ENHANCING SMART MANUFACTURING
AT BROSHUIS

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BROSHUIS
HOLLAND

Enhancing Smart Manufacturing at Broshuis

Master thesis Business Administration
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Voorwoord

Finis coronat opus. Het einde kroont het werk. Eind goed, al goed.

Bovenstaande spreuk is wat mijn gevoel omschrijft nu ik de laatste zinnen opschrijf die mijn scriptie compleet zullen maken. Voor u ligt namelijk het resultaat welke de afsluiting vormt van mijn opleiding Business Administration aan de Universiteit Twente, een adviesrapport voor Broshuis Parts Production ten behoeve van de aanschaf van de benodigde machines voor het produceren van metalen onderdelen.

Het einde kroont het werk, het einde van mijn opleiding heeft in mijn geval 'even' op zich laten wachten. In september 2011 vol goede moed aan mijn Masteropleiding begonnen en na nogal wat uitdagingen onderweg is dit, 7 hele jaren later, de kroon op mijn werk. Niet altijd het geloof gehad dat ik dit zou volbrengen maar trots dat ik hier nu sta. Een totaal ander mens als die aan de opleiding begon. De grootste verandering en tegelijkertijd verrijking die heeft plaatsgevonden is het feit dat ik mooiste mag zijn wat er bestaat: Mama van Finn. Ik kan met recht zeggen: Eind goed, al goed.

Dit was niet mogelijk geweest zonder de hulp van een heel aantal personen. Als eerst wil ik de Broshuis organisatie bedanken en in het speciaal Robin Kroon en Richard Jansen voor het mogelijk maken van het schrijven van mijn scriptie. Bedankt dat ik buiten mijn gewone werkzaamheden voor Broshuis de mogelijkheid heb gehad mijn opleiding te kunnen afronden. Robin, bedankt voor het volledig betrekken bij het project, het vertrouwen, het delen van kennis en ervaring, het pushen en het motiveren. Zonder jouw hulp en volharding had ik hier nu niet gestaan.

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Tenslotte wil ik mijn familie bedanken. Allereerst mijn gezin; Dedde en Finn. Het afronden van een studie kost tijd en vergt best wat van je humeur, bedankt voor de ruimte en benodigde afleiding die jullie mij hebben gegeven om dit tot een goed einde te brengen. Grote dank gaat uit naar mijn ouders, bedankt voor jullie steun op alle mogelijke manieren en het geloof in mijn kunnen gedurende al die (inmiddels 13) studiejaren. Het was nogal een achtbaan, maar uiteindelijk is het dan toch gelukt. Als allerlaatste een dankwoord naar mijn Opa, bedankt Opa voor alles wat je voor mij hebt gedaan en doet. Ik heb mijn belofte ingelost en bij het verlossende woord zei jij:
'Lang gewacht, stil gezwegen. Nooit gedacht, toch gekregen.' Daar is 'ie dan.

Veel leesplezier gewenst.

Melanie van Beek
Augustus 2018, IJsselmuiden

Management Summary

This research is part of a project at Broshuis: Broshuis Parts Production, where cutting and bending of metal is insourced. For this project, a project team has been appointed that is responsible for the success of this project. Cutting and bending metal is a completely new activity for Broshuis. This has advantages and disadvantages. The lack of experience of course involves risks. On the other hand, Broshuis is not affected by habits, holy temples and outdated methods that have slowly been shaped. Broshuis Parts Production is located in the newly built hall, hall 7.

Setting up a new company also involves purchasing new machines. This research was therefore aimed at making recommendations for the purchase of cutting and bending machines. Broshuis has opted to have QRM business philosophy as its guiding principle, as well as the Smart Industry idea. The objective of this research therefore can be formulated as below:

The purpose of this research is to give advice on the machines to be purchased for the production department of Broshuis Parts Production B.V. based on QRM and the Smart Industry concept.

To provide an answer to the research question, the conditions set by QRM and Smart Industry for the purchase of new machines were examined. Unfortunately, it turned out that research into QRM is still in its early stages. Therefore, there are not many conditions to filter. This also applies to Smart Industry, which means that the conditions imposed by the theory are limited in number. However, we have managed to select a number of them and used these together with the conditions, requirements and wishes of the project team to complete the list.

After drawing up the preconditions set by the theory and the project team, an analysis was made of the cutting and bending parts that are currently being purchased. It has been found that a large variety of products are purchased and different machines are required to be able to produce these products. Broshuis opted to choose standard machine configurations.

After the analysis of the current product portfolio, a brainstorming session took place. This session produced the drawing up of 4 scenarios for which the advantages and disadvantages are described:

- Scenario 1: Continue outsourcing; represents 0% of outsourced work
- Scenario 2: Insource laser cutting (3x1.5 meters) and bending; represents 60% of outsourced work
- Scenario 3: Insource laser cutting (up to 6x2 meters) and bending; represents 85% of outsourced work
- Scenario 4: Laser cutting, bending and cutting long items (up to 16 meters); represents 95% of outsourced work

These scenarios were tested against the criteria set according to the AHP method. This showed that scenario 2 and 3 both score about the same. Scenario 3, however, scores slightly higher than scenario 2. Due to the fact that the management of Broshuis wants to produce all steel parts inhouse in the future, scenario 3 has been chosen and further elaborated. For this scenario a shortlist of suppliers has been created.

On this basis, the purpose of this research is answered. Two lasers of 3 x 1.5 meters and onw of 6 x 2 meters are purchased in scenario 3. The latter can be equipped with a 2.5D head, which makes it possible to cut at an angle. A drill and tap unit can also be added to this laser, which means that rework can be kept to a minimum. The 3 lasers can cut up to 25 mm thick. Furthermore, in this scenario we have opted for a 320-ton press brake of 4 meters with bending assistance. With this scenario approximately 85% of the outsourced work is produced.

After the choice between the different scenarios the capacity utilization was calculated for an average mix of trailers. This showed that for some machines the capacity is exceeded. In this calculation, however, a single shift of 8 hours has been used. Broshuis intends to run 2 shifts of 8 hours each. The capacity problem is thus tackled. This meets one of the main conditions set by QRM: nothing should be planned for more than 70 – 85% of the capacity.

It is recommended to divide the purchase and setting up of the new organization into 2 phases. In phase 1 two 3 x 1.5-meter lasers (connected to an automatic supply) and 3 press brakes (4 meters, 320 tons) are purchased. When these machines are running, it is recommended to purchase the 6 x 2 meter laser. The reason for this is that setting up a new organization and adapting to a new operation process is intensive enough. When the scope immediately gets too big, problems arise and cannot as yet be fully evaluated.

The management board of Broshuis has chosen to implement QRM only in hall 7 for the time being. However, this not yields the desired reduction in lead time Broshuis is looking for. To realize this, Broshuis has to make the entire organization QRM. This results in the desired reduction in lead time. Therefore, it is recommended for Broshuis to investigate how they can introduce QRM within their entire organization.

Furthermore, Broshuis needs to carry out research into the steel parts currently outsourced. They need to have a close look into what the next step is to produce them theirselves. Perhaps these are not the sheet parts, but the turning and milling parts, for example.

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1. Introduction

As part of the completion of my studies Business Administration at the University of Twente this Master Thesis is written and research is being carried out into the machines to be purchased that are needed to insert the cutting and bending operations at Broshuis B.V. in Kampen. I have been working here for 2 years now as Process Engineer and I mainly take care of the design and optimization of business processes.

1.1 Broshuis

Broshuis was founded in 1885 and is a modern family business with currently Pieter-Bas Broshuis as CEO of the organization. It is the oldest manufacturer of semi-trailers for special transport and container chassis and is located in Kampen.

Broshuis is an innovative company, where employees, customers and suppliers work closely together to deliver high-quality products in an efficient way. The aim is a socially responsible and sustainable business operation with a healthy return for its shareholders. Broshuis stands for innovation, quality and flexibility. The company aims to be among the top 3 providers in its market within the bigger economies of Europe. Growth in return on invested capital and shareholder value prevail over growth in revenue.

1.1.1 Product development

Thanks to the professional engineering department, trailers are constantly developed to meet the needs and wishes in the market. The trailers of Broshuis are mainly extendable, with or without hydraulic control. It is this extendibility that characterizes a Broshuis trailer.

Figure 1-1 3-axle SL Semi low loader

In 1965, Broshuis was the first European manufacturer to produce a 3-axle semi low loader. Broshuis was also the first to develop and produce a 4-axle and 5-axle semi low loader.

In 2011, Broshuis introduced a new type of wheel suspension with its SL Series, as shown in Figure 1-1. This independent wheel suspension offers great advantages for its customers, as the trailers have more useful payload, more steering angle and a lower loading height. Moreover, this type of wheel suspension offers many advantages when it comes to maintenance costs.

In 2015, Broshuis developed the SL-AIR, which is shown in Figure 1-3. The air suspension and friction steered SL-AIR with independent wheel suspension has the advantages of the SL. In addition, the SL-AIR is lighter and requires less maintenance costs.

Broshuis is the first producer to market the Quatro Trailer, which is shown in Figure 1-2. This trailer can be extended four times and can be used for the transport of steel constructions, concrete beams and windmill wings, amongst others.

Figure 1-2 4-axle extendible platform trailer

Figure 1-3 5-axle SL-AIR

1.1.2 Market

The market for special and heavy transport is a worldwide niche market focused to transport goods of special dimensions and/or weight. This transport needs to generate the least possible burden on the environment, on the availability of raw materials and on the available road network. For Broshuis, it is important to quickly respond to developments in its relevant sectors like (wind) energy, infrastructure and construction, defense, public transport (trains, trams), and (multimodal) container transport. Flexible solutions need to be found for the longer and heavier transports. The trailers of Broshuis need to comply to more stringent Pan-European regulations.

Broshuis needs to focus on optimizing the kilometer/price ratio of special transport by producing high-quality products that fulfil specific customer requirements. By using innovative concepts, materials and production methods, Broshuis needs to remain a trendsetter in the market. The strength of Broshuis is to retain its character of a family business on the one hand and a professionally established international company on the other hand, which, due to its solid design and quality system, is also an attractive partner for large international customers. By focusing on flexible stand construction of series and single-piece orders in the production, the company is able to quickly respond to the developments in the markets of its customers.

Although Broshuis does not want to compete primarily on the cost price, the continuous pressure on the market prices of its customers forces the organization to optimally use its production capacity and keep the cost price as low as possible. Broshuis wants to attract additional production volume by expanding the heavy segment and as a result keep the rate part of the cost price low.

All trailers originate in Kampen where a production facility is located of more than 10 hectares. The trailers are produced at this location inhouse from drawing to delivery. At this moment, there are more than 350 employees and Broshuis has a turnover of 65 million a year. The company is also ISO 9001 and AQAP certified.

1.1.3 Product groups

The range of Broshuis for special transport consists of:

- Semi low loaders
- Low loaders
- Flatbed trailers

The range of Broshuis for container transport consists of:

- Multifunctional container chassis (Figure 1-4)
- Connectable container chassis: 2-CONnect (Figure 1-5)

Figure 1-4 Multifunctional Container chassis

Figure 1-5 2-CONnect

In addition, trailers are produced that have been specially designed for the installation of turbines and generators. These generate electricity at remote locations. GE (General Electric) is a major client of Broshuis and annually purchases 75 sets. S&W Energy is also working with Broshuis to develop a trailer for turbines and generators.

In most cases, Broshuis produces according to the Make-to-Order (MTO) principle. This does differ per product group as for some products a minimum stock of 1 or 2 trailers is made (MTS, Make-to-Stock). The value of a trailer has a big influence here. A lower value combined with relatively large sales reduces the economic risk. GE is an exception to this. These trailers are produced in stock as the sales are contractually settled.

In Table 1-1 the product groups are shown.

Table 1-1 Product groups

Product	Annual basis (2016)	Value (min-max)	Productionstrategy
Container chassis (MFCC)	353	€23,000 - €40,000	MTO & MTS
2CONnect	62	€60,000 - €70,000	MTO & MTS
Semi low loader, pneumatic, beam axles	88	€43,000 - €80,000	MTO & MTS
Semi low loader, pneumatic, independent suspension	34	€70,000 - €110,000	MTO
Semi low loader, hydraulic, beam axles	19	€90,000 - €200,000	MTO
Semi low loader, hydraulic, independent suspension	21	€130,000 - €230,000	MTO
Low loader, hydraulic steered, beam axels	25	€100,000 - €200,000	MTO
Low loader, hydraulic steered, independent hydraulic suspension	25	€130,000 - €230,000	MTO
Low loader, hydraulic steered, independent air suspension	2	€130,000 - €230,000	MTO
Flatbed trailers	41	€75,000 - €150,000	MTO/MTS
GE	151	€37,000 - €200,000	MTO
Super Specials	3	€200,000 - €500,000	MTO

1.2 Motivation of this study

After a difficult time period at the end of the last decade, Broshuis has found its way up again during the last seven years. More than most of its competitors, Broshuis has managed to increase its turnover considerably year after year and to increase its return up to the benchmark in the sector.

The success in recent years is mainly due to two factors. First, the organization was robust enough during the crisis and with the use of the right resources adapted to the lower volumes the market has seen in recent years. A second important success factor was the choice to look for the engineer-to-order niche and attract the customer with the combination of customer-specific solutions with a very high quality.

The playing field is now changing again. The demand for trailers for special and heavy transport has again increased considerably, which for Broshuis causes delivery times to have come to a level that they are an obstacle for sales and customer satisfaction. Broshuis therefore has no other choice than to adapt to the future market demand. In concrete terms, this means that delivery times need to be cut down considerably and that the difference in cost price between volume players and "quality suppliers" needs to be significantly reduced. This is the reason why it was decided to insource the production of cutting and bending parts.

1.2.1 Current situation

Everyone who follows the developments around the world agrees that a lot is changing and developments seem to be taking place in an accelerating pace. This certainly also applies to the markets in which Broshuis is active and even more if you look at the entire business column of the production of trailers.

For Broshuis, it is important to lay the foundation for future success during the current successful time period. In the future, the core activity will also be "building trailers for special and heavy transport as well as for transporting (sea) containers". The factors that determine if Broshuis will succeed here will probably change.

To serve the market in the future, Broshuis considers the following developments and principles important:

- A limited number of larger international players will remain active in the market. A major consolidation is not to be expected, but any serious player will have to be able to achieve a production level of at least € 100m. Broshuis also needs to create a situation in which the demand can be met during upturn, but where a time period of downturn can also be sustained financially. The foundation of the investments are based on a <u>turnover level of € 80m</u>, but which can be scaled up to € 120m without any major adjustments to processes and applications;
- To bind customers to Broshuis in the long term as well, standard delivery times need to be cut down considerably. The production processes needs to be adjusted in such a way that <u>90% of all trailers is ready for delivery within 2 months</u>. To this end, lead times of all production steps need to be reduced;
- In addition to short delivery times, a sharp cost price becomes more important in the future. The price difference between the most expensive in the market (now usually Broshuis) and the cheapest in the market (usually Faymonville) now increases to up to 25%. In the future, new technologies ensure that the cost price will drop even further, with the market appreciating the additional cost for a higher quality on a standard product of up to 10%.

To achieve both reduced delivery times and a lower cost price with a significantly higher turnover, the company needs to operate in a different way. This starts with sales. At the moment, Broshuis has a very extended range, where the customer also has plenty of possibilities within that large range to do adjustments. In the future Broshuis needs to operate more from a base of 100 – 150 well-developed base models, where the customer is able to create its trailer specifically with pre-developed standard options. The real engineer-to-order orders decline to a maximum of 5% of the total number of orders. The development and implementation of this change is already happening and is completed at the beginning of the fourth quarter.

In addition to standardization of products, Broshuis achieves a reduction in lead time and cost price by optimizing the flow in the production. At the moment, all production stages are still affected by a wide range of disruptions.

Insourcing the production of components makes sure that the number of disruptions caused by wrong, delayed or in parts delivered goods is significantly reduced. Missing or defective products can be supplied quickly using rush orders, where in case of defective products a short feedback line with the engineers is implemented. These engineers are therefore better able to optimize their designs and gain logistic advantages by delivering the goods "in sequence" to the production sites. This "in full, in time, in sequence" delivery implies that, through the smart delivery of complete parts of a trailer, the amount of research in material flows is greatly reduced.

