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Designing an improved production process layout for BR Products

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Preface

In front of you lies the final report of my bachelor thesis on improving the production process layout for BR Products, which marks the end of my time at the University of Twente and concludes my progress in the studies Industrial Engineering and Management.

For over half a year now, I have been working on this research and during every step of the process I learned new things; from working as part of a company to writing an academically accepted research report. During my time at BR Products, my enthusiasm to design a new, improved production layout for them and my interest in the company have grown enormously and I am glad to announce that this research has been successfully completed.

The goal of this research was to design an improved production process layout for BR Products, as the title suggests, and with that a lot of aspects of a business have to be accounted for. During the preparation for the research, I gradually became aware of all things that are important for designing a new layout and I noticed some aspects had to be left out because of time constraints, unfortunately. The final product of this research, the proposed production process layout, was therefore based on theoretical production capacity of the layout with the minimum investment.

The start of the research was slow as I did not receive the feedback I needed and wanted for quite some time, despite asking for it. My supervisors, however, have helped me wherever they could to increase the quality and thoughtfulness of my research and to allow me to finish the research as quickly as possible. My thanks go to my supervisors from the University of Twente, Dr. Ir. E.A. Lalla and Dr. A.I. Aldea, my first and second supervisor respectively, and to my supervisor within the company M. Rongen.

Lastly, I would like to thank my friends and family for supporting me throughout this journey and I hope the final report is worth the read.

With kind regards,

Ruben Brinkhuis

11-07-2019

Management Summary

BR Products is a company that mainly produces mainly heavy-duty storage racks. The production process takes place in Oss (Noord-Brabant, The Netherlands) in a small factory. Because they have reached the production capacity at this location and a large growth is expected, they need to move to a new facility and their production process layout needs improvement, which is where this research comes in. BR Products expected that from 2017 onwards their demand would grow to 500% in 5 years and wants to keep delivery time below 4 weeks. All of this cannot be accounted for in the current situation, which leads to the main question of this research:

How to optimize the production process layout at BR Products based on the requirements of a through literature research and BR Products deemed feasible production process layout?

In this research an improved production process for BR Products was designed by Ruben Brinkhuis, using the following research questions as handholds along the way:

1. *Which techniques for modelling the current production process layout at BR Products are there in literature?*
2. *How does the current production process layout at BR Products look like?*
3. *What are the requirements for a good production process layout for BR Products?*
4. *Which optimization methods are available for optimizing production processes such as that of BR Products?*
5. *How should the solution approach for generating the most suitable production process layout for BR products look like?*

The current situation consists of one punching line for beams, one welding station for arms, one for feet and a beam welding station (see Figure 4 and 5 in Section 2.1). The amount of produced beams in 2017 was 1900, which is their capacity at the moment, considering the many movements of products and other factors that take up time within the process due to imperfections in the production process layout and their expectations are that this amount will grow to 500% of its current value in 5 years, which would be 9500 beams in the year 2022. To accompany this demand a redesign of the production process layout was necessary.

By answering the research question through literature research, the various approaches needed for this research were determined. The overall research approach that was used is the Managerial Problem Solving Method (MPSM) by Heerkens & van Winden (2012).

After said literature research, optimization through simulation modelling was chosen as method for designing an improved production process layout. Together with the Systematic Layout Planning (SLP) method of Muther & Hales (2015), a proposed production process was designed, based on all the requirements and wishes of BR Products.

The proposition was tested on several performance indicators: maximum capacity, total handling time per product, total processing time per product and the number of employees required for operating the production, which showed that it was an improvement over the current production process: production capacity increased by 30%, production costs were reduced, the number of employees required reduced to 3 from 4, total handling and processing times went down and the use of more shifts accounts for the remaining coverage of demand and ability to cope with peaks in demand. The comparison of the current production process layout performance indicators and those of the proposed production process layout can be seen in Tables 6 until 9.

Contents

Glossary of terms

MPSM	Managerial Problem-Solving Method
KPI	Key Performance Indicator
SLR	Systematic Literature Review
MU	Movable Unit
DFD	Data Flow Diagrams
IDEF	Integrated Definition for Function Modelling
BPMN	Business Process Modelling Notation
SLP	Systematic Layout Planning

List of figures

List of tables

1. Introduction

1.1. Problem Identification

At this moment, BR Products produces mainly heavy-duty storage racks. The production process takes place in Oss (Noord-Brabant, The Netherlands) in a small factory. They have reached the production capacity at this location and are looking to move to a larger location and improve the current layout. The current layout can be found in Figure 5. A description and explanation of the current production process can be found in Chapter 2.

1.1.1. Action problem and research questions

The action problem is that with the present location and layout of the production process they cannot guarantee a high delivery reliability with a delivery time of 4 weeks, keeping the expected growth of 500% in 5 years in mind. This expected growth has been determined by BR Products. The action problem can be solved by answering the following research questions in chronological order:

1. *Which techniques for modelling the current production process layout at BR Products are there in literature?*
2. *How does the current production process layout at BR Products look like?*
3. *What are the requirements for a good production process layout for BR Products?*
4. *Which optimization methods are available for optimizing production processes such as that of BR Products?*
5. *How should the solution approach for generating the most suitable production process layout for BR products look like?*

The first research question is used to determine the best modelling method for the current production process layout, which is visualized by combining that technique with the information about the current production process layout in the second research question. By mapping the current situation correctly, the main issues are easily determined. The third question helps to understand what the needs of BR Products are for a new production process layout design and which requirements that leaves to satisfy. Finally, the fourth and fifth research question ensure that suitable optimization and solution generation methods are chosen such that a new design can be made in a correct manner.

Besides these research questions, there is the main research question this research will provide the answer to: *How to optimize the production process at BR Products based on the requirements of a through literature research and BR Products deemed feasible production process?*

To answer above stated questions, several data collection and research methods will need to be used. These methods are denoted in Section 1.2.2.

1.1.2. Problem cluster and motivation for core problems

The core problems that need solving for BR Products are the long delivery time combined with the low reliability and the high production costs. In Figure 1, a problem cluster is shown, where it can be seen that the two core problems have a lot of causes or underlying problems. From here on these will be called the components of the core problems. These components are old non-automated machines, few workers (which includes both the number of workers and the total working hours per day), expensive premanufactured holes, expensive paint outsourcing and many product movements. The latter component may be seen as a cause of a small storing facility and the lack of an automated sorting system for sections, but because these problems will not be included in this research, the problem of the many product movements will be solved instead, as this can be improved without solving the storing facility problem and the sorting system problem. The reason for excluding these two problems is that a larger facility will be chosen based on this research and that it simply takes up too much time to design a sorting system for BR Products, partly because the knowledge or experience needed are not available at the moment. In the problem cluster in Figure 1, you can also see the actions to undertake to solve the components of the core problems. The revising and upgrading of machines together with adding new machines is easily combined with the automation of the production process. For example, if the punching machine is upgraded so that it can automatically punch a beam in 15 minutes after a simple and quick check by a worker and the press of a button that leaves almost 15 minutes of time for the worker to complete another task, before returning to the punching machine. Besides, there is the action of simulating the production process layout and experimenting with this simulation. This can give insight in which decisions have which consequences without having to implement the solution in the real world (which is very costly and time-consuming). Through simulation, it will be shown where each product should be put at a given time, such that the products will never have to be moved more than strictly necessary. This will in turn reduce the number of product movements and save time for the workers, who can then keep operating the machines without delays caused by products being in their way.

Another action is the adding of punches to the punching machine(s). While this is only a part of revising and upgrading the machines, it is a rather specific action to reduce the cost per product, which is why it is separated from the action of upgrading machines. The adding of punches is needed to stop the premanufacturing of holes. By punching these holes themselves, BR Products can save a lot on purchasing costs, while the production costs will, expectedly, not significantly change, even with the initial investment costs of new punches and the additional variable costs.

Finally, the painting and coating of beams can be moved to the beams supplier, as this is cheaper and easier than staying with the paint supplier BR Products uses now. Now, the paint supplier is unreliable in its delivery schedule and because of the small scale of the supplier also relatively expensive. As has been researched by BR Products, moving the painting and coating to their beams supplier will be more profitable, both in direct costs, reliability and number of transportations of product parts (the beams supplier can deliver the beams painted and coated, so they do not have to be transported to a paint shop).

1.1.3. Relevance of core problems

The reason for tackling more than one core problem in this research is that the company has multiple constraints and requirements for a production process layout setup to be feasible and the high production costs can be solved rather easily. The main goal they have are a high reliability and low production costs with a delivery time of 4 weeks at 5 times the current production, so their competitive position improves. If we were to solve just one of the two core problems stated earlier, the final recommended solution can be extremely unfeasible. For example, if the production costs are lowered by 40% due to the new setup design, but the delivery time is a year and the delivery reliability is 50% (which is extraordinarily low for a production company), the company will not even consider implementing the design.

The expensive premanufactured holes and paint outsourcing will most likely be solved in little time, with relatively large benefits. The problem of many movements of product sections will also be easily solved as it is just a case of determining where products should be stored at each step in the production process, such that they do not obstruct anything. Lastly, the two remaining problems (machines and workers) will be solved by the combination of revising and upgrading machines and automating the production process.

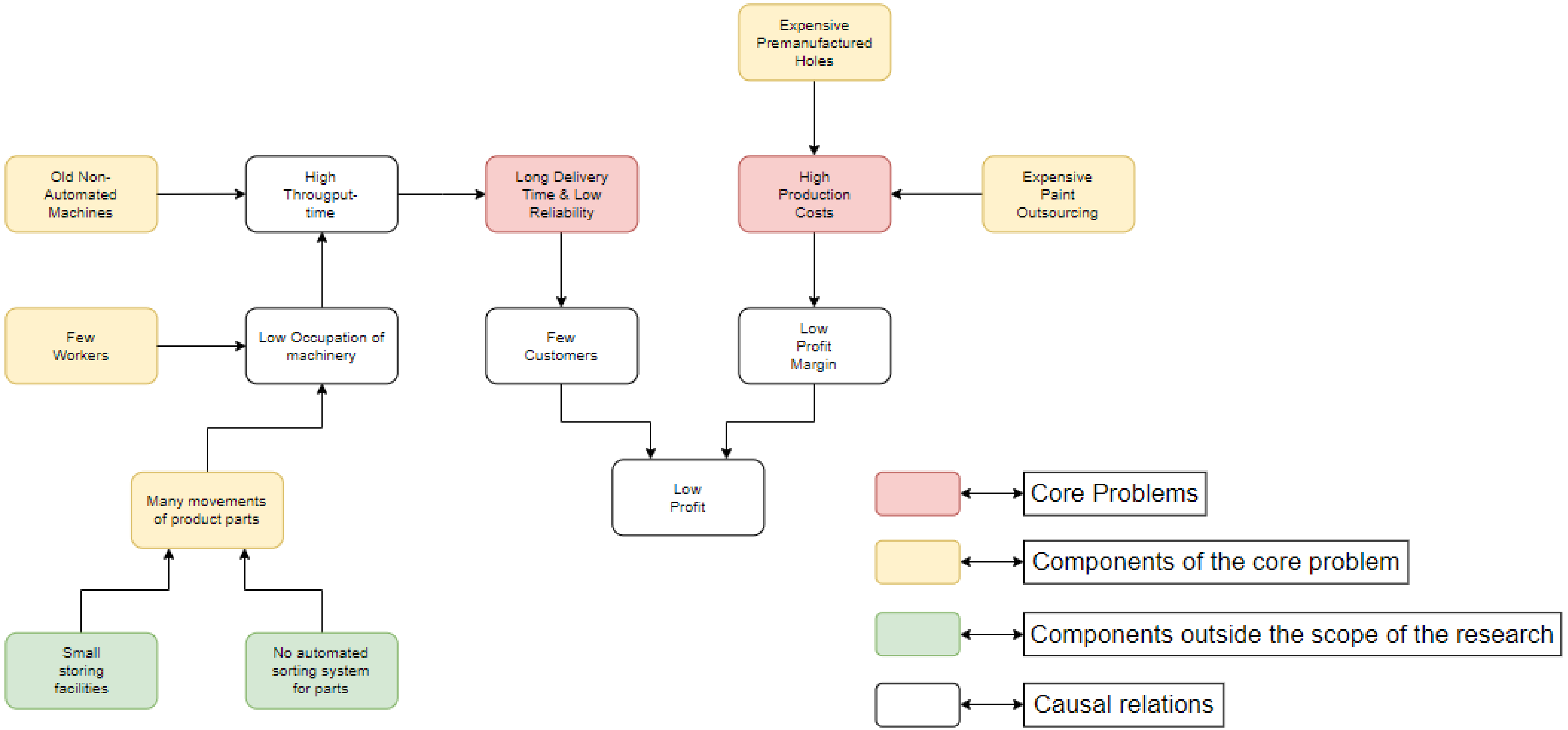


Figure 1: Problem cluster

1.2. Methodology

Research scope

The scope of this research is to aid in resolving the action problem of BR Products of not being able to guarantee a high delivery reliability, with a delivery time of 4 weeks and an expected growth of 500% in the upcoming 5 years, by designing production process layouts that are ready for the expected future growth to 500% and giving a substantiated recommendation afterwards for one of these designs. Once this is done, BR Products can review the production process layouts designed during the research and possibly implement one of them.

1.2.1. Formulation of problem-solving approach

Before starting with the research, three things need to be found out, according to 'Geen Probleem' by J.M.G. Heerkens and A. van Winden: which **actions** should you undertake, which **questions** should be answered, and which **decisions** have to be made during the problem-solving? Here, the actions to undertake are more concrete and detailed than the actions shown in the problem cluster. These actions range from arranging meetings to writing the final report. The questions that need to be answered are summarized by the research questions, but there are many more underlying, smaller design questions and the decisions range from how the work is planned to which data collection methods are used.

