give to Niverplast.

Problem definition

Since Niverplast is constantly growing, the expectation is that in the future there is not enough space anymore in the current building. In this research, we search for ways to increase the capacity of the current building. Next to that, we look what the limit of this building is and when a new building is necessary.

Research method

First, we identify the current production process layout and the occupation in the past years. With the information about the occupation in the past years, we know how much space is needed in the future. The expectation from the owner of Niverplast is that the production will double. After that, we search for ways to improve the production process layout in literature. Based on the literature, we advise about the production process layout. Based on a brainstorm session, we come up with solutions to increase the capacity. We work out the solutions that were chosen at the brainstorm session and test them with an Excel tool we made. With this Excel tool we also answer the question what the limit of the current building is.

Results

First, we did a literature research into production process layouts. There are four basic layout types that are mostly used in literature: fixed-position layout, functional layout, cell layout and line layout. The first layout is the most convenient when the variability is high and the volume is low, and the last layout when the variability is low and the volume high. Changing the layout to a layout that is more convenient for low variability and high volume can eliminate waste, and thereby increase the capacity. For example, changing from a fixed-position to a functional layout or from a cell layout to a line layout. We looked at the layout for both departments that exists at Niverplast: Stand-alone and Projects. At the Stand-alone department, they make stand-alone machines. At the Projects departments, they make whole packaging line consisting of one or more stand-alone machines with transporters between them. We saw that the current fixed-position layout for the Projects department is difficult to change, since the projects are too big and heavy to move. However, before the project is composed, the assembly of parts can be done at a different stage for more flexibility. In this way, the layout of projects moves a bit more towards a functional layout. The current cell layout for the Stand-alone department seems the most appropriate one. The P-Q analysis showed that the percentage of one of the machines out of all machines that are produced is high. Therefore it could be a good idea to split the layout at the Stand-alone department and use a line layout for this machine. However, we saw that the production number is currently too low that a line layout would work and there are some problems in the production why a line layout will be difficult. If the production number of this machine increases further, it can be worthful to investigate the possibility of a line layout for this machine.

During the brainstorm session, there were eight solutions mentioned that can increase the capacity at Niverplast. With a weighted decision matrix, we decided which solutions we further research and which not. The solutions that we researched further were the possibility to produce on the entresol, make use of flexible space, remove the demo line, shorten the throughput times, and cluster the project tasks. When the possibility of producing on the entresol is used, the best way to use it is to produce whole machines on it, and then transport the machine downwards for transport. The

current work floor can be divided into 16 pie wedges, since Niverplast is located in a round building. Producing machines on the entresol can approximately save 1.5 pie wedge on the work floor. When the demo line is removed, 2 pie wedges are saved. If the throughput times of building machines and projects is reduced with 10%, 2 pie wedges can be saved in the peak month. Since the production is not evenly spread over the year and the peaks at the two departments are not in the same month, using flexible space can increase the capacity.

To answer the question what the maximum capacity of the current building is, we looked at two scenarios. In the first scenario, only the solutions to use flexible space and to shorten the throughput time with 10% are implemented. In this scenario, the maximum capacity of the building is reached when the production increases with 40% compared to 2019. However, if the throughput times are reduced with 50% at the Stand-alone department and with 25% at the Project department, there is enough capacity in the current building to double in production in this scenario. In the second scenario, also the solutions to remove the demo line and use the entresol for production are implemented. In this scenario, the maximum capacity of the building is reached when the production increases with 70% compared to 2019. If the throughput times are reduced with 25% at the Stand-alone department and with 12.5% at the Projects department, there is enough capacity in the current building to double in production in this scenario. When nothing is changed, the maximum capacity is reached when the production increases with 5% compared to 2019.

Recommendations

First, we recommend doing research into the three other solutions that were mentioned at the brainstorm, which we did not researched further due to our limited time.

Further, we saw in this research that there are peaks in the production. The conclusions in this research are based on the assumption that these peaks are not reduced. When the peaks are reduced, there is less capacity necessary in the building. Therefore, we recommend finding a way how these peaks can be reduced.

The tool that we made to measure the impact of the solutions and find the maximum capacity can be used to look what happens in other scenarios than we showed in this report.

Further, we recommend making use of flexible space between the departments and to do research into how the throughput time can be shortened.

If the expectation is that the production will increase further than 40%, we think that it is better to construct a new building. Removing the demo line and using the entresol for production can be used as an emergency solution.

We recommend reducing the space that is used for Stand-Alone to 6 pie wedges, since the capacity problem mainly arises at the Projects department.

Lastly, we recommend making a change in the layout for the Projects department. We think it is better to perform the pre-assembly at a different location than where the project is built, such that all the pre-assembly tasks are grouped together. Then, the pre-assembly can probably be performed quicker and the movements to the storage can be shortened. Further, there will be more overview at the projects department.

Table of Contents

1 Introduction

This chapter provides an introduction to the research. Section 1.1 gives some background information about Niverplast. Section 1.2 explains what the motivation behind this research is. Section 1.3 gives a description of the action problem, and an overview of the other problems including a problem cluster. Section 1.4 describes the research objective. Lastly, Section 1.5 describes the plan of approach and the research questions.

1.1 Introduction to Niverplast

In 1984 Niverplast (Nieuwenhuis Verpakkingen and Plastics) started with trading in packaging materials. The handling of packaging materials was a great success. Soon, they started to produce bags themselves. Thereafter, a customer asked if it was possible to place bags automatically in the boxes. Therefore they made their first machine: the EasyPlast. Currently, Niverplast builds packaging lines for customers all over the world. (Nieuwenhuis, 2019)

At Niverplast, they distinguish between two departments: Stand-alone and Projects. At the Stand-alone department, they make as the name says, stand-alone machines. Currently, Niverplast has 19 different machines that are produced in this department on customer request. At the Projects department, whole packaging lines are built. These packaging lines consist of different stand-alone machines with transporters between them.

1.2 Research motivation

Since Niverplast is continuously growing, the expectation from the owner and the process engineers is that in the future there is not enough space anymore in the current building. The expectation from the owner is that Niverplast will double in production. The first plans for constructing a new building were already created, but then the questions were asked: *''Is it really necessary to build a new building?'' ''Can't we use the entresol in the current building for production?''*. To get an answer to these questions, the assignment was created.

1.3 Problem description

According to Heerkens & Van Winden (2012), an action problem is a discrepancy between the norm and reality perceived by the problem owner. The norm is that there still is enough capacity for the production of stand-alone machines and projects in five years, keeping in mind the continuing growth. In Chapter 2, we explain how much capacity is needed. The reality is that there is not enough space for the projects department for the continuing growth in the way the building is organized now. Currently, for stand-alone machines there are 13 workplaces for pre-assembly, 12 workplaces for main assembly and 10 workplaces for testing. The remaining space on the work floor is used for projects, this is 1783.3 m^2.

To find the core problem and create an overview of the problems and the relationship between them, we made a problem cluster. Figure 1.1 depicts the problem cluster. We give an explanation of the problems in the problem cluster below.

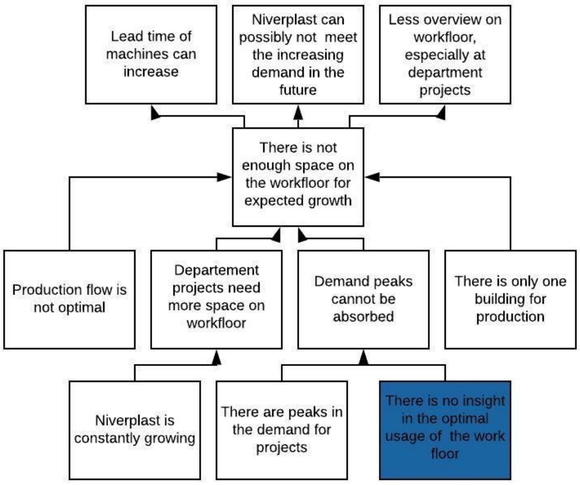

Figure 1.1: Problem cluster

There have been thoughts of constructing a new building for production. This would of course lead to much more production space; however, it is a very expensive solution. Since some plans for a new building were made, the fact that there is now only one building is included in the problem cluster.

Furthermore, Niverplast is constantly growing. Especially the projects department need more space on the work floor due to the growth. This is an important reason why there is not enough space on the work floor in the future.

Also, the production flow seems to be not optimal. Time is lost since the employees are not always productive. Further, the production is sometimes delayed when parts are not in stock or there are mistakes in the drawings. Therefore, workplaces are longer occupied than necessary which again leads to a shortage of workplaces.

Niverplast noticed that the demand for projects is not evenly spread over the year. Around Christmas, when there is a new budget for companies, a lot of new projects are ordered. In very busy times there is not enough space on the work floor for projects. However, at the Stand-alone department not so many capacity problems are encountered. Currently there is no insight in how the work floor can be optimally divided, with probably some flexible space to absorb peaks. This is also a cause of the fact that there is not enough space on the work floor for the expected growth since this problem mainly occurs in the peak times.

To summarize, there is a combination of problems that lead to too little space on the work floor. This problem is the cause of other problems. When the work floor is very busy, there is less overview, especially at the projects department since there are no clearly defined workplaces. Furthermore, the lead time of the machines can increase when there is not enough space since they cannot be made immediately. It could be the case that Niverplast has to cancel orders due to the fact that there is not enough space.

After making the problem cluster, we chose the core problem out of this cluster. The core problem must be a problem that has no direct cause itself. Furthermore, it must be possible for the researcher to influence the core problem. The fact that Niverplast is constantly growing is not a thing that should be influenced. Also, the fact that there are high peaks in the demand for projects cannot be influenced. Therefore, these problems cannot be the core problem. The production flow that is not optimal could be a core problem. However, this is not the focus of this research.

There are two problems that we could choose as the core problem: there is no insight in the optimal usage of the work floor, and there is only one building for production. These problems lead to the perceived problem that there is not enough space on the work floor for the expected growth. This problem is again the cause of other problems. The core problem where we focus on is that there is no insight in the optimal usage of the work floor. This problem does not have a cause itself and it is something that can be changed. The costs are relatively low. It would be strange to directly start to construct a new building, before researching the possibilities in the current building.

1.4 Research objective

The goal of this research is to find an improvement in the production layout to increase the capacity of the current building. We evaluate different solutions to increase the capacity of the current building. One solution was already mentioned before the assignment started: the usage of the entresol for production. An entresol is an open second floor, above part of the ground floor. We investigate the feasibility and impact of this solution. Another goal is to find the limit of the current building is and give advice when it is necessary to build a new building.

1.5 Plan of approach and research questions

This section explains the approach that we use to tackle the problem. For each phase of the problem solving approach, we define knowledge problems and research questions, with a short description of the research design that we use. The main question that we answer in this research is

> *"How can the capacity in the current building of Niverplast be increased and what is the maximum capacity?"*

Phase 1: Measurement current and past situation
In this phase we explain how the demand of projects and stand-alone machines was divided over the year in the past years. We give an overview of the time and space they took on the work floor or at the workplaces. Further, we explain what the scheduling procedure is and what the production layout is. We answer the following research question:

> *''What does the current production process look like?''*

For this research question, we defined three sub questions:

1. *"How was the occupation of the different workplaces for building stand-alone machines and for the workspace for projects in the past 6 years?"*
2. *"What is the scheduling procedure for the projects and stand-alone machines?"*
3. *"What is the production layout?"*

To answer the first question, we make a representation of the past situation. For the second question, we ask for information about the scheduling procedure and describe this. We answer the last question by describing the production layout as we saw it.

Phase 2: Define possible solutions to create more capacity in current building
We describe different solutions that can create more capacity in the current building. We answer the following two research questions:

1. *"Which theories for the design of a production process layout are there in literature?"*
2. *"Which solutions will be evaluated to create more capacity in the current building?"*

To answer the first question, we do a systematic literature review. To answer the second question, we held brainstorm sessions to come up with good solutions.

Phase 3: Evaluate the possible solutions
In this phase, we evaluate the solutions that we created in the previous phase on two aspects: the feasibility of the solutions and the impact of the solution. We answer the following research question:

"*What is the impact and feasibility of the defined solutions?"*

To answer the research question, we evaluate how much more capacity can be created by the solution with an excel tool we made. Thereafter, we define problems that might occur when the solution is used.

Phase 4: Select most appropriate solution(s)
Based on the evaluation in the previous phase, we make a trade-off between the impact of the solution and the efforts or costs. We answer the following research question:

"Which solutions should be implemented?"

Phase 5: Give final conclusion and advice
We make a final conclusion and give advice to Niverplast. This advice also includes the maximum capacity of the current building. So, it becomes clear when this building reaches its capacity limit and a new building is needed. We answer the following two research questions:

1. *"What is the maximum capacity of the current building?"*
2. *"What are the final conclusions and recommendations about the capacity problem in the current building of Niverplast?"*

Based on the solutions that were chosen in phase 4, we show how much capacity can be created in the current building with the excel tool we made. The final conclusion follows from the answers to all the other questions.

We need to define the scope of the research, to make sure that our research is manageable. The scope of our research is on finding solutions for a better usage of the current building. We focus on finding a better layout of the current work floor and evaluate the possibilities of producing on the entresol. The considerations that must be made for constructing a new building lie outside the scope of our research.

2 Context analysis

This chapter gives a description of the current and past situation. Section 2.1 describes the process flow of building stand-alone machines and projects. Section 2.2 gives an overview of the current and past situation for the stand-alone department. It describes the layout, planning procedure and the occupation in the past years. Section 2.3 describes the same for the projects department. Section 2.4 explains the norm and reality of this research. Lastly, Section 2.5 gives conclusions based on this chapter.

2.1 Process flow of building stand-alone machines and projects

As mentioned in Chapter 1, there are two departments at Niverplast: Stand-alone and Projects. An order of a new machine can consist of only one or more stand-alone machines, which will be produced at the Stand-alone department. An order could also be a project; this is a whole packaging line, consisting of one or more stand-alone machines with transport systems. In that case, the stand-alone machines will be built at the Stand-alone department and when they are ready, they will be moved to the Projects department where the whole project is built. A project is not always built at Niverplast, sometimes the different parts directly go to the end customer. Figure 2.1 gives an overview of the process flow. This process flow gives an overview of the steps that are taken from when an order is placed until the moment that the stand-alone machine or project reaches the end customer.

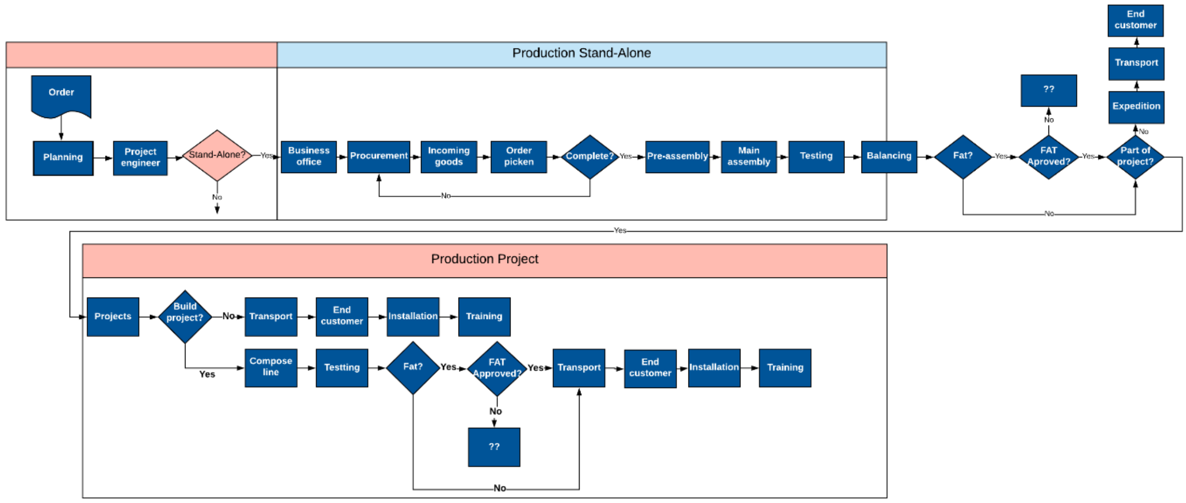

Figure 2.1: Process flow

2.2 Stand-Alone department

Niverplast has 19 different stand-alone machines that are produced at this department. There are three different tasks for building stand-alone machines that have different workplaces. The first is pre-assembly, where modules of the machines are built. The second one is main assembly, where the different components are combined to a working machine. The last one is testing, where the machines are tested and become ready for usage.