The advantages of producing components inhouse are not limited to reducing the disruptions. It is also possible to cut down the delivery time of approximately 3 weeks to approximately 3 days. In addition, the value of the stocks held could also drop significantly as no processed steel is stored, but only a smaller amount of base sheet material.

1.2.2 Towards the future

The management believes that insourcing the production of components in the current situation already offers many advantages. When making a decision, however, it should not be forgotten that the construction of trailers will change considerably in the next years. It is expected that the trend in Industry 4.0 will also find its way to trailer construction. A number of competitors is already busy adjusting the organization to far-reaching automation and robotics. Especially Faymonville and DTEC are good examples here. Broshuis cannot stay behind, because in the long term the cost prices of manual production will be completely out of synch with companies that have invested in automated production methods.

In the future, laser techniques and especially 3D lasers will prove their worth. It is expected that in the next 5 years the focus on structural work will shift from the traditional construction of chassis to the assembly of structural components. The assembly of the chassis will be greatly simplified by engravings and Poka Yoke techniques. Employees will no longer have to measure and drill but will be able to assemble the separate parts in one intuitive way. Due to the dimensional stability of working with lasers and molds, welding can be carried out to a large extent by welding robots.

Investments in molds, 3D lasers and welding robots are therefore inevitable. The pace at which this will take place must be determined in more detail. However, in the design of Hall 7 this is already taken into account.

1.2.3 Broshuis Parts Production B.V.

The project is part of a new B.V.; BPP B.V. (Broshuis Parts Production). By housing this project into a new B.V., the possibility is created to get a good picture of the development and profitability. In addition, it provides the possibility to start from phase 0 and investigate everything without having to take into account decisions from the past. This helps to make it a lot easier to implement new innovative ideas and to organize the organization with the current knowledge as efficiently as possible.

The activities are carried out in a new, yet to be built, production hall. This hall has a surface area of approximately 6000 m2. The views of the new hall can be seen in Figure 1-7. Figure 1-8 displays the floor plan of the new building.

Figure 1-7 Views of new production hall

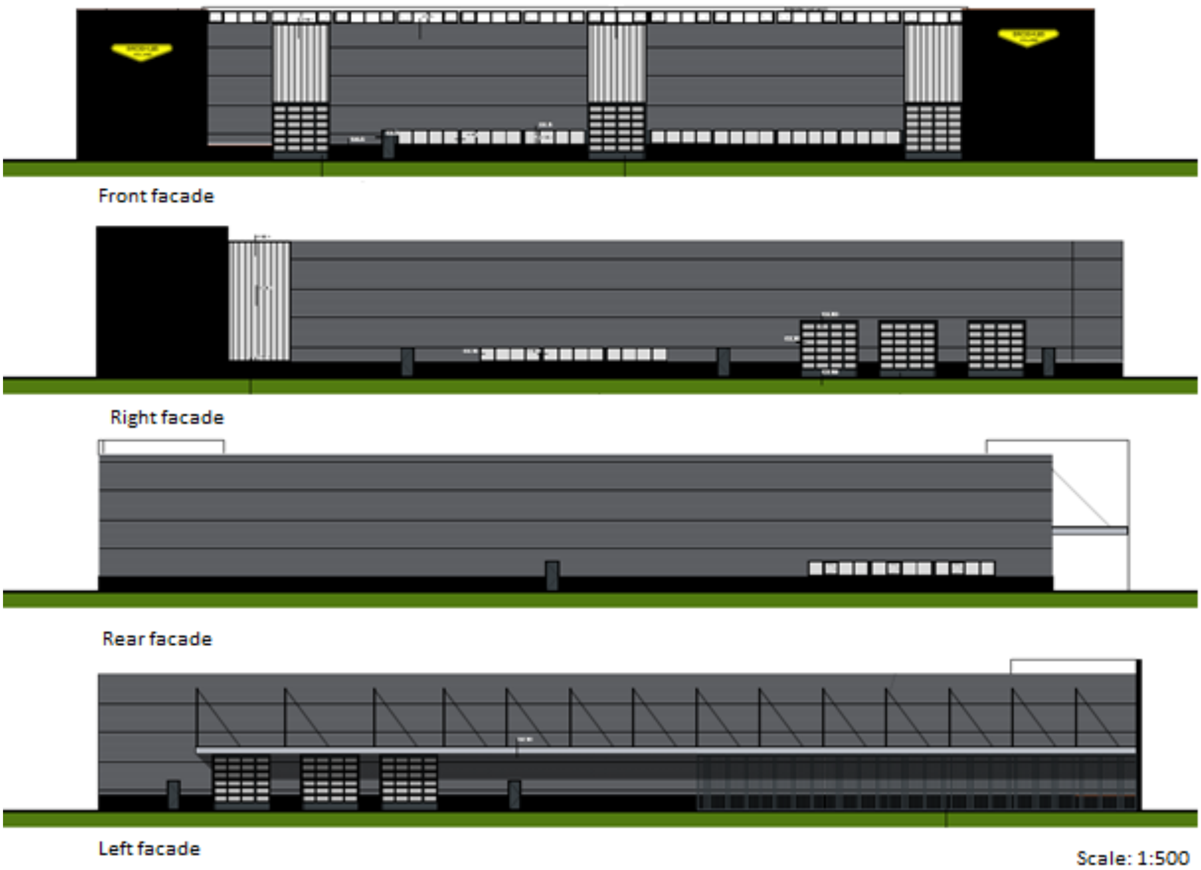
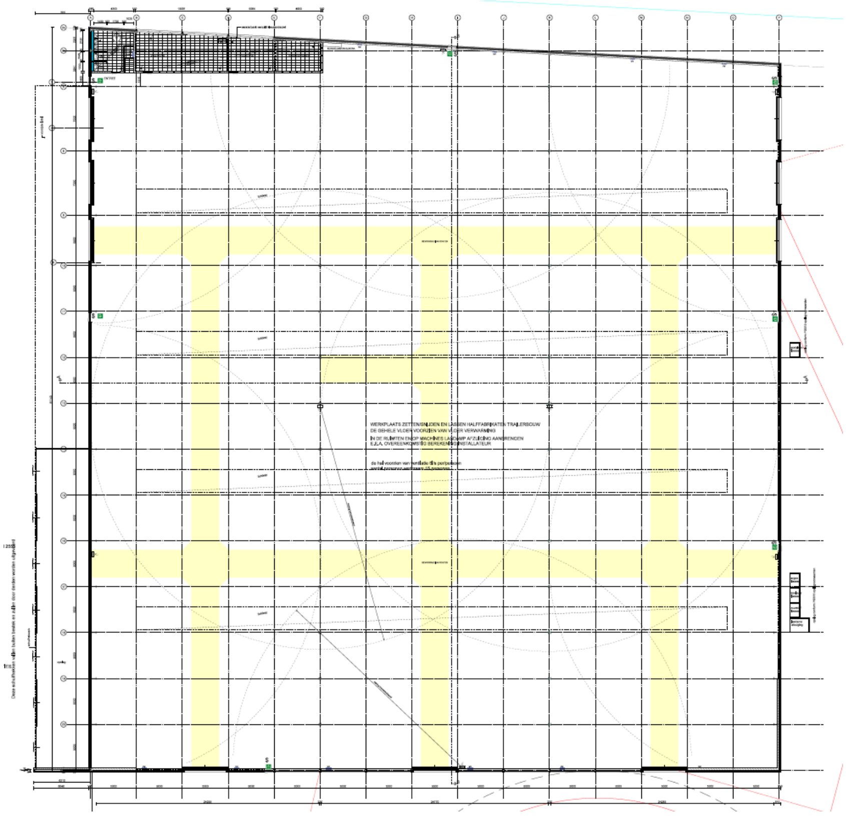


Figure 1-8 Floorplan of the new production hall



Scale: 1:800

1.3 Project description

As indicated above, it has been decided to start a project. The project involves the entire process of insourcing cutting and bending parts. The project team working at his project currently consists of four people. Figure 1-9 shows in a schematic way who these project members are, what their function within Broshuis is and what role they fulfil during this project.

1.3.1 QRM

Cutting and bending material is a completely new activity for Broshuis. This provides advantages and disadvantages. The lack of experience of course involves risks. On the other hand, Broshuis is not affected by habits, holy temples and outdated methods that have slowly been shaped. There is a blank sheet with the possibility to design all the processes from scratch, optimally and prepared for the future.

Time has become an important factor for the competitiveness of companies (Demeter, 2013) because customers continue to expect shorter delivery times. At the same time, flexibility and the ability to adapt have become fundamental factors for an organization to be able to meet the demands of the customer. They keep asking for an ever-higher product variety, high quality, low price and short delivery times (Suri, 1998). The large variation in the Broshuis range and the even bigger variety of used components mean that a high degree in flexibility is required in the production of components. To guarantee both flexibility and efficiency, Quick Response Manufacturing (QRM) was chosen as company philosophy. QRM primarily focuses on cutting down lead time, which leads to a low price with optimum flexibility. This is further discussed below in the theoretical framework.

1.3.2 Smart Industry

Smart Industry also plays an important part within the organization. It is investigated in what way the 'Smart Industry' idea can be applied to this process. The choice for this focus is based on Charles Darwin's quote below.

"It is not the strongest species that survive, nor the most intelligent, but the ones most responsive to change."

Changes are accelerating nowadays, the life cycles of products are getting shorter, series are getting smaller and the customer increasingly wants a custom-made product. In addition, almost everything and everyone is connected nowadays. This provides enormous opportunities for companies that know how to deal with this the right way.

TNO coined the term 'Smart Industry' and their concept is based on the German 'Industry 4.0'. In Germany they are investigating how companies can cooperate better with ICT within a certain sector. This is further discussed below in the theoretical framework.

Figure 1-9 Projectteam

Name	Job title	Project activities
	CEO Broshuis Parts Production	CEO Broshuis Parts production. Responsible for the overall project.
	Process Engineer	Responsible for the integration between BPP and Broshuis and the total production process.
	Technical Manager	Is available for technical advise and responsible for al the real estate within the Broshuis Group.
	Project Managaer	Has a lot of experiance with Engineering, CAD and PLM within Broshuis. Is responsible for the technical integration between Broshuis and BPP.

The project team has already completed a number of phases and a smaller part of the total project is part of this research.

The main objective of the project is:

Optimizing the production by cutting down the delivery time of cut and bent components to 3 days and deliver it to production in time, fully error-free and complete.

The project passes the following steps:

- Insourcing or outsourcing research
- Submit plan to the Supervisory Board for approval
- ERP: research, purchase, layout, planning, etc.
- Machines: research into product variation, research machines and suppliers, requirements, software, automation, future vision, purchase, etc.
- Design of new production hall: location, positioning machines, logistics, production methods, means of transport, physical planning systems, ICT, etc.
- Logistics: within department, hall, deliver and supply, planning, etc.
- Implementation: setting up, starting, roll out within organization, training, etc.
- Control: improvements, 2nd phase, etc.

As indicated, this research only describes a part of the project. It was decided to focus this thesis on the research and purchase of the machines. Broshuis is aware that it is essential to purchase the right machines for the purpose to be served. Furthermore, the aim is towards an extensive automation. This automation contributes to the ultimate objective of the project.

1.4 Purpose

The purpose of this research is to make recommendations for purchasing cutting and bending machines for the production department of BPP. Broshuis has opted to do this in line with the Quick Response Manufacturing (QRM) concept. This concept helps to cut down lead times, which is the purpose of the entire project.

Another philosophy BPP wants to use, is Smart Industry. The choice for this focus is based on Charles Darwin's quote below:

"It is not the strongest species that survive, nor the most intelligent, but the ones most responsive to change."

Due to new production technologies and the further integration of ICT throughout the process of designing, fabricating and distributing, the industry is changing radically, to which BPP has to respond.

This leads us to the purpose of this research, which can be summarized as follows:

The purpose of this research is to give advice on the machines to be purchased for the production department of Broshuis Parts Production B.V. based on the QRM and Smart Industry concept.

1.5 Research questions

To answer the key question of this research, a number of research questions is formulated of which the answers provide the necessary knowledge:

1. What is Quick Response Manufacturing, how can this theory be applied to the advice for the purchase of the required machines and what are the conditions for applying the QRM concept to the choices for the machines?
    a. What is QRM?
    b. How can this theory be applied to the advice for the purchase of the required machines?
    c. What are the conditions for applying the QRM concept to the choices for the machines?
2. What is Smart Industry, how can this theory be applied to the advice for the purchase of the required machines and what are the conditions for applying the Smart Industry concept to the choices for the machines?
    a. What is Smart Industry?
    b. How can Smart Industry be applied to the advice for the purchase of the required machines?
    c. What are the conditions for purchasing the required machines based on the Smart Industry concept
3. How can the current product portfolio be characterized and which machines are required to be able to produce these products?
    a. Which cutted and bended components are currently outsourced?
    b. Which cutting techniques exist to cut these products?
    c. Which bending technologies exist to be able to bend these products?
    d. Which standard machine configurations are available in the market?
    e. How can the range of cutting and bending components be divided among the different machines?
4. What conditions, requirements and wishes are required for the purchase of machines for cutting and bending and which approaches are available?
    a. What requirements and wishes are set by the project team?
    b. What conditions are set by QRM?
    c. What conditions are set by Smart Industry?
    d. Which approaches are available, taking the conditions set by QRM, Smart Industry and the requirements and wishes of the project team into account?
5. Which approach should be chosen, taking the conditions set by QRM, Smart Industry and the requirements and wishes of the project team into account?
    a. Which scenario should be chosen, taking the set conditions, requirements and wishes into account according to the analytical hierarchical process?
    b. Which proposal was finally chosen?

The first two research questions outline the theoretical framework of this research. The QRM and Smart Industry concepts are described. Furthermore, the conditions imposed by the concepts on the machines to be purchased, is investigated.

By making an analysis of the current product mix and by looking at the techniques and machines available in the market, a clear understanding can be given to which machines are required to be able to produce the products inhouse. Sub-question 3 answers this question.

Sub-question 4 gives an understanding of the requirements and wishes of the project team. In sub-question 5 everything comes together and different scenarios are outlined and advantages and disadvantages are listed.

1.6 Issue approach and data collection

The research is mainly focused on design and is partly diagnostic. The theory on QRM and Smart Industry is investigated and focusses on the purchase of machines. Furthermore, an analysis is made of the steel parts that are currently outsourced. According to this analysis and the conversations with stakeholders it is determined what the requirements and set conditions are for purchasing the machines. Subsequently, a number of scenarios are drawn up and advice is given on the machines that need to be purchased.

Table 1-10 below indicates how the answers to the research questions are obtained.