Actions

First, the part of which actions to undertake will be addressed. This starts with the writing of this project plan. It helps to understand what exactly will be researched and how to do that. Then data should be gathered about every piece of the present production process: purchasing, production and sales, but also about which machines BR Products recommends using. With that comes the question of which modelling techniques there are for modelling the current production process. After that a new layout for the production process can be setup, in which all norms will be implemented. In the meantime, some meetings with the principal of both 'BR Products' and 'Begra Magazijninrichting' should be held to update the company about the progress and ask for information need to continue the work. It was agreed to do this once a week, so the progress would be substantial, but also not a lot has to be rewritten if something does not fit the company's needs.

Questions

Secondly, the questions that need answering to set up a new production line layout. The research questions are the main questions, but these are rather large and summarizing questions. The underlying questions like "how much does the company produce per hour in present conditions?" are implied to have to be answered by these larger knowledge problems but are not clearly pointed out yet. Basically, all these questions refer to the company's state now to use the data gathered from the answers for calculations. All the answers to these questions will be gathered by using the data collection and research methods described in Section 1.2.2.

Decisions

Furthermore, the decisions to make refer to the decisions before starting the research (e.g., who will take section in this research, which problems will be solved) as well as to the decisions during this research (e.g., which setup should be recommended, how to present the findings). The decisions to make during this research are unknown at the moment, these will be denoted in the final report. Regarding the questions before starting the research, the first decision was who will participate in the research. As said, both principals of 'BR Products' and 'Begra Magazijninrichting' will participate in the meetings and therefore have an influence. It also should be decided what aspects of the designing to disregard. As earlier mentioned, the research will not be taking the small storing facility and lack of an automated sorting system into account, because they lie outside the scope of this project. The working conditions and accompanying costs (heating, cooling, cantina, etc.) will also not be added in the research for this is not a significant factor in determining the most optimal production layout.

1.2.2. Data collection and research methods

As stated in Section 1.1.1. (Action problem and research questions), several data collection and research methods will be apprehended to answer the research questions. In the following section, the methods that will be used for each research question are explained and a reasoning for why these are used is given.

1. *Which techniques for modelling the current process are there?*

The first research question has been answered through literature reviews. As there is a lot of knowledge already available on the topic of process modelling, making use of a literature review seems easy and logical. By searching for academic articles, all required information can be obtained to make a well-considered decision on which technique fits this research best.

2. *How does the current production process layout look like?*

For the second research question, unstructured and semistructured interviews will be used. Unstructured means that you do not prepare questions up front and just let the conversation flow to several topics within the scope of this bachelor assignment. The semistructured interviews will be held with some questions in mind that were encountered during the work on this bachelor thesis. These interviews are, however, also free to go in any direction, as long as the predetermined questions are answered. The reason for choosing unstructured and semistructured interviews instead of structured interviews is that at the start of this bachelor assignment, a lot of general information about the company and its current production process layout is required. Because unstructured and semistructured interviews leave a lot of room for the discussions to flow to 'undiscovered' questions (by which it is meant that these questions were not thought of beforehand), all the aspects of this research are easily mapped, and it is quickly determined which aspects this research will and will not focus on. As the Oxford Handbook of Qualitative Research (2014) states: "(structured interviews) do not take advantage of the dialogical potentials for knowledge production inherent in human conversations." and that semi-structured interviews make better use of the knowledge-producing potential of dialogues.

3. *What are the requirements for a good production process layout for BR Products?*

The third research question can also be answered through semi- and unstructured interviews. By using these interviews, the vision of the principal of BR Products was clarified, which lead to the requirements and KPIs used in this research, as stated in Section 1.1.4. These interviews were combined with the interviews for the second research question. By interviewing the principal of BR Products about the future of the company, all information required for answering these questions can be acquired, not necessarily in the order the research questions are in.

4. *Which optimization methods are available for optimizing production processes such as that of BR Products?*

Then there is the fourth question, which will be handled a bit differently from the other three. This research question will be answered through a systematic literature study about and analysis of optimization methods for production processes. The full systematic literature review can be found under Section 3.1.

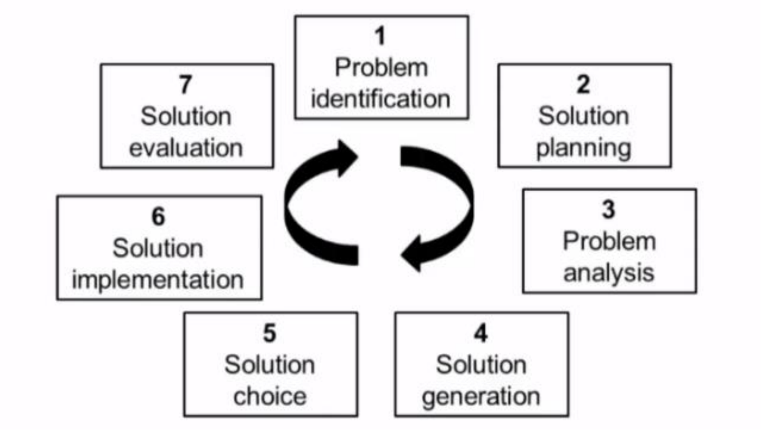
5. *How should the solution approach for generating the most suitable production process layout for BR products look like?*

The fifth research question, will also use literature review as information gathering method, as a lot of information about solution approaches is available in literature, which can be used to make a substantiated choice for an approach. The literature research for this can be found in Section 3.3.

1.2.3. Research design

During the research, the managerial problem-solving method or MPSM (Heerkens & van Winden, 2012) will be used. The MPSM is very widely applicable methodology to identify, analyse and then resolve an action problem. Especially because multiple models will be made, the phase of comparing solutions suits this research well. However, the implementation and evaluation phase will have to be based on the opinions of the managing directors of BR Products and Begra, instead of observations, because the scope of this bachelor assignment is not to implement the final solution, but just to find this solution.

Figure 2: MPSM



The research that will be done is descriptive of nature. Data from the previous year of production, data on new machines, etc. will be used to set up the solution approach. The outcome of calculations within the possible optimization methods will be the results, so no relations between variables have to be explained (which is explanatory research).

The MPSM consists of 7 phases, as shown in Figure 2. Here each phase, together with what needs to be done in that phase, will be explained, including which knowledge problems will be solved and how.

Phase 1: Problem Identification

This is the phase where you choose the problem that you want to solve. Here the action problem is found by analyzing the present situation. In this research, it was discussed with the principal of BR Products what he would like to have researched. As he said they are planning on expanding and redesigning the production process, it was decided that the research would be about optimizing the production process. The main action problem he stated was that the present location and layout of the production process have a delivery time and delivery time reliability that are too low and also that they cannot provide for the expected growth of 500% in 5 years with the norms of a delivery time of 4 weeks, a drastic increase in delivery reliability and a cost reduction of 20%.

Phase 2: Solution Planning

In this section of the MPSM you plan the way to the solution. This consists of three things: do, know and choose. This phase of the MPSM has already been completed.

Phase 3: Problem Analysis

Here you should dissect the problem; find out all that you need to set up for finding a solution. What is the exact nature of the problem? What are the causes of the problem? What are your limitations? During phase 2 and 3 one derives the knowledge problems one will have to solve and translate these into research questions.

Phase 4: Solution Generation

In this phase you set the requirements for a solution, check whether these requirements are good, generate solutions. In this phase, the chosen optimization method will be executed. The comparison of optimization methods and solution approaches can be found in Chapter 3. The semi- and unstructured interviews were used in the first four phases of the MPSM and therefore the answers to the second and third research question were found in phase 4, shortly after making them in phase 3. By conducting these interviews in phase 4 a proposition for a production process layout could be made in phase 5. Only the proposed production layout is discussed in this research as other discussed layouts were quickly confirmed to be unsuitable.

Phase 5: Solution Choice

Phase 5 covers the final choice between the alternative solutions that have been generated in phase 4. In this research this will be done by proposing a production process layout, using the in Section 3.3. determined process layout planning approach.

Phase 6 & 7: Solution Implementation and Evaluation

As said earlier on, the implementation phase of the MPSM is not included in this bachelor assignment. However, instead of skipping both the implementation and evaluation phase and leaving them for someone else to do, the evaluation will be done by comparing the current situation with the proposed situation and by presenting the final result to BR Products and asking them what they think of it.

1.2.4. Validity and reliability

Validity and reliability are of great importance when conducting a research. If a research is not valid, it means the researcher has misinterpreted either numbers or relationships, which makes the outcome useless if it is also unreliable. If it is reliable you must account for the difference between your measurements and the reality. If your research is unreliable, that means that the measurements will not produce identical results every time you repeat it. Unreliable results cannot be used for proper research because they generate too much uncertainty around the results.

Of this research only two aspects are susceptible to reliability issues, which are the measuring of certain production or transportation times and the exclusion of human errors. However, most of the times that must be known are confirmed by the manufacturer of the machine and if not, a stopwatch will be used for this research. By elaborately defining what has been measured (e.g., from the push on the start button of the machine to the 'beep'-sound of that machine which indicates that it finished the job), no significant errors can be made regarding reliability of the measurements. The possibility of starting or stopping the stopwatch slightly to earlier or late will not significantly influence the results and will therefore not be compensated. The exclusion of human errors enables easier designing, but also ensures differences between the results of this research and the reality. These differences will be accounted for in the form of adjustments to the final results. A note on this reliability issue will be added to the results and conclusion of this research as to ensure the reader understands that these numbers are not likely to occur in reality and are slightly optimistic. No further steps of the research have a factor that could cause reliability issues, these are all part of the validity check.

There are 3 common types of validity according to Dr. J.M.G. (Hans) Heerkens: internal, construct and external validity. Internal validity is about whether you are measuring exactly what you want to measure. In this bachelor assignment the formulas or theories used will need to be checked on their internal validity. Many relations between values can be checked through use of widely accepted formulas (such as $E=mc^2$), however, some values are slightly more uncertain to be true as there is no database available within BR Products that confirms this. To make sure these are valid, interviews will be held with the principal of BR Products.

Construct validity concerns the question: Are your variables operationalized properly and are these variables and indicators based on the scientific body of knowledge? The scientific body of knowledge holds all knowledge that has been proven for a specific situation. Through use of theorems and theories from the scientific body of knowledge, the variables will be checked on their construct validity.

With external validity the validity of results outside of the research population for that specific research is meant. In this case the research is relatively generic. The results of this research might benefit other companies that are in a similar situation (expecting a large growth and not being able to cope with it with some requirements in mind) and even companies who are just looking to improve their production process layout might learn from this research. This does, however, not mean that the exact same research with the exact same numbers leads to a solution for a different company, just that the improvements made to the production process layout during the research might be suitable for other production companies.

1.2.5. Limitations

As the production process layout that will be modeled will not be implemented for at least 5 years, it is hard to evaluate the found optimal solution any time soon. This is a big limitation for the final product of this research, as we cannot check the results other than in the theoretical situation. Another limitation is the time available. This is also the main reason for excluding the automated sorting system and storage facility core problem components from the research. In addition, the data acquired from the company is assumed to be correct, however, this may be a bit off as there is no database available except for the produced goods in 2017. This data has been checked by the principal of BR Products, but still the reliability of this data is a bit uncertain. This in its turn means that the results from the research are as reliable as this initial data acquired through interviewing the principal of BR Products and are therefore also a bit uncertain. As a last limitation, there is the fact that this research will not be taking human errors into account and is purely theoretical. This might lead to some differences between the theoretical results of this research and the reality (once the results are implemented). As stated earlier, an explanation on why the results look so optimistic will be added to the final report to illustrate this difference.

2. Current situation

In this chapter, the answer to the second research question:

2. *How does the current production process layout at BR Products look like?*

is found through semi- and unstructured interviews, as stated in Section 1.2.2. By asking company representatives about their production process layout and walking through the facility myself, the current situation could be modelled, thus answering this.

2.1. Description of production process

At the moment, the production is run by about 6 people at a time; 4 handling the equipment and 2 doing the management, planning and communications tasks. Of the 4 people handling the equipment, one drives the forklift for moving the beams and crates of arms and feet around, one welds the beams, one welds the feet and one operates the welding machine for the arms. In the meantime, either of these 4 operates the beam punching machine when the machine is done with a beam and one of the workers has time to spare. As mentioned before, the production takes place in a small factory in Oss. The layout of the production facility and a schematic view of the production process layout are shown in Figure 3. Here we can see that the production process starts with the delivery of the purchased order from the supplier. The supplied materials are steel beams, arms and the hooks for them and feet. Besides these, there are several other (smaller) parts, but these do not influence the production process layout as they are not manufactured or altered by BR Products.

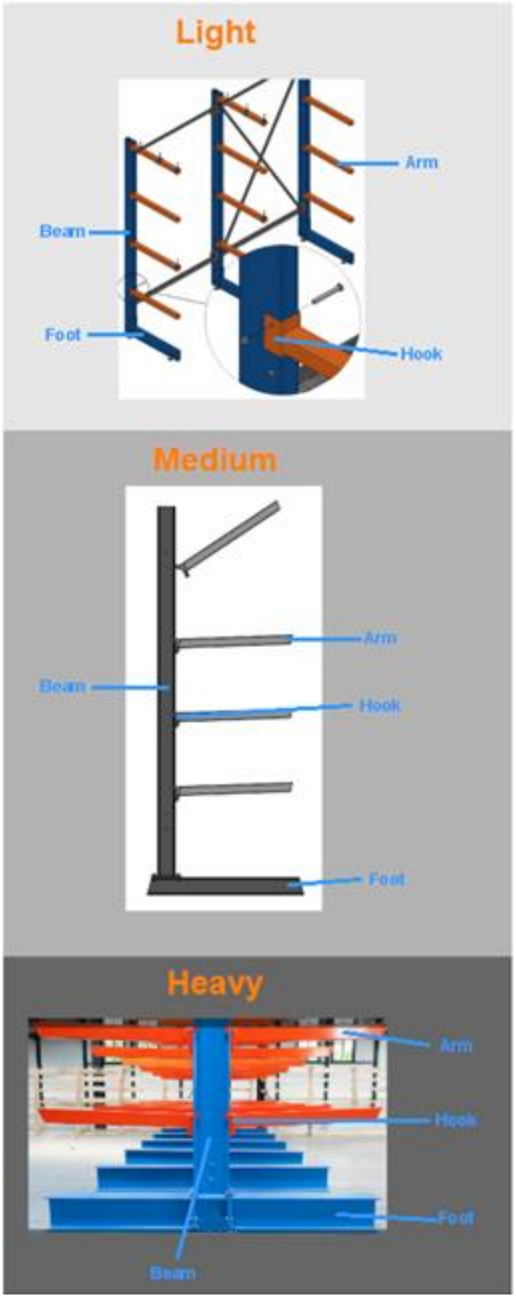


Figure 3: Types of storage racks

In Figure 3, all parts can be seen for each of the three types of storage racks: light, medium and heavy.