2.2.1 Layout Stand-alone

Niverplast is located in a round building. Therefore, the work floor can be divided in different ‘’pie wedges’’. The department Stand-alone uses 7 out of 16 pie wedges. There are 13 workplaces for pre-assembly, 12 workplaces for main assembly and 10 workplaces for testing. The workplaces are grouped per tasks. The pre-assembly workplaces are located in the first 2 pie wedges, the following 3 wedges are used for main-assembly and the last 2 wedges for testing. Figure 2.2 depicts a simplified floor map of the work floor, where the yellow part is the space for stand-alone.

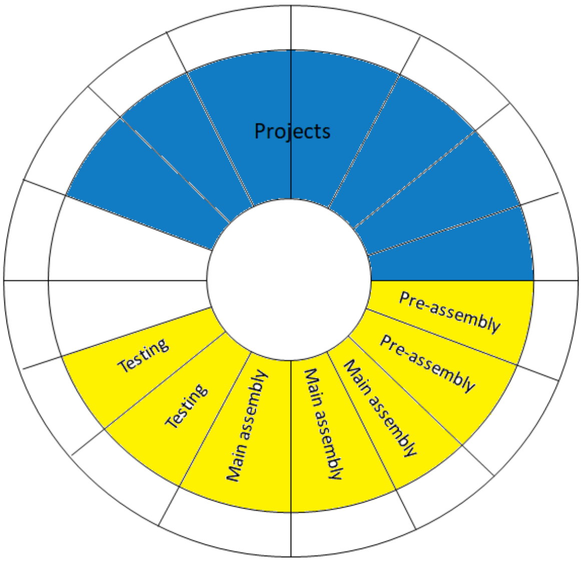

Figure 2.2: Simplified floor map

When a machine is done in the pre-assembly, the different modules are moved to a main assembly workplace. If the main assembly is done, the whole machine is moved to a testing workplace. At every workplace there is a storage rack, where the needed components are placed. Plans are made to locate the needed equipment at the working spot, such that the employees that work at those spots, do not need to move to the storage every time they need something.

2.2.2 Occupation Stand-alone workplaces

To get a better insight in how many workplaces are necessary for the production of stand-alone machines, we made a representation of the past. The outcome of this representation is the average workplaces that were occupied per month. Since only the delivery date of the machine was available, it was necessary to make this representation. We made an overview of when which machine has been on a certain workplace. We used the throughput time per type machine and per task. Appendix A depicts the throughput times that were used. In this representation, we made an assumption about the time when a machine was at a workplace for testing. This was set to the number of working days of the throughput time of that machine for testing, before the delivery date. In the same way, we counted backwards when the machine was at a main assembly and pre-assembly workplace. Thereafter, we made an overview of how many workplaces, per task, were occupied on average per month. This method has some limitations, so it is not an exact representation of how it has been in the past. The throughput times are an estimation; therefore a machine can have been a few days more or less at a certain workplace. Since we used the average per month for the analysis, a fluctuation of a few days will not have a high impact on the outcome. Appendix B shows the table with the average occupied workplaces per month. We describe the important findings from this representation below.

The average occupied workplaces are way less than the available workplaces. The are 13 workplaces for pre-assembly, but the calculations shows that over the years, the average occupation is 3.1. For main assembly this is 12 versus 5.0 and for testing 10 versus 4.7. Figure 2.3 shows the average occupation of the workplaces per year. In this figure, we see that the demand for the machines is growing. In 2019, the average occupied workplaces are about half of the available workplaces.

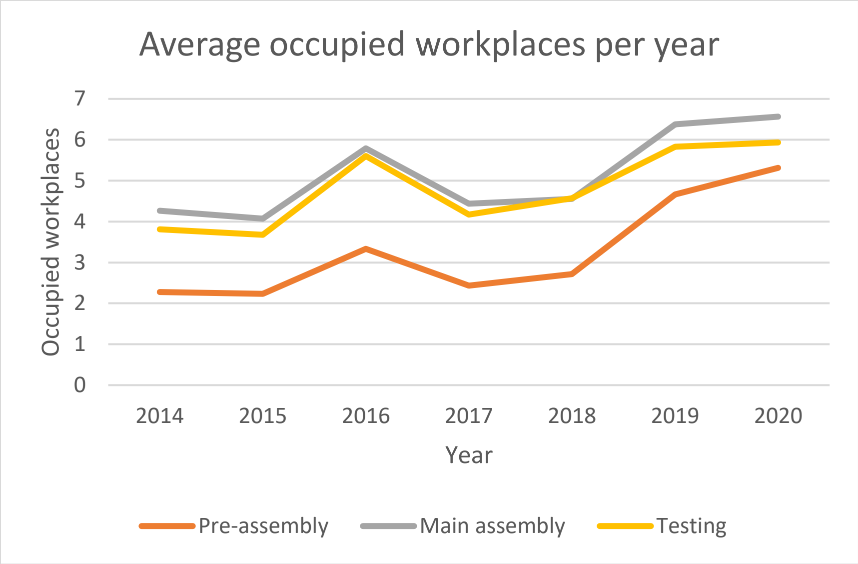

Figure 2.3: Overage occupied workplaces per year

Figure 2.4 shows the average occupied workplaces of 2014 till 2019 per month of the year. Figure 2.4 shows that the occupation is not equally spread over the year. We see two periods where the average occupation is higher: around April and September. The peak comes first at the department pre-assembly, then the peak occurs also at main assembly and testing. These peaks are important to keep in mind, since although in 2019 on average about half of the capacity was used, in September the occupation of pre-assembly was 12.6/13 and in October at main assembly 10.7/12 and at testing 8.6/10.

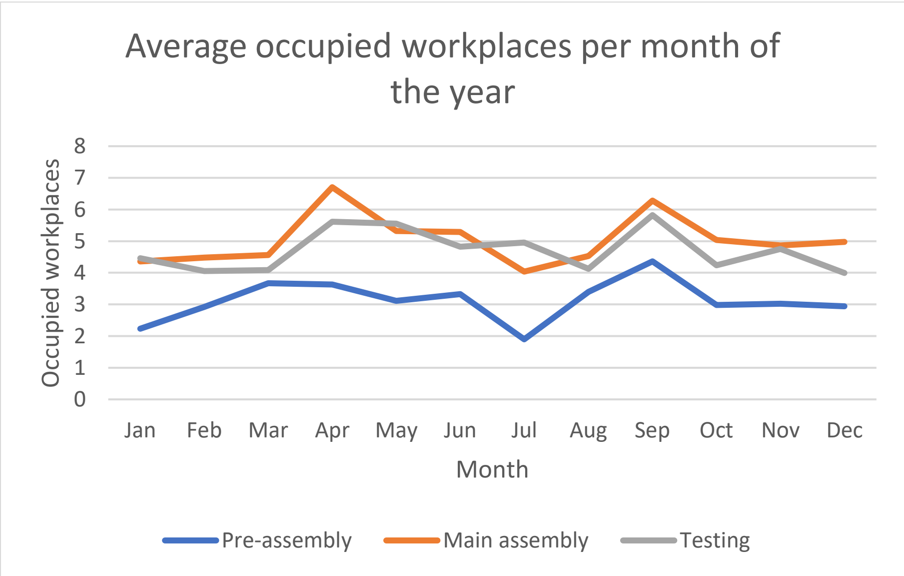

Figure 2.4: Average occupation per month of the year

2.2.3 Planning/Scheduling procedure Stand-alone

Niverplast gives a lead time of 20 to 25 weeks for a stand-alone machine to the customer, or to the Projects department. There is a buffer in this lead time, so the machines can be produced quicker. To determine the day when to start building a machine, they keep in mind this lead time and look in the planning to find a period when there is space. They use the ‘First come, first served” method, so stand-alone machines that are ordered first gets priority over stand-alone machines that are ordered later.

2.3 Projects department

At the Projects department, whole packaging lines are built. These packaging lines consist of different stand-alone machines with transporters between them.

2.3.1 Layout Projects

At the Projects department, there are no workplaces defined. The Projects department uses 7 out of 16 ‘’pie wedges’’. This can be seen in Figure 2.2, where the blue space is the space for the projects. The total surface of this workspace is 1783.3 m^2. When a new project is started, it will be placed somewhere on the workspace. Composing the packaging line and testing it for usage is done at the same place.

2.3.2 Occupation Projects space

We tried to make an overview or representation of the occupation of the space for projects in the past years. However, this turned out to be impossible. We know the surface from about 70 projects that they took on the work floor. From these projects, we calculated how many times the total surface of the project was bigger than the surface of the stand-alone machines that were in the project, from which we knew the surface. When this factor was stable, we could estimate the surface of the other projects, by multiplying the surface of the stand-alone machines with this factor. However, this factor had a lot of variation per project. This factor had a mean of 8 with a standard deviation of 7. Since there is so much variation in this factor, we will make big mistakes when using it. A project can have been multiple times bigger or smaller than the estimation with the factor.

We also looked at other factors, for example the factor between the number of items in a project and the surface they took on the work floor. The correlation coefficient between these two variables turned out to be 0.33. A correlation coefficient of 1 would mean that there is a perfect linear relation, a correlation of 0 means that there is no relation. A correlation coefficient of 0.33 tells us that the correlation between the variables is small and therefore we cannot make conclusions about the surface the project took on the work floor based on the number of items in the project. A reason for the variation can be that the whole project is not always built at Niverplast, but we do not know which parts are built at Niverplast and which not. A project that looks big based on the different components, can have been small on the work floor if only a small part is built.

Also the time the projects have been on the work floor was not known. Based on the planning of the previous year, we know the time for around 50 projects. The mean time they were on the work floor was 8 weeks, but it also had a standard deviation of 3 weeks. We tried to find a pattern between the number of weeks the projects were on the work floor and the number of items in the project, but the correlation of these two variables was 0.33 as well. Therefore, we could not estimate the time the projects took on the work floor based on their sizes. Since both the size and the time of the projects were unknown for us and we could not estimate it based on reliable information, we cannot make a clear overview of the occupation for the projects in the past years.

For the projects in 2019, we know from 63% of the projects the surface they took and the time they were on the work floor. For the other projects, we know either the time or the surface and we took the average time or surface over all known projects for the missing one. Table 2.1 shows a representation about how much space was occupied on the work floor on average per month in 2019. Within the occupied surfaces, we counted 2 meters around every project, that is needed to move with a forklift truck for example, and 50m^2 that is needed as workspace. In this workspace, there are workbenches that are used to build the modules, read the drawings etc. Further, there is space for storage of parts.

Month	Surface (m^2)	Percentage total surface
January	1244.6	70%
February	1943.4	109%
March	2046.1	115%
April	2051.2	115%
May	1630.0	91%
June	1993.0	112%
July	2122.1	119%
August	1120.4	63%
September	1296.8	73%
October	1046.4	59%
November	790.0	44%
December	797.4	45%

Table 2.1: Average occupation per month in 2019

We see in Table 2.1 that the busiest month in 2019 for the projects was July. In this month, 119% of the total space was necessary. In total, there are 5 months where the space that was needed was more than 100%. In these months, they used another storage hall for the project(s) that do not fit into the building. This storage hall is not available anymore.

Since the machines in the projects are first produced at the Stand-Alone department, we expected that the peak at the Projects department follows after the peak at Stand-Alone. In Section 2.2.2 we showed that the peak at stand-alone was around April/May and September. We see in Figure 2.5 that the projects department has a peak around June/July in 2019, so right after the peak at the stand-alone Department. However, we do not see a peak in October in 2019.

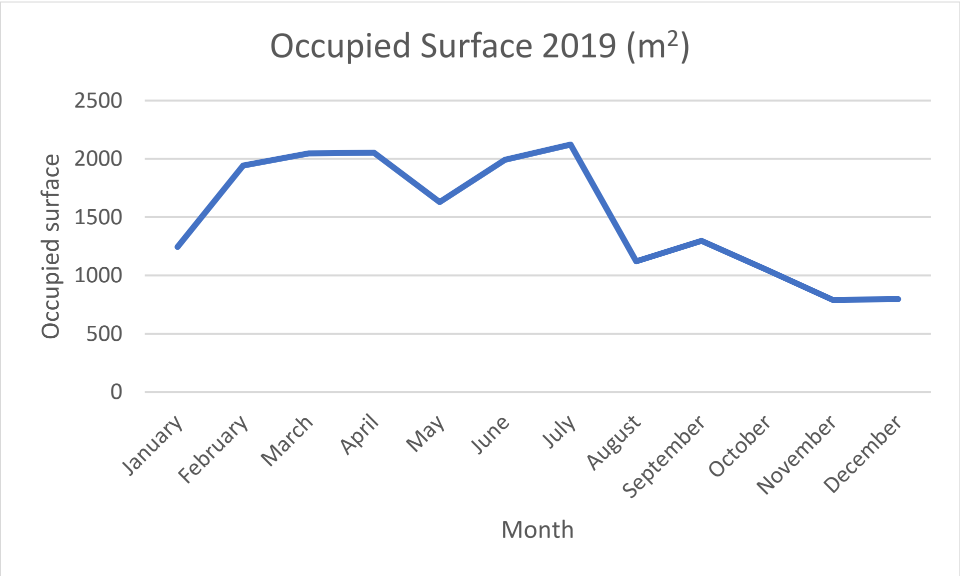

Figure 2.5: Average occupied surface per month of 2019

2.3.3 Planning/Scheduling procedure Projects

When an order is requested by a customer, a negotiation will take place about when the project can be delivered. Mostly, the customer demands a certain delivery time. Looking at the available capacity at that moment, it is evaluated if this delivery time is achievable. Since the projects also consists of stand-alone machines, it should be tuned with that department. The Stand-alone department gives a lead time of 20 to 25 weeks for their machines. Also at the Projects department they use the "First come first serve'' principle, but they keep in mind that a project can only be started after the first payment.

2.4 Measurement norm and reality

2.4.1 Norm and reality Stand-alone

In Chapter 1, we mentioned a norm and reality for the action problem. The norm was that there should be enough space for the continuing growth. We are going to look how much space there is (reality) and how much space is needed (norm) for the Stand-alone department.

We use an FTE (full-time equivalent) of 1840 hours (40 hours per week, 46 weeks) to calculate the available hours of pre-assembly, main assembly, and testing. We do this by multiplying the number of available workplaces with the FTE. On the basis of the throughput times, we calculate the hours that were needed in 2019. To know what the norm would be, we doubled these hours, since the expectation is that the production will double, as mentioned in Section 1.2. Table 2.2 shows an overview. Since not all workplaces for main assembly can be seen as the same, we split them in three types. Type 1 has a lift bridge and two of the three workplaces from type 1 have a crane. Type 2 only has a crane and type 3 does not have a crane or lift bridge.

Stage	**Available (hours)**	**Needed in 2019 (hours)**	**Needed in case of doubling (hours)**	**Workplaces needed**	**Current workplaces**
Pre-assembly	23920	[redacted]	[redacted]	11	13
Main assembly type 1	5520	[redacted]	[redacted]	5	3
Main assembly type 2	3680	[redacted]	[redacted]	3	2
Main assembly type 3	12880	[redacted]	[redacted]	7	7
Testing	18400	[redacted]	[redacted]	12	10

Table 2.2: Available and needed hours per stage of producing stand-alone machines.

Now, we know the hours that are needed for pre-assembly, main assembly, and testing. We calculate this back to the number of workplaces that are needed, since that is more convenient to work with. We divide the hours that are needed by the FTE and round them up, see the fifth column of Table 2.2.