Table 1-10 Overview research questions

Research question	Type of data	Data collection
1. What is Quick Response Manufacturing, how can this theory be applied to the advice for the purchase of the required machines and what are the conditions for applying the QRM concept to the choices for the machines?		
a. What is QRM?	Literature review	- Articles about QRM - Books about QRM - Critical reviews about QRM
b. How can this theory be applied to the advice for the purchase of the required machines?	Literature review	- Articles about QRM production - Books about QRM production - Critical reviews about QRM production
c. What are the conditions for applying the QRM concept to the choices for the machines?	Literature review	- Articles about QRM production - Books about QRM production - Critical reviews about QRM production
2. What is Smart Industry, how can this theory be applied to the advice for the purchase of the required machines and what are the conditions for applying the Smart Industry concept to the choices for the machines?		
a. What is Smart Industry?	Literature review	- Articles about Smart Industry - Critical reviews about Smart Industry - Interviews

b. How can Smart Industry be applied to the advice for the purchase of the required machines?	Literature review	- Articles about Smart Industry - Critical reviews about Smart Industry - Interviews
c. What are the conditions for purchasing the required machines based on the Smart Industry concept?	Literature review	- Articles about Smart Industry - Critical reviews about Smart Industry - Interviews
3. How can the current product portfolio be characterized and which machines are required to be able to produce these products?		
a. Which cutted and bended components are currently outsourced?	Analysis	- Analysis production - Analysis purchased articles
b. Which cutting techniques exist to cut these products?	Research	- Research cutting techniques - Contacting suppliers - Visiting fairs - Visiting reference companies
c. Which bending technologies exist to be able to bend these products?	Research	- Research bending techniques - Contacting suppliers - Visiting fairs - Visiting reference companies
d. Which standard machine configurations are available in the market?	Market analysis	- Contacting suppliers - Visiting fairs - Visiting reference companies
e. How can the range of cutting and bending components be divided among the different machines?	Analysis	- Analysis production - Analysis purchased articles - Analysis trailers
4. What conditions, requirements and wishes are required for the purchase of machines for cutting and bending and which approaches are available?		
a. What requirements and wishes are set by the project team?	Analysis	- Analysis strategy Management Team - Analysis requirements and wishes
b. What conditions are set by QRM?	Literature analysis	- Analysis theoretical framework
c. What conditions are set by	Literature analysis	- Analysis theoretical

Smart Industry?		framework
d. Which approaches are available, taking the conditions set by QRM, Smart Industry and the requirements and wishes of the project team into account?	Analysis	- Analysis requirements and wishes - Brainstorm session
5. Which approach should be chosen, taking the conditions set by QRM, Smart Industry and the requirements and wishes of the project team into account?		
a. Which scenario should be chosen, taking the set conditions, requirements and wishes into account according to the analytical hierarchical process?	Design	- Literature about QRM and Smart Industry - Analysis requirements and wishes
b. Which proposal was finally chosen?	Design	- Analysis solutions - Analysis requirements and wishes

1.7 Deliverables

A number of products derived from the research that is carried out to write this thesis. The following products are delivered:

- Literature review QRM
- Literature review Smart Industry
- Analysis current procurement of steel parts
- Advice on machines to be purchased including a time-line

1.8 Reading guide

This report shows the results of the research carried out to give advice on the machines to be purchased for Broshuis Parts Production. Chapter 1 describes the backgrounds of Broshuis, the reason for this research and deals with the main and sub-questions. Chapter 2 describes the theoretical framework for Quick Response Manufacturing and Smart Industry. Chapter 3 provides an overview of the current product portfolio and an analysis of it. Furthermore, it describes which techniques and machines are required to be able to produce this product portfolio. Chapter 4 provides an overview of the conditions, wishes and requirements that are set for purchasing the machines. Using these conditions, wishes and requirements, scenarios have been drawn up and elaborated. In Chapter 5 these scenarios are tested according to the Analytical Hierarchical Process. Finally, the result is the chosen scenario with the associated machines. Chapter 6 provides room for discussion and final consideration, followed by the conclusions and recommendations in Chapter 7.

2. Theoretical framework

This chapter outlines the theoretical framework within which the research is carried out. This chapter answers the following research questions:

What is Quick Response Manufacturing, how can this theory be applied to the advice for the purchase of the required machines and what are the conditions for applying the QRM concept to the choices for the machines?

And;

What is Smart Industry, how can this theory be applied to the advice for the purchase of the required machines and what are the conditions for applying the Smart Industry concept to the choices for the machines.

The research is approached from two perspectives where possible. First of all, from the QRM idea and Smart Industry is also playing a major part. The research focusses on the approach of the organizational structure and how to apply it to the choice of purchasing the required machines. This is achieved by describing the techniques and concepts provided by QRM and Smart Industry. Next, the conditions are described for a successful implementation of these concepts. Finally, the way in which these concepts can be applied to the purchase of the machines is examined.

In section 2.1, an answer is given to research question 1: What is Quick Response Manufacturing, how can this theory be applied to the advice for the purchase of the required machines and what are the conditions for applying the QRM concept to the choices for the machines? First, an answer is given to question 1a: What is QRM? The basic concepts of QRM are explained. The first concept is "The power of time" where terms like lead time and Manufacturing Critical-path Time are elaborated. The second concept "Organizational Structure" focuses on response time spirals, QRM cells, team ownership, investing in cross-training and the need for an unconditional focus on the MCT. In the third concept "System Dynamics", the pitfalls of a utilization that is too high are discussed. The final concept "Company-wide approach" discusses how to use the different approaches for all departments of the organization. Section 2.1 is then concluded with an explanation of the application of concepts for Broshuis, which answers research questions 1b and 1c: How can QRM be applied to the advice for the purchase of the required machines? And: What are the conditions for applying the QRM concept to the choices for the machines. Finally, a summery is given of this section.

Section 2.2 provides an answer to research question 2: What is Smart Industry, how can this theory be applied to the advice for the purchase of the required machines and what are the conditions for applying the Smart Industry concept to the choices for the machines? In this section we start by answering research question 2a: What is Smart Industry? It explains what the initiative is for and it elaborates the principle of Fieldlabs. Subsequently, it concludes with what Smart Industry can mean to Broshuis, which answers research questions 2b and 2c: How can Smart Industry be applied to the advice for the purchase of the required machines? And: What are the conditions for applying the Smart Industry concept to the choices for the machines. These are followed by a summary.

2.1 Quick Response Manufacturing

'A company-wide approach to reduce lead time'

The production of goods has made a giant leap forward since the beginning of the 20th century. Where Henry Ford could completely changed the production technique with a conveyor belt, production companies are now designed "Lean" and "Smart" to be able to meet the demands of the market. Customers want quality and a product that meets their needs. This product should also preferably be as cheap as possible and be delivered quickly.

Lean Manufacturing meets almost all of these requirements. Except that Lean is not engaged in meeting all the wishes of the customer. Lean aims to extract all the variables and losses from a process. Broshuis, however, offers a customer-specific solution with many variables with its trailers. Therefore, within Broshuis the suitability of Lean is only limited.

In 1998 Rajan Suri introduced a new alternative: Quick Response Manufacturing. QRM does meet the all the requirements of the market and is very suitable for Broshuis. QRM is a company-wide strategy focused on reducing lead time. A division is made here between internal and external. QRM provides two key needs from the perspective of the customer: companies manage to quickly design and quickly produce products according to a customer-specific demand, which is the external aspect of QRM. The internal aspect regards the company's own organization. By implementing QRM throughout the organization, the lead times are reduced. The consequence of reducing this lead time is: better quality, a lower cost price and of course a faster delivery and response to the customer demand. QRM uses Time Based Competition: using speed as a competitive weapon.

Over the past few years, QRM has been successfully implemented at various companies. Lead times have in some cases been reduced by 90% up to 95%. Furthermore, these companies observed an increase in customer satisfaction (Tubino et.al., 2000).

It can be applied to industrial companies like Broshuis/BPP with the following characteristics:

- Large production variety
- Low volume (small series)
- Customer-specific products.

The QRM strategy is based on four basic concepts:

1. The power of time
2. Organizational Structure
3. System Dynamics
4. Company-wide approach (not just production, but everything)

These four basic concepts explain what QRM is and how this strategy can drastically reduce lead time.

2.1.1 Basic concept 1 – The power of time

The traditional belief that everyone needs to work faster and harder and that they have to work longer hours to get the job done, appears to be incorrect over the years. There is a limit to how hard a machine or person can be pushed. When this limit is exceeded, the task is no longer executed reliably, the quality drops and machines shut down due to overload, etc.

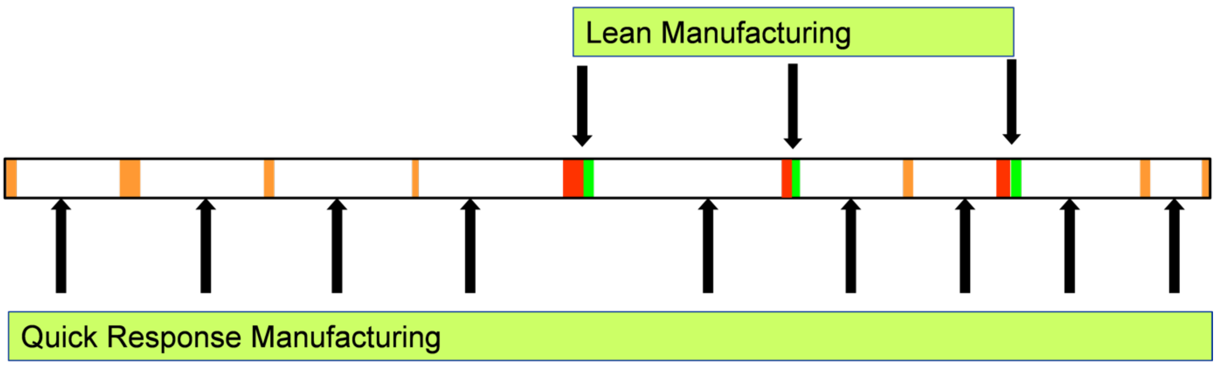
QRM therefore indicates that new ways need to be found to get the job done by primarily focusing on minimizing lead time. The first question is, what exactly is lead time. A distinction can be made between:

- External lead time: the lead time experienced by the customer (delivery time)
- Internal lead time: the time for orders to flow through the organization
- Quoted lead time: the lead time that salespeople pass on to the customers
- Planning lead time: the value used for each process step in a computer system with MRP or ERP
- Lead time of suppliers: the time needed to obtain the materials of the suppliers.

Of course, there are many more types of lead times, each with their own definitions, but for this research only the first two are considered: the internal and external lead time.

Within the total lead time of a production process, there are a number of steps that add value: the touch time. Traditionally, these directly measurable hours are looked at. The traditional focus in optimizing the production process is focused on these steps, which are indicated in green in Figure 2-1. The orange blocks are activities where no value is added. Red blocks indicate wastes. If we look at Figure 2-1, which depicts the total lead time of a process, we can observe that the green and orange blocks only take on a fraction of the lead time (approximately 5%). Most of the time – and therefore money – is used for the white blocks. This is the waiting time between the process steps.

Figure 2-1 Traditional time path



Source: QRM vs Lean. Retrieved from: https://www.qrm-managementcenter.nl/wat-is-qrm/qrm-vs-lean/

The gain therefore cannot be on the touch time, but actually the waiting times offer an excellent opportunity here. QRM focuses on these waiting times and involves all departments in this approach. For the purchasing department, for example, this means that not the cheapest supplier is chosen, but the one that best suits the short lead times.

To make lead time measurable, a measurement method has been developed from the QRM idea that clarifies the strategy. This lead time measurement is called the Manufacturing Critical-path Time (MCT) and is defined below:

The typical amount of calendar time from when a customer creates an order, through the critical-path until the first, single piece of that order is delivered to the customer.

Detailed data is not necessary, as data collection must be kept simple for two reasons;

- The purpose of MCT is to provide an overview and to get a global picture showing the most important points for improvement. It should not cost too much trouble.
- After determining the MCT ratio, it is important to compare it with the amount of touch time. It is not necessary to know the MCT exactly as long as it indicates that a large amount of white space exists.

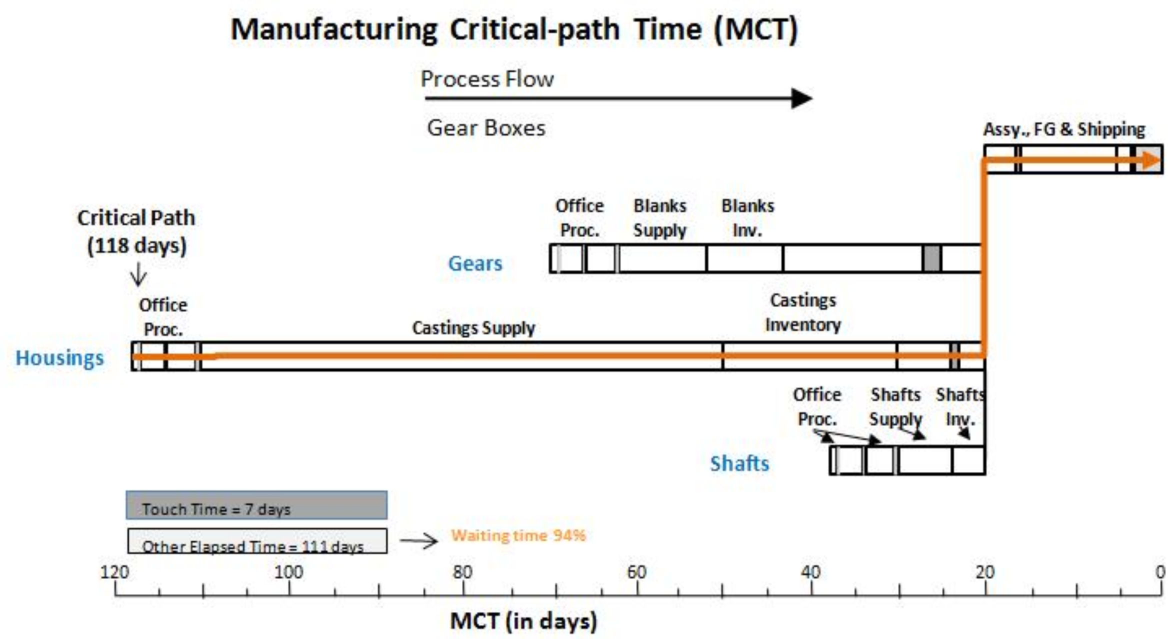
Three important rules are indicated when calculating the critical path:

1. It must be assumed that all activities are carried out entirely from starting point 0.
2. The MCT calculation must include all normally applicable waiting times, including other delays on orders and not the values that apply to a rush order.
3. Where stocks are used in the production industry to reduce lead time, with QRM these times spent in all stages must be added to the MCT value.

Figure 2-2 shows an MCT diagram. In this diagram the starting point (day 0) is located on the right. At this point, all activities come together and the product of service is delivered to the customer. From this point, the different lead times of the processes can be derived. In this random example it can be seen that creating the cast takes 118 days and therefore is the longest and most critical path.

By using an MCT diagram, it becomes clear what the critical path is within the organization. In addition, waiting times are represented proportionally so it can be quickly decided where the largest reduction in lead time can be achieved.

Figure 2-2 Manufacturing Critical-path Time



Source: MCT. Retrieved from: https://www.qrm-managementcenter.nl/mct/

Production is not the only focus in calculating and improving the MCT, other processes also require attention like:

- Delays in information flows
- Planning time
- Raw material stocks
- Delivery times for suppliers
- Logistical time.

The basic concepts below further describe how the lead time can be reduced and later in this report measures relating to Broshuis are listed. Significantly reducing lead times, has a large number of important consequences:

- Understanding due to the decrease in the amount of work in progress (WIP)
- Less stocks in the process
- Delivery reliability increases because shorter and simpler processes can be planned more easily
- Less overhead due to less transfers
- Costs decrease due to decreasing stocks, WIP and overhead

Another import aspect that has a great impact in cutting down the MCT is that the production time most likely increases. However, when the MCT decreases, the additional production costs pay for themselves in terms of stock and lead time. This results in a lower cost price of the product.

Cutting down the MCT creates new opportunities. Possibilities arise to win the market by being able to offer shorter delivery times of the current products and to beat the market and win it by launching new products with improved functionalities very quickly.