The beams are moved to the punching machine where the holes for both the hooks are punched. The duration of this process is dependent on the length of the beam. As of now, BR Products produces a wide variety of lengths which gives the client a lot of possibilities, but also increases the number of setups needed. The light beams are already punched, so these do not need to go to the punching machine (as shown in Figure 4). After a beam has been punched, the beam will be transported by forklift to the beam welding station. Here a worker manually welds a bottom plate to the underside of the beam, which is also used for attaching the feet or supporting piece.

The arms and feet will be sent to the welding machine. Here the hooks will be welded onto the arms and the feet will be welded to a metal plate that is vital for bolting the feet and beam together. The welding is a slow process at the moment, because the arms and feet need to be rotated by a worker half-way through the welding process.

Besides the production, the purchasing of components will be quickly looked into (as stated in the problem cluster). Now, the beams are purchased with some holes in them already. This removes the need for extra punches but is more expensive. Another thing is the painting of the storage rack components; the small painting company adjacent to the facility of BR Products paints the finished sections. However, this is a painting company with little capacity and communication about order due dates is either absent or unclear. The painting and coating of the production is not taken into account in this research as this would increase the complexity by too much.

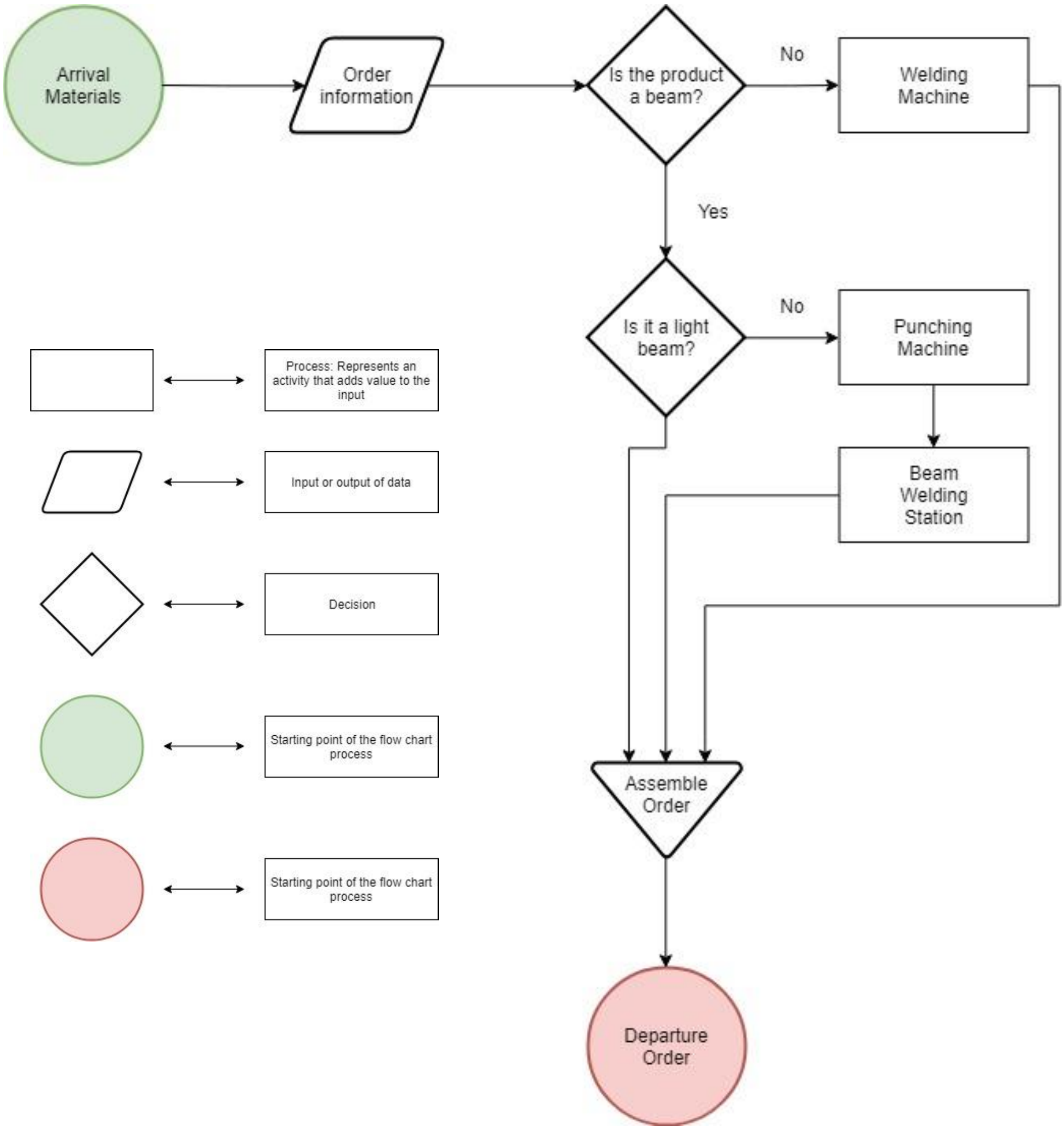


Figure 4: Flow chart of current production process

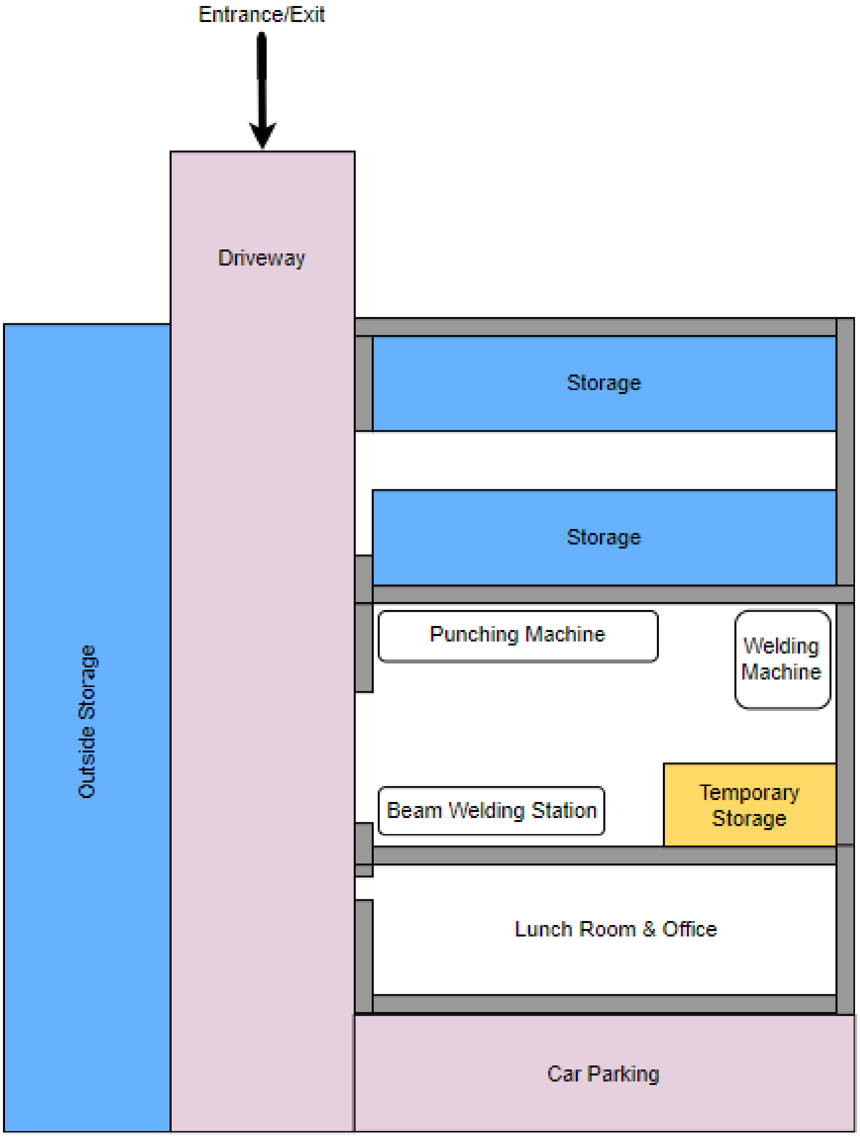


Figure 5: Map of current production facility

2.2. Requirements and measurement of production process

In this section, semi- and unstructured interviews were used to acquire the requirements of a good production process layout as seen by BR Products, the answer to the third research question:

3. *What are the requirements for a good production process layout for BR Products?*

These interviews were steered slightly to what the wishes of BR Products are for a production process layout as to gain insight in their view on what a good production process layout should look like.

As of now, the company encounters the problem of being too expensive for their customers compared to other competing companies. According to earlier research by BR Products, the selling price of BR Products is about 20% higher than the competitors' prices, which immediately shows us the difference between the norm and reality of 20% in selling price. It is assumed that all companies use the same costs to selling price ratio, so the difference in selling price can be translated to a cost price difference of 20%. For a production process layout to be feasible, however, BR Products agreed that a reduction in cost price of 20% is not strictly necessary, but the cost price should stay at least the same. Another section of the norm is the production capacity. BR Products expects to grow to 500% of the production now in the upcoming 5 years, which makes a capacity of 5 times the production now another requirement for a new production process layout. Here it is assumed that BR Products is now running at full capacity, so the capacity now is equal to the production, which has been confirmed by BR Products. The capacity in 5 years will be estimated according to the capacity of the machines in the production line. This will be purely theoretical, so no malfunctioning machines and no delays due to human error (e.g., workers being late, elongated lunch breaks, etc.). Then, there is the issue of the delivery time. BR Products would like to see a delivery time 4 weeks, however, the current delivery time is not being recorded, so there is no data available to set the reality for the delivery time. This makes the delivery time of 4 weeks unsuitable as a performance indicator, but useful in speculations about capacity flexibility. The requirements stated above will be summarized by several key performance indicators (KPIs) that will be used to evaluate both the current production process layout and the improved production process:

KPI	**Linked requirement**	**Meaning**
Maximum capacity	Coping with demand	The maximum amount of products that can be produced in 1 shift of 8 hours
Total handling times per product	Coping with demand	Beams: time it takes to go from storage to punching line and punching line to beam welding Arms: time it takes to go from storage to arm welding Feet: time it takes to go from storage to feet welding
Total processing times per product	Coping with demand	Beams: time it takes to punch the holes in a beam and weld the beam Arms: time it takes to weld an arm Feet: time it takes to weld a foot
Number of employees required	Reducing production costs	Number of employees required inside the production facility at each time to keep the whole operation running

2.3. Simulation model of current situation

The plant simulation model of the current layout can be seen in Figure 6 and is divided into two separate panels: the 'Control Panel' and the 'Production Line'. The control panel is then also divided into boxes to ease the use:

The "Production Line"-box in the control panel is used for opening the production line model.

The "Settings"-box is for the controlling variables, generators and methods. Here the opening time (start of production), closing time (end of production) and some demand variables are shown. The method InitDay sets the starting values of all variables and creates the number of products stated in the variables above it. The reset method removes all products from the process once a day is finished and deletes the contents of the tables in the "Perfomance Measurement"-box, which will be addressed shortly after this. The two generators "Morning" and "Evening" make sure that InitDay and Reset are called at OpeningTime and ClosingTime, respectively.

The "Factory Control"-box contains the EventController, which sets the duration of a run and the method TrackProductionTimes. TrackProductionTimes tracks the time attributes that the products have been assigned, as its name suggests, but also controls when and where a product is passed on to for every step of the production process for each product.

The "Perfomance Measurement"-box is mainly for researching purposes. This box contains the variables and tables that show the most important output information. These update throughout the run, so at every moment in the run these are good indicators of either successful production or failure somewhere in the process. These were also used to confirm that the plant simulation model works exactly as intended, such that it corresponds with the reality.

The "Experiments"-box holds the two variables used for testing and comparing: the number of shifts and the number of beams demanded that day. These are used as input for the ExperimentManager, which can conduct multiple runs with different input values, as to ease the process of conducting large amount of experiment runs.

Then there is the production line panel. Here the current production facility layout is used as to show the positioning of the machines and storages. When the model is running, the parts can be seen flowing through the various buffers and processing stations until they arrive at the storages. The buffers are used as storages, from which the first item is moved to the processing station corresponding with it when this station is empty. The SinglePunching and DoublePunching processing stations are one processing station in reality. The reason for splitting this up into two in the model is to make the implementation of the different punching times for beams easier. To ensure that one beam is punched at a time (as is the situation currently) a constraint is used that both processing stations need to be empty before a new beam is moved to one of them. This is also used in the proposed production process layout. The rest of the objects in the production line panel speak for themselves: a buffer (queue) for each production step and the production steps themselves.