This outcome are the average workplaces that are needed. However, the demand is not equally spread over the year. In quiet times, not all workplaces will be occupied. Therefore, in the busy periods there can be capacity problems to reach the lead times. Out of the representation we made in Section 2.2.2 for the occupation, we made an overview of the percentage of the capacity that is needed per month. This is based on the average between 2014 till 2019. A percentage of 100% means that the average number of workplaces are needed, for example 13 workplaces for pre-assembly. We assume that these percentages will stay the same, so the peaks will not reduce when the production doubles. Next to this percentage, we show what that would mean for the number of workplaces needed per month. Table 2.3 shows this overview.

	Pre-assembly		**Main assembly 1**		**Main assembly 2**		**Main assembly 3**		**Testing**	
	Percentage	Workplaces	Percentage	Workplaces	Percentage	Workplaces	Percentage	Workplaces	Percentage	Workplaces
Jan	67%	7	80%	4	96%	3	80%	6	104%	13
Feb	76%	8	93%	5	51%	2	76%	5	70%	8
Mar	101%	11	96%	5	89%	3	75%	5	83%	10
Apr	108%	12	110%	6	152%	5	123%	9	110%	13
May	104%	11	122%	6	98%	3	107%	8	124%	15
Jun	105%	12	114%	6	104%	3	93%	7	104%	12
Jul	66%	7	71%	4	83%	2	103%	7	109%	13
Aug	119%	13	104%	5	85%	3	86%	6	90%	11
Sept	145%	16	127%	6	90%	3	158%	11	125%	15
Oct	104%	11	99%	5	116%	3	100%	7	93%	11
Nov	102%	11	92%	5	122%	4	85%	6	101%	12
Dec	103%	11	92%	5	113%	3	113%	8	88%	11

Table 2.3: Workplaces needed per month

Table 2.3 shows that in the peak month, 16 workplaces for pre-assembly are necessary, 6 for main assembly type 1, 3 for main assembly type 2, 11 for main assembly type 3 and 15 for testing.

2.4.2 Norm and reality Projects

For the Projects department, the norm is that there is currently 1783.3 m^2 available. As explained in Section 2.3.2 we could not make a clear overview of the space that is used in the past for the projects. We only have an overview of 2019, which contains estimations. In the peak month, 2122.1 m^2 was necessary, which is 119% of the total space. When the production doubles, around 4244.2 m^2 is needed in the peak month.

2.5 Conclusion context analysis

We now have a better overview over the current situation at Niverplast. We know for both departments what the current production layout looks like and what the planning/scheduling procedure is. Further, we have an overview about the occupation in the past. For the Stand-Alone department, this overview is better and more reliable than for the Projects department, since we had more information about the Stand-Alone department. With the information required in this chapter, we could find our norm and reality.

3 Literature review

This chapter describes the different theories that we used in this research. We made the theoretical framework by answering the following question: Which theories for the design of a production process layout are there in literature? Section 3.1 describes what the design of a process includes and how it can be measured. Section 3.2 shows different types of layout that are commonly used in literature. Section 3.3 explains the theory of the P-Q analysis, Section 3.4 the theory of Systematic Layout Planning and Section 3.5 the theory of Lean. Lastly, Section 3.7 depicts the conceptual framework.

3.1 The design of a process

According to Slack et al. (2016), the design of a process includes identifying all the individual activities that are needed to complete the process, deciding on the sequence in which these activities should be done and who is going to do them. We explain some constructs that Slack et al. (2016) give on which a process design can be measured.

Three constructs on which a process design can be measured are the throughput time, cycle time and work-in progress. The elapsed time between the moment that an item enters the process and leaves it, is the throughput time. The cycle time is the average time between the processing of different items. Work-in progress is the number of items that are being processed at the same time. The relationship between them can be described with Little's law:

$Throughput\ time = Work\text{–}in\ progress\ x\ Cycle\ time.$

Two other aspects on which a process can be judged are the throughput efficiency and value-added throughput efficiency. Mostly, a significant amount of time, no useful work is being done in the process. The percentage of the time that the item is really being processed is called the throughput efficiency. However, sometimes not all the time that is worked on an item is giving value to the item. Therefore, value-added throughput efficiency restricts the concept of work only to those tasks that are adding value.

3.2 Types of layout

There are four basic layout types that are mostly used in literature: fixed-position layout, functional layout, cell layout and line layout (Slack et al., 2016) (Muther & Hales, 2015). Figure 3.1 depicts the different types of layout.

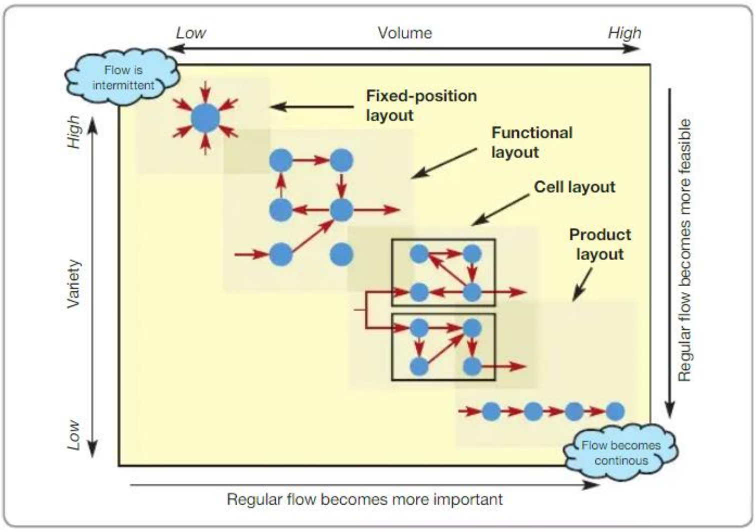

Figure 3.1: Different types of layouts (derived from Slack et al. (2016))

Qin and Huang (2010) describe the fixed-position layout as a layout where the tools, materials and workers are moved to an assembly site (often called an assembly island) while the product remains in one location. This is useful when products are too large, heavy, or fragile to move. Some advantages are that it can handle very high mix and product flexibility and the variety of tasks is high for staff. A disadvantage is that the unit costs are very high, and the scheduling of space and activities can be difficult. Huang et al. (2007) describe another disadvantage of the fixed position layout. The volume and variety of materials needed during the assembly job have a lot of variation, therefore different items become critical. Movements of people and equipment to and from the workplace can be expensive.

Slack et al. (2016) describe the functional layout as a layout where similar resources or processes are placed together. The products take a route from activity to activity through the operation, according to their needs. Different products have different needs and can therefore take different routes. This layout can also handle a high mix and product flexibility and it is relatively robust in the case of disruptions. However, the facility utilization is low, and it can have very high work-in progress. The detailed design of a functional layout is complex. Benjaafar (2000) says that when product variety is high and/or production volumes are small, a functional layout offers the greatest flexibility. However, the material handling is inefficient and making a schedule can be complex. Therefore, it often results in long lead times, poor resource utilizations and limited throughput rates.

According to Slack et al. (2016), the cell layout brings order to the complexity of flow that characterized the functional layout. The item that is been processed moves to one cell where all the transforming resources are located that are needed. After being processed in the cell, the item can go on to another cell. This layout is a good compromise between costs and flexibility, it also has a fast throughput. However, it can require more equipment and give a lower equipment utilization. Benjaafar (2000) writes that a cell layout can be very inflexible, because they are often designed with a fixed set of part families in mind whose demand levels should be stable. Once a cell is formed, it is often dedicated to a single part family. This may be convenient when part families are clearly identifiable and demand volumes are stable. However, when there are significant fluctuations in the demand of existing products or with the frequent introduction of new products, they become inefficient. Junior (2019) describes a special kind of the cell layout: the virtual cell layout. Virtual cells operate virtually as cells from a logical point of view. Just like the traditional cell layout, resources are dedicated to manufacture a family of parts. When this manufacturing is done, the virtual cell formation is undone, such that each individual resource can re-group with other resources to a new cell. According to Junior (2019) a virtual cell layout has better performance than the traditional one. This layout out showed better processing times, reduced throughput, and resource utilizations. Also, the transition costs to a virtual cell layout turned out to be lower than to a traditional cell layout.

Slack et al. (2016) says that in the line layout, each product follows a standard route where the activities that are needed are in the right order. This gives low units costs and opportunities to specialize the equipment. However, it can handle only a low mix flexibility and it is not robust if there is disruption.

The layout that should be chosen for an operation depends on the volume and variety characteristics. For products with low volume and high variety, a fixed-position layout is likely to be appropriate. For products that have a higher volume and lower variety, a line layout is more likely to be appropriate. This can also be seen in Figure 3.1.

Benjaafar (2000) did research towards the design of plant layouts in environments where the product mix and product demand are subject to variability and where duplicates of the same department type may exist in the same facility. They show that having duplicates of the same departments, which can be strategically located in different areas of the plant floor, can reduce material handling costs. However, this costs reduction is the most with relatively few duplicates. The distribution of similar departments over the plant increases the accessibility of those departments from different directions of the layout.

3.3 P-Q analysis

In Section 3.2 we described that the layout that should be chosen for an operation depends on the volume and variety characteristics. Muther & Hales (2015) give an approach for a Volume-Variety Analysis to know what kind of layout is appropriate. The key data for this analysis are the product (what is to be produced) and the quantity (how much of each item is to be produced). Therefore the analysis is also called Product-Quantity analysis (or P-Q analysis). The first step in the P-Q analysis is to make a division or grouping of the different products. The second step is to count the quantity of each division or grouping, or of each product or variety within each division of grouping. Then the results are plotted in a graph (the P-Q chart). The product with the highest quantity is placed first, then the next highest and so on. Figure 3.2 depicts an example of a P-Q chart. The P-Q chart has a relationship to the layout that should be used. At one end of the curve are large quantities of relatively few different products. These products are best produced by mass production methods, such as the line layout. On the other end there are many different products, each with small quantities. These products favor a functional or fixed position layout. When the P-Q curve is ‘deep’ dividing the products and producing them in two different types of layout seems a good idea, since then efficiency is obtained for both product groups. When the P-Q curve is ‘shallow’ on the other hand, one general layout for all items is better. Most of the production is in the center of the curve in this case.

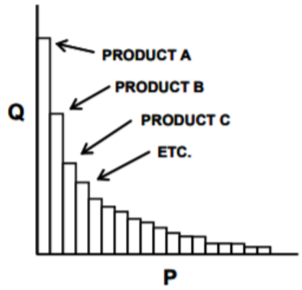

Figure 3.2: Example P-Q chart (derived from Muther & Hales (2015))

3.4 Systematic Layout Planning

Muther & Hales (2015) describe an organized way to conduct layout planning. They give a framework of phases, a pattern of procedures and a set of conventions for identifying, rating, and visualizing the elements and areas involved in planning a layout.

They give the following four phases of layout planning:

1. Location: Determine the location of the area to be laid out.
2. General Overall Layout: Establish the general arrangement of the area, for which a layout must be made.
3. Detailed Layout Plans: Locate each specific piece of machinery and equipment.
4. Installation: Plan the installation, make sure the plan is approved and make the necessary moves.

Further, they describe three fundamentals where each layout rest on: relationships, space, and adjustment. With relationships they mean the degree of closeness desired or required among things. For space, the amount and shape or configuration of the things that have to be laid out is needed. And adjustment is the arrangement of things into a best fit.

We focus on phase two of the layout planning: General Overall Layout. Muther & Hales (2015) describe a five step approach for this phase: The Systematic Layout Planning Pattern of Procedures. We explain these five steps below.

The first step is to analyze the inputs and the possible types of layout. The output of this step is a list of Activity-Areas, like departments, cells, workgroups, exits and physical features.

The second step is to establish and visualize the relationships that are important while designing the layout. The flow of materials is often an important part, to get a nice flow through the area, with as little as possible material handling effort and cost. Also the supporting areas, such as storage, must be integrated and planned. These two investigations should be combined into a flow and/or activity relationship diagram. In this diagram, the activities, departments, or areas are geographically related to each other. The actual space each requires does not have to be taken in account here.

In step three, the space required for each activity-area must become clear. These requirements must be balanced against the available space. This should lead to a space relationship diagram; this can be derived from the relationship diagram from the previous phase with the area allowed for each activity included.

In the fourth step, the layout must be adjusted and manipulated on behalf of every consideration, that can modify the layout. Modifications can be made for operating practices, storage, scheduling etc. Thereafter, the ideas must face the practical limitations such as costs, employee preference and safety. After abandoning the plans that do not seem worthy or have other practical limitations, there should be a list of alternative layouts.

In the last step, a cost analysis should be made for purposes of comparison. The alternative layouts should be evaluated on different factors. In the end, one of the alternatives must be chosen. It could also be the case that a combination of two or more layout is chosen. This will result in the layout plan.

Zakirah (2018) used the Systematic Layout Planning (SLP) method in her research and she concluded that it is a suitable method for designing an efficient layout, because it considers relationship value and material workflow precisely. Buchari (2018) has as result when using the SLP method that the previously irregular flow pattern was changed into a better flow pattern and the length of the production line decreased with 37.2%. Maina C. et al. (2018) conclude that in their case study SLP is a good procedure in solving a layout design and improvement problem. However, they say that any misrepresentation of facts at any stage in the procedure will result in inefficient decision making. Therefore, the analysis of the existing layout design should be carried out by competent facility designers. Further, it is important to capture accurate input data to get reliable results.

3.5 Eliminating waste: Lean

To improve the production process layout, the theory of Lean can be used. Wilson (2010) describes the philosophy of Lean as *''a long-term philosophy of growth by generating value for the customer, society and the economy with the objectives of reducing costs, improving delivery times, and improving quality through the total elimination of waste.''* The most significant part of Lean is the focus on eliminating waste. Waste can be seen as any activity that does not add value.

Skhmot (2017) divides the waste in 8 types. The first waste is waste in transportation, this includes movements of people, tools, equipment, inventory, or products further than necessary. The second type of waste is inventory. Having more inventory than necessary can lead to problems such as product defects, greater lead time in the production process or an inefficient allocation of capital.

The next waste is motion. This includes any unnecessary movement of people, equipment, or machinery. The other wastes are waiting, overproduction, over processing, defects, and skills. With over processing doing more work, adding more components, or having more steps in a product than what is required by the customer is meant. With skills, the waste of human potential is meant. This can include insufficient training or placing employees in positions below their skills and qualifications.

Slack et al. (2016) give various ways to eliminate waste. A layout change that bring processes closer together, improvements in transport methods and workplace organizations can eliminate waste. A smooth flow of an operation is an important aspect of Lean. With long process routes, there is a higher chance of delay and inventory build-up. Therefore, it might be a good idea to reconsider the basic layout of the process. In Section 3.3 we described different types of layouts. Figure 5 depicts these different types of layouts. Mostly, to get a more streamlined flow, a process should move one process design down the diagonal line as depicted in Figure 5. So, for example from functional layout to cell-based layout. It is necessary to have a layout that brings more systematization and control to the process flow.

Also the increase of flexibility of the process can eliminate waste. Increasing flexibility means for many processes reducing the time taken to change over the process from one activity to another. This could be done by separating the external and internal activities. External activities can be carried out while the process is continuing, internal activities not. By separating them, the intention is to do as much as possible while the process is continuing. Another way is to convert internal to external activities. This could be done by preparing activities or equipment instead of doing it during changeover periods.

Bertolini (2017) indicates that adopting Lean in Make-To-Order (MTO) job shop is very difficult. Make-To-Order job shops produce products with high-variety and low-volume. They only start producing a product when it is ordered. An alternative is using hybrid Production Planning and Control systems, such as Workload Control (WLC) or Constant Work in Process (CONWIP). These systems should make it possible to achieve the benefits from Lean in MTO companies. The idea is the same for both systems. The aim of the systems is to keep the work-in progress (WIP) at a predefined level, to optimize the trade-off between high-throughput rates and short and stable lead times. To achieve this, jobs should only be started if they do not exceed some pre-defined limits, known as 'workload norms'. This should keep queues length in front of each working stage as short as possible, without reducing the throughput rates.

3.6 Conceptual framework

Out of the literature that was found and evaluated in the previous parts of this section, we made a conceptual framework.