2.1.2 Basic concept 2 – Organizational Structure

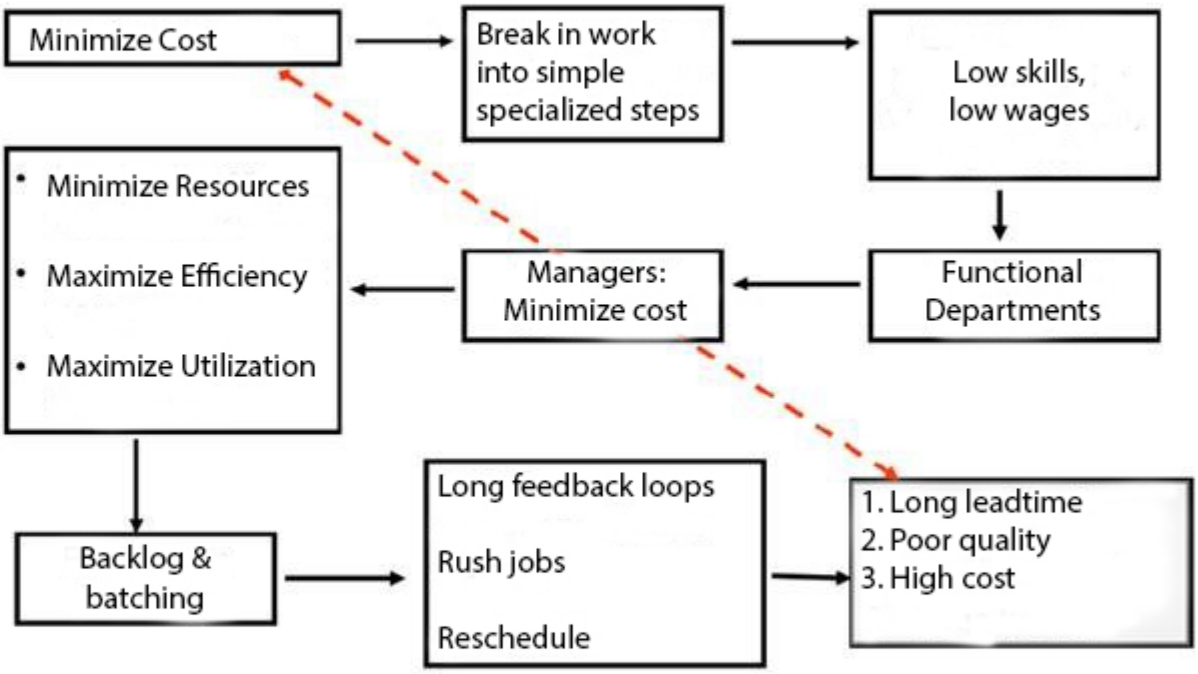
To reduce lead time, the operations within the organization must be addressed in a different way. This requires restructuring of the entire organization.

2.1.2.1 Response time spirals

QRM recognizes several types of spirals that arise as a result of thinking in scale and costs. These spirals are called response time spirals and occur in traditional organizations.

Thinking of costs forms the basis of the occurrence of response time spirals. This is explained in Figure 2-3. To be able to reduce costs, the aim is to maximize efficiency. As we can see in the figure, reducing costs has an adverse effect on the quantity of time. The utilization also causes a delay based on thinking of costs, which leads to the opposite of being responsive to the customer. The philosophy of thinking of costs did work for Henry Ford and many others in the past. However, with the high variety in products and increased customer-specific products, unfortunately this is no longer possible.

Figure 2-3 Response time spiral



Within QRM the organizational structure significantly deviates from the traditional structure on four points. This is clearly indicated by Figure 2-4.

Figure 2-4 Organizational structure

Organizational structure	Traditional	QRM
1. Organization	Functional	Cellular
2. Management	Top-down control	Team ownership
3. Team members	Narrow | Specialized	Cross-trained
4. Quick response Mindset	Efficiency and utilization goals	Relentless focus on MCT reduction

1. **From functional to cellular:** The organization no longer works with functional departments. Different cells need to be formed: QRM cells. The concept of cells is in itself very old, but this concept is extended with QRM cells to achieve new levels in flexibility.
2. **From top-down control to team ownership:** Instead of managers and supervisors controlling the departments, the QRM teams control themselves and have ownership over the entire process within their own cell.
3. From **specialized employees** with a narrow focus to **multi-deployable people:** Contrary to the current scientific management approach, in which every employee performs one task to their best abilities, an organization is created in which people are trained to perform several tasks (cross-training).
4. From **efficiency / utilization** as objective to **MCT reduction** (time from the moment of customer order until the delivery of one product). To support this new structure, the traditional objectives based on costs need to be replaced by QRM objectives based on time, which implies an unconditional focus on MCT reduction. With these three changes, linked to this new focus, surprising reductions are achieved in the MCT. When the objectives regarding the cost price are abandoned, there are remarkable reductions in the costs. A continuous improvement in quality and delivery performance arises.

2.1.2.2 QRM cells

Working in manufacturing cells has proven to be flexible and has been done for decades. They have a linear flow with a fixed sequence of operations and takt times. QRM cells are always set up around a well-defined Focused Target Market Segment. This specifies where the focus needs to be. It is impossible to change the entire organization at once.

The FTMS must be a well-framed part of the operation. In most cases, we start looking at where the market possibilities are. The market segments with possibilities for a strategy based on a quick response are the most suitable here. The market can be seen as an internal or external customer who wants shorter response times. This is called TMS: Target Market Segment. Research into what exactly this product is, would be required. It is not always a physical product but can also be a service. The process to determine the FTMS must be performed by a cross-functional group that consists of different departments. This allows the formulation of a good FTMS, which is the basis of the success of a QRM cell.

A QRM cell is defined as: a set of several dedicated, aggregated, multifunctional sources which have been chosen in such a way that these sources can completely perform a number of consecutive operations for all orders belonging to the FTMS. The sources must consist of a team of cross-trained, multi-deployable people who have full ownership of the production process within the defined cell. The ultimate objective of this cell is a reduction of the MCT within this cell.

- **Dedicated sources**: are sources within a QRM cell that are fully dedicated to this cell. For example, a press brake may only be used for orders belonging to that dedicated cell and to the FTMS and therefore no other orders. If this does happen, the process immediately is disrupted.
- **Aggregated sources**: are sources within a cell that have to be positioned closely together in a compact space that clearly limits the cell.
- **Multifunctional sources**: it is important to move away from a functional layout for a group of sources to execute a number of different functional operations within a room.
- **Performing consecutive operations**: when an order arrives at a cell, it must be subjected to a number of operations before it leaves the cell. The product is not allowed to leave the cell in between and come back later.

2.1.2.3 Team ownership

To fully use QRM, a change in the traditional structure is expected. Within a QRM cell there are no managers and supervisors that tell the employees what to do. Instead, there must be teams with complete control over what happens in their cell. The teams get full control over their own work and how they organize the cell and what happens in it. They are liable and actually have something to say on their own work. This stimulates the professional growth and they are able to exceed the expectations.

2.1.2.4 Investing in cross-training

Cross-training is essential and should be a strategic objective of the company. If an employee is only able to perform its own operations and is absent due to illness or leave, an entire operation of a cell comes to a standstill. In addition, another argument to invest in cross-training is that the job of an employee becomes more varied, less monotonous and more interesting. For QRM, however, there are 3 main reasons for cross-training:

- Large differences in the various orders of a cell cause bottlenecks to shift daily from order to order. Cross-training ensures a flexible deployment where you can always shift with capacity.
- With automated machines, not always 1 person per machine is required to operate it. When someone has a broader training, they can operate several machines at once.
- It results in a continuous long-term improvement program.

As the training takes place within a QRM cell, it is more focused and defined, causing it to take place in a shorter time period. The cell is designed for a specific FTMS. As a result, it is not necessary to know everything about a specific machine, except for the actions required within the specific cell.

2.1.2.5 Unconditional focus on MCT reduction

Measurements based on traditional thoughts are the final key point in creating the correct structure of the organization. Measuring based on efficiency is therefore incorrect, as one should have to look at the MCT. When the MCT drops, the cell functions properly. In addition to the MCT measurement, the QRM number must also be examined. This number is calculated by taking the average MCT over a base period which must be chosen. In case of measurements per quarter, it is possible to opt for 3 months. This yields the following formula:

$$Current\ QRM\ Number = \frac{Base\ Period\ MCT}{Current\ Period\ MCT} \cdot 100$$

In Figure 2-5 an example of the calculation of the QRM number is shown. Here, a measuring period of 3 months was chosen. An average MCT of 12 days is measured in the first quarter. This is the MCT of the base period. During the next quarters this is reduced, resulting in an increase of the QRM number.

Figure 2-5 Example of the QRM number

Calender Quarter	Average MCT for Cell	Details of calculation	QRM Number
January – March	12 days	(12/12) x 100	100
April – June	10 days	(12/10) x 100	120
July – September	8 days	(12/8) x 100	150
October - December	7 days	(12/7) x 100	171

Source: Reprinted from “It’s About Time”, Suri, R.,2010, p. 61, New York, NY: CRC Press.

The QRM number has a number of advantages:

- When a cell works properly, the MCT drops while the QRM number increases. People react more positively to a rising trend than to one that drops.
- The QRM number increases faster with each period that expires. When 2 periods in a row show a reduction of 2 days from, for example, 12 days to 10 or from 10 to 8, the second one is more important. This helps people to ensure that the first simpler improvements are less important than the more complicated improvements, which rewards them with a higher score.
- As the QRM number is designed to continue to increase, it also continues to motivate.
- It can be set up throughout the organization, resulting in a competition in a friendly way. As all cells start with the base number 100, a difference in lead time is eliminated.

It is important that the QRM number is applied correctly. A number of issues are relevant here. First, it is essential that both the start and end point of the MCT are clearly defined for each cell. It must be clear when the measurement starts and when it ends. Furthermore, the measurement can only start when the cell actually has ownership over this period of time. When a cell has to wait for an order, the measurement has to be stopped. Otherwise a distorted image is obtained. Finally, it should be the case that when a measurement for one cell stops, it starts running for another cell. Someone must always own the order.

2.1.3 Basic concept 3 – System Dynamics

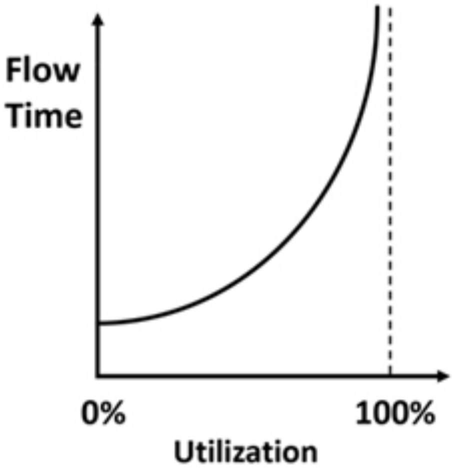
Entering QRM cells is no guarantee to reduce lead times. It is important that in case of large investments, they should not be done based on traditional management measurements. They state that attention should be paid to capacity utilization. QRM, however, states that even with a capacity utilization of, for example, 40%, financial benefits can still be achieved. It must be considered whether the reduction of the MCT and the additional benefits justify the low capacity utilization.

2.1.3.1 Pitfall excessive utilization

Traditionally, to minimize costs, sources are used where possible. However, everywhere applies: when the crowds increase, the waiting times increase as well. This also applies to the use of machines. When the utilization increases, the waiting times of the orders becomes longer and longer. This would be contrary to what needs to be achieved with QRM, which is a quick response and lead time.

To be able to get a quick response, one should approach the use of the machines in a different way. A strategic plan for the spare capacity should be drawn up. QRM states that the planned utilization of sources should be between 70% and 85%. The reason for this spare capacity is variability due to a high variation in orders, changeover times and adverse issues like deliveries or quality issues. A high variability in combination with a high capacity utilization leads to considerable waiting times. The relationship between lead time, utilization and variability is shown in Figure 2-6. Here you can see that with a low utilization, the lead time is relatively low. This lead time increases as the utilization increases. Furthermore, it can be seen that the lead time increases at a higher rate when the variability is higher.

Figure 2-6 Relationship between lead time and utilisation



Source: Reducing Time-To-Market through Quick Response Manufacturing. Retrieved from: https://www.qrminstitute.org/nl_NL/qrm-case-denmark

The definition of utilization according to QRM is the ratio between all the time a machine is used for any task, including maintenance, and the total time the facility is open and running. The difference to a traditional approach is that, for example, maintenance, changeover and downtime due to faults are included in the utilization. The question to ask, therefore, would be: How much time is the machine really available to start an unexpected order? The answer to this question is the actual spare capacity of the machine.

Another important concept is flowtime. The flowtime of an order is defined as follows: The flowtime is the average time an order has to wait until the previous order is finished, plus the start of the work on the order and the final time to complete the order.

The utilization has a huge effect on flowtime and subsequently also on the MCT. The time actually spent on an order is a small part of the MCT, the rest is waiting time. It is therefore important to know how this time can be reduced. Waiting times increase exponentially when the capacity utilization is higher. This is shown in the formula below:

$$Effect\ of\ Utilization = \frac{u}{1-u}$$

Where the capacity utilization is expressed in a decimal number in value *u*. The resulting values here are proportional to the waiting times. With a capacity utilization of 75% the bullwhip effect is 3, at 90% it is 9. It can be concluded here that an increase of 15% in capacity utilization triples the waiting time.

To demonstrate that a small investment in spare capacity results in a large reduction of the flowtime, the following formula is used:

$$Effect\ of\ Spare\ Capacity = \frac{1-s}{s}$$

Here *R* is the spare capacity which is calculated as follows: $s = 1 - b$. At 10% spare capacity, and therefore a utilization of 90%, the effect of the spare capacity is 9. At 20% spare capacity this is 4. An additional 10% spare capacity shows a reduction of 55% of the flowtime.

The MCT is the result of interactions and dynamics between available sources and tasks to be performed. In an overflown system, components influence each other at a given moment. The flow can be positively affected by 3 factors:

- **Reduction of variability / the difference in arrival time or processing time of orders:** No sales campaigns, quantity discounts and collecting orders until the end of the week.
- **Increase spare capacity:** Provide a reduction of changeover time and processing time and ensure a pure utilization of the production factors.
- **Reduce the total time per order:** Get the closest to One-piece-flow through SMED (Single minute exchange of dies). For small series, the lead time is the shortest.

2.1.4 Basic concept 4 – Company-wide approach

In general, processes are improved at the workplace. Here it is clear which steps need to be taken and the lead times are easy to measure. However, a large part of the lead time does not take place in the production hall, but at the office. In addition, office work largely determines how the orders are processed downstream. Therefore, it is important not only to reform the organization at the workplace, but also to include the office in the improvements. In addition, it is also possible to combine office and production operations in one cell, if this proves to be beneficial.

Implementing QRM in Broshuis calls for many changes in how the work is dealt with, but the social system also needs to be reformed. Broshuis has a long history and in all those years a completely individual company culture has developed. Initially there will probably be resistance to the change. In addition, it would not be realistic to have Broshuis suddenly take a different business strategy. This would be disastrous for the production within the current hustle and bustle. It is not desirable to simply change the current course - which is definitely not wrong – to a business strategy that has not even been tested.

So, the idea is to experiment with QRM on a small scale. The project working with hall 7 is extremely suitable for this and for the following reasons:

- In terms of process, we start with a "clean sheet", so all QRM principles are considered.
- The initiators of this project are very enthusiastic about the QRM strategy.
- The effect of QRM is financially easy to measure, as the project housed in a separate B.V.
- The new process also includes additional office work, which can also be arranged according to QRM.
- A quick response for the relevant products is desirable. The short lead times of QRM are an ideal match here.

2.1.5 Application of QRM at Broshuis

As indicated above, management has decided to implement QRM as a company strategy. This means that the new organization will be organized according to this philosophy.

QRM has a number of basic concepts, which are:

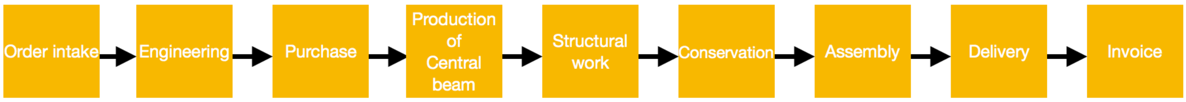
- The power of time;
- Organizational Structure;
- System Dynamics;
- Company-wide Approach

These concepts have been extensively discussed in the sections above. They provide a number of principles that should be considered in purchasing the machines and the further organization of the company.

To see where and in what way QRM can be implemented, the current situation at Broshuis was scanned. This scan consisted of interviews with the leaders of Beam Construction, Preparation of Structural Work, Logistics Manager, Head of Engineering, Head of Inspection and Testing, Purchasing Manager and the Managing Director of Broshuis Parts Production. In addition, a number of measurements were conducted, resulting in an image of the material and product flows throughout the organization. The scope of the scan is focused on all the processes for structural work but cannot be seen as a separate operation. It concerns the entire flow through the organization.

First of all, the flow throughout the organization was examined, which is illustrated in Figure 2-7.