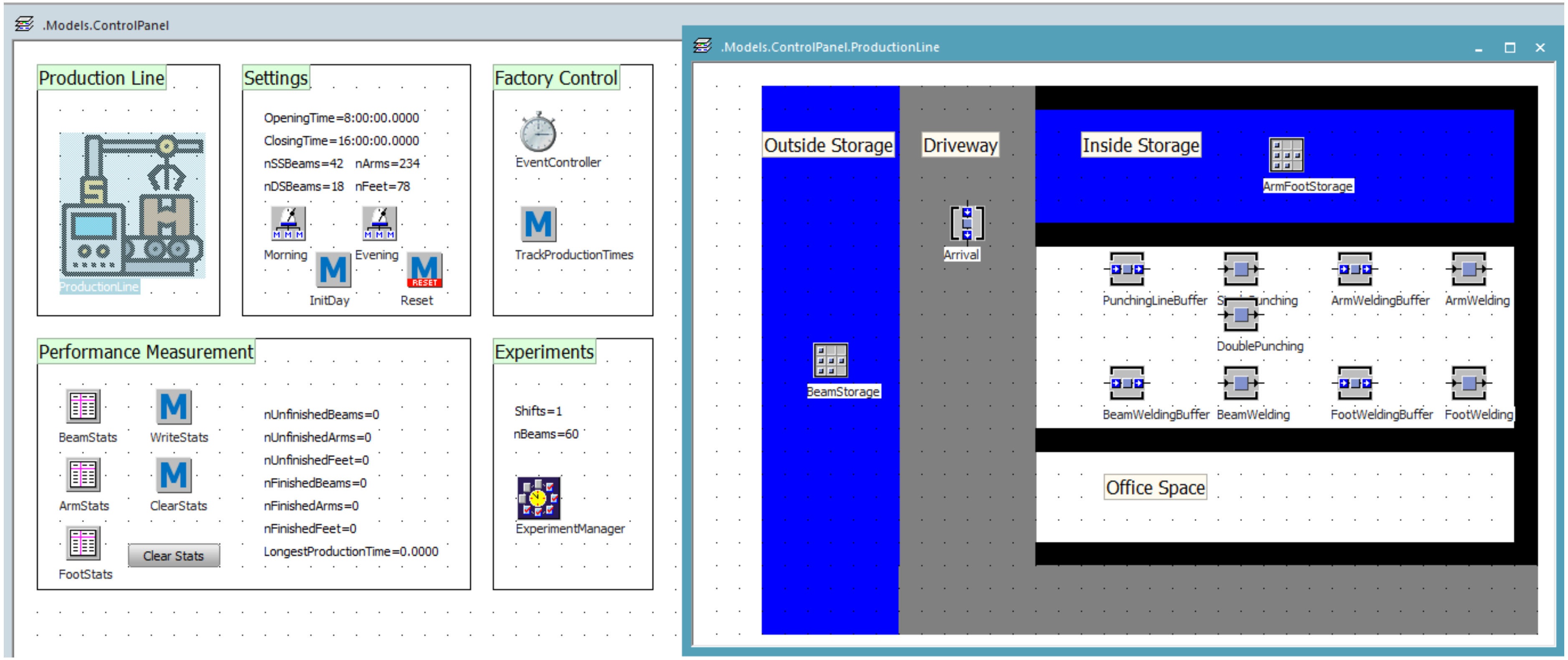


Figure 6: Simulation model of current production process layout

2.4. Evaluation of current situation

To evaluate the current situation, the four KPIs from Section 2.2. are used. The values for these KPIs show the performance of the production processes so that they can then be compared to validate and verify the improvements in the proposed production process.

Maximum Capacity

The maximum capacity of the current production process was determined to be 20 beams, 46 feet and 88 arms per shift of 8 hours.

Total Handling Time and Total Processing Time

The handling times and processing times for each product were derived from the interviews with BR Products. On average the handling surrounding the beam punching line is 5 minutes per beam, the handling for the beam welding station is another 5 minutes per beam, the handling for an arm is 1.5 minutes and the handling for a foot is 3 minutes.

Processing times have been determined to be 8 minutes for punching a beam, 18 minutes for welding a beam, 7.25 minutes for welding a foot and 3.5 minutes for welding an arm.

The total times can be seen in Table 1 below. These times were measured by stopwatch and are used as input variables for the simulation model of the current production process layout.

Table 1: Total Handling and Processing Times Current Situation

Product	**Total Handling Time (min)**	**Total Processing Time (min)**
Beam	10	26
Arm	1.5	3.5
Foot	3	7.25

Number of employees required

As stated at the beginning of this chapter, the production process runs with the help of 4 employees operating the machines and equipment.

3. Theoretical Framework

In the theoretical framework the theories used in this project plan are shown by a systematic literature review. The question that will be answered through the systematic literature review is the fourth research question: "*4. Which optimization methods are available for optimizing production processes such as that of BR Products*?". This systematic literature review can be found in Section 3.1, the systematic literature review protocol can be found in Appendix A: Search Queries Literature Review and Appendix B: Studies Used In Literature Review. Besides the systematic literature review, the various business process modelling methods available for this research will be compared, providing the answer for research question 1: "*1. Which techniques for modelling the current production process layout at BR Products are there in literature?*" and the choice for one of these is substantiated. Finally, the last literature research on solution approaches for generating the most suitable production process layout will provide the answer to the fifth research question: "*5. How should the solution approach for generating the most suitable production process layout for BR Products look like?".*

3.1. Systematic Literature Review on Optimization Methods

There are two well-known methods for solving problems such as the one in this research: mathematical optimization and optimization through simulation modelling. In this section a systematic literature review (SLR) will be executed to find out more about both these methods and choose the one that suits this research best. This SLR will focus on explaining the basics of the methods and the usefulness of each method, rather than an in-depth research on the theories. The main knowledge question that will be answered in this section is the fourth research question:

4. *Which optimization methods are available for optimizing production processes such as that of BR Products?*

The learning goal of this literature review is to be able to determine which optimization method suits this research best. The search queries used during this literature review can be found in Appendix A, the studies and articles used for the literature review are stated in Appendix B and the concept matrix in Appendix C. For this systematic literature review, Google Scholar will be used as data base.

The systematic literature review starts with the decision on inclusion and exclusion criteria; when should an article be considered? These criteria and the reasons for them can be seen in Table 2. After the in Table 2 shown criteria, the SLR will explain some more concrete sub-methods of both the mathematical optimization and the optimization through simulation modelling concepts and finally, a comparison will be made between the optimization methods, from which the most suitable option will then be chosen.

Table 2: Inclusion and Exclusion Criteria

Inclusion Criterium	**Reason**
Article is about the use of open shop scheduling and/or simulation models	The scope of this systematic literature review is to find out about these two types of models
Article is written in English or Dutch	Personal understanding of these languages is sufficient to comprehend the article
Exclusion Criterium	**Reason**
Useful sections of the article are not freely accessible	No budget is available for this literature review
Article is written in a language other than English or Dutch	Personal understanding of other languages is not sufficient to comprehend the article

3.1.1. Mathematical optimization

Mathematical optimization knows many forms. It would be impossible to explain and compare every (slightly) different optimization method that has been written. Therefore, this SLR will focus on two widely used examples of mathematical optimization: linear and dynamic programming. The programming does not refer to 'computer programming' but to the 'preparation of a schedule of activities'.

Linear programming is the "maximization or minimization of linear functions over a region determined by linear inequalities" (Robinson, 2013, p.1). Basically, a main formula is set up with several variables that each stand for the total amount of a product that is produced, together the constraint formulas, which contain the same variables as the main formula. Both a graphical method and a so-called simplex method can be used to maximize or minimize the main formula, however the graphical method is only useful when the number of separate variables is low, because the difficulty of drawing the graphs will increase drastically with the increase of the number of variables. The simplex method can be used even when there are a lot of variables but will require many calculations if the number of variables is high. Besides, linear programming only provides the optimum at a single point in time and therefore does not take the preceding and following events into account. To quickly summarize, linear programming works best when the number of variables is low, and an optimum is needed for a single moment in time, independent of other events in the past or future.

Dynamic programming, on the other hand, does take several periods of time into account to achieve an optimal solution. There are two possible situations where dynamic programming can be used: a finite-horizon problem or an infinite-horizon problem. Finite-horizon means that the number of time periods over which to solve is known, whereas an infinite-horizon means that there is no final period known to calculate the optimal solution for. Dynamic programming solves a case recursively, one period at a time. An infinite-horizon problem will therefore be much more complicated to solve than a finite-horizon one. For a finite-horizon case, dynamic programming can solve a single value of a function at a point in time. In the infinite-horizon case an equation needs to be solved for a function. This shows that dynamic programming is best to be used for cases where more than one period of time requires a solution and the number of periods is finite.

3.1.2. Optimization through simulation modelling

"Many real-world manufacturing problems are too complex to be modeled analytically and in these settings simulation-based optimization is a highly valuable tool." – (Persson, Andersson, Grimm, & Ng, 2007)

The quote above highlights the already stated limitation of mathematical modelling. In complex multi-objective problems such as the main problem in this research, it may be beneficial to use simulation modelling instead of a mathematical optimization method. When using a simulation model to optimize a production process, a lot of mathematical functions have to be implemented. However, these functions are much simpler than the procedure of mathematically modelling and optimizing the problem. After all these functions are implemented in the simulation model, experimenting with various values of parameters is easily done. Also, the simulation model can be adjusted easily if needed; e.g., by altering the processing time of a 'machine' component of the simulation model when a new machine with different specifications needs to be used. There is a wide variety of simulation modelling programs available, but here, for the sake of simplicity, just two programs will be addressed: MATLAB's Simulink and Plant Simulation 13. This choice is not completely random as these are programs well-known to students and frequently used on the University of Twente, which means that there is free access to either of them.

Firstly, Simulink will be explained. Simulink is a commercial software system that uses the MATLAB programming language. As said before, it is a widely used method for simulating systems. Simulink makes use of so-called model blocks. These model blocks can be customized to meet the user's needs, which makes it usable for almost every production process that needs modelling. User-generated blocks can be made through combining already existing blocks or by using a programming language to specify its capabilities. It also makes the built models easily readable by a clear dashboard. The model blocks can be linked together to show the pathing of products or information and text can be added to further clarify the process modeled.

Secondly, we have Plant Simulation 13. Plant Simulation 13 is in many aspects quite similar to Simulink. It is based upon the same idea of using modelling blocks to setup the simulation. However, Plant Simulation already has some pre-defined blocks that remove the need for explicitly programming or building every piece of the production process. For example, Plant Simulation makes use of user interface objects such as the 'SingleProc', which basically symbolizes an activity in the production process a machine or worker would execute with all the possible variables included (processing time, intervals, capacity, batches or single products). All these variables can be easily adjusted to match the wanted situation. Plant Simulation also allows the user to define reusable objects, comparable to the block-making of Simulink. Plant Simulation also has a function to experiment with several values of a variable. This makes researching different variations of a production process layout easier.

3.1.3. Conclusion

In this research, simulation modelling will fit best. The reason for this is that because by designing the process from scratch, all decisions will be connected to each other. For example, if a machine suddenly needs two operators instead of one, the amount of personnel needed increases too. Simulation allows for easy changes if a problem is encountered, whereas mathematical modelling with various objectives will be much harder to adjust once finished and will be a lot more work than adjusting the simulation model. Also, from own experience, simulation modelling is easier than mathematical optimization and requires less manual calculating.

Then, even though there are not many differences between Simulink and Plant Simulation 13, the latter will be used. This is because this program has already been used for a couple of months, so the skill to work with it is far higher than for Simulink. From own experiences, the program is easy to use and the dashboard is understandable for everyone, so showing the stakeholders what has been designed and how the process works will not cause any problems. This, in combination with the research function where it compares different inputs, makes it perfectly suitable for the research that will be conducted.

3.1.4. Plant Simulation 13

To understand the basics of the dashboard, the most basic elements will be explained here. For a detailed tutorial on Tecnomatix Plant Simulation 13, see 'Simulation Modelling using Practical Examples: A Plant Simulation Tutorial' by M.R.K. (Martijn) Mes.

Material Flow Objects

These objects generate, move and hold and dismiss 'MUs' (movable units). They can act as machines and waiting rooms.

Information Flow Objects

The Method object can hold any code you have created to add, e.g., restrictions or delays to MUs passing from one material flow object to another, but also to store data in a certain TableFile object or show the value of a variable on the dashboard in the Variable object.

User Interface Objects

The Comment object lets you add text in your dashboard without influencing the process and the Button object can be assigned to do whatever you want and will activate when clicked.

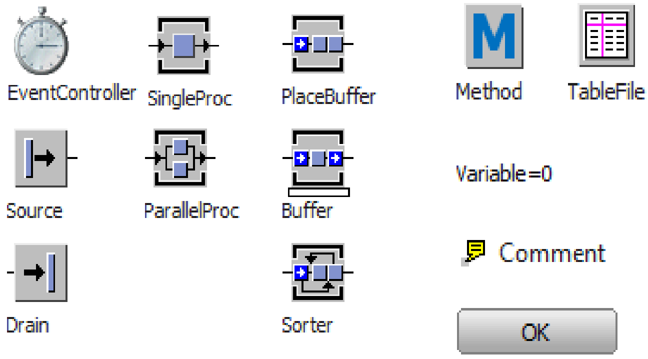


Figure 7: Dashboard elements of Plant Simulation 13

3.2. Business process modelling techniques

There are many well-known business process modelling techniques available, so choosing the right technique may be challenging. To make it manageable, only a couple of these techniques will be considered: the flow chart modelling method, data flow diagrams (DFD), Integrated Definition for Function Modelling (IDEF) and the Business Process Modelling Notation (BPMN). In this section, these four techniques will be shortly explained and compared to each other. Finally, the best modelling technique for this research will be chosen, based on the comparison of the techniques.