Key construct	Definition
Throughput time	The elapsed time between the moment that an item enters the process and leaves it.
Cycle time	The average time between the processing of different items.
Work-in progress	The number of items that are being processed at the same time.
Value-added throughput efficiency	The percentage of the time the item is really being processed, with tasks that literally add value.
Fixed-position layout	Layout where the items that have to be transformed, do not move between the transforming resources.
Functional layout	Layout where similar resources or processes are placed together. The products flow takes a route from activity to activity through the operation, according to their needs.
Cell layout	Layout where the item that is been processed moves to one cell where all the transforming resources are located that are needed. After being processed in the cell, the item can go on to another cell.
Virtual cell layout	Layout where each individual resource can group with order resources to form a cell, this formation will be undone after the manufacturing.
Line layout	Layout where Each product follows a standard route where the activities that are needed are in the right order.
Lean	Lean is a philosophy and a method of operations planning and control, and an approach to improvements. The aim of Lean is to meet demand, with perfect quality, no waste and at low costs.
P-Q analysis	An analysis based on Products and Quantities to get more insight in which production layout is appropriate
Workload control (WLC)	The goal of WLC is to maintain a balance between production flexibility and lead time's variability.
Systematic Layout Planning	An organized way to conduct layout planning, consisting of a framework of phases, a pattern of procedures and a set of conventions for identifying, rating, and visualizing the elements and areas involved in planning a layout.

Table 3.1: Conceptual framework

4 Solution design

This chapter describes the different solutions that could create more capacity in the current building of Niverplast. Section 4.1 looks at an improvement in the current layout, based on the theory. Section 4.2 describes the brainstorm session that we held. Sections 4.4, 4.5, 4.6 and 4.7 explain each a different solution. Lastly, Section 4.8 gives conclusions based on this chapter.

4.1 Improvement layout

First, we look at the current layout of both departments and compare them with the layouts types we found in literature. Further, in Section 3.5 we describe the philosophy of Lean; the most significant part of Lean is the focus of eliminating waste. Slack et al. (2016) give various ways to eliminate waste. The one that we will look into in this section is the point that a layout change that bring processes closer together and can eliminate waste.

4.1.1 Projects

In Section 3.3 we described 4 types of commonly used layouts. The layout of the Projects department can be seen as a fixed-point position. The projects stay at the same place, while the people and equipment needed move around them.

According to Slack et al. (2016) the way to get a more streamlined flow, is to move one process design down the diagonal line as depicted in Figure 3.1. This would mean that Projects should change from a fixed-position layout to a functional layout. We evaluate the possibility to change to functional layout below.

If the layout for Projects changes to a functional layout this would mean that there should come different stages, where the projects go from activity to activity according to their needs. Therefore, we need an overview of the activities that are done for building projects. Figure 4.1 depicts the process flow of building projects. We explain it below.

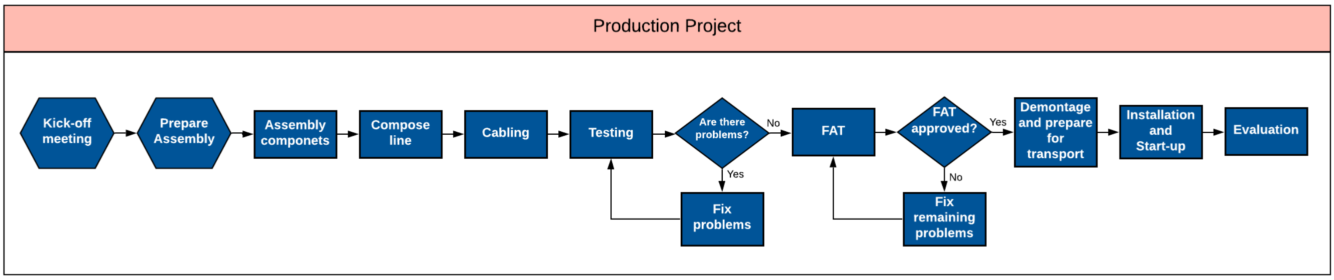

Figure 4.1: Production process flow projects

The production of a projects starts with the Kick-off meeting. In this meeting, the project is explained and discussed. Then, the assembly of the project will be prepared. During the preparation, the mechanical ideas about the project are evaluated, the cable routing and length of the cables are determined, the different parts are collected, etc. After that, the modules that are not made at the stand-alone department and those that are not purchased as a whole, have to be assembled. When all parts are complete, the project line can be composed. When the line is composed, the modules and machines are connected with cables to a main control module. After that, the line is tested. It is tested if every movement of the machines works. The production line will be tested with the products and maximum capacity of the customer. When a problem is encountered during the testing, this will be fixed. After the testing, the FAT (Fabrication Acceptance Test) takes places. If there are remaining problems that came forward during the FAT, they will be fixed. If there are no problems, the project will be disassembled and prepared for transport. Then the projected will be installed at the customer and the project will be evaluated.

From the assembly of the modules, all activities are done at the same place. Since most projects are big, it would be inconvenient to move the projects. Therefore, from the point that the project line is composed, it will be impossible to change to a functional layout and the current fixed-position layout is the best option. However, the assembly of the modules could be done at a different stage. In this case, as soon as the project is ordered and designed, the modules that are needed are assembled at a different stage. So, the pre-assembly becomes a different stage and is executed at another location than the main assembly and testing. When doing this, the production layout will move a bit more to a functional layout. We explain this option further in Section 4.7.

4.1.2 Stand-alone

The layout of the Stand-Alone department can be seen as a cell layout. Every machine follows a prearranged route of activities, from pre-assembly to main assembly to testing. At every stage, still a lot of different activities have to be done. Therefore, every stage can be seen as a cell. The machines are produced at a cell where all resources are according to the needs of the machine. Some machines need a crane or a lift bridge to be produced for example. So, at every cell a family of stand-alone machines are produced.

At the moment, the layout is the same for all stand-alone machines. Muther & Hales (2015) showed that it might be a good idea to make a distinction between layouts for different products. Therefore we made a P-Q chart as described in Section 3.4. Figure 4.2 depicts this P-Q chart.

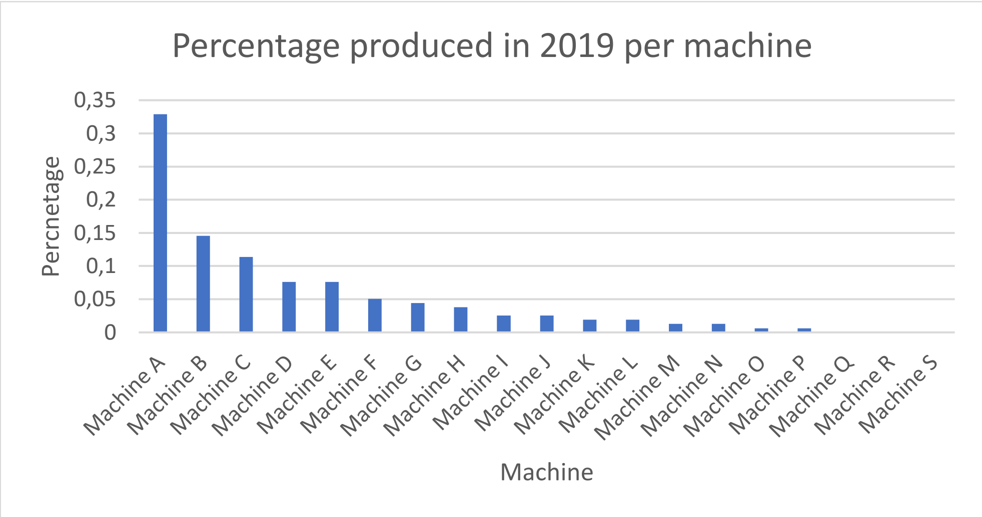

Figure 4.2: P-Q chart stand-alone machines

We can see that P-Q curve is relatively 'deep'. In 2019, machine A accounts for 33% of the sold machines. Overall from 2014 till 2019 this is 44%. According to the theory of Muther & Hales (2015) it would be a good idea to use another layout for the production of Machine A. A layout that is more streamlined, so one that goes more towards a line layout could be better to produce Machine A.

After we discussed the possibility of a more streamlined layout for Machine A, we saw that this is not a good idea. Although the percentage of Machine A is high, the production number is too low that a production layout that goes towards a line layout would work. The total hours that were needed in 2019 to build all machines of type A, based on the throughput times is [redacted]. With an FTE of 18400 hours, we see that there is not always a machine of type A on the work floor.

Further, there are some problems why a line layout would cause problems. Slack at al. (2016) tells us that a line layout can handle only a low mix flexibility and it is not robust if there is disruption. There is no control over the supply of parts for machine A, whereby it is difficult to say how long it takes to produce a certain part of machine A. If the supply of some parts delays, this can cause congestion in the production line. Further, the 2D, 3D and electrical drawings contain often mistakes, which causes delays in the production, which can also cause congestion when the machines are produced in a line layout. Lastly, the production of Machine A has a lot of variation in the production, which is not suitable for a line layout.

When the production number of machine A increases, such that there are always for example at least 3 machines of this type on the work floor, it can be worth it to reconsider the option to use a line layout for this machine. However, the above mentioned problems have to be fixed before it would work.

We conclude that the current cell layout for the Stand-Alone department seems to be the best layout and there is no need to change it.

4.2 Brainstorm session

To come up good solutions for increasing the capacity in the current building of Niverplast, we held a brainstorm session. Multiple stakeholders of the problem where present during the brainstorm session: Two process engineers, one project engineer, one stand-alone engineer and one logistic planner. We first asked them to come up with ideas, which we wrote on a yellow post-it. Then we asked them to put the advantages on green post-its, the disadvantages on red post-its and ideas to realize the solution on blue post-its. Appendix C shows the outcome of this post-it wall, that is made digital. Below, we give a short description of the solutions that came forward.

1. Use entresol for production

The first solution that came forward, is the solution that was already mentioned at the beginning of the assignment: use the entresol for production.

2. Use the outer ring for production of small projects

The outer ring of the work floor is now used for storage, the idea came forward to use this space for the production of small projects.

3. Remove the demo line from the work floor

There is a huge demo line placed on the work floor, which is used to show the machines and everything that Niverplast can realize to potential customers. This demo line takes two pie wedges on the work floor.

4. Cluster project tasks

Another idea was to cluster the tasks of building projects. Currently, a fixed-position layout is used at the projects department. With this idea, this would go more towards a cell or functional layout.

5. Remove stock from work floor

On the work floor, some storage racks are placed. If they are removed from the work floor, space will be saved on the work floor.

5. Flexible space between projects and stand-alone

A solution for the capacity problem can be to introduce flexible space, which can be used for Stand-alone when this department is at his peak times. Thereafter, when the Stand-alone department does not need the extra workplaces anymore, the space can be used for the Projects.

6. Do not build whole project lines on the work floor

Currently, the production lines that are sold to customers are built at Niverplast, to test them and to save time for the installation at the customer. When the projects are not built first at Niverplast, or not as a whole, space will be saved.

7. Shorten the throughput time

When the throughput time of building projects is shorter, the projects will take less time on the work floor. Then, more projects can be built at the same space, in the same time.

To decide which solutions are worth to research further, we made a weighted decision matrix that those present at the brainstorm filled in. We made the choice for a weighted decision matrix, because not all criteria are equally important. We first defined different criteria. Then these criteria are weighted and a score for each solution is given to each criterium. Thereafter, the weighted score per solution is calculated.

First, we explain the different criteria. The first is budget/investment: 'How big will the investment in terms of money be to realize the solution?'. The second criterium is the feasibility: 'How much effort will it take to realize the solution?'. The third criterium is the applicability for the products: 'Is the solution convenient for the kind of products Niverplast makes?'. The fourth criterium is the working convenience: 'How will the solution influence the working convenience of the employees?'. The fifth criterium is the amount of space savings: "How much space will the solution save?". The last criterium is logistics: 'How will the solution influence the logistics of the production process?'.

Heerkens and van Winden (2017) describe three ways to weight the criteria: Awarding marks to different criteria, distributing a number of points between criteria and using pairwise comparison valuation. We chose the first option: Awarding marks to different criteria. We asked them to give a mark between 1 and 6 to the different criteria, where one point means that the criterium is less important and six points means that criterium is very important.

To assign scores to criteria, we used the method Heerkens and van Winden (2017) describe: Awarding points on a scale of 1 to 5 to each of the different criteria. A value of 1 is the worst possible score and a value of 5 the best possible one.

Appendix D shows the outcome of the weighted decision matrix, where we add up the different scores. Table 4.1 depicts the final score, sorted from best to worst.

Solution	**Score**	**Description**
Solution 5	20.8	Flexible space between projects and stand-alone
Solution 3	19.5	Remove demo line
Solution 7	19.4	Shorter throughput time
Solution 8	18.4	Cluster project tasks
Solution 2	18.3	Use outer ring for production
Solution 4	17.7	Remove stock from work floor
Solution 6	14.1	Do not build whole projects on work floor
Solution 1	11.4	Use entresol for production

Table 4.1: Outcome weighted decision matrix

The first remarkable point is that the usage of the entresol for production, has the worst score. At the beginning of this assignment the question was asked if the entresol can be used for production. The reason why it has a low score is that the logistics will be more difficult, since using a lift is necessary and the supply of parts will be more difficult. Further, it can be hot on the entresol in the summer. Therefore, the working convenience is lower. Further, there is currently one lift to the entresol in the building. There is a possibility to make another lift, but therefore the investment for this solution is also high. However, the score for the criteria about the amount of space savings is not that low. We want to show how much space can be saved by working on the entresol, such that a better consideration can be made if this outweighs the disadvantages. Therefore, we do not exclude it directly for further research. The three other worst solutions will be excluded for further research since we do not have the time to do research on all solutions. However, these solutions can be kept in mind for further research. The solutions that remain are worked out in the remaining of this chapter. In this chapter, we only explain the idea behind the solution and give in some cases some suggestions on how the solution should be realized. In Chapter 5, we evaluate the solutions, make trade-offs and a final choice.

4.3 Producing on the entresol

The first solution that we describe is the usage of the entresol for production. An entresol is an open second floor, above part of the ground floor. This idea came forward during a discussion about the capacity of the current building of Niverplast. The entresol will not be suitable for the Projects department, since the projects are too big and the space on the entresol is limited. We look into the possibility of producing stand-alone machines on the entresol. If a part of the production of stand-alone machines can be done at the entresol, space can be saved at the work floor. Then, the Projects department will also have more space. We look at two different options of producing on the entresol.

The first option is to produce whole machines at the entresol. Then there will be workplaces for pre-assembly, main assembly and testing on the entresol. A whole machine can be produced on the entresol and when it is ready, it will go downwards with a lift and can then be transported to a customer. The other option is to only make workplaces for pre-assembly at the entresol. In this case, the pre-assembly will be done at the entresol. The different modules will be transported downwards, where the main assembly and testing will be done. With this option, no big machines have to be transported downwards.

For these options, we show how much space is needed on the entresol if, for option 1, the whole product family is produced on the entresol and for option 2, all pre-assembly is done on the entresol and if this fit.

4.3.1 Produce whole machines on entresol

Not all machines are suitable to produce on the entresol. Only the machines that are produced at a main assembly workplace of type 3 (no crane) are suitable to be produced on the entresol. Next to that, also some machines are not suitable to be produced on the entresol since they are too high or difficult to move. After evaluating the possibilities, we conclude that machine K, machine P, machine G, machine D, machine Q and machine J are suitable to be produced on the entresol.

Based on the throughput times of these machines and the number of sold machines in 2019, we calculated how much workplaces are needed to produce these machines in case of doubling, on average and in the peak month. Appendix E shows the calculation. The result is that on average 3 pre- and main assembly workplaces are needed and 2 testing workplaces. In the peak month one more workplace of every stage is needed. The entresol can also be divided in 16 “pie wedges”; about 7 of these pie wedges can be cleared for production. We show how much workplaces of each kind can be created on one pie wedge of the entresol.