Figure 2-7 Production flow at Broshuis

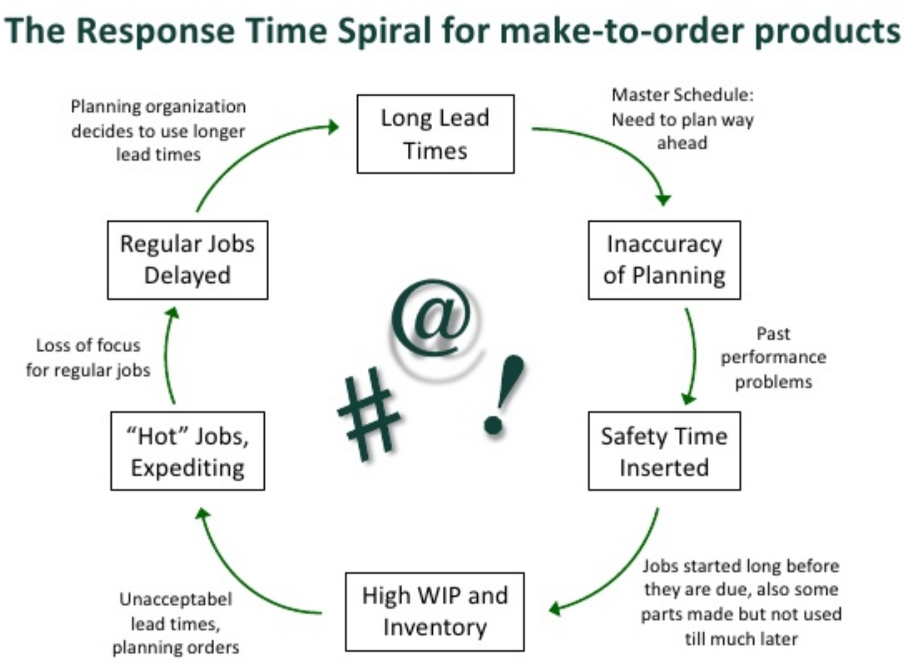


2.1.5.1 The power of time

It is important for Broshuis that the focus is on reducing the lead time. This implies that the Manufacturing Critical-path Time must be calculated. The lead time of a trailer from beam construction to final assembly is on average 3 to 4 weeks. The lead time from Engineering to delivery is on average 14 weeks. An agreement has been made that 14 weeks before delivery everything should be known and Engineering should be started.

The MCT can be cut down by restructuring the organization. The second basic concept focuses on this aspect. First, it describes what response time spirals are. QRM recognizes several types of spirals that arise as a result of thinking in scale and costs. The spiral most comparable to the situation at Broshuis, is the spiral of “Making on Order”. Only when a customer has actually ordered a trailer, an order is made and production is started. Broshuis creates customer-specific trailers that are specially designed for every specific application of the customer. As the Broshuis trailers are specific, they are not built in stock and cannot be built on a prognosis. Instead, Broshuis uses planning lists of end products that need to be built including a date when the product has to be ready for delivery. This planning is used to control the purchase and production of components and assemblies with the delivery date as timing. As Broshuis has long lead times (from 8 weeks up to 12 months!) the planner has to plan far ahead. This obviously does not benefit the reliability of the planning. In the meantime, a lot can happen: other important orders could be enlisted, quality issues could occur, machine problems, raw material problems, changes in the design, etc. As a result, the planner must embed safety margins within the schedule based on his knowledge and expertise. The delivery times at Broshuis have now risen so far that Sales are now facing problems. The only way to get large ‘important’ orders through the organization more quickly, is to treat them as rush orders with priority. These orders, however, take up a lot of time and energy to get them through the organization in time. This makes it more difficult for the planner to plan it correctly, creating a spiral as in Figure 2-8.

Figure 2-8 Responstime spiral for make-to-order products



Source: Reprinted from “It’s About Time”, Suri, R.,2010, p. 40, New York, NY: CRC Press.

The interviews have shown that they feel the bottleneck is located in the section between Structural Work and Assembly, i.e. preservation. Engineering is also considered a bottleneck. However, the total count of the intermediate stocks in the process shows that there are no real bottlenecks at the moment. No inventories may arise behind a bottleneck, as an increased pulling process exists behind a bottleneck. During the scan 9 intermediate stocks were seen between beam construction and structural work. Between structural work and preservation 23 trailers were counted and between preservation and assembly another 13 trailers were counted. Trailers that have already finished assembly and therefore are ready for production amount to more than 100 at the time of counting. The measurements took place on October 31, November 13 and 16 2017. These intermediate stocks negate the existence of a bottleneck. The work in progress positions in the various departments were not included in the counts.

2.1.5.2 Organizational structure

It can be deduced from the schematic flow, the work in progress positions and the intermediate stocks that there are functional layouts, each with its own priorities. These priorities are often not aligned. The work is done to run the production where every department makes its own choices based on available people and an optimal organization of their own department. The lack of alignment leads to a lot of work in progress, which in its turn results in disorder. Often, it is not clear where an order is located in the production or when it is ready.

The functional department at Broshuis causes an unclear planning and efficiency in the workplace. The distances between the different departments lead to loss of alignment, many movements, consultations and transport of products. During the various multi-snapshots, the actual activities of the employees were examined. This showed that 44% of the time is converted into productive labour, the time in which the employee is actually working on adding value to the product. The effectiveness was not considered here.

By introducing QRM, where the focus needs to be on is reducing lead time, transparency and an overview arise. In addition, less secondary needs to be satisfied, like: less plans, rescheduling, consultations, logistics and changes. Employees spend more time on adding value to the product and productive hours rise. A reduction in work in progress, stocks and intermediate stocks can also be expected. As the lead time of an order is reduced, the delivery reliability increases. This is because the latter can be better predicted and maintained with less orders in the system.

To achieve this, a number of adjustments need to be made within the organization. The dynamics of the organization need to be channelled. This could include separating the product flows to ensure that the different trailers with different lead times do not interfere with one another. This helps them get their own control and a better mutual alignment of the involved departments. In case of more alignment, the number of transfers can be reduced, causing the order to run more quickly through the organization. A reduction of transfers also means that no time and quality are lost. Employees should be working as a team more.

It is also important that a planning becomes more leading. The planning should be driven based on the pull system. At this moment, the planning is mainly push-driven. It is essential to plan on the shortest possible lead time. This can be achieved by working with more employees on 1 order, which ensures the factor time remains in view. It is now often seen that trailers take such a long time that their assembly is assumed to take longer than the set hours. This shows that the pressure to get the trailer ready within the set hours, disappears. By working with defined time blocks, one can ensure that the trailer is pulled through the organization as quickly as possible.

Within the new organization it is essential to deviate from the traditional organizational structure. One of the conditions is that the work has to be done in QRM cells. Here it is important that first a well-defined Focused Target Market Segment is drawn up. Broshuis needs to determine and record this.

When this FTMS is defined, it must be examined how the QRM cell are set up. These cells must be arranged in such a way that series of several dedicated, merged, multifunctional sources are created that can complete a number of consecutive operations for all orders belonging to the FTMS. This means that the press brake and lasers are fully dedicated to the cell and cannot be assigned to other orders. This immediately disrupts the process. It is also important that the sources are set up closely together and that the space of the cell is clearly indicated by, for example, lines on the floor. Another important action point is to abandon a functional classification. This is another challenge for Broshuis. It means that several operations need to be combined in one cell and the order is not allowed to leave the cell. The ultimate objective of the cell is the reduction of the MCT.

2.1.5.3 System dynamics

In the third concept, the principle of System Dynamics is discussed. This states that the pre-set financial benefits are not achieved with an excessive use of machines. Even with a machine utilization of 40% the financial benefits can turn out to be higher than with a higher capacity utilization. A pitfall is an excessive utilization. Therefore, it is important to consider a utilization between 70% and 85% of the machines to be purchased.

2.1.5.4 Company-wide approach

The final concept “Company-wide approach” indicates that the QRM idea is not only implemented at the production department, but also vertically throughout the company. It is fundamental that when designing the new organization, this is also considered.

2.1.6 Application of QRM on the choice of the machines

Despite the fact that QRM is implemented at a large number of companies around the world, the research on QRM is still only just beginning. Most literature on QRM contains descriptions and research into the development of its principles. Practical studies on the application of techniques for the reduction of lead time are lacking. Many studies have been done that describe the implementation of other modern production techniques (Lean, Total Quality Management), but the literature on QRM does not include any research with such an objective. Real guides or so-called “best practices” are missing in QRM research. Applicating QRM on the choice of the machines is therefore not very specific. Real conditions are not available.

However, there are a number of conditions that can be filtered from the available literature and that can be used for the purchase of the machines. QRM states that the capacity utilization of the machines should not be higher than between 70% and 85%. It is essential here that we include this condition and do a capacity calculation for the machines to be purchased.

Ten Hoonte (2012) also conducted research into a maturity model for QRM. A tool was developed with which organizations can quickly measure the extent of implementation of QRM and look for new improvements. A list of interview questions has been drawn up to score maturity. From these questions the following conditions can be filtered that can be used for the choice of the machines:

- The machines must be able to handle a wide variety of products
- It must be simple to create new products on the machines
- It must be simple to quickly adjust the capacity
- It should be possible to quickly implement design changes
- Changeover time must be low

- Maintenance should be easy
- The machines should provide information on maintenance, productivity, downtime, downtime due to defect, quality, lead times. All this to collect Big Data which can be used to perform the necessary analyses.
- Machines must ensure that work is removed for the employees where possible (automation)
- The machines must ensure that the steps are shortened and integrated.
- The aim is maximum flexibility

These conditions are later on be used in the final choice for the machines.

2.1.7 Summary

This section dealt with the theoretical framework on Quick Response Manufacturing. An answer was given to the research question: "*What is Quick Response Manufacturing, how can this theory be applied to the advice for the purchase of the required machines and what are the conditions for applying the QRM concept to the choices for the machines?*".

First, it was discussed what exactly QRM means. The basic concepts of QRM were explained and described. These 4 basic concepts are:

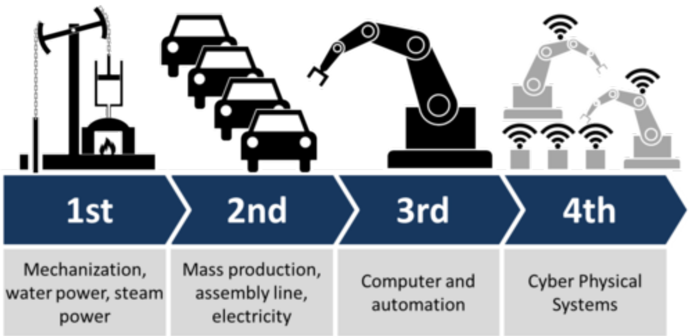
- The power of time;
- Organizational Structure;
- System Dynamics;
- Company-wide Approach.

Based on these 4 basic concepts, the basic principles of QRM were described. Then the applicability of QRM for Broshuis was discussed. The results of the performed investigation were displayed and explained. The final part of this section provides guidelines for the purchase of the machines. In this part the conditions are listed set by QRM. Now that the conditions from the literature on QRM are clear, it can be investigated which requirements and preconditions are set by the literature on Smart Industry for the purchase of the machines. These are discussed in the next section.

2.2 Smart Industry

At the end of the 18th century James Watt designed the first economically profitable steam engine and unleashed the first industrial revolution. From that moment on, technological developments occurred in succession in a rapid pace. The second revolution started with a new energy source: electricity. With it, conveyer belts in factories could be driven to allow mass production. During the third revolution capital-intensive production was introduced and the human factor was largely replaced by computers and robots. In 2011 Henning Kagermann, Head of the Deutsche Akademie der Technikwissenschaften (Acatech), gave the current developments a name: Industry 4.0. This fourth industrial revolution was also called "Smart Industry", because machines work autonomously and communicate with each other to regulate the process. In the Netherlands, Smart Industry is defined as "smart use of ICT where machines are connected to each other for an intelligent operation" (Huizinga et al., 2015). The revolutions are schematically shown in Figure 2-9.

Figure 2-9 Industrial revolutions



Source: Industrial revolutions. Retrieved from: https://www.smartindustry.nl/category/publicaties/toolkits/

The Dutch industry has to develop along during this 4th revolution. Worldwide, a strongly changing structure is observed and this change is expected to accelerate the next decade. Due to new production technologies and the further integration of ICT in the entire process of designing, manufacturing and distributing, the industry is radically changing, to which the Netherlands has to respond in time. Smart Industry therefore plays an important role here.

Due to the strong position of the Netherlands in design, system design and logistics, this development also offers many opportunities for the Dutch industry. Following the German program "Industry 4.0", now the Dutch initiative "Smart Industry – Dutch Industry fit for the future" exists. This initiative was launched in 2014.

The initiative for the Smart Industry comes from:

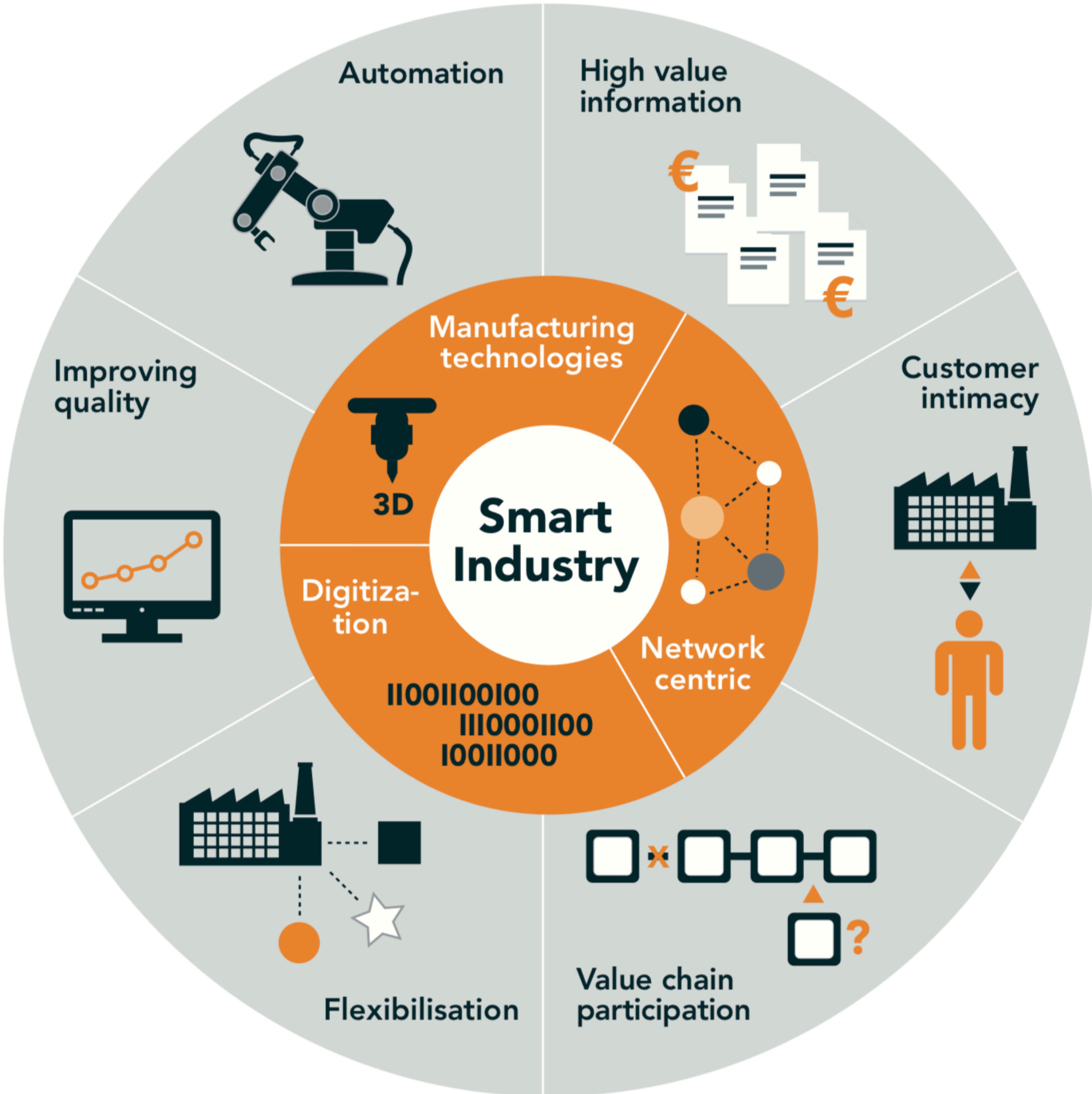
- FME
- TNO
- The Ministry of Economic Affairs
- VNO-NCW
- Chamber of Commerce
- Nederland ICT

The objective of this initiative is to strengthen the Dutch industry in the broadest sense by using the latest information and technologies. This helps the industry to deliver more efficient, flexible and qualitatively better customer-specific products and services, which leads to a stronger competitive position of the Dutch industry.