3.2.1. Flow chart modelling method

The definition of a flow chart is: "a formalized graphic representation of a program logic sequence, work or manufacturing process, organization chart, or similar formalized structure" - (Lakin, R., Capon, & Botten, 1996). Like the other three techniques that will be addressed in this section, the flow chart is a graphical representation where one uses symbols to visualise, e.g., activities and flows. The flow chart model is known for its flexibility and ease of use. The flow charts support a wide variety of ways to describe a process and are usually quickly drawn. Although this method has been used for many years and probably will be for many years to come, the method has some considerable disadvantages. The flow charts used for this method are sequential and do not support the parallel modelling of activities. Also, in a flow chart there is no visual distinction between main activities and sub-activities. Besides this, there are no clear boundaries for the modelled process and the models tend to be extremely large, which makes it hard for the viewer to get information out of it easily. The main use for this modelling method is to model processes that require a high level of detail as Aguilar-Savén (2004) states. The main no-go for the method is giving an overview of a process.

3.2.2. Data flow diagrams

Data flow diagrams (DFD) show us the flow of data or information within a process. It is a leveled model of the data flows within a process, showing the viewer the path data takes through the business and how the processes (data processing) link together and relate to the outside world. A limitation of DFDs, is that they show no information about the flow of materials, but just about the flow of data. DFDs are mainly used to show the dependencies between processes; the path the data takes, from entering the process to exiting it; which activities change the data and where the data is stored in the process.

3.2.3. Integrated Definition for Function Modelling

The Integrated Definition for Function Modelling (IDEF) family of methods, as it is called, provides a paradigm capable of modelling an enterprise and its activities. The main IDEF process-modelling method is IDEF0. This will be the one that will be reviewed in this section. IDEF0 is used a method to visualize processes or complex systems as enterprises. The IDEF0-model shows the main activities in the enterprise as well as the informational and material input and output and mechanisms connected to this activity. The IDEF0 process-modelling method is the most popular on the market (Aguilar-Savén, 2004). Two advantages of the IDEF0 are that the strict rules make it suitable for implementation as computer software and it can be improved through backwards analysis of the model. A disadvantage of using IDEF0 is that if the processes need to be decomposed to show lower-level activities, another additional notation might be required.

3.2.4. Business Process Modelling Notation

The Business Process Modelling Notation (BPMN) was developed with the primary goal of providing a graphical model that is understandable and easy to read for every business user. BPMN is based on the flow chart method that is earlier stated in this project plan. However, the BPMN combines the description of activities in an enterprise (flow chart method) with the notation of information and data flows. Because of this, a BPMN model provides a detailed overview of all activities and flows within a company and can be used to easily gather information about each activity in the company. BPMN also creates a bridge between business process design and process implementation (White, 2004). The main use of BPMN is to create an easily readable and complete model of the activities, participants and information flows in a business process.

3.2.5. Comparison and conclusion

Many techniques are available in literature for modelling a production process, however, to keep things manageable, the following were chosen based on popularity: Flowchart, Data flow diagram, IDEF and BPMN. This answers the first research question:

1. *Which techniques for modelling the current production process layout at BR Products are there in literature?*

Each of the four business process modelling methods has strengths and weaknesses. The flow chart modelling method is mainly useful for modelling the of solely activities in a process, whereas the DFD technique is useful for describing solely the data flow within a process. The IDEF0 and BPMN combine the depiction of activities, material flows and data flows. The IDEF0 method might get complex quickly though, whereas the BPMN might be just as complete as the IDEF0 but stays simple and clear. However, because this research will mainly be focusing on the activities within the process, the BPMN would be an overkill method to describe the process. The DFD technique is not a suitable technique as well as a cause of the focus on activities rather than data flows. Because the flow chart method gives a clear and complete overview of the activities in the process, while being adjustable to the level of detail needed, this method should suffice for this research and will therefore be apprehended in this research.

3.2.6. Flow chart

As the most suitable business process modelling technique has been determined to be a flow chart, this section will explain what each component in the flow chart stands for. The flow chart model made for this research can be found in Figure 4. The flow chart shows the current production process, as described in Chapter 2 of this project plan, by using symbols. The symbols used in the flowchart are denoted and explained in Figure 4 as well.

3.3. Process layout planning approach

To design a new production process layout, many things should be known and considered. In the past, a lot of approaches to successfully design such a new layout have been constructed. To determine which approach should be used, several case studies will be shortly reviewed on their choice for layout planning approach and argumentation for this. Then from this, the suitable method for this research will be drawn.

In the first case study about process layout planning with simulation "Optimizing Facility Layout Through Simulation" (Kriel, 2010), Muther's Systematic Layout Planning or SLP is used. Kriel's reasoning for this is that the SLP is "versatile" and can be used in many situations or companies. In Kriel's research, several approaches have been compared and the case is quite similar to this research (optimization of a production process through simulation), which leads to believe that Muther's SLP is a suitable approach for this research as well.

The second reviewed case study is "Facility Planning: An approach to optimise a distribution network at Clover SA" (Grassie, 2009). Here the conclusion after an elaborate comparison of layout planning approaches is the same as that of Kriel: SLP. Grassie adds that the SLP of Muther "is well known…and has been proven to work effectively in the designing of facility layout."

Another benefit of the SLP is that it is broadly applicable and can be easily adjusted to your research. In this case for example, the space requirements and space available are not part of the design, so these steps can be skipped without this rendering the SLP useless. Also, every step in the SLP can be done as extensively as needed for the research. Even if e.g., a process has a small number of material flows but a lot of practical limitations, the SLP is still a perfectly fine method to use, due to its flexible nature.

Conclusion

As at least two of very similar case studies use the SLP approach of Muther, it can be safely assumed that the SLP is a suitable method for determining the proposed production process layout in this research. Modifications can be made such that the steps taken suit the research completely and still every aspect of designing a new production process layout in this case is taken into account when passing through the steps.

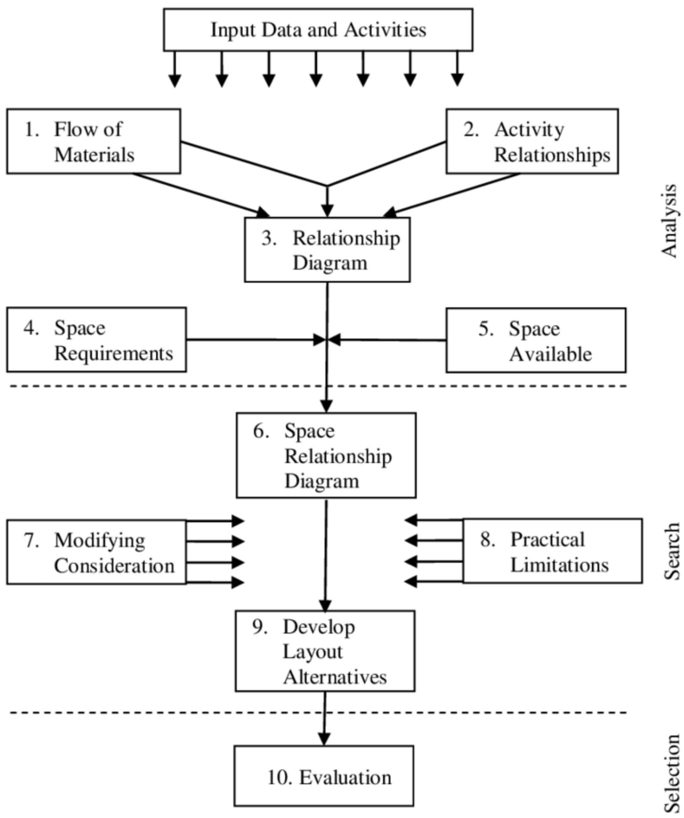


Figure 8: Muther's SLP Steps

3.4. Summary and conclusion

In this chapter, several methods for different parts of the designing process were compared and discussed. Now that for every section a choice has been made, the answer to the research questions stated at the beginning of Chapter 3 can be summarized:

1. *Which techniques for modelling the current production process layout at BR Products are there in literature?*
4. *Which optimization methods are available for optimizing production processes such as that of BR Products?*
5. *How should the solution approach for generating the most suitable production process layout for BR products look like?*

A flowchart was chosen for the first research question, simulation optimization for the fourth research question and the SLP for the fifth research question. The flowchart was used to map the current production process, the SLP is the main solution generation approach and the simulation is used to model and evaluate the solution.

4. Proposed production process

In this chapter, the process of designing a new and improved

for BR Products is described. It starts with all steps taken to come to this proposition, then the evaluation of the proposed production process, a comparison with the simulation model of the current production process, to determine if the proposed production process layout is better than the current one, and finally some further performance measuring of the process together with the possibilities within the newly designed layout and the opportunities for further expansion or improvement. Afterwards, in Chapter 5, the conclusion and recommendations are given.

4.1. Proposed production process

In this section, Muther's SLP and simulation will be used to design a new production process layout for BR Products. Each subsection will delve deeper into a step of the SLP until the 'Development'-phase. The evaluation will be done in Section 4.3. For an overview of all steps of the SLP, see Figure 9 in Section 3.3.

4.1.1. Flow of materials

The first step of the SLP is to determine the flow of materials. In the case of BR Products, there are several components of the end product (storage rack) that are modified within BR Products' production facility. All components can be seen in Figure 3 in Section 2.1 and the flowchart in Figure 4 shows the path of these components through the production process. In this research, only the heavy storage rack production is taken into account, as a request from BR Products. Because by far most of their production at this moment is the heavy storage racks production, they want to base their new production process layout on this part of the production, without considering the light or medium storage racks.

4.1.2. Activity Relationships

In the second step, the relationships between production activities are gathered. BR Products has several production activities: punching of beams, welding of beams, welding of arms, welding of feet, storage of incoming materials and outgoing products and the regulation from the front office. As there are three components of the final product (a storage rack) that BR Products produces, three paths need to be taken into account: those of the beams, arms and feet. These all start together in the arrival of the products activity, after which they are separated into different storage areas from where they will start their production path. The beams move from the storage to the punching line, where the punching activity is performed, and then move on to the beam welding activity. Afterwards, they are moved to the end product storage where they wait for the order to be completed to be shipped to the customer. The feet share the welding activity with the beams, because investment costs are too high for the beam welding and feet welding to each have an own welding robot. Therefore the feet move from their pre-production storage to the same welding activity as the beams and then also to the end product storage. Finally, the arms have their own path, which they start at the pre-production arm storage. Then they proceed to the arm welding activity and finally they arrive at the same end product storage as the beams and feet. The front office should be at least somewhat close to the arrival and departure of the products and the end product storage as to be able to check incoming and outgoing goods.

4.1.3. Relationship Diagram

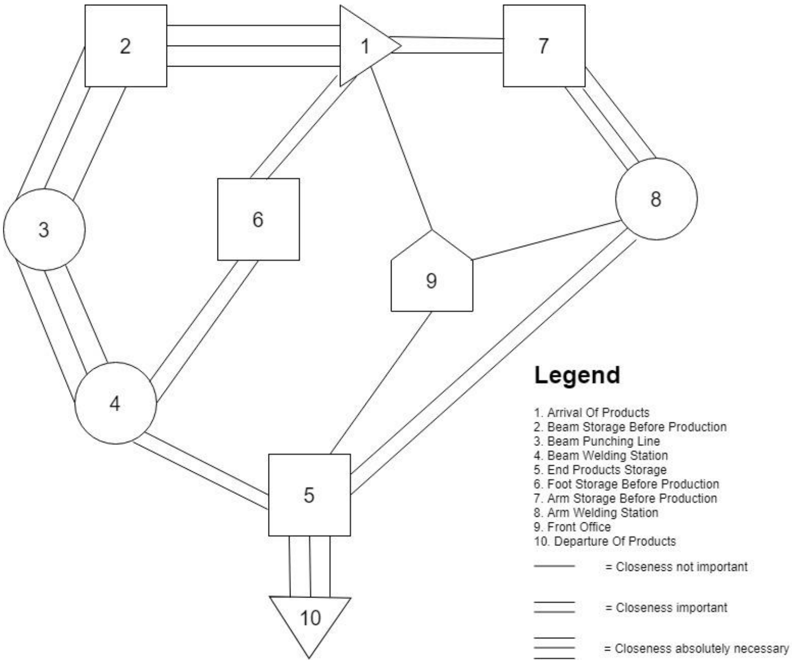


Figure 9: Relationship Diagram

Step 3 of the SLP is to combine the flow of material with the activity relationships and visualize this in a relationship diagram. The relationships between activities and production processes described in Section 4.1.2. are shown in Figure 10, together with the importance of closeness between these activities, illustrated by the number of lines between them (see Legend in Figure 10).

4.1.4. Space Requirements, Space Available and Space Relationship Diagram

Step 4, 5 and 6 look at the spatial possibilities and restrictions of the production process. However, as BR Products has not yet found a new production facility, the space required and available are not taken into account in this research. Only the importance of closeness as shown in Figure 10 will be apprehended in designing a new production process layout.

4.1.5. Modifying considerations, practical limitations and proposed production layout

As can be seen in Figure 9, the modifying considerations and practical limitations are the final steps for generating alternative solutions. In the generation phase of the SLP, an important thing to look at is the general direction in which the products will move through the facility. Muther & Hales (2015) divide the possible flow directions into four: Straight Thru, U-Flow (also called Circular), L-Flow and Comb (or Spine). The decision for which type of flow the production should have can lay the basis for the design. In the case of BR Products, the Straight Thru approach offers some benefits: easy to expand with minimum rearrangement and accommodates different items at receiving and shipping (Muther & Hales, 2015). Because in this production process, there are indeed different items and further expansion is likely to happen (expected growth rate is high), this approach will be kept in mind for the solution generation.