One pie wedge at the entresol has a surface of 691.2 m^2. The width on the outside of the circle is approximately 19.4 meter. On the inside the width is 15.6 meters. The length of the entresol is 9.8 meters. We estimate how much workplaces can be created on one pie wedge per stage, on behalf of the space that the workplaces take in the current layout on the work floor.

Pre-assembly: In the current layout, the total occupied space for the pre-assembly workspace for the machines that are suitable to be produced on the entresol, has a width of 7.3 meter and length of 9.2 meter. This workspace contains two workplaces. Therefore, 4 workplaces for pre-assembly can be created on one pie wedge on the entresol.

Main assembly: One main assembly workplace, including space for pallets and walk/workspace has a width of approximately 6 meter and length of 9.5 meter. Therefore, 2 main assembly workplaces can be created on one pie wedge.

Testing: For testing, the whole machine has to fit on the workplace, including some space for walking. The average width of the machines that are suitable to produce on the entresol is 1.7 meters. The average length of the machines is 2.8 meters. Since also space is needed to walk and work, and to transport the machines towards the lift, only one testing workplace can be realized in the length. We count 1 meter of work and walk space between the machines in width. In that case 4 testing workplaces could be created on one pie wedge.

To create all the necessary workplaces, in case of doubling and in the peak month, for these machines, we need four pie wedges on the entresol. Figure 4.3 depicts a proposal for which pie wedge to use for which stage. Lift 1 already exists; at the place where lift 2 is drawn, there is a possibility to build a lift. Lift 2 can be used to transport the components upwards and lift 1 can be used to transport the whole machines downwards after they are tested.

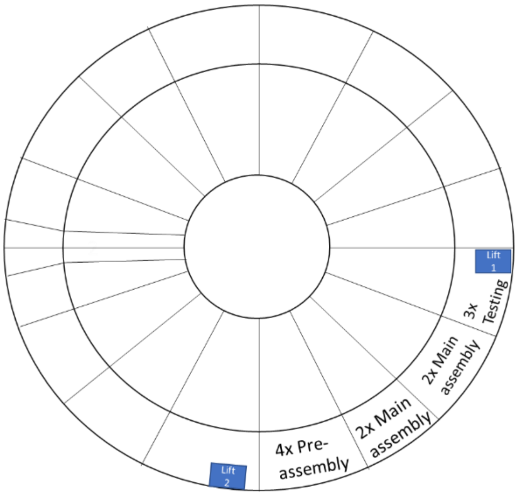

Figure 4.3: Production on entresol

4.3.2 Pre-assembly on the entresol

The other option is to only make workplaces for pre-assembly at the entresol. On average, 11 workplaces are needed for pre-assembly as showed in Section 2.4.1. In the peak month, 16 workplaces are needed.

To create the workplaces that are currently on the work floor on the entresol, 4 pie wedges are needed. So in that case, 13 workplaces will fit and on average there are enough workplaces. With one more pie wedge, there will also be enough space for workplaces in the peak month.

4.4 Flexible space

As shown in Chapter 2, the demand for stand-alone machines is not evenly spread over the year. As a result, the number of workplaces needed throughout the year is not constant. On basis of the previous years, we showed, for example, that 7 workplaces are needed for pre-assembly in July, while 16 workplaces are needed in September. Unfortunately, we could not make such a clear overview for projects as we did for stand-alone, as explained in Chapter 2. However, since a lot of stand-alone machines are built for projects, we can assume that the peak for project comes after the peak for stand-alone machines. Therefore, a solution for the capacity problem might be to introduce flexible space, that can be used for stand-alone when this department is at its peak times. Thereafter, the Stand-alone department will not use the extra workplaces anymore and the space can be used for the projects.

To implement the use of flexible space, at the beginning of each (peak) month a prognosis should be made about how much space each department needs, based on the machines and projects that are planned to be build. Then a division of the work floor can be made and the departments know how much space there is available. Based on the previous years, we expect that in April and May Stand-alone needs more space; in June and July the Projects need more space. Then in September, Stand-alone needs again some more space. In the other months, we expect that a standard division of the work floor satisfies.

When there is no flexible space, both departments should have the space that is needed in the peak months throughout the whole year. Then, this space will be unused most of the times and the capacity limit will be reached sooner. In Chapter 5, we test the solutions and show how much sooner the capacity limit is reached without the use of flexible space.

4.5 Removing the demo line

Currently, there is a huge demo line placed on the work floor, which is used to show the machines and everything that Niverplast can realize to potential customers. This demo line takes 2 out of 16 pie wedges of the work floor. Therefore, it is obvious that a lot of space is saved when this demo line is removed. The only problem with this space is that part of it is beneath the walking bridge, so the height is limited there. This walking bridge has a width of 3.1m. This space could be used for pre-assembly or storage racks.

4.6 Shorten the throughput time

To shorten the throughput time is also a solution that was mentioned during the brainstorm session. When the projects are for a shorter time period on the work floor, more projects can be built in the same time on the same space. How the throughput time can be shortened is a complex question, for which extensive research is needed. We do not have time to include that in this research. One point that was mentioned is that there is a lot of safety time included in the planning, for the case that there are problems. Therefore, the projects are longer on the work floor than necessary. When the safety time is shortened, the throughput time will be shorter. A disadvantage is that there is a higher chance that the projects are not ready on time when there are problems. Also the work pressure is higher with a shorter throughput time.

We cannot do research on how to shorten the throughput time, but in Chapter 5 we show what the impact of the throughput time is on the capacity.

4.7 Cluster project tasks

To increase the flexibility and shorten the throughput time, a solution can be to cluster the tasks at the Projects departments. As explained in Section 4.1.2, the main task that can be done separately, is the pre-assembly of the different modules in the projects, that are not made at the Stand-alone department and those that are not purchased as a whole.

When this is done separately, the other preparations can continue in the meanwhile. The assembly of the modules does not yet take place on the work floor space for building projects, but on a separate space. This space will be close to the storage.

Also, since the building of the modules is then grouped together, the modules can be constructed quicker and therefore time can be saved. Time will also be saved by the fact that the movements that the employees make to construct the modules will be shorter. Skhmot (2017) mentions that waste of movements is a type of waste in the context of Lean, so it might be a good idea to eliminate this waste. Currently the employees have to walk to the storage to get their materials and resources from the place where their project is placed. When the pre-assembly is combined, this can be placed next to the storage and all the resources will be available. Next to that, there will be a better overview at the Projects department when the modules are constructed at a different stage.

Further, Slack et al. (2016) mention that waste can be eliminated by increasing the flexibility. This can be done by turning internal activities into external activities. By separating the pre-assembly, this activity is turned from an internal to an external activity. Therefore, the flexibility will increase and it should lead to more capacity.

4.8 Conclusion solution design

In Section 4.1 we looked at the current production layout and tried to find an improvement of this layout with the theory. We concluded that the current fixed-position layout for the Projects department is difficult to change, since the projects are too big and heavy to move. However, before the project is composed, the assembly of parts can be done at a different stage for more flexibility. The current cell layout for the Stand-alone department seems the most appropriate one. If the production number of the CombiPlast increases, it can be worthful to investigate the possibility of a line layout for this machine. In the remaining of the chapter, we defined different solutions for the capacity problem, which we are going to evaluate in Chapter 5.

5 Solution tests

This chapter evaluates the solutions we defined in the Chapter 4 on basis of two terms: feasibility and impact. We evaluate the impact with an Excel tool, which we explain in Section 5.1. Section 5.2 shows the outcome of the tool. Section 5.3 discusses the feasibility of the solutions. Section 5.4 explains the choice for the final solutions. Section 5.5 shows the outcome of the tool if the chosen solutions are combined.

5.1 Excel tool

This section explains the Excel tool that we made using Visual Basic for Applications (VBA), which is a programming language that is used to automate or expand the functions of Excel. With this tool, we show what the impact of the solutions is on the capacity of the building.

5.1.1 Assumptions

In the tool we made some assumptions that were necessary to make, due to time limitation or lack of knowledge. The list below contains all assumptions that we made.

Division over the months stays the same

We assume that the division over the months stays the same. With the division over the months we mean the percentage of the machines and projects that are built per month. For the Stand-alone department, the division is based on the average between 2014 and 2019. For the Projects department, this is unfortunately only based on 2019, since we do not have more information.

Division over the machine types stays the same

For the Stand-alone department, we assume that the percentage of the total sold machines stays the same per type machine. We base this percentage on the percentages of 2019, since not all machines were already produced in the previous years. There is a chance that new machines will be developed or that a machine increases or decreases in popularity, but since we cannot predict something like this, we leave it out of consideration.

When demo line is removed, all space can be used

One solution that we test, is to remove the demo line. This demo line takes two pie wedges on the work floor. A part of this space is beneath a walking bridge, so this has a limited height. We assume that although this limited height, all space can be used. When this space is used smartly, for example for storage or pre-assembly, it should not be a problem.

Division of the work floor is based on pie wedges

The tool searches first for the best division of the work floor. The work floor is divided based on pie wedges. In total, there are 14 free pie wedges, see the simplified floor map in Figure 2.2. We assume that the division can only be made in half pie wedges. So, for example a division can be 6.5 pie wedges for Projects and 7.5 for Stand-Alone, but 6.4 and 7.6 is not possible.

Maximum workplaces on entresol

As explained in Section 4.3 there are 7 pie wedges on the entresol that can be used for production. Based on the space that one workplace on the entresol takes, also explained in Section 4.3, we assume that a maximum of 22 pre-assembly workplaces can be created on the entresol. When whole machines are produced on the entresol, we assume that a maximum of 10 pre-assembly, 10 main assembly and 8 testing workplaces can be created, also based on the calculations in Section 4.3. The choice of this division of the stages is based on the workplaces that are needed.

Layout stays the same

To know how much space one workplace takes, we used the current layout. For example, there are currently 13 workplaces for pre-assembly placed on two pie wedges. So, we count that one workplace takes the space of 2/13 pie wedge. Further, we explained in Section 4.7 a solution for a change in the Projects layouts, such that is goes more towards a functional layout. With this tool, it is not possible to show what the impact on the capacity is of this solution; therefore we leave it out of consideration in this tool.

5.1.2 Input data

This section explains the data that we used as input.

As explained in Section 5.1.1, we assume that the division over the months and over the machine types stays the same. Table F.1 in Appendix F shows the percentage of the hours that are performed per month per stage for the Stand-alone department and for the Projects department that we used as input. Table F.2 in Appendix F shows the division over the machine types.

Next, we need to know how big the projects should be that are used as input. Each project is unique and has a different size. To have a reliable division of projects sizes, we look at the 70 projects that are built in the past for which we know the size. Between the minimum and maximum size of these projects, we make five equal bins. Then, we count the frequency of the projects for which we know the size in each bin and calculate the percentage of projects in each bin. We use the outcome of this as input for the project sizes for our tool, see table F.3 in Appendix F.

Next to these input data, there are some input variables. Figure 5.1 show the variables that can be changed; we explain them below.

Options	**Yes/No**
Make use of flexible space	No
Use entresol for production lines	No
Use entresol for pre-assembly	No
Remove demo line	Yes
Factors	**Factor**
Throughput time Stand-alone	0.9
Throughput time Projects	0.9
Production rate stand-alone	2
Production rate projects	2

Figure 5.1: Input Variables

The first variable is to make use of flexible space or not. When this is turned to “No”, the division of the work floor cannot change per month. If this is turned to “Yes”, the division can change per month. The next variables are “Use entresol for production lines” and “Use entresol for pre-assembly”. If one of these variables is turned to “Yes”, the entresol can be used for pre-assembly or for a whole production line of a machine, as explained in Section 4.3. If the variable “Remove demo line” is turned to “Yes”, there are two more pie wedges available. The next variables are factors that can be changed. If the factors for the throughput times are 1, then the throughput times are the same as what they currently are. Appendix A shows the current throughput times of the stand-alone machines. The throughput times for the projects are based on the 50 projects for which we know the time they took on the work floor. Also here, we made different bins and looked at the percentage of projects that fits in that bins, see table F.4. When this factor is 0.9, it means that the throughput times are 90% of the current throughput times. The last variables are the production rates. If this variable is 1, then the production rate stays the same as in 2019. For the Stand-alone department, this means that 158 machines are built. For the Projects department, this means that 38 projects are built. When this factor is 2, these numbers double.

5.1.3 Output data

This section explains the output data of the excel tool. Figure 5.2 shows an example of an output, which we explain below. Thereafter, we explain the steps that are performed by the tool to come up with the outcome.

Divsion work floor per month (pie wedges)

Month	Projects	Stand-alone	Needed projects	Needed Stand-Alone
January	8.5	5.5	8.19	5.18
February	8.5	5.5	11.94	4.45
March	8.5	5.5	12.65	5.25
April	8.5	5.5	10.68	6.89
May	8.5	5.5	9.27	6.80
June	8.5	5.5	14.20	6.20
July	8.5	5.5	14.80	5.31
August	8.5	5.5	7.11	5.80
September	8.5	5.5	8.59	7.83
October	8.5	5.5	6.54	5.93
November	8.5	5.5	4.92	5.85
December	8.5	5.5	5.10	5.83

Workplaces on the entresol

Month	Pre-assembly	Main assembly	Testing
January	1.2	1.8	1.7
February	1.3	1.7	1.1
March	1.7	1.7	1.3
April	1.9	2.7	1.8
May	1.8	2.4	2.0
June	1.8	2.1	1.7
July	1.1	2.3	1.7
August	2.0	1.9	1.5
September	2.5	3.5	2.0
October	1.8	2.2	1.5
November	1.8	1.9	1.6
December	1.8	2.5	1.4

Average shortage per month	2.5
Maximum shortage	6.4

Figure 5.2: Example output excel tool

The second and third column of the first table show the best division of the work floor in pie wedges. In this example, the use of flexible space is not possible. In a month where a capacity problem arises, the cell becomes red. The fourth and fifth columns show the space that is actually needed, also expressed in pie wedges. The second table shows the number of workplaces that are needed on the entresol. In this example, we made the choice to use the entresol to produce whole machines. The last table shows the average shortage per month and the maximum shortage in a month, expressed in pie wedges. Further, the tool shows the number of workplaces that are needed per stage for the Stand-alone machines, but we only show this is Section 5.5.

There are several steps taken, before the tool comes with the output. Figure 5.3 shows a schematic diagram of the steps taken; we explain the most important steps below.