In the Dutch industry a development is observed with ever more closely collaborating chains and networks in which complex and knowledge-intensive products are developed that are sold on the worldwide niche markets with customer intimacy as the distinguishing factor. Due to the high complexity, the share in innovative and specialized companies is increasing. Much standard production has been moved to low-wage countries, but now a reverse movement is starting to emerge. These changes are accelerated by the fourth industrial revolution, which is characterized by far-reaching digitization and networking of products, machines and people through the use of new production technology. With the development of this Smart Industry, new ways of producing, new business models and new sectors are emerging. Smart Industries have a very flexible production capacity in terms of production specifications (quality, design), volume (quantity), timing (delivery time), raw material and cost efficiency. Due to this development and due to a strong digitally integrated chain of suppliers it is possible to deliver customer-specific products and services to every customer.

The driving force behind Smart Industry is the proper use of ICT. Machines should be interconnected, not only within the production facility but also between mutual companies and customers. Figure 2-10 shows the Smart Industry wheel. In this Figure a threefold division is made in Industrial Production Technologies, Digitization and Networking. Smart Industry uses sensors and high-quality ICT networks to achieve far-reaching digitization of product and process information. Furthermore, it uses new production technologies that change the industry. An example is industrial robotics. Production systems are present in a network in which production equipment and people are even connected outside the value chain. The developments lead to the following six business changes that can be seen in the outer ring of Figure 2-10. Due to the increasing degree of digitization, the value of information increases. This big data can be used for different purposes and can be valuable. The customer relationship increases as more customer-specific products are delivered and customers are given the opportunity to participate in the design process. Furthermore, this has consequences for the value chain and the organization of it. Through digitization and networking, the collaboration within the value chain is strengthened. The development of new production technologies makes it easier to adapt production processes. This leads to a high degree of flexibilization. Furthermore, these new production technologies lead to strengthening the knowledge about and the control on the production process, thus improving the quality. Robotization on the production floor furthermore leads to further automation of the production process.

Figure 2-10 Smart Industry wheel



Source: Smart Industry Wheel. Retrieved from: https://www.smartindustry.nl/smart-industry-roadmap/

A study by the Boston Consulting Group showed that Smart Industry causes an increase in productivity of 5% up to 8% at the same cost. To strengthen its competitive position in the market, increase its output and ensure its continuity, Broshuis must take part in these developments. This intention has been picked up by the management team (MT) and is one of the reasons for starting the project. For this project, the principles of Smart Industry serve as a guideline for shaping the new process.

Customers of Broshuis demand customer-specific products, unique and composed of numerous options. High quality, competitive pricing and short delivery times are also important matters for customers and ultimately the competitive position of Broshuis. This development in the market asks for a flexible production that delivers a large output. Reduced changeover times and fast information flows should make small series possible. Smart Industry can be seen as the action plan with which changes can be achieved.

Smart Industry is built on three pillars:

1. Horizontal integration of all the companies within the chain
2. Vertical integration of all steps within the production process
3. Flexible, intelligent production based on digital communication between machines and people.

The horizontal integration of all the companies within the value chain focuses on an optimum collaboration by freely exchanging information through digitization. Companies no longer only improve their production, but exchange knowledge to do the same for suppliers and follow-up steps in the value chain. This integration offers the opportunity for end-to-end engineering for the entire lifecycle of the product. This regards the design of a product, considering all the stages: from raw materials to production, maintenance and recycling.

Vertical integration optimizes the collaboration between process steps. The organizational structure of companies changes from a division of isolated departments to a division of flexible, multidisciplinary working cells.

The flexibility required for the large production variation is provided by a production where machines communicate with each other, new production techniques and a focus on data instead of on the product. This focus also largely shifts optimization from the workplace to the office processes.

To realize all this, the team of Smart Industry has drawn up an agenda for action in collaboration with Economic Affairs, companies, knowledge institutions and other parties. This agenda serves to encourage the industry to use ICT more intelligently with the aim of creating a more competitive industry.

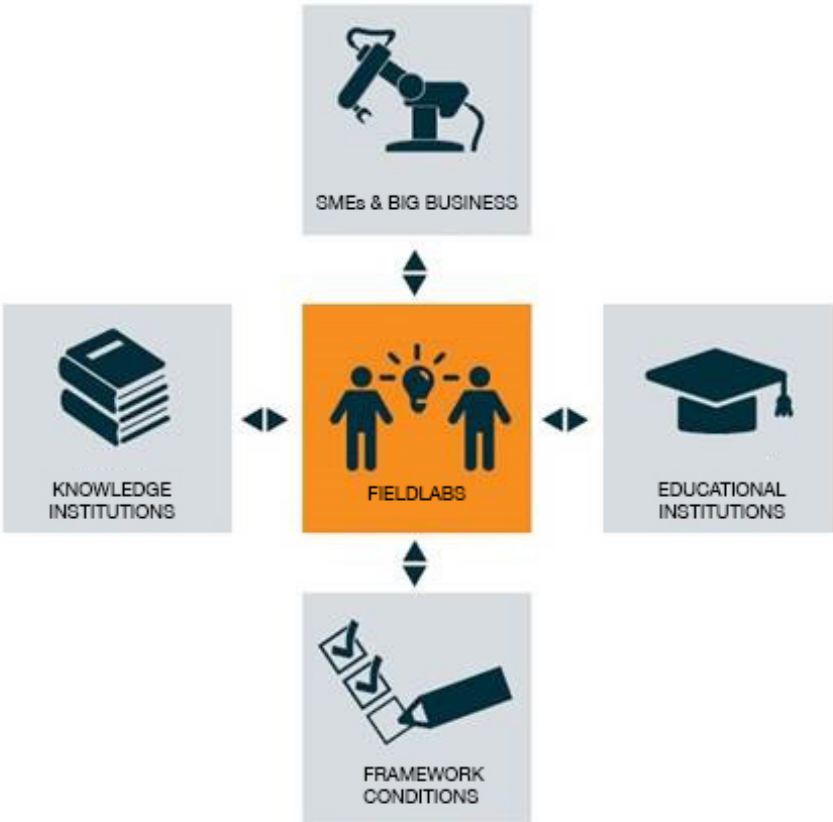
2.2.1 Fieldlabs

As companies are faced with major technological and organizational challenges it is often, despite the knowledge, too complex to realize innovations entirely on their own. Often, the costs involved are a reason why they are not able to do this. To solve this problem, the Smart Industry team chose to create Fieldlabs. The purpose of this Fieldlabs is to build alliances and consortia around the core principles of Smart Industry. These are practical environments in which both companies and knowledge institutions efficiently develop, test and implement Smart Industry solutions. The definition of a Smart Industry Fieldlab is therefor: *'A Fieldlab is a practical environment where Smart Industry solutions are being developed, tested, implemented, as well as an environment where people learn to apply these solutions.'*

The purpose of the Fieldlabs is to realize innovations to strengthen the Dutch industry. In collaboration with knowledge institutions, a study is conducted on new applications and business models. Sub-areas are designated per Fieldlab to see which specific innovations are needed and useful for each branch of the industry. Due to the shared costs and risks it is also possible for small companies to test what Smart Industry can mean for them. As a result, new technologies do not only become available for larger wealthy companies, but also for the smaller SMEs.

Figure 2-11 shows that the Fieldlabs are a bridge between companies, educational institutions and knowledge institutions. Furthermore, preconditions and recommendations for policies are made within a Fieldlab to be able to protect intellectual property, for example. A Fieldlab is never just a location, a clear program must also be formulated which has a clear objective and accompanying plan for at least 3 years.

Figure 2-11 Fieldlabs



Source: Fieldlabs dragen bij aan concurrende maakindustrie. Retrieved from: https://www.mt.nl/dossiers/made-in-nl/fieldlabs-dragen-bij-aan-concurrerende-maakindustrie/89157

2.2.2 Application of Smart Industry on Broshuis

In setting up the new organization for Broshuis with the latest technologies, Smart Industry can of course play a part. They also want to implement a high level of automation. This means that they want to work with robots and automate human activities as much as possible. Broshuis is considering becoming a part of the Fieldlabs as described above. They want to be a pioneer in the field of the metalworking industry through innovation and automation. To achieve this, they are prepared to invest considerably, not only in hardware but also in software. Partnerships need to be established with suppliers, companies and knowledge institutions to continue innovations. Broshuis wants to investigate any possibilities to become a Fieldlab and further develop it with an enthusiastic group.

2.2.3 Application of Smart Industry on the purchase of machines

In purchasing the machines, it is important to consider to what extent the production can be automated. Where can robots be used? How can data be returned? How can machines be controlled without people intervening? Which suppliers are the most advanced in the field of automation? This leads to the following conditions for purchasing the machines:

- Machines must be able to collect data and share it
- Machines should operate in a network and be able to communicate with each other
- High degree of automation (repetitive actions should be automated)
- High degree of robotization (where possible)

2.2.4 Summary

This section dealt with the theoretical framework around Smart Industry and answers the research question: "*What is Smart Industry, how can this theory be applied to the advice for the purchase of the required machines and what are the conditions for applying the Smart Industry-concept to the choices for the machines?*".

First, it was explained what the initiative is used for and how it is set up. Furthermore, the core values of this initiative were discussed. Next, it was examined where Broshuis can apply the Smart Industry concept and how to focus it on the choice of the machines. Finally, the conditions of the choice for the machines were filtered and listed.

Now that the conditions for purchasing the machines is clear, it is possible to look at the conditions Broshuis sets for the purchase. These requirements and preconditions are discussed in Chapter 4. Chapter 5 links the literature and practice and the final selection of the machines is made. First of all, Chapter 3 looks at the current product portfolio and which machines are required to produce these products.

3. Current product portfolio and machines

After framing the research, this chapter provides an analysis of the current product portfolio and looks at the solutions offered in the market. The different techniques are discussed and the standard machine configurations in the market are examined. This chapter gives an answer to research question 3:

How can the current product portfolio be characterized and which machines are required to be able to produce these products?

This chapter answers the research question mentioned above by answering the various research questions that have been formulated. Section 3.1 indicates what analysis is executed and how it is addressed. This section answers research question 3a: Which cutting and bending components are currently outsourced? The following section answers research question 3b: Which cutting techniques exist to cut these products? It explains what techniques are available now in the market and what the advantages and disadvantages are for the different techniques. Section 3.3 answers research question 3c: Which bending technologies exist to be able to bend these products? The existing bending technologies are discussed and the so-called free bending is discussed in more detail. Research question 3d: Which standard machine configurations are available in the market? is answered in section 3.4. First, the cutting machines are considered and next the press brakes. In the final section of this chapter the answer is discussed of research question 3e: How can the range of cutting and bending components be divided among the different machines? In this section the products that emerged from the analysis are discussed and classified for the machines that are typically available in the market.

3.1 Outsource analysis

To get an idea of the product variation, the author performed an analysis of the products that were purchased at KMT, Zuidberg and SBW throughout 2016 and the first quarter of 2017. This analysis gives an indication of the different machines that are required to be able to produce this product range inhouse.

During the period of January 2016 up to March 2017 more than 10,000 different items were ordered from the suppliers mentioned above. Unfortunately, the ERP system used at Broshuis does not provide the information required to perform a good analysis. Aspects like dimensions, thickness and type of material unfortunately cannot be filtered. This forced us to obtain the STEP files from these items from the Windchill environment. STEP files are created from the drawn 3D model and constitute a default format to share data of 3D models. With these STEP files, it is possible to analyse the drawings using software, i.e. SDI. This way, a flat result of the product is created with which any cutting machines can later generate the cutting program. This software offers the possibility to extract all the required data from the STEP file.

Unfortunately, there are no STEP files available for all the products. This still concerns a relatively large part of the product file. In collaboration with Richard Jansen, it was decided to also include all the items with an order size of 10 or more in the period from January 2016 to March 2017 in the analysis. As a result, for some 3500 items all drawings were opened manually to extract the required information. The items for which a STEP file was available were passed through SDI and independent of their order size included in the analysis.

In total we were able to retrieve the data of 7333 different items and included them in the analysis. These items together were purchased 315,421 times in total.

The data is further discussed in section 3.4.

3.2 Cutting techniques

For cutting steel, a laser is used. A laser offers a high precision CNC controlled method for cutting metals, plastics and ceramic materials. It is a merchandised, thermal and contact free process to cut most materials with high quality and precision.

For a long time, two types of lasers were generally used for cutting, the CO_2 laser and the Nd:YAG laser. In addition to the nature of the laser active medium, the main difference is the wavelength of the laser beam. This is 10.6 µm for the CO_2 laser and 1.06 µm for the ND:YAG laser.

In both cases the cut is made in the same way, i.e. by using lenses and mirrors to focus a monochromatic light beam in a very small spot. The energy density that is created in the focus point is more than 106 W/cm², sufficient to locally melt all the material or even evaporate it. As soon as melted or evaporated material is created across the whole depth of the plate, the cutting gas, that is coaxially supplied from the cutting nozzle, is able to blow this material out of the cut.

The nature of the laser cutting process is determined by the fact that the laser beam can be focused to a spot of less than 0.5 mm, creating very high energy densities. As a result, highly angled cuts are obtained at high cutting speeds. Another consequence of this combination is that the heat affected zone is extremely small, resulting in a minimum deformation of the cut part. As the wavelength of the Nd:YAG laser light is much shorter – this approaches the visible light – this laser beam can be guided through a fiber optic cable. This helps to make the manipulation much easier and the beam can be used in combination with, for example, a robot for three-dimensional cutting. In contrast, the CO_2 laser is normally used for cutting a flat surface.

3.2.1 Laser cutting now and in the future

The disadvantages of the CO_2 laser (no constant cutting image and the cutting result gets worse over time) and those of the YAG laser (problems with cooling and a very low efficiency, between 3 and 5%) has led to the search for other techniques. In the telecom sector, a combination of optical fiber and light was already used. The laser industry used this as well for the development of the fiber laser, in which light is transported directly to the head via a special optical fiber cable using diodes.

Producing the fiber cable is a very expensive process and partly determines the high price that has to be paid for this type of laser. At the moment, they are busy developing a laser that can cut directly from the diode without using the fiber cable. The first suppliers are now experimenting with this and the first machine has already been launched in the market.

An important additional advantage is that with the arrival of the diode laser, the efficiency rises to around 40%. This means that 40% of the energy that is put into it is converted into heat to cut with. For the other lasers, the values are:

CO_2	20%
YAG	3-5%
Fiber	30-35%
Diode	40%

3.2.2 Overview of techniques

There are different techniques for cutting steel, with each their own characteristics. The overview below discusses them.

3.2.2.1 Oxyfuel/autogenous cutting

With autogenous cutting, the plate is heated with multiple burners up to auto-ignition temperature: approximately 1250 degrees. With pure oxygen (>99.5%) a strong exothermic reaction is then started which oxidizes the material. Due to the kinetic force of the oxygen jet, this oxide is blown away from the material and a cutting gap is created.

3.2.2.2 Plasma

Contrary to autogenous cutting, with plasma the material is not burnt but melted. A plasma arc connects the negatively charged electrode to the positively charged product and melts the material with a temperature of up to 20,000 degrees. The molten material is blown away from the cut by the jet of the plasma gas.