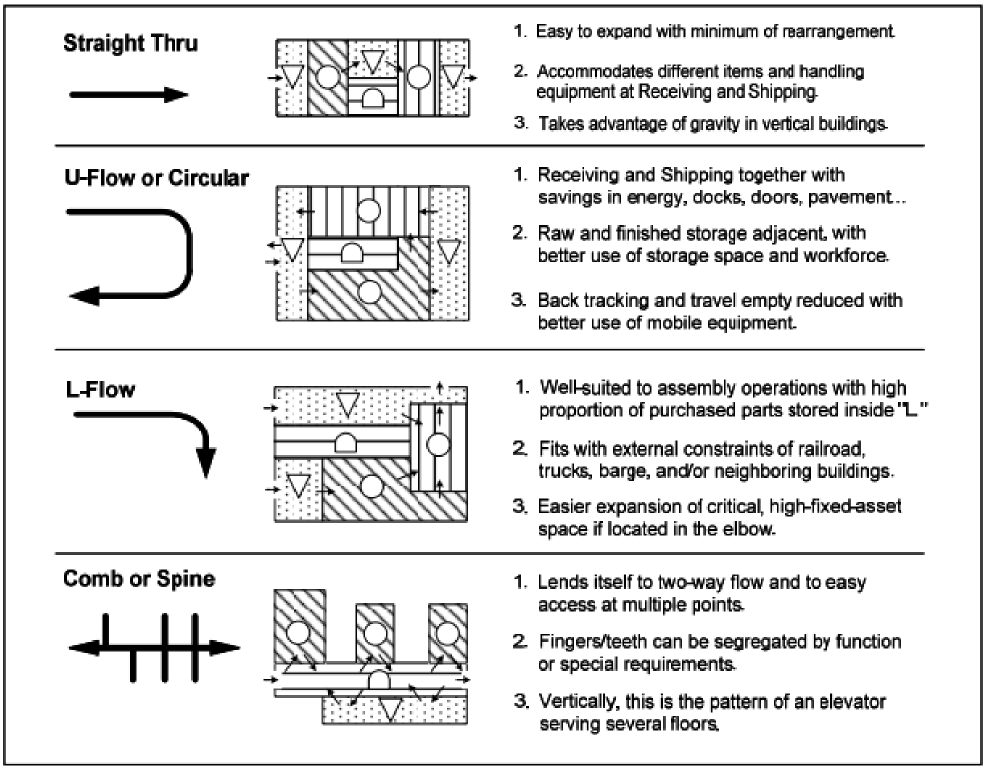


Figure 10: Figure on types of product flows taken from Muther & Hales (2015)

However, not only the product flow is something to account for, there are several other requirements and constraints for a production layout to be useful. One of them is the capacity of the production process. From the numbers from 2017, the expected demand in 2022 has been derived. As BR Products expects the demand to grow to 500% of that in 2017 within 5 years, the demand in 2022 has been calculated to be the following:

Table 3: Expected Demand in 2022

Product	Expected demand
Beams	9500
Arms	37050
Feet	12350

From these three numbers, the beam demand has been calculated through the prognosis of BR Products. The demand in 2017 was 1900 beams, multiplied by 5 this is 9500. As BR Products would like to compare the results from this research with their own prognosis, this research needs to use the same arms and feet per beam. Therefore 3 arms per punched side of a beam are assumed, together with 1 foot per punched side of a beam. This means that a single-sided beam would need 3 arms and 1 foot and a double-sided beam would need 6 arms and 2 feet. Because 30% of the beams are requested with double-sided punching, which leaves 70% to be single-sided, this should be taken into account when calculating the expected demand in arms and feet. Therefore the calculation for the expected demand in feet and arms are as follows:

$$ExpectedNumberOfFeet = 1 * 0.7 * 9500 + 2 * 0.3 * 9500 = 12350$$

$$ExpectedNumberOfArms = 3 * 0.7 * 9500 + 6 * 0.3 * 9500 = 37050$$

Besides the number of arms and feet, the type of beam, arm and foot to build the production layout around were also determined by BR Products, in order for the research to be useful for comparison with their own calculations. This means that all calculations are based on the production times of an IPE 180 beam of 4 meters, IPE 180 feet and 100 x 40 x 3 k arms (lengths of arms and feet do not matter for welding times). Also the handling times of arms and feet have been incorporated in the production time, so handling times are not explicitly mentioned for these components.

If 9500 beams need to be punched equally spread throughout the year, which contains 230 working days in the case of BR Products, the punching machine(s) should have a capacity of 9500 / 230 = 41,3 ≈ 42 beams per day, which would be 42 / 3 = 14 per shift of 8 hours in the worst-case scenario where 3 shifts per day are needed. But because 30% of the beams will have to be punched double-sided, some of the beams will have to pass through the punching machine twice. To be able to cope with double-sided beam orders and peaks in demand the proposed punching line should be able to handle 0.3 * 42 = 12.6 double-sided beams and 0.7 * 42 = 29.4 single-sided beams in 2 shifts or less, as 2 shifts are preferable to BR Products. This means that the beam punching line should have a capacity of at least 14.7 single-sided beams and 6.3 double-sided beams per shift of 8 hours in this research. The current punching machine can handle this, as the total of punching and handling time for a single-sided beam is 8.08 minutes, which means the amount of single-sided beams it can punch in 8 hours is 59 and the amount of double-sided beams is 31. This can easily cope with the demand of 14.7 single-sided beams and 6.3 double-sided beams per shift.

But this is not the bottleneck of the beam production line as, to save investment costs, a single welding robot will weld both the beams after punching as well as the corresponding number of feet for each beam welded, which will take more time than punching the beam, regardless of it being single-sided or double-sided. This welding robot will take 11.54 minutes to weld a beam and 5.12 minutes to weld a single foot. A double-sided beam will not take more time to weld than a single-sided one, so the 11.54 minutes of welding time apply to both types of beams. This means that the total welding time for one beam and one foot is 16.66 minutes and the time for one beam and two feet is 21.78 minutes. Therefore 28 single-sided beams with feet can be welded in a shift or 22 double-sided sets. To fulfill demand when it is evenly spread out over the year, 6.3 double-sided beams should be punched in a shift. This leaves (28800 – (6.3 * (21.78 * 60))) / 60 = 342.786 minutes in a shift for single-sided beams. This is enough to fulfill the 14.7 demand of single-sided beams, however this does not offer a lot of space to counter peaks in demand (20 can be produced in the remaining time).

Then there is the production of arms, which will be done by a single welding robot, similar to the beam and foot welding robot. Based on the prediction of 37050 arms per year, a total of 161 arms should be welded per day, so 81 per shift at least. The welding time of a single arm is 2.725 minutes. This leads the capacity of a single welding robot to be 175 per shift, meaning that the daily production of arms could be completed in under 1 shift, which leaves a lot of room for peaks in demand (or e.g., feet welding).

Another part of the production process layout which has been decided on is the transportation system for the beams. The handling of a beam now takes up too much time and space, so BR Products has decided on using a special type of crane to replace the handling that is now done by forklift. Because of the high speed of the crane chosen by BR Products, only one is needed with the expected demand of 9500 beams per year. This crane can move the beams from the storage to the beam punching line, from the punching line to the welding robot and then finally from the welding robot onto a cart or into another storage, all within the time it takes for a beam to be punched or welded. The investment of such a crane system lies within budget as discussed with BR Products.

An improvement regarding costs is to punch the, now pre-manufactured, holes with the punching machine that BR Products already has, in order to save costs. Each pre-manufactured hole costs €1,- and each beam has 10 holes when it arrives at BR Products. This means that by punching these themselves, they save €10,- per beam. This saves them €95000,- if the demand is 9500 beams. The costs for adding the punches required for making these holes themselves are €30000,- in total, which has been confirmed by BR Products. Maintenance costs of these punches are negligible, which means that in just a third of the year 2022, the investment costs of the punches have already been earned back and that from that point onward, the production cost of a beam drops with €10,-.

As there are many other possibilities to counteract peaks in demand besides adding more machines, which will be stated later on, and a production layout with 1 punching machine, 1 welding robot for beams and feet, 1 welding robot for arms and 1 crane transportation system is the minimum setup that can handle the expected demand, this will be the proposed setup of machines. The design can be seen in Section 4.2.

4.2. Simulation model of proposed production process.

The plant simulation model of the proposed production process layout can be seen in Figures 12 and 13. This model is also divided into the two panels 'control panel' and 'production line'. The control panel has the same layout as that of the current layout model. There are, however, some differences. One of the differences is the content of the "Factory Control"-box. Where there was just one method in the current layout model, there are 6 here. This is simply because the different movement constraints and actions are separated into different methods. This eases the finding of possible problems with the simulation model and also allows for quicker changes. Because while discussing with BR Products and designing a proposed production process layout, it was very likely that changes needed to be made to the model, which was not the case with modelling the current production process layout.

Another difference is in the "Performance Measurement"-box. Here there are much more variables, the FeetStats table has been removed and a method Reset is added. The increase in variables is because more and different experiments will be done with this model than the current layout model. The ones they have in common are mainly used to confirm that the proposition is better than the current layout. The other variables are used as indicators for experiments with peaks in demand and shifts. The FeetStats table has been removed, because the production of feet is not explicitly shown in this model. This is a result of the choice for using one welding robot for both the beam welding as well as the feet welding. As stated earlier this robot will weld a beam and then directly turn around to weld the corresponding amount of feet, which removes the need to model the feet production. In the production line panel (see Figure 13), however, the flow of the feet is shown by the blue area.