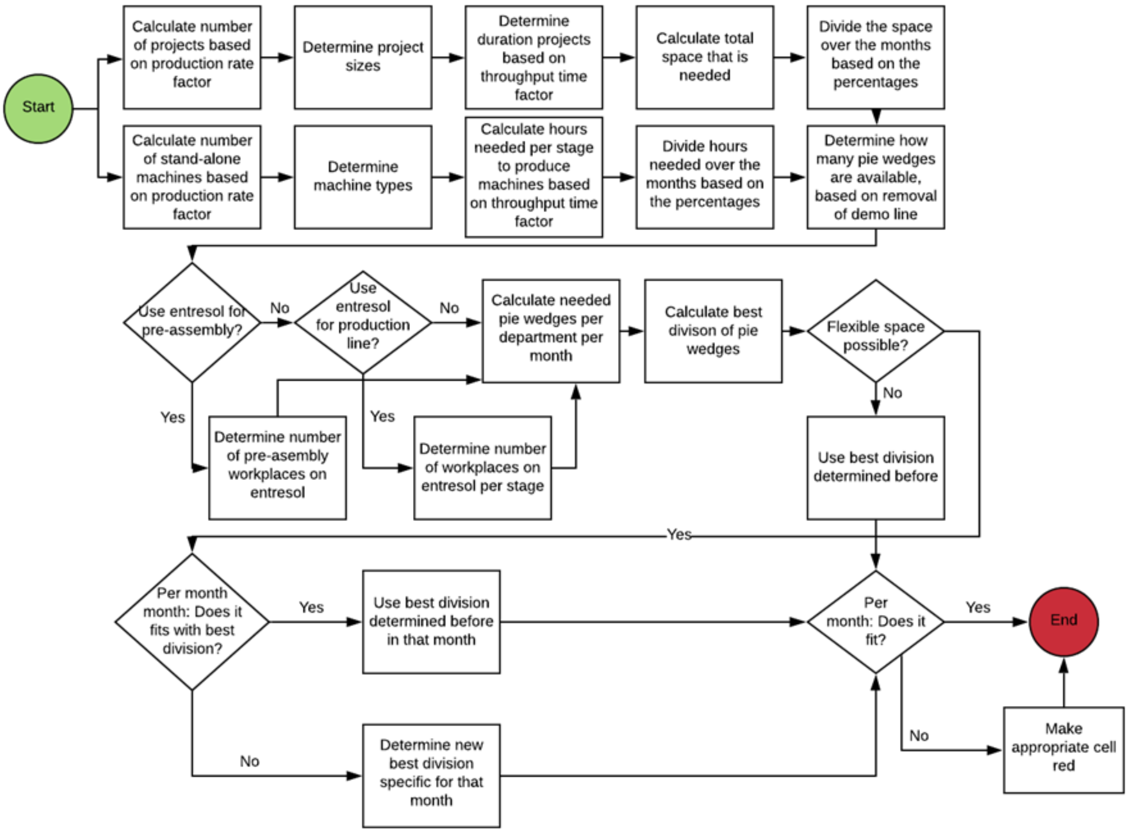

Figure 5.3: Steps taken in Excel tool

First, the tool calculates how much space is needed for the projects per month and how many workplaces are needed for the Stand-alone department per month. If the entresol can be used for one of the options, the tool calculates how much workplaces are needed on the entresol, keeping the maximum in mind. Then, the tool calculates how many pie wedges on the work floor are needed per department, per month. Thereafter, it calculates the best division of the available pie wedges. This is done by looking at by which division, the total space that is short, is as small as possible. Another option was to look by which division, there was enough space in as many months as possible. We think the first option is better, since small shortages in multiple months will lead to less problems than a big shortage in one month. If flexible space is not an option, this is the final division and the tool looks per month if it fits. When flexible space is an option, it will calculate a best new division in the months where it does not fit with the before determined best division.

5.2 Outcome of the tool

In this section, we test the impact of the solutions by using the tool. There are four solutions that we test by using the tool. We do this by turning one solution 'on' in the tool, and the others 'off'. We look at the difference with the case when no solution is turned on, to show what the impact of the single solution is. In Section 5.5, we show the results if the chosen solutions are combined. First, we perform the test when no solution is turned on. Figure 5.4 shows the input variables for test 1. We used a factor of 2 for the production rate, since the expectation is that the production will double. Figure 5.5 shows the output of the tool, we discuss it below.

Options	Yes/No
Make use of flexible space	No
Use entresol for production lines	No
Use entresol for pre-assembly	No
Remove demo line	No
Factors	**Factor**
Throughput time Stand-alone	1
Throughput time Projects	1
Production rate stand-alone	2
Production rate projects	2

Figure 5.4: Input variables test 1

Divsion work floor per month (pie wedges)

Month	Projects	Stand-alone	Needed projects	Needed Stand-Alone
January	6.5	7.5	7.06	7.33
February	6.5	7.5	10.29	5.93
March	6.5	7.5	10.90	6.69
April	6.5	7.5	9.20	9.40
May	6.5	7.5	7.99	9.10
June	6.5	7.5	12.24	8.45
July	6.5	7.5	12.76	7.28
August	6.5	7.5	6.12	7.45
September	6.5	7.5	7.40	10.21
October	6.5	7.5	5.63	8.00
November	6.5	7.5	4.24	7.95
December	6.5	7.5	4.40	8.05

Workplaces on the entresol

Month	Pre-assembly	Main assembly	Testing
January	0.0	0.0	0.0
February	0.0	0.0	0.0
March	0.0	0.0	0.0
April	0.0	0.0	0.0
May	0.0	0.0	0.0
June	0.0	0.0	0.0
July	0.0	0.0	0.0
August	0.0	0.0	0.0
September	0.0	0.0	0.0
October	0.0	0.0	0.0
November	0.0	0.0	0.0
December	0.0	0.0	0.0

Average shortage per month	2.9
Maximum shortage	6.7

Figure 5.5: Output test 1

When the current way of working is used and the production doubles, we see that there is a shortage in 11 months in one of the departments. So, when nothing is done, the current building will not satisfy, when the production doubles.

5.2.1 Producing on the entresol

For this solution we look at the two different options and compare them. In the second test, we look at the option when a whole production line is made on the entresol, for the machines that can be built there. In the third test, we look at the option when the entresol is used for pre-assembly. Figure 5.6 shows the input variables for test 2. Here, only the solution to use the entresol for production lines is turned to “yes”. For the other tests, we do not show the input variables again. Figures 5.7 and 5.8 show the outcome of the tool for test 2 and 3, which we discuss below.

Options	Yes/No
Make use of flexible space	No
Use entresol for production lines	Yes
Use entresol for pre-assembly	No
Remove demo line	No
Factors	**Factor**
Throughput time Stand-alone	1
Throughput time Projects	1
Production rate stand-alone	2
Production rate projects	2

Figure 5.6: Input variables test 2.

Divsion work floor per month (pie wedges)

Month	Projects	Stand-alone	Needed projects	Needed Stand-Alone
January	7.5	6.5	7.06	6.31
February	7.5	6.5	10.29	4.91
March	7.5	6.5	10.90	5.52
April	7.5	6.5	9.20	7.79
May	7.5	6.5	7.99	7.56
June	7.5	6.5	12.24	7.07
July	7.5	6.5	12.76	5.98
August	7.5	6.5	6.12	6.11
September	7.5	6.5	7.40	8.19
October	7.5	6.5	5.63	6.62
November	7.5	6.5	4.24	6.64
December	7.5	6.5	4.40	6.61

Workplaces on the entresol

Month	Pre-assembly	Main assembly	Testing
January	1.7	2.1	1.8
February	2.0	1.9	1.2
March	2.6	1.9	1.4
April	2.8	3.2	1.9
May	2.7	2.8	2.1
June	2.7	2.4	1.8
July	1.7	2.6	1.9
August	3.1	2.2	1.6
September	3.8	4.1	2.1
October	2.7	2.6	1.6
November	2.7	2.2	1.7
December	2.7	2.9	1.5

Average shortage per month	1.9
Maximum shortage	5.3

Figure 5.7: Output test 2.

Divsion work floor per month (pie wedges)

Month	Projects	Stand-alone	Needed projects	Needed Stand-Alone
January	8.0	6.0	7.06	6.10
February	8.0	6.0	10.29	4.55
March	8.0	6.0	10.90	5.00
April	8.0	6.0	9.20	7.55
May	8.0	6.0	7.99	7.25
June	8.0	6.0	12.24	6.60
July	8.0	6.0	12.76	6.05
August	8.0	6.0	6.12	5.45
September	8.0	6.0	7.40	7.75
October	8.0	6.0	5.63	6.15
November	8.0	6.0	4.24	6.10
December	8.0	6.0	4.40	6.20

Workplaces on the entresol

Month	Pre-assembly	Main assembly	Testing
January	8.0	0.0	0.0
February	9.0	0.0	0.0
March	11.0	0.0	0.0
April	12.0	0.0	0.0
May	12.0	0.0	0.0
June	12.0	0.0	0.0
July	8.0	0.0	0.0
August	13.0	0.0	0.0
September	16.0	0.0	0.0
October	12.0	0.0	0.0
November	12.0	0.0	0.0
December	12.0	0.0	0.0

Average shortage per month	1.8
Maximum shortage	4.8

Figure 5.8: Output test 3.

In Figures 5.7 and 5.8 we see that the optimal division of the work floor is different when the entresol is used for production. Since a part of the production for stand-alone machines is done at the entresol in this case, the Projects departments can use more space on the work floor, but it still does not fit in most of the months. We see that the second option, using the entresol for pre-assembly, has more impact than using it for whole production lines, but the difference is small; the average shortage is 1.9 for the first option and 1.8 pie wedges for the second option. Since not all machines can be produced on the entresol, the number of workplaces on the entresol does not reach its maximum. If we compare the maximum shortage per month with the maximum shortage if no solution is used, we see that this is reduced from 6.7 to 5.3 pie wedges with the first option and to 4.8 pie wedges with the second option. So, approximately 1.5 pie wedges can be saved by producing on the entresol.

5.2.2 Use flexible space

If flexible space is used, the division does not have to be the same for every month. Figure 5.9 shows the outcome if flexible space is used, which we discuss below.

Divsion work floor per month (pie wedges)

Month	Projects	Stand-alone	Needed projects	Needed Stand-Alone
January	7.0	7.0	7.06	7.33
February	10.0	4.0	10.29	5.93
March	6.5	7.5	10.90	6.69
April	9.0	5.0	9.20	9.40
May	5.5	8.5	7.99	9.10
June	12.0	2.0	12.24	8.45
July	12.5	1.5	12.76	7.28
August	6.5	7.5	6.12	7.45
September	7.0	7.0	7.40	10.21
October	6.0	8.0	5.63	8.00
November	6.0	8.0	4.24	7.95
December	5.5	8.5	4.40	8.05

Average shortage per month	2.6
Maximum shortage	6.7

Figure 5.9: Output test 4.

When flexible space is used, we see that the optimal division changes a lot per month. If the production doubles, we see that the flexible space does not have so much impact. The average shortage is reduced from 2.9 to 2.6 pie wedges. The reason why it has not so much impact, is that if the total needed pie wedges does not fit in a month, the flexible space does not have impact on the total shortage. Only if the total space that is needed does fit in the building, but not with the optimal division for a whole year, the flexible space has impact. We can see that if we compare the months October, November, and December with the outcome of test 1 in Figure 5.5, when the flexible space is not used. In October, November and December, the total space that is needed fits in the building, but when the optimal division over a whole year is used, there is still a shortage at the Stand-alone department, see Figure 5.5. The Projects department has some free space then, so this can be used for Stand-alone when flexible space is used, see Figure 5.6. Therefore, the impact of this solution will be higher if there are less shortages.

5.2.3. Removing demo line

When the demo line is removed, there are two more pie wedges available. Figure 5.10 show the outcome of the tool, which we discuss below.

Divsion work floor per month (pie wedges)

Month	Projects	Stand-alone	Needed projects	Needed Stand-Alone
January	8.0	8.0	7.06	7.33
February	8.0	8.0	10.29	5.93
March	8.0	8.0	10.90	6.69
April	8.0	8.0	9.20	9.40
May	8.0	8.0	7.99	9.10
June	8.0	8.0	12.24	8.45
July	8.0	8.0	12.76	7.28
August	8.0	8.0	6.12	7.45
September	8.0	8.0	7.40	10.21
October	8.0	8.0	5.63	8.00
November	8.0	8.0	4.24	7.95
December	8.0	8.0	4.40	8.05

Average shortage per month	1.7
Maximum shortage	4.8

Figure 5.10: Output test 5.

When the demo line is removed, the new optimal division is 8 pie wedges for both departments. The average shortage per month is then reduced from 2.9 to 1.7 pie wedges and the maximum shortage from 6.7 to 4.8 pie wedges.

5.2.3. Shorten the throughput time

An estimation from a process engineer at Niverplast is that on the short term, it should be possible to reduce the throughput time with 10%. Therefore, we turned these factors in the input variables to 0.9 to test this solution. Figure 5.11 shows the outcome, which we discuss below.

Divsion work floor per month (pie wedges)

Month	Projects	Stand-alone	Needed projects	Needed Stand-Alone
January	7.0	7.0	6.35	6.38
February	7.0	7.0	9.26	5.58
March	7.0	7.0	9.81	6.34
April	7.0	7.0	8.28	8.34
May	7.0	7.0	7.19	8.24
June	7.0	7.0	11.01	7.34
July	7.0	7.0	11.48	6.73
August	7.0	7.0	5.51	7.10
September	7.0	7.0	6.66	9.61
October	7.0	7.0	5.07	7.39
November	7.0	7.0	3.82	7.24
December	7.0	7.0	3.96	7.44

Average shortage per month	1.8
Maximum shortage	4.5

Figure 5.11: Output test 6.

We see that the optimal division changes when the throughput times is reduced with 10%. Further, we see that the average shortage reduces from 2.9 to 1.8 pie wedges and the maximum shortage from 6.7 to 4.5 pie wedges. So, in the busiest month, a reduction of the throughput times with 10% can save two pie wedges.

In Section 5.5 we look by which reduction of the throughput times in combination with the other solutions we choose in Section 5.4, there is enough capacity when the production doubles.

5.3 Feasibility

In Section 5.2 we showed what the impact of the solutions is on the capacity. In this section, we explain more about the feasibility. We take the term feasibility here broadly. We discuss the disadvantages of the solutions here and if it can be realized easily.

First, we discuss the possibility of producing on the entresol. In Section 4.2 we showed that this option scored low on the criteria we defined. We already explained reasons why the score was low. The long and short of it was that the logistics of building machines will be more difficult, the working convenience is lower on the entresol and the investment is relatively high. However, it was mentioned during the brainstorm session that the logistics will be less difficult when a whole machine can be produced on the entresol. If only the pre-assembly is done at the entresol, the movements with the different modules from the entresol to the work floor becomes difficult. Therefore, the feasibility of producing whole machines on the entresol is higher than the feasibility of doing only pre-assembly on the entresol.

The second solution is the use of flexible space. This solution has the best score of all solutions. So the feasibility of this solution is high. There were only two problems mentioned. The first one being that there still is a problem when both departments would need the flexible space, which we also saw in Section 5.2.2. The second is that it can be difficult to change the space from being appropriate for the Stand-alone department to the Projects department. This can be solved by mainly making the space for testing at the Stand-alone department flexible, since the workplaces there do not deviate much from what is needed at a space where a project is built.

The solution to remove the demo line, scored high. The reason for this is that it is a relatively simple solution and has a lot of impact. However, this demo line is currently used to show potential customers everything that Niverplast can realize. It gives a nice view when customers enter the building. When this demo line is removed, there is a chance that customers will be lost or that less machines are sold.

The next solution is to shorten the throughput time. As explained in Section 4.6, we cannot do research into how the throughput time can be shortened. Therefore it is difficult to say for us what the feasibility of this solution is. During the brainstorm session, this solution has an average score of 3.2 out of 5 for the feasibility criterium. So, the stakeholders of the problems do think that it is possible to shorten the throughput time.

5.4 Solution choice

In this section, we make the trade-offs for the solutions and make choices about which solution should be implemented and which not, on the basis of the previous sections.

First, we discuss the possibility of producing on the entresol. As explained in Section 5.3, the feasibility of this solution is low and the working convenience will also be low on the entresol. In Section 5.2 we showed that approximately one and a half pie wedge can be saved by producing on the entresol for both options, but the option to do only the pre-assembly on the entresol saves slightly more space. However, we explained in Section 5.3 that the feasibility of the option to produce whole machines on the entresol is higher. Therefore, we advise to use this option, since the difference in feasibility is greater than the difference in the amount of space that is saved. However, we think that at the time that producing on the entresol is necessary, it will be better to construct a new building to keep the working convenience high. The entresol can be used as emergency solution when the space is necessary, but there is not a new building yet.

Next, we discuss the possibility of flexible space. We saw in Section 5.3 that the feasibility of this solution is high. In Section 5.2 we saw that this solution is mainly useful when there are not so much shortages. Since the peak months of both departments are not in the same months, the use of flexible space can make sure that it fits longer in the current building. Therefore, we advise to use this solution.

Then the option to remove the demo line. The impact of this solution is that two pie wedges will be saved on the work floor. However, the solution has also a big disadvantage, as explained in Section 5.3. Removing the demo line cannot be done without consequences. Therefore, we advise to use this solution only as emergency solution and that constructing a new building will be better when removing the demo line is necessary.

The last solution is to shorten the throughput time. In Section 5.2 we showed that when the throughput time is reduced with 10%, two pie wedges can be saved in the peak month when the production doubles. So, the impact of this solution is high. Therefore, we advise to do research into how the throughput time can be reduced.

To conclude, we advise to use the entresol and remove the demo line only as emergency solution, but that it is better to construct a new building when this is necessary, to keep the working convenience high. Further, we advise to use flexible space as a solution and to do research into how the throughput time can be shortened.