3.2.2.3 Laser cutting

The material is melted with a laser beam of a few millimetres in diameter. The molten material is blown away from the cut by the related air flow. Due to the low heat input, the high cutting speed and the absence of rework, this is an ideal cutting technique.

3.2.2.4 Diode laser

With a fiber laser the beam is generated by several diodes and then transported to the head of the laser cutter with an optical fiber cable. With a diode laser the beam is generated by one diode which is situated on the bridge of the laser cutter. Until recently, it was hard to make a laser beam this way that was powerful and accurate enough for cutting steel parts, but the technique is rapidly developing and a sheet thickness of 25 millimetres is already possible now. The diode laser has some advantages compared to the fiber laser:

- An efficiency of 45% compared to 35% for the fiber laser
- A cutting speed that is 15% higher than for the fiber laser
- Smaller machine, because the compact source is situated on the bridge
- Higher cutting quality

3.2.2.5 Water jet cutting

A water jet up to 6000 Bar with abrasive cuts up to 200 millimetres thick steel. The water jet is only a few millimetres in diameter and does not add any heat to the product.

Figure 3-1 below displays the different techniques in a table

Figure 3-1 Overview cutting techniques

	Fiber laser	Diode laser	Plasma	Oxyfuel/Autogenous	Water jet
Sheet thickness	=/<25 millimetre	=/<25 millimetre	Tot 45 millimetre	<1200 millimetre	<200 millimetre
Materials	Metal, wood, plastics	Metal, wood, plastics	Electrically conductive materials	Steel	Extensive range of materials
Heat input	Low	Low	Average	High	None
Cutting holes	Sheet thickness x 0.8	Sheet thickness x 0.8	Sheet thickness x 1	None	Sheet thickness x 0.8
Cutting width	0,8 mm	0,8 mm	2 mm	5 mm	1,1 mm
Cutting speed	High, lower for thicker sheets	Highest achievable speed at this moment. Lower for thicker sheets	Average	Average	Low
Investment costs	High	High	Low	Low	Average
Operating costs	Average	Average, less power consumption than a fiber laser	High	High	High
Perpendicular	Yes	Yes	No	Yes	No
Cutting quality	Excellent, no post-processing required	Excellent, no post-processing required. Nicer cut than fiber laser	Average quality, post-processing required	Low quality, post-processing required	Excellent, no post-processing required
Remaining	Common cutting lines possible. High automation possible	Common cutting lines possible. High automation possible			Contaminated products and working environment due to water and abrasive

3.3 Bending

Converting a flat sheet into a three-dimensional product is often done by bending it. Bending is a rather complex technique because there are many factors that affect the end result: type of material, thickness of material, rolling direction, heat influences, tool wear, groove width, upper blade, reduction values, angles, inner radius, influence of holes, etc.

3.3.1 Free bending

At the new B.V. we are going to use so-called free bending, because this is the most flexible way to bend around a corner. By moving the stamp downwards, the sheet to be bent is pressed in the lower mold. The resulting angle does not depend on the tools, but on the depth of the impression and the thickness of the sheet. As both the stamp and the lower molds consist of separated parts, a setup can be made for each product to optimally bend it.

3.3.1.1 Bending force

The bending force (kN/m) is calculated using the formula below:

$$Bendingforce = \frac{\mathrm{C} \cdot \mathrm{Rm} \cdot \mathrm{B} \cdot \mathrm{s}^2}{\mathrm{V}}$$

C = correction factor
Rm = tensile strength
B = product width
s = sheet thickness
V = groove width

The maximum bending force is 400 kN/m bending length.

3.4 Standard machine configurations

To be able to give advice on the machines to be purchased, the standard setups that are available in the market were investigated. A number of suppliers have been approached for this. Broshuis has indicated that it only wants to use established brands.

3.4.1 Cutting machines

A wide range of cutting machines are offered by several different suppliers. However, most suppliers offer standard setups. This also has to do with the standard dimensions of the sheets available in the market. The standard dimensions of the cutting machines are:

- 3 x 1.5 meters
- 4 x 2 meters
- 6 x 2 meters

Other dimensions are available, but these are special machines.

Various providers for cutting profiles are available that offer tube lasers in the market. When purchasing these machines, we need to look at how the work is offered. The standard machines have a maximum input and output length of 15 meters. Above this number we speak of special machines.

3.4.2 Press brakes

Also in the field of press brakes, a wide range of machines is offered. However, the purchase of a press brake is mainly based on the work offered for this machine. The length and tonnage are chosen accordingly. The machines can be produced from a length of 1.5 meters with 80 tons up to 8 meters and 640 tons. Above we speak of special machines.

The machines can be configured with a wide range of tools.

3.5 Product selection

This section analyses the products that are currently outsourced and which are produced on the newly purchased machines. First, the cutted parts are looked at, followed by the parts with a bending operation.

3.5.1 Cutting parts

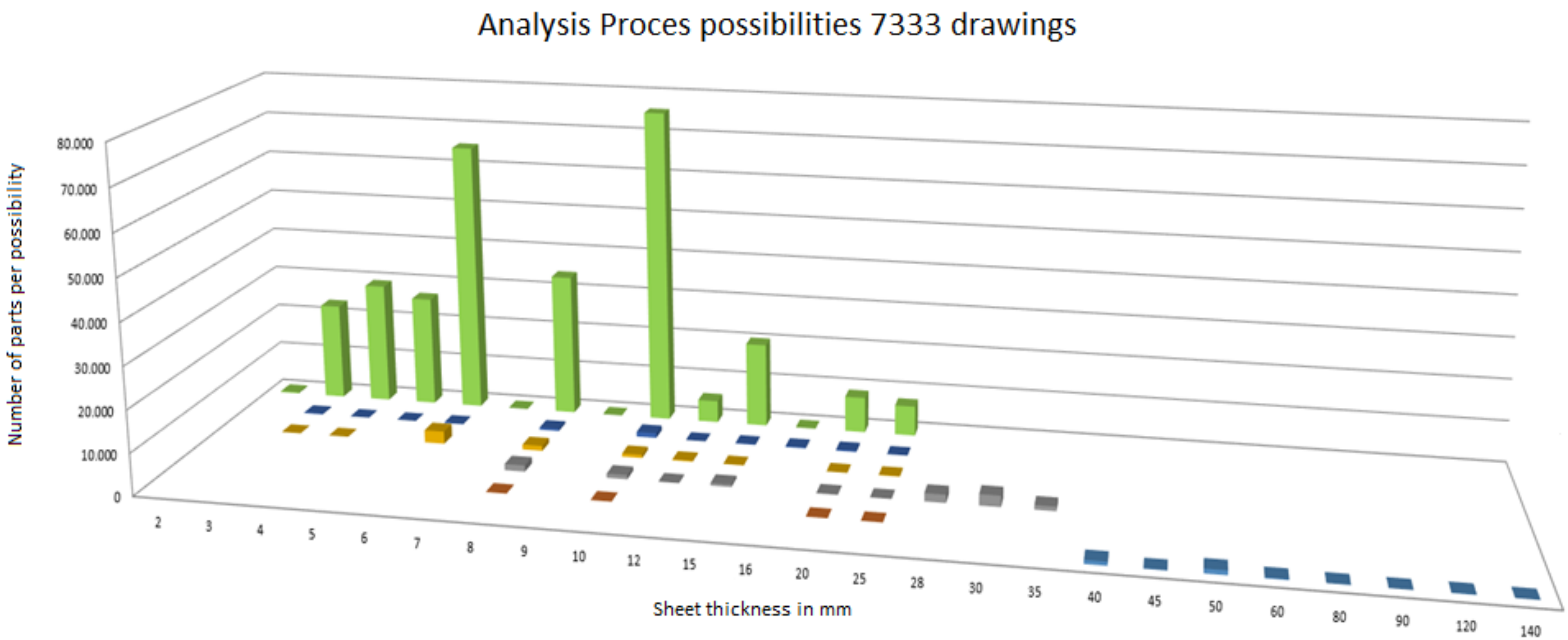
Figure 3-3 displays the items across the different machines available in the market. It can be seen that by far the majority of the items can be passed over a standard fiber laser of 3 by 1.5 meters (displayed in green). These machines can cut a range of 2 mm up to 25 mm thick from sheets of 3 by 1.5 meters. The big advantage is that this is the default dimension within the industry, far-reaching automation is possible, relatively little logistic handling and the investment compared to larger machines is much lower. This is later on elaborated in the investment overview.

The number of items that cannot be passed over the 3-meter fiber laser, is relatively small. Therefore, the investment for a fiber laser of 6 by 2 meters cannot be justified. If you also include the additional logistic handling and the fact that the sheets are not typically available in the market, this option also drops out. The items that should pass over this laser, can also be cut on a portal laser that supports the long items.

The number of products within the range of the portal laser are indicated in yellow. The portal laser can process items of up to 14 meters and 25 mm thick. The cutting speed of a fiber laser is considerably slower within this range than the HD plasma and the quality of the cut depends on the quality of the steel.

What remains is so thick and long that for now it cannot be processed. This number is very limited and needs to be purchased for the time being.

Figure 3-3 Distribution of products per machine

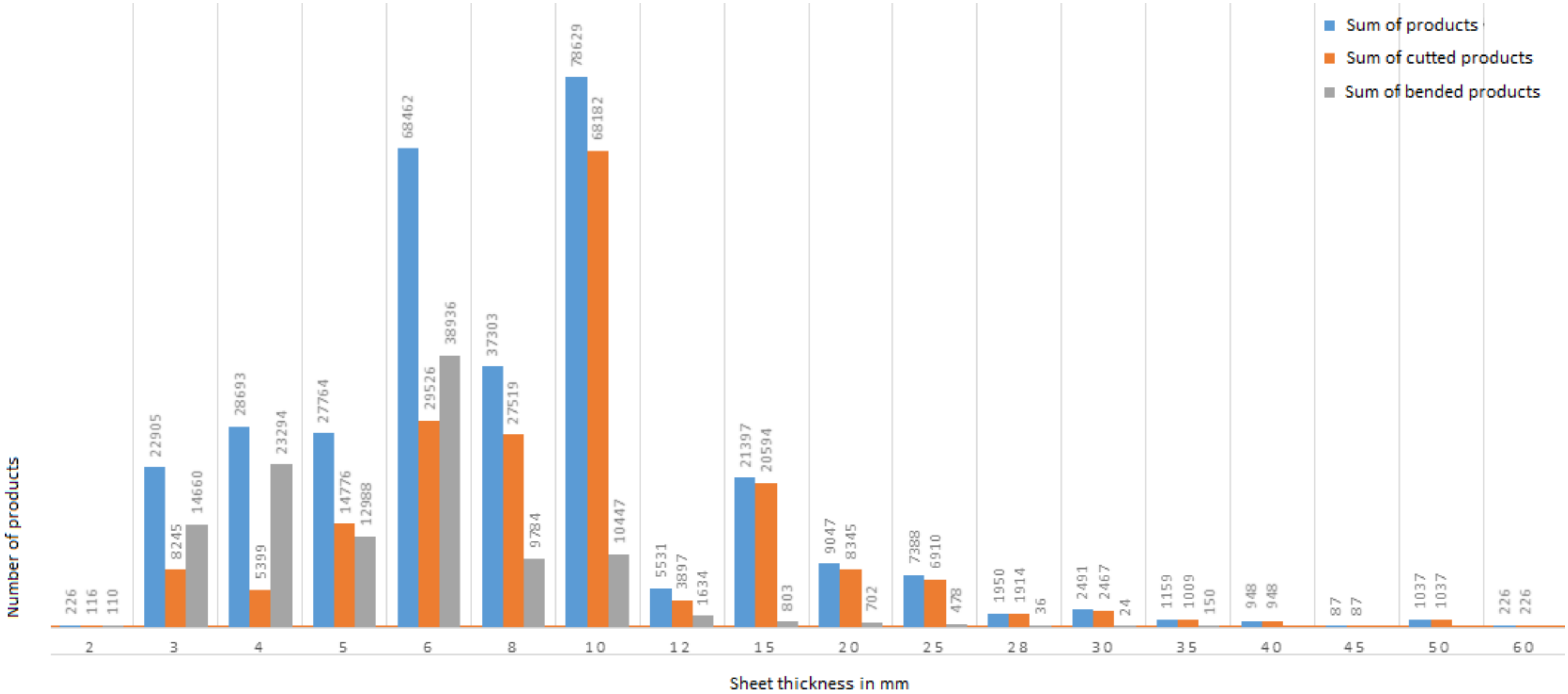


	2	3	4	5	6	7	8	9	10	12	15	16	20	25	28	30	35	40	45	50	60	80	90	120	140
6. Too thick																		901	97	1.056	200	46	2	91	22
5. Too long							50		24				13	3											
4. HD Plasma							1.484		1.006	14	609		157	49	1.918	2.637	1.057								
3. Laser 6 meter		26	16		2.989		1.197		779	234	61		33	116											
2. Laser 4 meter		168	19	1	115		528		1.150	16	140	238	291	44											
1. Laser 3 meter	244	23.391	29.230	26.578	65.168	13	34.157	10	75.761	5.267	20.165	76	8.561	7.203											

3.5.2 Bending

An analysis has also been done for bending the current products that are now being purchased. Figure 3-4 displays a distribution of the products to be bent. As it takes a lot of time to constantly change the tools on the press brake, it has been decided to see if the setup of the press brake could remain the same where possible. This can be achieved by combining the thicknesses closest to each other. A case study has been conducted into the different setups. This case study can be found in Chapter 6. Furthermore, it should be considered that the thicker the material is, the longer a bending operation takes. The capacity of the press brake must, therefore, also be kept in mind.

Figure 3-4 Distribution bended products



Therefore, it has been decided to combine thicknesses 2 to 5 mm, which are displayed in Figure 3-5. The quantity of the items combined in thickness should be feasible for 1 press brake.