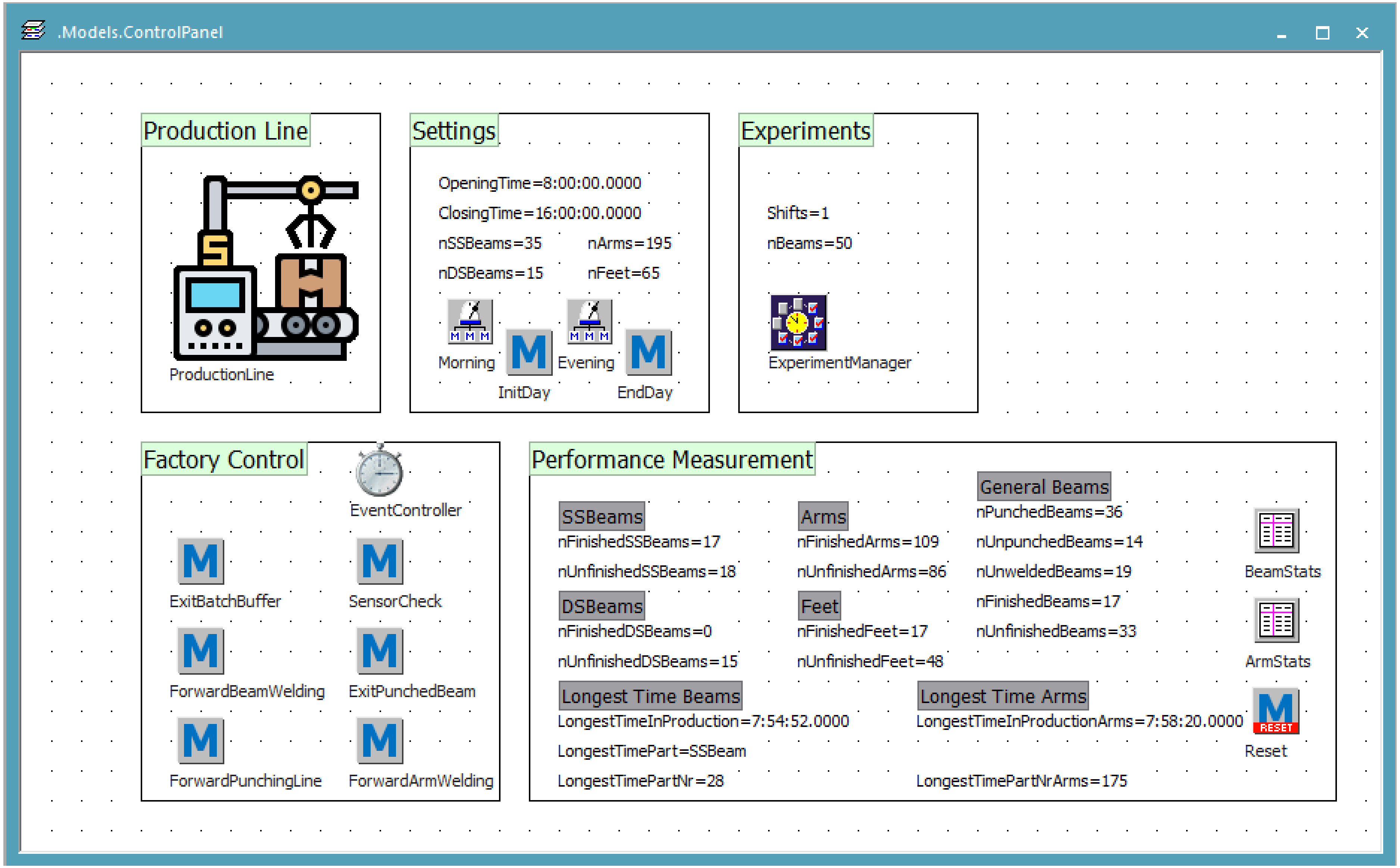


Figure 11: Simulation model control panel of proposed production process layout

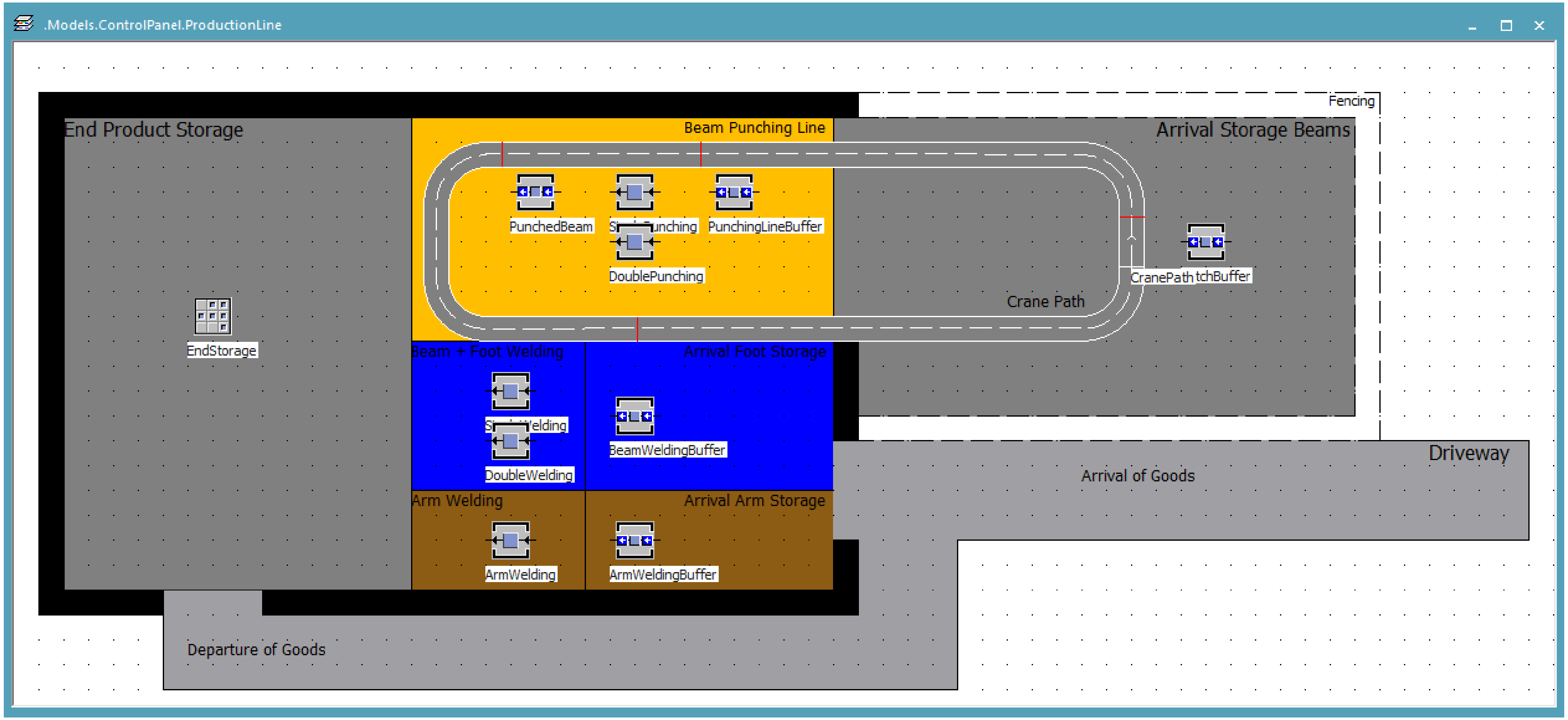


Figure 12: Simulation model production line of proposed production process layout

Reset method simply sets all counters in the box to their initial value (0) when the reset button in the EventController is pressed.

Besides the control panel there is also the production line panel. This panel shows the proposed layout of the facility and processing stations. This is just an example of how the facility could look. Besides the arrival part of the driveway, crane placement and processing station placement, the layout is not fixed, because a new facility has not yet been designed/found for the production. Therefore the storage, exit of goods, wall placements etc. are just one possibility of many.

In this panel a track can be seen, named "Crane Path". This is where the new crane for handling the beams will be placed. For visual purposes this track has been made into a rounded rectangle, however, this crane can move in any direction at any point in a defined space and also transports the beams way above the processing stations, meaning the route shown is longer than its route in reality. As the handling takes the crane such little time that the extra meters of routing do not harm the production in any way, this does not form a problem and therefore the choice for better visual representation was made.

4.3. Evaluation of proposed situation compared to current situation

The proposed production process layout will now be evaluated in the same way as the current production process: through use of the four KPIs.

Capacity

The capacity of the proposed production process layout is 26 beams with corresponding number of feet and 175 arms per shift of 8 hours.

Total Handling Time and Total Processing Time

The handling times in the new situation, as calculated by BR Products, are much lower, but because the speed and path of the crane are not completely certain, the handling times for the beams are assumed to be half of the current production process. This leaves the handling times used for evaluation of the proposed production process layout somewhat higher than what they will be in reality, but it shows the large difference the crane will make. The processing time for the punching line remains the same as the same machine will be used for this layout, the welding times however are lower, because this work is done by a robot, whereas now it is done by an employee. The welding time for a beam has been calculated to be 11.5 minutes roughly. The welding time for a foot is around 4 minutes, with a handling time of 1 minute and the welding for an arm is almost 2 minutes with a handling time of 0.5 minute.

Table 4: Total Handling and Processing Times Proposed Situation

Product	Total Handling Time (min)	Total Processing Time (min)
Beam	5 (punching = 2.5, welding = 2.5)	19.5 (punching = 8, welding = 11.5)
Arm	0.5	2
Foot	1	4

Number of employees required

The number of employees required to run the production process layout is 3 in the proposed production process layout: one employee refills the foot-part of the beam and foot welding robot, one refills the arm welding robot and one is responsible for transporting the final products to the end product storage.

Comparison

In this subsection, a comparison between the current production process layout and the proposed production process layout is made based on the KPIs stated in Section 2.2. The total handling times and total processing times from the evaluation of the production process layouts are used as inputs for the simulation models, together with the number of beams and accompanying arms and feet that are stated in the tables below. The outputs can be seen in the second and third columns of Table 6 and 7. As a final part of the comparison, the performance in terms of demand coverage over the upcoming 5 years is shown, assuming that demand will linearly progress from 1900 to 9500. Here the two models are both run with 2 shifts per day.

Capacity

Table 5: Comparison Input Variables and Values

ExperimentNr.\Input Variable	Number of Beams
1	10
2	20
3	30
4	40
5	50
6	60

Table 6: Current Layout Output Values

Number of Beams/Output Variable	Number of Unfinished Beams	Number of Unfinished Arms
10	0	0
20	0	0
30	10	29
40	20	68
50	30	107
60	40	146

Table 7: Proposed Layout Output Values

Number of Beams/Output Variable	Number of Unfinished Beams	Number of Unfinished Arms
10	0	0
20	0	0
30	4	0
40	12	0
50	22	20
60	32	59

When comparing these tables, the difference in capacity is clear: the proposed production process layout can cope with much more beams and arms per shift. By using the proposed layout the production capacity increases by 30%.

Total Handling Time and Total Processing Time

Table 8: Current Layout Times

Product	Total Handling Time (min)	Total Processing Time (min)
Beam	10	26
Arm	1.5	3.5
Foot	3	7.25

Table 9: Proposed Layout Times

Product	Total Handling Time (min)	Total Processing Time (min)
Beam	5 (punching = 2.5, welding = 2.5)	19.5 (punching = 8, welding = 11.5)
Arm	0.5	2
Foot	1	4

As can be seen in the tables above, both the handling time and processing time are much lower in the proposed situation than in the current situation. This further indicates that the proposed production process layout is indeed better than the current.

Number of employees required

In the current situation, four employees are required to run the production process. In the proposed situation, however, this is reduced to three employees. This reduces the personnel costs for production by 25%, which is a big improvement.

Graphical representation of performance over upcoming 5 years

Figure 13 shows the expected performance over the years 2017 to 2022. Here it is visible that the proposed production process layout will perform better overall with an especially large advantage on the production of arms. Also because the production of feet is now combined with the production of beams, some of the production of arms can be converted into production of feet, which would increase the coverage on beams in the proposed situation while decreasing the coverage of arms. The current situation does not have this possibility as both the arm welding and foot welding are stuffed.

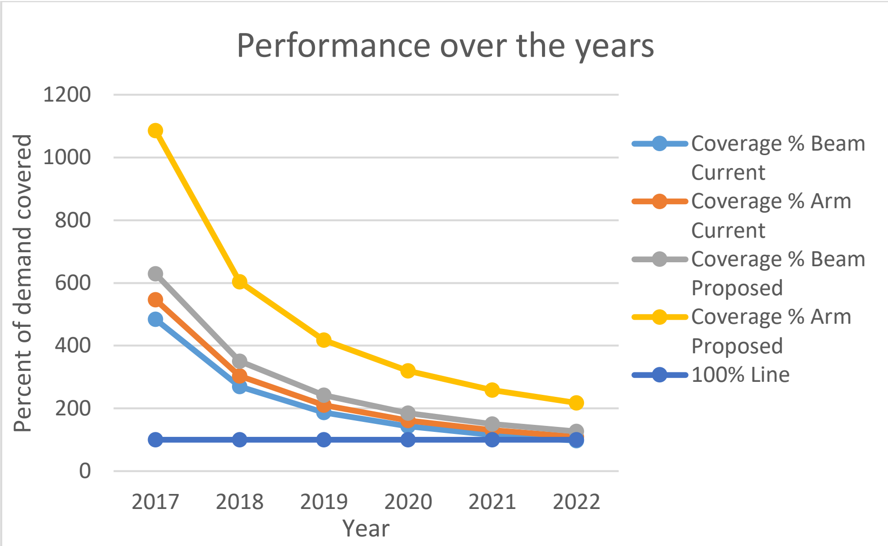


Figure 13: Graphical representation of performance of both models over the upcoming 5 years

Summary

Each of the four KPIs (partly) represents one of the performance indicators of a production process layout that BR Products wants to improve on. The fact that all four of these KPIs have better values for the proposed production process layout than the current production process layout therefore shows that the proposed production process layout performs better under any given circumstance, with all the associated benefits.

4.4. In-depth performance measurement and opportunities of proposed production process

Now that it is established that the proposition is an improvement compared to the current production process layout, the performance features will be explained in more detail. Table 10 shows that the maximum capacity of a single shift is 26 beams, of which 8 are double-sided, with corresponding number of arms and feet. This, logically, means that the beam production capacity in a month with 1 shift per day is:

$$MonthlyCap1Shift = 26 * 5 * 4 = 520$$

Every extra shift will add another 26 to this number, which means that with permanent production (3 shifts) the total capacity would be 1560 beams per month, theoretically. However, because this simulation assumes perfect production without errors, a more realistic calculation would be with an occupation of 87.5%, which means the capacity would be 455 a month with 1 shift per day and 1365 as absolute maximum. Considering the middle man of 2 shifts per day, this would be 910. Multiplying this by 12 gives a capacity of 10.920 beams per year, which is enough to cover demand (if equally spread out across the year).

Table 10: Maximum capacity of a single shift

	Root.nBeams	Root.nUnfinishedBeams	Root.nUnfinishedArms
Exp 1	25	0	0
Exp 2	26	0	0
Exp 3	27	1	0
Exp 4	28	2	0

Another performance indicator is the ability to cope with fluctuation in demand. Realistically, with 2 shifts per day and considering the occupation rate, the capacity would be 910 per month of 20 working days. However, there is a lot of extra time available for production by either adding a working day to a week (working 6 days per week instead of 5) or, if absolutely necessary, working an extra shift on some days. This means that in extreme cases, the capacity can be raised to 1911. As the average demand per month is 792 and extreme case capacity goes up to more than twice that, the ability to cope with peaks can be considered sufficient at the least. Also inversely, labor costs can be easily cut by reducing the number of shifts in a week if demand in a month is low.

Furthermore, production capacity could be increased by improved resource planning. Because the arm welding process takes half the time of the beam and foot production processes, a possibility could be to let the arm welding machine weld some feet, which leaves the beam- and foot welding robot more time to weld beams. This does come with the disadvantage of having to switch molds on the arm welding robot, but it is certainly a possibility in the proposed layout as the storage of feet is close to the arm welding robot.

And finally, the production costs. The reduction of personnel required from 4 people per shift to 3 has reduced production costs, but the proposed production process layout has another benefit for BR Products. Because welding robots are used instead of welders, BR Products does not need to hire a welder with a certificate, because the robots weld everything, which means a standard, cheaper employee can be hired for the job. The exact gain from this is unknown, because the personnel hired depends on BR Products, but an employee to pay less will certainly make a difference.

Another improvement regarding the costs was the already mentioned choice for punching the now pre-manufactured holes in the beams themselves. By implementing this change, the production cost per beam is reduced by €10,-. Considering the investment cost of the punches and potential saving up for future investments, the €10,- is an estimate reduction in costs and is likely to be a bit less when taking the investments into account. Still, this reduction is relatively large, considering the total costs for a beam in the current situation being €257,55.

5. Conclusion

In this final chapter of the report, the research questions, purpose, approach and results are summarized and discussed, recommendations for BR Products are given, based on the gained results, and the contribution to theory and practice, together with further research opportunities, is explained.

5.1. Conclusion

At the start of this report, the main research question was stated: "*How to optimize the production process at BR Products based on the requirements of a through literature research and BR Products deemed feasible production process?"*. The research purpose of designing a new and improved production process layout for BR Products showed the way to answering this question: an improved production process layout and especially the approach to make it would be the answer.

To start with a research, first the core problems needed to be found and for that the current production process layout had to be reviewed. The first research question was important for the review of the current production process: "*Which techniques for modelling the current production process layout at BR Products are there in literature?"* and was answered by the literature review on production process modelling techniques. In this literature review a flow chart was determined to be the most suitable for this research and therefore this technique was used. Then through this flow chart, interviews with the company and a walk around the production facility, a problem cluster was constructed, which shows the core problems of the current production process: long delivery time with a low delivery reliability and high production costs. Because many causes of these two problems were connected to the production facility and the production process layout, this has been the main area of improvement during this research.

Another part of the research included the requirement for a production process layout to be viable, according to BR Products. This was partly derived from the problem cluster and partly through more interviewing. BR Products confirmed that a high delivery reliability with a delivery time of 4 weeks, a reduction in production costs and the capability of handling the expected growth in demand were their most important wishes for a newly designed production process.

Now that the criteria for a new production process layout were known, the choice for an optimization method was apparent. Through more literature research it was determined that simulation modelling is a good optimization method for the case of BR Products. By using simulation and following the steps of the SLP (Systematic Layout Planning) method of Muther, a proposed production process layout was designed. This new production process layout consists of one punching machine with added extra punches to punch all holes themselves, two welding robots and one crane handling system and provides a 30% increase in production capacity compared to the current situation. Also its capabilities to handle peaks in demand are good as it can handle twice the average expected demand per 4 weeks, providing consistent high delivery reliability. Finally, the production costs are also reduced in the proposed production process layout because less personnel is required and self-punching all holes in the beams reduces the production costs per beam significantly.