5.5 Final solution tests

In this section, we look at what happens if the chosen solutions are combined. We answer the question: “What is the maximum capacity of the building?”. We look at two scenarios. In the first scenario, we implement only the solution to use the flexible space and reduce the throughput time with 10%. In the second scenario, we also implement the solution to use the entresol for a whole production line and remove the demo line. With the second scenario, we measure the absolute maximum of the building. First, we look at by which production rate, the maximum capacity is reached. Thereafter, we look by which reduction of the throughput times, there is enough capacity when the production doubles. Before looking at these scenarios to find the maximum capacity of the building, we look at the current situation. When nothing is changed, the maximum capacity of the building is almost reached. An increase of 5% is possible, but with an increase of 10%, a capacity problem arises.

5.5.1 Scenario 1

First, we look at what happens if the solutions to use flexible space and to shorten the throughput times with 10% are implemented when the production doubles. Thereafter, we search for the moment when the maximum is reached, by increasing or decreasing the production rate with 0.05, till we find the point where it changes from fitting into the building in every month, to when it does not fit anymore. Then, we search for the moment when there is enough capacity when the production doubles, by increasing or decreasing the throughput time factors. Figure 5.12 shows the outcome when the production is doubled, which we discuss below.

Divsion work floor per month (pie wedges)

Month	Projects	Stand-alone	Needed projects	Needed Stand-Alone
January	7.0	7.0	6.34	6.63
February	9.0	5.0	9.24	5.43
March	7.0	7.0	9.79	6.54
April	8.0	6.0	8.27	8.14
May	7.0	7.0	7.18	7.84
June	10.5	3.5	10.99	7.44
July	11.0	3.0	11.46	6.48
August	7.0	7.0	5.50	6.94
September	6.5	7.5	6.65	9.45
October	6.5	7.5	5.06	7.24
November	6.5	7.5	3.81	7.19
December	6.5	7.5	3.95	7.04

Average shortage per month	1.4
Maximum shortage	4.4

Figure 5.12: Output scenario 1 with production rate 2.

In Figure 5.12 we see that when the solutions are implemented, the current building does not have enough capacity when the production doubles. The average shortage per month is 1.4 pie wedges and the maximum shortage is 4.4 pie wedges.

After iteratively changing the production rate, we found the maximum capacity of the building in this scenario. The maximum capacity is reached when the production rate is 1.4, so 40% more than in 2019. Figure 5.13 shows the outcome of the tool with a production rate of 1.4, which we discuss below. Here we also show the number of workplaces that are needed per stage for the Stand-Alone department.

Divsion work floor per month (pie wedges)

Month	Projects	Stand-alone	Needed projects	Needed Stand-Alone
January	8.0	6.0	4.36	4.77
February	8.0	6.0	6.36	3.72
March	8.0	6.0	6.74	4.28
April	8.0	6.0	5.69	5.58
May	8.0	6.0	4.94	5.63
June	8.0	6.0	7.56	5.18
July	8.0	6.0	7.88	4.37
August	8.0	6.0	3.79	4.88
September	7.5	6.5	4.58	6.34
October	8.0	6.0	3.48	4.98
November	8.0	6.0	2.62	5.18
December	8.0	6.0	2.72	4.98

Needed workplaces per month

Month	Pre-assembly	Main assembly type 1	Main assembly type 2	Main assembly type 3	Testing
January	5.0	3.0	2.0	4.0	8.0
February	5.0	3.0	1.0	3.0	6.0
March	7.0	3.0	2.0	3.0	6.0
April	8.0	3.0	3.0	5.0	8.0
May	7.0	4.0	2.0	5.0	9.0
June	7.0	4.0	2.0	4.0	8.0
July	5.0	2.0	2.0	4.0	8.0
August	8.0	3.0	2.0	4.0	7.0
September	10.0	4.0	2.0	6.0	9.0
October	7.0	3.0	3.0	4.0	7.0
November	7.0	3.0	3.0	4.0	8.0
December	7.0	3.0	2.0	5.0	7.0

Figure 5.13: Output scenario 1 with production rate 1.4.

We see that the optimal division seems to be 8 pie wedges for Projects and 6 pie wedges for Stand-alone. There is one month where the optimal division does not satisfy and the use of flexible space is necessary. In September, Stand-Alone needs more space. In this scenario, 10 pre-assembly workplaces are needed in the peak month, 4 main assembly of type 1, 3 of type 2, 6 of type 3 and 9 testing workplaces.

Next, we look at by which throughput times factors there is enough capacity when the production doubles, in this scenario. The process engineers at Niverplast expect that it is easier to reduce the throughput times at the Stand-alone department than at the Projects departments. We assume here that reducing the throughput times at the Projects department is twice as hard as at the Stand-alone departments. Therefore, we reduce the throughput time factor for stand-alone with steps of 0.05 and at the same time for projects with 0.025. After iteratively reducing the throughput time factors, we found that with a reduction of the throughput times with 50% at the Stand-alone department and with 75% at the Projects department, there is enough capacity when the production doubles, in this scenario. Figure 5.14 shows the outcome of the tool with these production rates, where we see that the optimal division changes to 9 pie wedges for projects and 5 pie wedges for stand-alone, since the throughput times are more reduced at the Stand-alone department.

Divsion work floor per month (pie wedges)

Month	Projects	Stand-alone	Needed projects	Needed Stand-Alone
January	9.0	5.0	5.22	3.77
February	9.0	5.0	7.60	3.37
March	9.0	5.0	8.06	3.77
April	9.0	5.0	6.80	4.57
May	9.0	5.0	5.91	4.62
June	9.5	4.5	9.04	4.32
July	9.5	4.5	9.43	4.02
August	9.0	5.0	4.53	4.12
September	8.5	5.5	5.47	5.18
October	9.0	5.0	4.16	4.22
November	9.0	5.0	3.13	3.97
December	9.0	5.0	3.25	4.22

Figure 5.14: Output scenario 1 with throughput time factors 0.5 and 0.75

5.5.2 Scenario 2

Figure 5.15 shows the outcome if the solutions of scenario 2 are implemented and the production doubles, we discuss it below.

Divsion work floor per month (pie wedges)

Month	Projects	Stand-alone	Needed projects	Needed Stand-Alone
January	10.0	6.0	6.96	5.47
February	11.0	5.0	10.14	4.61
March	10.0	6.0	10.75	5.19
April	9.0	7.0	9.07	7.03
May	9.0	7.0	7.88	6.64
June	12.0	4.0	12.07	6.30
July	12.5	3.5	12.58	5.24
August	10.0	6.0	6.04	5.84
September	8.5	7.5	7.30	7.30
October	10.0	6.0	5.56	5.69
November	10.0	6.0	4.18	5.76
December	10.0	6.0	4.34	5.69

Workplaces on entresol

Month	Pre-assembly	Main assembly	Testing
January	1.5	1.9	1.9
February	1.7	1.8	1.3
March	2.3	1.8	1.5
April	2.5	2.9	2.0
May	2.4	2.6	2.2
June	2.4	2.2	1.9
July	1.5	2.5	2.0
August	2.7	2.1	1.6
September	3.3	3.8	2.2
October	2.4	2.4	1.7
November	2.3	2.0	1.8
December	2.3	2.7	1.6

Average shortage per month	0.4
Maximum shortage	2.4

Figure 5.15: Output scenario 2 with production rate 2.

We see that even if all solutions are implemented, the building does not satisfy when the production doubles. The problem arises when the Projects department is at his peak months. The maximum shortage occurs in June, then there are 2.4 pie wedges short in total.

After iteratively changing the production rate, we found the maximum capacity of the building in this scenario. The maximum capacity is reached when the production rate is 1.7, so 70% more than in

2019. Figure 5.15 shows the outcome of the tool with a production rate of 1.7, which we discuss below.

Divsion work floor per month (pie wedges)

Month	Projects	Stand-alone	Needed projects	Needed Stand-Alone
January	10.0	6.0	5.54	4.35
February	10.0	6.0	8.07	3.83
March	10.0	6.0	8.55	4.49
April	10.0	6.0	7.22	5.92
May	10.0	6.0	6.27	5.91
June	10.0	6.0	9.60	5.39
July	11.0	5.0	10.01	4.67
August	10.0	6.0	4.81	5.12
September	9.0	7.0	5.81	6.53
October	10.0	6.0	4.42	5.19
November	10.0	6.0	3.33	5.44
December	10.0	6.0	3.45	5.40

Workplaces on entresol

Month	Pre-assembly	Main assembly	Testing
January	1.1	1.5	1.5
February	1.3	1.4	1.0
March	1.7	1.4	1.2
April	1.8	2.3	1.6
May	1.8	2.0	1.8
June	1.8	1.7	1.5
July	1.1	1.9	1.6
August	2.0	1.6	1.3
September	2.5	2.9	1.8
October	1.8	1.8	1.3
November	1.7	1.6	1.4
December	1.7	2.1	1.3

Average shortage per month	0.0
Maximum shortage	0.0

Needed workplaces per month

Month	Pre-assembly	Main assembly type 1	Main assembly type 2	Main assembly type 3	Testing
January	6.0	3.0	2.0	4.0	10.0
February	6.0	4.0	1.0	4.0	7.0
March	8.0	4.0	2.0	4.0	8.0
April	9.0	5.0	3.0	6.0	11.0
May	9.0	5.0	2.0	6.0	12.0
June	9.0	5.0	2.0	5.0	10.0
July	6.0	3.0	2.0	5.0	11.0
August	10.0	4.0	2.0	5.0	9.0
September	12.0	5.0	2.0	8.0	12.0
October	9.0	4.0	3.0	5.0	9.0
November	9.0	4.0	3.0	5.0	10.0
December	9.0	4.0	3.0	6.0	9.0

Figure 5.16: Output scenario 2 with production rate 1.7.

We see that the optimal division in this scenario is 10 pie wedges for Projects and 6 pie wedges for Stand-alone. There are two months where the use of flexible space is necessary: July and September. In the peak month, 3 workplaces for pre-assembly are needed on the entresol, 3 for main assembly and 2 for testing. On the main floor, 12 pre-assembly workplaces are necessary, 5 of main assembly type 1, 3 of main assembly type 2, 8 of main assembly type 3 and 12 testing workplaces.

Next, we look at by which throughput times factors there is enough capacity when the production doubles, in this scenario. After iteratively reducing the throughput time factors in the same way as in Section 5.5.1, we found that there is enough capacity in this scenario when the production doubles if the throughput times at the Stand-alone department are reduced with 25% and at the Projects department with 12.5%. Figure 5.17 shows the output of the tool with these throughput time factors, where we see that the optimal division is 10.5 pie wedges for stand-alone and 5.5 for projects and flexible space is necessary in June, July, and September.

Divsion work floor per month (pie wedges)

Month	Projects	Stand-alone	Needed projects	Needed Stand-Alone
January	10.5	5.5	6.09	4.12
February	10.5	5.5	8.87	3.78
March	10.5	5.5	9.40	4.43
April	10.5	5.5	7.93	5.24
May	10.5	5.5	6.89	5.43
June	11.0	5.0	10.55	4.91
July	11.5	4.5	11.00	4.25
August	10.5	5.5	5.28	4.65
September	9.5	6.5	6.38	6.28
October	10.5	5.5	4.86	4.96
November	10.5	5.5	3.66	4.77
December	10.5	5.5	3.79	4.97

Figure 5.17: Output scenario 2 with throughput times factors 0.75 and 0.875.

5.6 Conclusion solution test

We advise to use flexible space and to do research into how the throughput time can be reduced. Further, the solutions to use the entresol for production and remove the demo line should only be used as emergency solutions. Therefore, we looked at two scenarios: one scenario were the emergency solutions are not implemented, and a scenario where these are also implemented, to find the absolute maximum. In the first scenario, the maximum capacity is reached if the production increases with 40% compared to 2019. However, if the throughput times are reduced with 50% at the Stand-alone department and with 25% at the Project department, there is enough capacity in the current building to double in production in this scenario. In the second scenario, the maximum capacity is reached if the production increases with 70% compared to 2019. If the throughput times are reduced with 25% at the Stand-alone department and with 12.5% at the Project department, there is enough capacity in the current building to double in production in this scenario. When nothing is changed, the maximum capacity is reached if the production increases with 5% compared to 2019.

6 Conclusions and recommendations

This chapter gives in Section 6.1 the conclusions of the research. Section 6.2 describes the recommendations we give to Niverplast.

6.1 Conclusions

This section answers the main question: "How can the capacity of the current building of Niverplast be increased and what is the maximum capacity?"

We conclude that the current fixed-position layout for the Projects department is difficult to change, since the projects are too big and heavy to move. However, before the project is composed, the assembly of parts can be done at a different stage for more flexibility. The current cell layout for the Stand-alone department, seems the most appropriate one. The P-Q analysis showed that the percentage of machine A out of all machines that are produced is high. Therefore it could be a good idea to split the layout at the Stand-alone department and use a line layout that lays lower on the diagonal line for the machine A. However, we saw that the production number is currently to low that a line layout would work and there are some problems in the production why a line layout will be difficult. If the production number of machine A increases further, it can be worthful to investigate the possibility of a line layout for this machine.

There are also other solutions that can increase the capacity of the current building. The first one is to use the entresol for production. Machines of the Stand-alone department can be produced on the entresol. The best way to use it, is to produce whole machines on the entresol and transport them downwards when ready. This solution saves approximately one and a half pie wedge on the work floor, which is 1/16 of the total space. The next one is to use flexible space. Since the production is not evenly spread over the year and the peaks at the two departments are not in the same month, using flexible space can increase the capacity. Another solution is to remove the demo line, which will save two pie wedges on the work floor. The last solution is to shorten the throughput time. A reduction of the throughput time with 10% can save two pie wedges on the work floor in the peak month.

To answer the question what the maximum capacity of the current building is, we looked at two scenarios. In the first scenario, only the solutions to use flexible space and to shorten the throughput times with 10% are implemented. In this scenario, the maximum capacity of the building is reached when the production increases with 40% compared to 2019. However, if the throughput times are reduced with 50% at the Stand-alone department and with 25% at the Project department, there is enough capacity in the current building to double in production in this scenario. In the second scenario, also the solutions to remove the demo line and use the entresol for production are implemented. In this scenario, the maximum capacity of the building is reached when the production increases with 70% compared to 2019. If the throughput times are reduced with 25% at the Stand-alone department and with 12.5% at the Project department, there is enough capacity in the current building to double in production in this scenario. When nothing is changed, the maximum capacity is reached if the production increases with 5% compared to 2019.

6.2 Recommendations

First, we recommend doing research into the three other solutions that were mentioned at the brainstorm, which we did researched further due to our limited time. Although the score for these solutions was not that high, there is still a chance that they can save space. The first one is to remove the storage racks that are placed on the work floor. The second one is to use the outer ring of the building for the production of small projects. The last one is to build (part) of the projects at a different location than at Niverplast.

Further, we saw in this research that there are peaks in the production. The conclusions in this research are based on the assumption that these peaks stay the same. When the peaks are reduced, there is less capacity necessary in the building. Therefore, we recommend finding a way how these peaks can be reduced, for example by using another planning/scheduling method.

The tool that we made and described in Chapter 5 can be used to also look what happens in other scenarios than we showed in this report. For example when it turns out to be not possible to reduce the throughput time, a new scenario should be tested.

We recommend making use of flexible space between the departments. To implement the use of flexible space, at the beginning of each (peak) month a prognosis should be made about how much space each department needs, based on the machines and projects that are planned to build. Then a division of the work floor can be made, such that both departments know how much space they have available.

Further, we saw that the throughput time has a high impact on the capacity. Therefore, we recommend doing research into how the throughput time can be shortened.

When flexible space is used and the throughput times are reduced with 10%, we saw that the maximum capacity is reached when the production increases with 40% compared to 2019. If the expectation is that the production will increase further than 40%, we think that it is better to construct a new building. Removing the demo line and using the entresol for production can be used as emergency solution.

Looking at the scenario where the demo line is not removed, and the entresol not used for production, but the flexible space is used and the throughput time is 10% shorter and the production is at its maximum capacity (140%), we showed that the best division between Projects and Stand-alone is 6 pie wedges for Stand-alone and 8 for projects. So, it should be possible to reduce the space that is currently used for Stand-Alone (7 pie wedges), such that Projects have some more space. Only in September, the Stand-alone department needs more space (6.5 pie wedges). Therefore, we recommend reducing the space that is used for Stand-Alone to 6 pie wedges, since the capacity problem mainly arises at the Projects department.

Lastly, we recommend making a change in the layout for the Projects department. We think it is better to perform the pre-assembly at a different location than where the project is built, such that all the pre-assembly tasks are grouped together. Then, the pre-assembly can probably be performed quicker and the movements to the storage can be shortened. Further, there will be more overview at the projects department.

References

Benjaafar, S. (2000). *Design of flexible plant layouts.*

Bertolini, M. (2017). *2MTO, a new mapping tool to achieve lean benefits in high-variety low-volume job shops.*

Buchari. (2018). Production layout improvement by using line balancing and Systematic Layout Planning (SLP) at PT. XYZ.

C., M. E., N., M. P., & N., K. J. (2018). Improvement of Facility Layout Using Systematic Layout.

Heerkens, H., & van Winden, A. (2017). *Solving Managerial Problems Systematically.*

Huang, G. Q., Zhang, Y. F., & Jiang, P. Y. (2007). RFID-based wireless manufacturing for walking-worker assembly islands with fixed-position layouts. *Robotics and Computer-Integrated Manufacturing*, 469-477.

Junior, C. (2019). *Assesment of shop floor layouts in the context of process plans with alternatives.*

Li, J. (2003). *Improving the performance of job shop manufacturing with demand-pull production control by reducing set-up/processing time variability.*

Li, J. (2005). *Investigating the effiacy of exercising JIT practices to support pull production control in a job shop environment.*

Muther, R., & Hales, L. (2015). *Systematic Layout Planning.* Marietta: Management & Industrial Research Publication.

Nieuwenhuis, G. J. (2019). *Niverpedia*. Retrieved from Niverplast.com: https://www.niverplast.com/niverpedia/4/once-upon-a-time

Qin, W., & Huang, G. Q. (2010). *A two-level genetic algorithm for scheduling in assembly islands with fixed-position layouts.*

Skhmot, N. (2017, august 5). *The Lean Way Blog*. Retrieved from The Lean Way: https://theleanway.net/The-8-Wastes-of-Lean

Slack, N., Brandon-Jones, A., & Johnston, R. (2016). *Operations Management.* Pearson.

Wilson, L. (2010). *How to implement lean manufacturing.*

Zakirah, T. (2018). Warehouse layout and workflow designing at PT. PMS using systematic layout planning method.

Appendix

A. Throughput times per machine

Removed in public version

B. Representation of average occupied workplaces per month for Stand-Alone

Month	Average Pre-assembly	Average Main assembly	Average Testing
2014	**2.3**	**4.3**	**3.8**
Jan	3.1	6.5	3.5
Feb	1.5	2.5	4.7
Mar	2.3	3.1	2.0
Apr	3.3	8.3	4.4
May	3.4	5.2	6.0
Jun	2.7	4.4	5.9
Jul	1.2	3.5	3.8
Aug	1.4	2.0	2.1
Sep	3.0	5.3	3.5
Oct	3.6	4.9	3.3
Nov	0.6	3.9	6.0
Dec	1.3	1.5	0.8
2015	**2.2**	**4.1**	**3.7**
Jan	0.5	1.5	2.1
Feb	1.4	1.4	1.3
Mar	2.7	5.0	2.6
Apr	3.1	5.7	6.1
May	1.0	3.2	4.5
Jun	1.0	0.8	1.1
Jul	1.5	3.4	2.6
Aug	2.3	3.5	2.7
Sep	3.2	4.4	5.3
Oct	2.4	5.3	5.1
Nov	3.6	4.5	5.0
Dec	4.0	9.8	5.5
2016	**3.3**	**5.8**	**5.6**
Jan	2.6	3.7	7.4
Feb	3.5	8.2	4.7
Mar	1.1	2.9	5.7
Apr	4.4	4.0	2.0
May	4.7	7.1	7.3
Jun	2.4	8.8	6.2
Jul	1.0	1.5	4.0
Aug	6.3	5.6	3.9
Sep	1.2	8.4	11.1
Oct	3.6	3.2	1.0
Nov	5.4	9.5	6.2
Dec	3.9	7.0	7.8
2017	**2.4**	**4.4**	**4.2**
Jan	0.8	3.2	4.4
Feb	2.4	4.1	2.7

Mar	2.3	3.4	4.3
Apr	3.5	6.6	3.8
May	4.0	6.7	6.8
Jun	3.8	7.8	7.3
Jul	1.4	3.3	5.4
Aug	3.5	3.6	3.0
Sep	3.4	6.2	5.0
Oct	0.5	2.6	4.0
Nov	1.3	2.2	1.6
Dec	2.4	3.6	1.5
2018	**2.7**	**4.6**	**4.6**
Jan	3.1	5.6	5.6
Feb	1.7	4.7	4.9
Mar	3.0	3.8	2.7
Apr	2.1	4.3	6.0
May	1.8	4.2	3.7
Jun	4.5	4.8	2.9
Jul	**2.2**	**5.9**	**8.6**
Aug	3.1	6.1	5.5
Sep	2.7	4.2	4.4
Oct	2.8	3.5	3.4
Nov	2.5	4.6	4.3
Dec	2.9	2.9	3.0
2019	**4.7**	**6.4**	**5.8**
Jan	1.6	4.1	5.1
Feb	3.8	3.4	2.7
Mar	6.0	7.2	5.4
Apr	3.3	7.7	8.9
May	3.7	5.9	4.4
Jun	4.3	5.6	5.3
Jul	4.1	6.6	5.3
Aug	3.8	6.4	7.6
Sep	12.6	9.3	5.6
Oct	4.9	10.7	8.6
Nov	4.7	4.4	5.5
Dec	3.1	5.1	5.4
2020	**5.3**	**6.6**	**5.9**
Jan	3.8	5.9	3.1
Feb	6.2	7.1	7.4
Mar	8.3	6.5	5.9
Apr	5.9	10.3	8.1
May	3.2	4.9	6.2
Jun	4.6	4.9	5.1
Total average	**3.1**	**5.0**	**4.7**

Table B.1: Representation of average occupied workplaces per month for Stand-Alone

C. Brainstorm

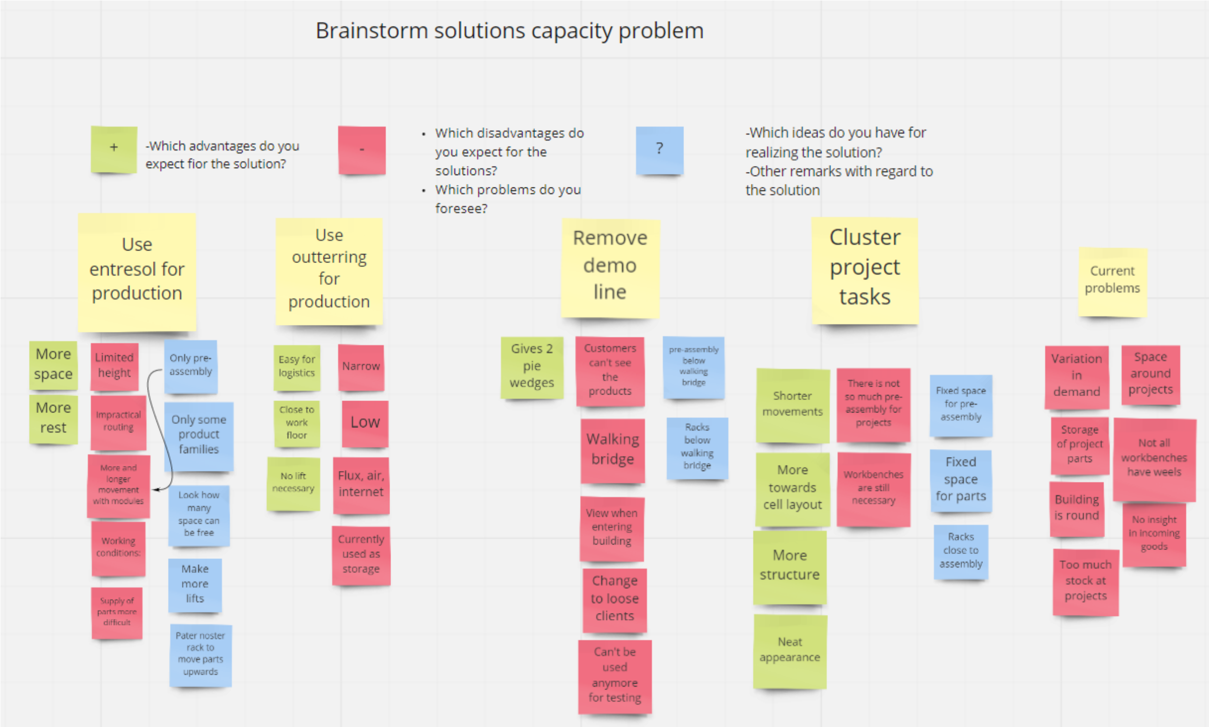

Figure C.1: Picture of brainstorm outcome (1/2)

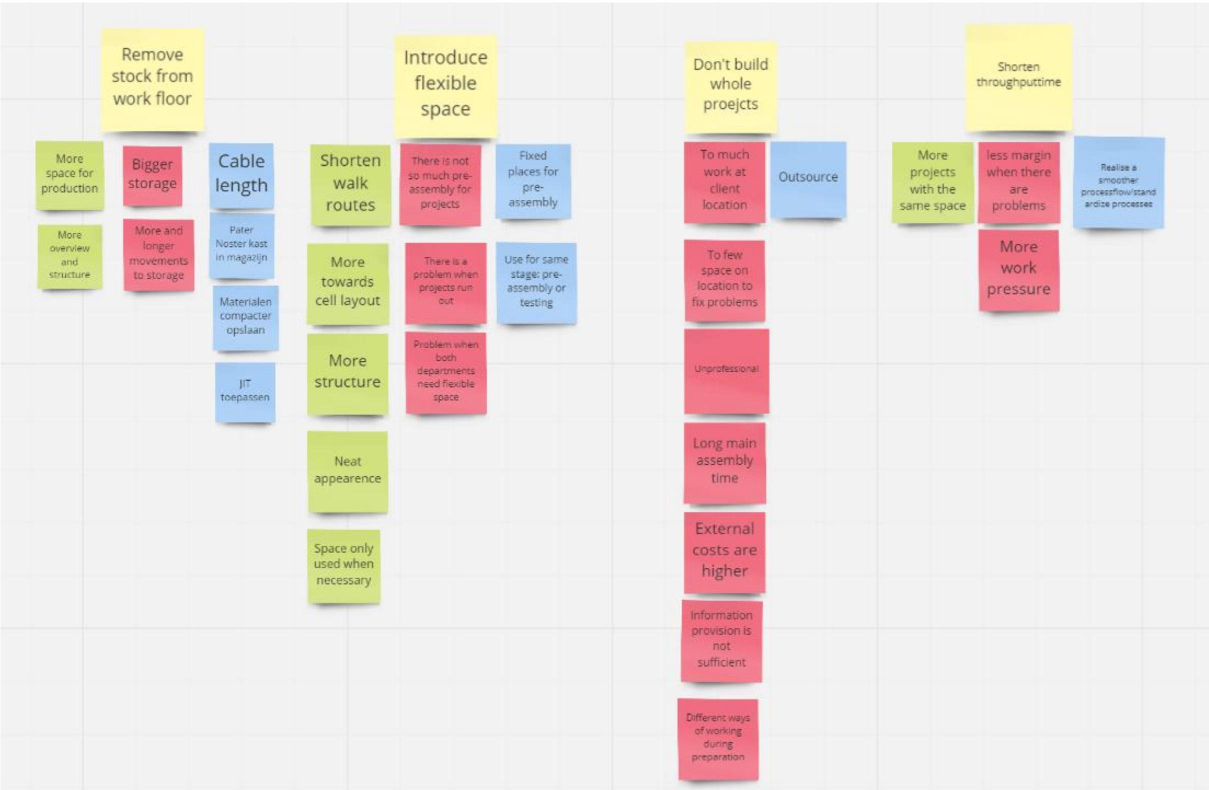

Figure C.2: Picture of brainstorm outcome (2/2)

D. Weighted decision matrix

	Weight		Solution 1		Solution 2		Solution 3		Solution 4		Solution 5		Solution 6		Solution 7		Solution 8	
Criteria	Total points	Percentage	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
Budget/Investment	16	15%	10	1,5	20	3,0	18	2,7	16	2,4	22	3,4	16	2,4	18	2,7	20	3,0
Feasibility	19	18%	8	1,4	18	3,3	15	2,7	19	3,4	19	3,4	8	1,4	16	2,9	21	3,8
Applicability for products	14	13%	11	1,5	19	2,5	17	2,3	21	2,8	22	2,9	9	1,2	18	2,4	19	2,5
Amount of space gain	22	21%	17	3,6	17	3,6	23	4,8	18	3,8	20	4,2	20	4,2	20	4,2	19	4,0
Working conveniece	19	18%	13	2,4	16	2,9	21	3,8	18	3,3	22	4,0	15	2,7	23	4,2	17	3,1
Logistics	15	14%	7	1,0	21	3,0	22	3,1	14	2,0	20	2,9	15	2,1	21	3,0	14	2,0
Total	105	1	66	11,4	111	18,3	116	19,5	106	17,7	125	20,8	83	14,1	116	19,4	110	18,4

Table D.1: Weighted decision matrix

E. Calculation needed workplaces at entresol for option 1

Machine	Sold in 2019	Pre-assembly	Main assembly	Testing
Machine L	[redacted]	[redacted]	[redacted]	[redacted]
Machine Q	[redacted]	[redacted]	[redacted]	[redacted]
Machine I	[redacted]	[redacted]	[redacted]	[redacted]
Machine E	[redacted]	[redacted]	[redacted]	[redacted]
Machine R	[redacted]	[redacted]	[redacted]	[redacted]
Machine K	[redacted]	[redacted]	[redacted]	[redacted]
Total	[redacted]	[redacted]	[redacted]	[redacted]
Doubled		[redacted]	[redacted]	[redacted]
Workplaces needed		2,2	2,3	1,7
Needed in peak month		3,2	3,6	2,1

Table E.1: Calculation needed workplaces on entresol for option 1

F. Input data excel tool

Month	Pre-assembly	Main assembly type 1	Main assembly type 2	Main assembly type 3	Testing	Projects
January	6%	7%	8%	7%	9%	7%
February	6%	8%	4%	6%	6%	10%
March	8%	8%	7%	6%	7%	11%
April	9%	9%	13%	10%	9%	9%
May	9%	10%	8%	9%	10%	8%
June	9%	10%	9%	8%	9%	12%
July	6%	6%	7%	9%	9%	13%
August	10%	9%	7%	7%	8%	6%
September	12%	11%	7%	13%	10%	8%
October	9%	8%	10%	8%	8%	6%
November	9%	8%	10%	7%	8%	4%
December	9%	8%	9%	9%	7%	4%

Table F.1: Percentage of production per month

Machine	Percentage
Machine D	11%
Machine P	1%
Machine J	3%
Machine B	33%
Machine H	4%
Machine L	2%
Machine Q	1%
Machine I	4%
Machine E	8%
Machine R	1%
Machine N	1%
Machine G	5%
Machine C	14%
Machine K	3%
Machine O	1%
Machine M	2%
Machine T	1%
Machine F	8%

Table F.2: Percentage per machine

Project size (m2)	Percentage
92-171	21%
171-250	33%
250-329	30%
329-408	9%
408-487	6%

Table F.3: Percentage per project size

Number of weeks	Percentage
2 till 5	20%
6 till 8	41%
9 till 11	18%
11 till 14	16%
14 till 15	4%

Table F.3: Percentage per throughput time projects