As the proposed production process layout contains all aspects of improving the situation at BR Products, it is the answer to the main research question of "*How to optimize the production process at BR Products based on the requirements of a through literature research and BR Products deemed feasible production process?"*.

5.2. Discussion

This research has completed its purpose, however, there are some things that can still be improved upon, either for similar future researches or future researches building up from this one. In this section, these possible improvements will be discussed.

5.2.1. Usefulness for other researchers

Simulation can reflect reality perfectly, but the simulation model made in this research has some 'simplifications'. For this research, these simplifications were useful, either to save time or to keep the complexity level of the research manageable. For further research, however, these simplifications could be removed and instead more aspects of reality can be implemented into the simulation model. For example, human error or machine failure. This could be used to make a more in-depth analysis of the delivery reliability, but also takes much more time to research. As the possibilities are virtually endless within a simulation, the model made in this research can be taken as a basis for further expansion, which it is perfectly good for.

Then there is the structure and approach of the research. This can be a very valuable thing for researchers that are planning to do a simulation study or any other similar research. The approaches used in each step of the research and the overall structuring can be used as a handhold by other researchers, acting as a guide for conducting a study on optimization of a production process.

5.2.2. Usefulness for BR Products and other companies

The results of this research are particularly useful for BR Products as the simulation model and proposed production process layout are modeled to their wishes and production. They will use the outcome to check the correctness of their own prognosis and will keep them in mind when deciding on future investments and facility layout planning issues.

As for other companies, this research might, on first glance, not look that useful. However, the complete process of determining the requirements for and designing the layout of an improved production process is not a rare phenomenon in business researches. As many companies are looking to improve their businesses by redesigning their processes or facility layout, this research may prove extremely useful in how to conduct such a research. Also, other companies of the same size operating in the same branch might find that this research helps them in improving their production process layout as the simulation model can be modified for other companies. E.g., if another company has a similar production process but also paints the products themselves, some more processing stations can be added to simulate the painting process.

5.3. Recommendations

The largest part of the recommendations to BR Products is summarized in the proposed production process. Because this proposition was based on the wishes BR Products has and accounts for the constraints and requirements, the recommendation for BR Products is to partially implement the proposed production process layout now and gradually implement more once revenue increases. Because some investments are quite large compared to the current yearly revenue of the company, they can be added later on or partially integrated at first and fully integrated later. A good example of this is the crane handling system. Estimated to be an initial investment of €250.000,-, it is a good portion of the €1.750.000,- revenue in 2017, which might only start to be a smart investment after a certain production level is reached. An investment that should be made as soon as possible, however, is that of the extra punches on the punching line in order to punch all holes at the production facility of BR Products, instead of buying them pre-manufactured. This saves a lot of costs and will pay itself back in little time, so implementing this change now is recommended strongly.

Together with the implementation of the proposed production process layout, making use of extra shifts (either on working days or on days off) to cover peaks in demand is another recommendation. As the production process itself has a very fixed capacity, but the employees do not, using this flexibility may prove advantageous.

5.4. Further research opportunities

An opportunity for further research is the earlier mentioned investment schedule. Not every investment might be healthy for the company at every moment. Some large investments need a certain production level to be useful and some small investments might offer benefits when implemented as soon as possible. Because this has not been researched in-depth in this research, but possible benefits from it are large, a follow-up research on investment scheduling could be done.

Another possibility is to continue working on the simulation model and start implementing more and more aspects of reality as to gain increasingly more insight in the complete structure of the company. This research might be focusing on other indicators, such as e.g., worker occupation time or maintenance.

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Appendix A: Search Queries Literature Review

Search Query	Scope	Acquire Date	Nr. of entries	Nr. of entries used
allintitle: introduction to mathematical optimization	Title, abstract	09/04/2019	10	3
allintitle: introduction simulation optimization	Title, abstract	09/04/2019	30	1
allintitle: simulation-based optimization technique	Title, abstract	13/04/2019	27	1
allintitle: simulink process modelling	Title, abstract	13/04/2019	7	1
allintitle: simulation and mathematical optimization	Title, abstract	13/04/2019	89	1
Total entries			163	
Duplicates			56	
Removed due to inclusion/exclusion criteria			93	
Removed after reading abstract			6	
Removed after reading completely			1	
Total used in review			**7**	

Appendix B: Studies Used In Literature Review

Article	Author(s)	Publishing Year	Usefulness
Chemical Process Retrofitting and Revamping: Techniques and Applications	Gade Pandu Rangaiah	2016	Explanation of mathematical modelling and simulation for process designing
An integrated simulation-based optimization technique for multi-objective dynamic facility layout problem.	Mohammad Reza Pourhassan, Sadigh Raissi	2017	Explanation of how both mathematical algorithms and simulation-based optimization can be used for facility layout problems
Metamodel-Assisted Simulation-Based Optimization of a Real World Manufacturing Problem.	Anna Persson, Marcus Andersson, Henrik Grimm, and Amos Ng	2007	Explanation why simulation-based optimization can be more useful than analytical modelling in solving real-world manufacturing problems
Mathematical Programming: An Introduction to Optimization	Melvyn W. Jeter	2010	Explanation of linear programming
Introduction to Mathematical Optimization	R. Clark Robinson	2013	Explanation of linear and dynamic programming
Practical Introduction to Simulation Optimization	Jay April, Fred Glover, James P.	2003	Explanation of simulation optimization.

	Kelly, Manuel Laguna		
Introduction to Mathematical Optimization: From Linear Programming to Metaheuristics	Xin-She Yang	2008	Explanation of linear and non-linear programming

Appendix C: Concept Matrix SLR

Year	Author	Mathematical Optimization	Optimization by Simulation	Review	Framework	Conceptual	Analytic	Case study
2016	Rangaiah		x		x	x		x
2017	Pourhassan et.al.	x		x	x	x		
2007	Persson et.al.	x	x	x	x	x	x	
2010	Jeter	x			x	x		
2013	Robinson	x			x	x		
2003	April et.al.		x		x	x		
2008	Yang	x			x	x		

Appendix D: Reflection on PDP M12

As stated in my Personal Development Plan (PDP) for Module 12, my goal for Module 12 was to improve my planning skill, because I noticed that there are some improvement possibilities. In this PDP I decided on an approach to quantify my progress after each of the three improvement cycles I would go through. This approach was divided into the following steps: making an activity planning for the upcoming week, checking which activities were completed on time and which were not, weighing the not completed activities based on their complexity and adding these scores for a total of the week. Afterwards I could review what has gone wrong that week and where improvement opportunities lied and could then include this into the new planning for the next week. A method I used throughout all three improvement cycles is the looking for and reading articles with tips and trick for planning. Each week I apprehended some of these tips and determined their usefulness at the end of the week.

Improvement cycle 1

The planning for the first week I already completed in my project plan, because part of the assignment was to set up a detailed time plan for Module 12. The planning for the first week can be seen in Table 11 below; the only difference is the added complexity column. In the first week I did not include any tips and tricks, to see what improvement I could make by just making an actual written planning instead of trying to remember everything and switching between tasks of different complexities.

Table 11: Planning Improvement cycle 1

Date	Weekday	Section of the day	Activity	Complexity
21/04	Sunday	Afternoon	Setting up schedule for upcoming week (PDP)	Medium
22/04	Monday	Morning Afternoon	Finishing touches on project plan Starting work on bachelor assignment	Easy Medium
23/04	Tuesday	Morning Afternoon	Setting up mathematical framework for simulation Building basic simulation models	Hard Medium
24/04	Wednesday	Morning Afternoon	Setting up mathematical framework for simulation Meeting with University of Twente supervisors	Hard Easy
25/04	Thursday	Morning Afternoon	Travelling to and working in Oss (progress meeting company) Travelling from and working in Oss (progress meeting company)	Medium Medium
26/04	Friday	Morning Afternoon	Implementing feedback from supervisors Reflecting on PDP progress and improving/changing methods	Easy Medium

In the first week, I did not finish two of the activities I planned, namely: 'setting up mathematical framework for simulation' and 'building basic simulation models', both on Tuesday. This results in a total score for the first week of 3 + 2 = 5 for missed activities. As for the reason for it, I believe my sleeping schedule is to blame. I did not get a good night of sleep on the night of Monday to Tuesday, which led me to be less motivated on Tuesday. This is why in the second improvement cycle, I included one of the tips from the Australian Professional Skills Institute (APSI): include your sleeping time in your schedule[1]. However, because I had written down all activities I needed to do, I had not run into any activities that I didn't account for in my planning, which was often the case before (when I did not make a planning). I also noticed that sometimes I worked too long on a single activity, which meant having less time for another.

Improvement cycle 2

As I said, I noticed that my lack of sleep caused motivational issues and therefore some activities were not completed. This showed me that in some way sleep should be accounted for in the schedule, which was confirmed by the tips I found from the APSI. One of them was "Get a good night's sleep", which stated that the required 7 to 8 hours of sleep one requires to be fully productive the next day should be included in the planning, which also meant adding expected completion time for all activities. Another tip I implemented in my learning cycle this week was to use a calendar. This meant that I would copy my planning into the calendar on my phone, so I would get reminders of tasks whenever I should do them, which would hopefully solve the problem of working too long on one activity. The newly designed time plan for week 2 is shown below in Table 12.

Table 12: Planning Improvement cycle 2

Date	Weekday	Section of the day	Activity	Time required (Hrs)	Complexity
21/04	Sunday	Afternoon	Setting up schedule for upcoming week (PDP)	1	Medium
		Night	Sleep from 00:00 to 08:00	8	Easy
22/04	Monday	Morning	Writing Thesis	4	Easy
		Afternoon	Setting up mathematical framework for simulation	4	Medium
		Night	Sleep from 00:00 to 08:00	8	Easy
23/04	Tuesday	Morning	Setting up mathematical framework for simulation	4	Medium
		Afternoon	Implementing mathematical framework into simulation and programming the simulation	4	Hard
		Night	Sleep from 00:00 to 08:00	8	Easy
24/04	Wednesday	Morning	Implementing mathematical framework into simulation and programming the simulation	6	Hard
		Afternoon	Meeting with UT Supervisors	1	Medium
		Night	Sleep from 00:00 to 08:00	8	Easy
25/04	Thursday	Morning	Writing Thesis chapter on mathematical framework	4	Medium

[1] APSI Blog. (2016, April 9). *7 Time Management Tips for Students - APSI*. Retrieved from APSI: https://www.apsi.edu.au/7-time-management-tips-students/

		Afternoon Night	Implementing mathematical framework into simulation and programming the simulation Sleep from 00:00 to 08:00	4 8	Medium Easy
26/04	Friday	Morning Afternoon Night	Implementing feedback from supervisors Reflecting on PDP progress and improving/changing methods Sleep from 00:00 to 08:00	6 2 8	Easy Medium Easy

By keeping my sleeping schedule as stated in the planning, I did not encounter the same motivational issue as in improvement cycle 1, so including my sleeping schedule in my overall planning for the week definitely helped in completing all tasks. Using the calendar on my phone provided the advantage of receiving reminders when I should sleep or when I should switch tasks, which made sure I slept enough and did not overcommit on a single activity. However, I still noticed that during some activities motivation was low and my productivity was suboptimal, which resulted in two activities not being fully completed: 'Implementing feedback from supervisors' and 'writing thesis chapter on mathematical framework'. This leads to a score of 1 + 2 = 3 for improvement cycle 2. So cycle 2 resulted in an overall improvement but still some room for improvement is available.

Improvement cycle 3

In improvement cycle 3 I tried to further lower the performance indicator by choosing a method to increase motivation during some activities. Another tip found on the internet was to schedule rewards, such that I would have a few minutes to relax every hour of studying. During the third week I implemented this by finishing every hour with one of the following activities:

- Watch a short video on YouTube
- Walk around the house/faculty
- Chat with friends/family
- Make a snack

The planning schedule for the third week looks similar to that of the second week, because the general implementation of 'treats' every hour is not written down.

Date	Weekday	Section of the day	Activity	Time required (Hrs)	Complexity
21/04	Sunday	Afternoon Night	Setting up schedule for upcoming week (PDP) Sleep from 00:00 to 08:00	1 8	Medium Easy
22/04	Monday	Morning and Afternoon Night	Implementing mathematical framework into simulation and programming the simulation Sleep from 00:00 to 08:00	8 8	Hard Easy

23/04	Tuesday	Morning and Afternoon Night	Implementing mathematical framework into simulation and programming the simulation Sleep from 00:00 to 08:00	8 8	Hard Easy
24/04	Wednesday	Morning Afternoon Night	Implementing mathematical framework into simulation and programming the simulation Meeting with UT Supervisors Sleep from 00:00 to 08:00	6 1 8	Hard Medium Easy
25/04	Thursday	Morning and Afternoon Night	Writing Thesis section on simulation modelling process Sleep from 00:00 to 08:00	8 8	Medium Easy
26/04	Friday	Morning Afternoon Night	Implementing feedback from supervisors Reflecting on PDP progress and improving/changing methods Sleep from 00:00 to 08:00	6 2 8	Easy Medium Easy

By using the ‘treats’ at the end of every hour, I no longer felt the need for any distractions anymore while working, which meant that I was more productive overall. This resulted in me being able to finish all tasks planned in the time set for each activity, providing a total score of 0 for the third and final week.

Conclusion

After the three improvement cycles described above, I reached the ultimate goal I could achieve for this personal development: reach a total score of 0 for missed or unfinished activities. During the improvement cycles I found things that held me back and solved the occurring problems by using tips. The tips that finally lead to my improvement were: schedule a good night’s of sleep into your planning, schedule rewards and use an agenda. All of these improved my planning capabilities, the most important change, possibly, being that I actually write my planning down.