Figure 3-5 Press brake 1 (t/m 5mm)

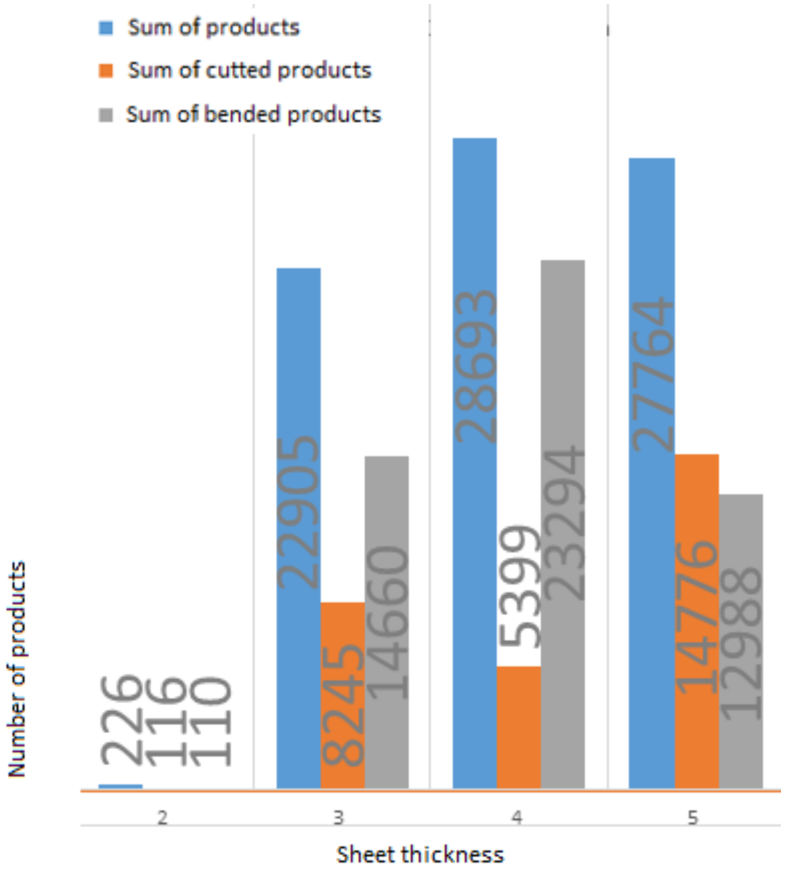
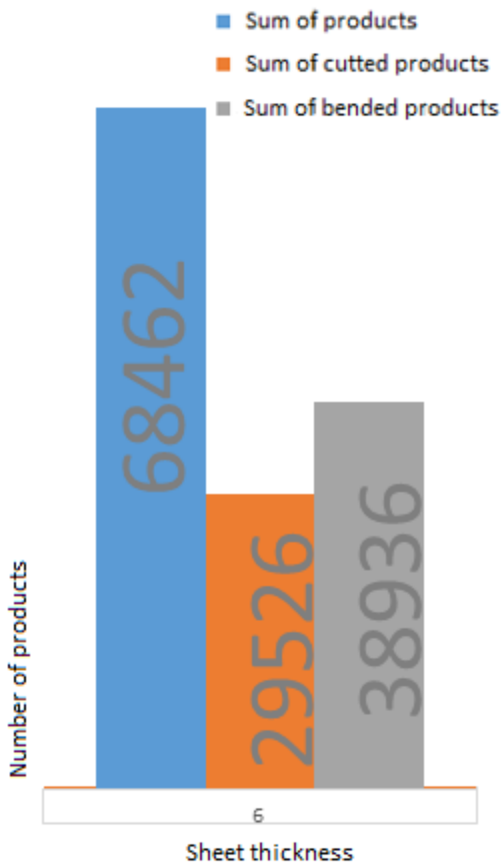


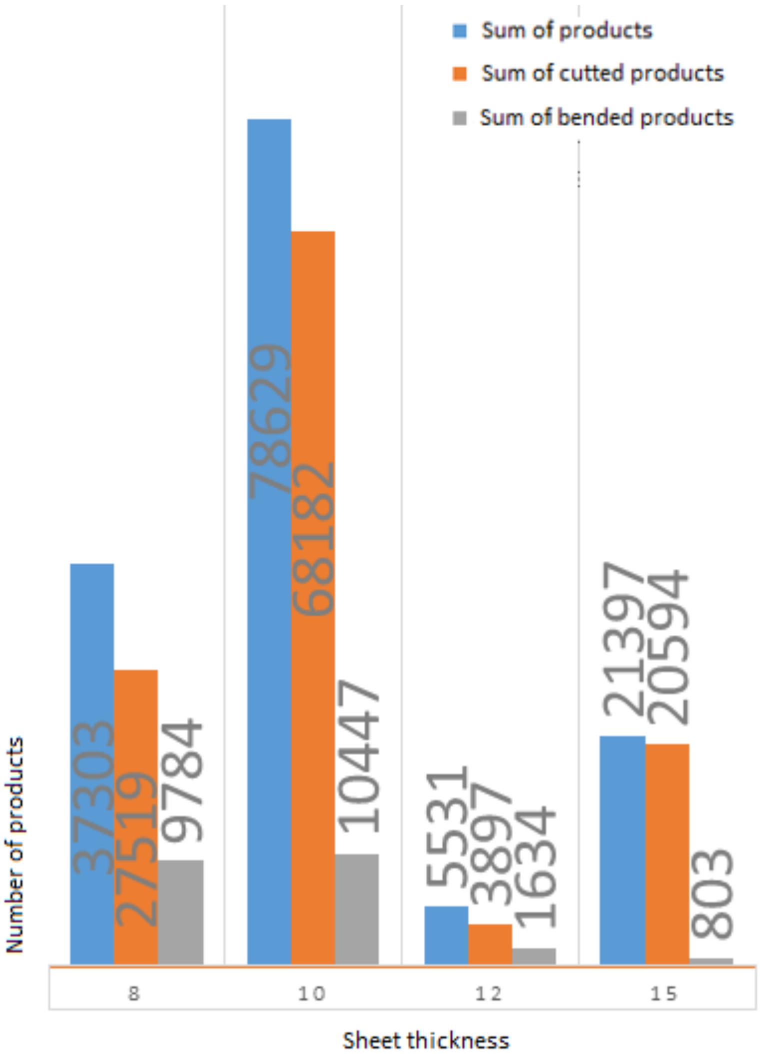
Figure 3-6 Press brake 2 (6mm)



As could be seen in Figure 3-6, the number of products to be bent with a thickness of 6 mm is the largest. Therefore, it was decided to only have this pass over a 2nd press brake.

The remaining products belong to the thicker range that is bent. The numbers within this range decrease but the time for every bending operation increases considerably. At this moment, products up to 15 mm thick are bent. The range above 15 mm thick is very small. If you want to bend these products, the press brakes would need to be heavier which requires a considerable additional investment that cannot be justified. The distribution can be seen in Figure 3-7.

Figure 3-7 Press brake 3 (8 t/m 15mm)



3.6 Summary

This chapter discussed the current product portfolio and an answer was given to the research question: *"How can the current product portfolio be characterized and which machines are required to be able to produce these products?"*.

First, an analysis was performed on the cutting and bending items that are currently outsourced. To be able to subdivide them on the available machines in the market, first we looked at the possibilities to cut and bend these items. An overview of the cutting techniques has been discussed as well as bending techniques. Then it was examined which standard machine configurations are available in the market. After this information was known, we looked at how the purchased items could be divided over the available standard machine configurations.

4. Conditions, requirements, wishes and scenarios

After analyzing the purchased parts and after an investigation into the solutions offered in the market, this chapter outlines the requirements and wishes. Subsequently these requirements and wishes are converted into different scenarios. This chapter therefore answers the research question below:

What conditions, requirements and wishes are required for the purchase of machines for cutting and bending?

To answer this research question, the conditions, requirements and wishes of QRM, Smart Industry and the project team are aggregated and categorized in section 4.1. This section therefore directly answers research questions 4a, b and c: What requirements and wishes are set by the project team?, What conditions are set by QRM? and What conditions are set by Smart Industry?.
The following section discusses the different scenarios that are considered possible. These scenarios were created in various brainstorm sessions with the project team. Section 4.2 therefore answers research question 4d: Which approaches are available, taking the conditions set by QRM, Smart Industry and the requirements and wishes of the project team into account?

4.1 Requirements and wishes

To make the right decision on the machines to be purchased, conditions, requirements and wishes must be drawn up. The conditions set by QRM and Smart Industry have already been discussed in Chapter 2 and are included here in the overview. The project team has drawn up requirements and wishes together with the Management Board. These have been combined with the conditions that have emerged from the theoretical framework and are displayed in the tables below.

General requirements		
Requirements	**Required / wished**	**Source**
Designed for growth	Required	Broshuis
The status of the production of each part must be traceable	Wished	Broshuis
Production runs on 70-80% of its capacity	Required	QRM
Paperless production	Required	QRM/Smart Industry /Broshuis
Work is organized in such way that the that the safety and the health of the employee is guaranteed.	Required	Broshuis/Arbo

Laser		
Requirements	**Required / Wished**	**Source**
Standard machines. No customization.	Required	Broshuis
Laser must cut with at least the fiber technique	Required	Broshuis
Laser needs to cut up to 25 mm	Required	Broshuis
Can produce great variance of products	Required	Broshuis/QRM
New products must be easy to produce	Required	Broshuis/QRM
Easy design changes	Required	QRM
Low change over time	Required	QRM
Easy and predictive maintenance	Required	QRM/Smart Industry
Machines need to be connected and sharing information	Required	QRM/Smart Industry
High level of automation	Required	QRM/Smart Industry
High level of flexibility	Wished	QRM
Equipped with a monitor to check and control the process	Required	QRM/Smart Industry
Laser must be automatically load and unload	Required	Smart Industry
Laser must be connected and sharing information with the press brakes, the sheet metal storage system and the ERP.	Required	Smart Industry

Press brakes		
Requirements	**Required / Wished**	**Source**
Standard machines. No customization.	Required	Broshuis
Must be equipped with an adaptive bending system	Required	Broshuis
Minimum amount of change overs	Wished	Broshuis
Programmable sheet followers	Required	QRM/Arbo
Can produce great variance of products	Required	QRM
New products must be easy to produce	Required	QRM
Easy to expand capacity	Required	QRM
Easy design changes	Required	QRM
Low change over time	Required	QRM
Easy and predictive maintenance	Required	QRM/Smart Industry
Machines need to be connected and sharing information	Required	QRM/Smart Industry
High level of automation	Required	QRM/Smart Industry
High level of flexibility	Wished	QRM
Press brakes must be connected and sharing information with the laser, the sheet metal storage system and the ERP.	Required	Smart Industry

Sheet metal storage system		
Requirements	**Required / Wished**	**Source**
Standard machines. No customization.	Required	Broshuis
Modular system	Required	Broshuis
Autonomous system	Wished	Broshuis
Compatible with different laser brands	Required	Broshuis
Easy to expand capacity	Required	QRM
Low change over time	Required	QRM
Easy and predictive maintenance	Required	QRM/Smart Industry
Machines need to be connected and sharing information	Required	QRM/Smart Industry
High level of automation	Required	QRM/Smart Industry
High level of flexibility	Wens	QRM/Smart Industry
The sheet metal storage system must be connected and sharing information with the laser, the press brakes and the ERP.	Required	Smart Industry

4.2 Scenarios

After drawing up the conditions, wishes and requirements of QRM, Smart Industry and the project team, several brainstorm sessions took place. During these brainstorm sessions, different scenarios were outlined. Four scenarios are described below. These scenarios are drawn up and classified according to the amount of work they outsource.

4.2.1 Scenario 1. Continue outsourcing: represents 0% of the outsourced work

In this scenario all steel products are still produced and delivered by third parties. Long delivery times and a varying quality are the biggest problems in the current situation where everything is outsourced. Integration with the supplier could reduce these problems. By starting a collaboration with the supplier, arrangements could be made on delivery time, quality and Broshuis can play a part in improving deliveries of the supplier. Probably, another supplier needs to be found for this. SBW and KMT Wijchen are situated geographically at such a great distance that a close collaboration would be difficult to realize. In addition, third parties always have to balance the interests of Broshuis and those of other customers.

The pros and cons are:

Pros

- Low investment required;
- Production area at Broshuis remains available for other processes;
- Reduction of rejection and limited reduction of delivery times possible.

Cons

- Delivery time longer than producing inhouse
- Added value of the processing ends up with the supplier;
- Little influence on the quality and production costs;
- Much rework during production;
- More and longer disruption for rejection of rush orders;
- Less accurate and timely delivery in production sequence of structural work possible;
- Optimization of structural work less easy;
- Dependent on supplier;
- Longer communication lines with supplier;
- Large logistic distance, longer delivery time as a consequence;
- Higher (intermediate) stocks;
- With increasing pressure supplier always has to consider whom to serve;
- Purchasing departments remains more charged;
- Technique of manufacturability remains outsourced.

4.2.2 Scenario 2. Insource laser cutting and bending (3x1.5 meters): represents 60% of outsourced work

In this scenario cutting and bending parts are produced using two laser cutters and three press brakes. The two laser cutters of 3 x 1.5 meters are linked to a fully automated sheet metal supply and the cut parts are automatically sorted out (3rd quarter of 2018). By choosing only two lasers of 3 x 1.5 meters not all the cutting and bending parts can be produced. The larger dimensions and sheet thicknesses cannot be produced on the selected laser cutters and need to be outsourced. For these parts, a laser, plasma, autogenous or water jet cutter with larger dimensions is required.
In this scenario we opted for press brakes with a diameter of 4 meters and 320 tons. Using these, all bending operations within the range of 3 x 1.5 meters can be resolved. With these machines approximately 60% of the products can be produced internally.

Pros

- Lead time <1 day;
- Added value of processing remains within the company;
- High quality with little rejection, less disruption on steelwork up to 3 meters;
- Little or no rework, higher flow speed on material up to 3 meters;
- Fast delivery in case of problems or rush order;
- Good, timely and delivery in production sequence up to 3 meters;
- Optimization of structural work is easier;
- Not dependent on supplier
- Partial discharge of purchasing department due to automated order and processing;
- Less stock;
- Considerably automated/less labour required relative to manual sorting;
- Dimensionally stable (suitable for further automation and molds);
- Flow optimization becomes internal process instead of external process with supplier;
- Optimization of product due to short feedback to and awareness of engineering in the field of costs/manufacturability.

Cons

- Investment required;
- Production area required;
- Approximately 40% of the components cannot be produced in this scenario;
- Limited to 3 x 1.5 meters. Larger sheets impossible;
- Thicker range remains outsourced;
- No full grip on the entire flow.

4.2.3 Scenario 3. Insource laser cutting and bending (up to 6x2 meters): represents 85% of outsourced work

The analysis showed that a large number of products is not within the range of 3 meters but within the range of 4 and 6 meters. In this scenario it was decided to add a laser up to 6 meters to the machines of scenario 2. An additional plus of the 6 meter lasers is that they can be equipped with a 2.5D head. This makes it possible to cut at an angle, preventing chamfers to be added later. It is also possible to add a drill unit to the machine, eliminating rework.

Within the range of 6 meters there are only cutting parts that do not need a bending operation. Should they need a bending operation, this can be performed on a press brake of 4 meters. Another press brake therefore would not be required.

All cutting parts outside the range of 6 x 2 meters and thicker than 25 mm must be purchased in this scenario. When this scenario is opted for, approximately 85% of all the outsourced work can be produced inhouse.

Additional pros with respect to scenario 2:

- Lead time <1 day for larger range;
- Added value of increased number of operations adds to own revenue;
- Dependency on supplier further reduced;
- Laborious operations with low added value (like chamfering and drilling) can be eliminated for the most part;
- Extensive possibilities for Design for Assembly.

Cons

- Larger investment;
- The 6 x 2 laser with automated supply requires a large production area;
- Thicker range (above 25 mm) remains outsourced;
- Limited to 6 x 2 meters. Larger sheets impossible;
- No full grip on the entire flow.

4.2.4 Scenario 4. Laser cutting, bending and cutting long items (up to 16 meters): represents 95% of outsourced work

In this final scenario a long item laser cutter is added to the 2 laser cutters (3x1.5). With these machines approximately 95% of all cutting operations can be executed and a large part of the strips can be processed. This laser for long items can be equipped with a drill unit and a 2.5D head to cut chamfers.

Additional pros with respect to scenario 3:

- Lead time <1 day for virtually all components;
- Components larger than 3 x 1.5 meters can also be cut;
- Further reduction of steelwork stock;
- Not dependent on supplier;
- Considerably automated/less labour required;
- Grip on the entire flow by insourcing almost everything.

Cons:

- Big investment required, laser for long items is expensive;
- Large production area required;
- Laser for long items offers few additional options with regard to additional investment costs;
- Logistic operations on laser for long items cannot be automated;
- Thicker range (above 25 mm) remains outsourced.

4.3 Summary

This chapter answers the question: "*What conditions, requirements and wishes are required for the purchase of machines for cutting and bending?*". The conditions established by the theoretical framework have been incorporated together with the wishes and requirements of the project team. All these conditions, wishes and requirements have been combined in a table which forms the basis for section 4.1. In the following section, different scenarios have been outlined. In Chapter 5, these scenarios are be tested against the conditions, wishes and requirements outlined in this chapter and a final choice is made.

5. Machine selection

In Chapter 4, the conditions, requirements and wishes for the purchase of the machines have been set and arranged. Afterwards, different scenarios were outlined that emerged from brainstorm sessions with the project team. These scenarios are tested and an answer is given to the research question below:

Which approach should be chosen, taking the conditions set by QRM, Smart Industry and the requirements and wishes of the project team into account?

To answer the research question, sub-questions have been formulated. Section 5.1 answers research question 5a: Which scenario should be chosen, taking the set conditions, requirements and wishes into account according to the analytical hierarchical process?
The following section answers research question 5b: Which proposal was finally chosen? In this section the findings of section 5.1 are discussed and the final scenario is chosen. Subsequently section 5.2 looks at the machines selected for the chosen scenario. In section 5.3 the capacity of the machine tools is calculated. Section 5.4 provides an overview of the required investments.

5.1 Analytical hierarchical process

To make an orderly choice between the 4 scenarios outlined in Chapter 4, we opted to use the AHP method. The AHP method is developed by Thomas L. Saaty in the seventies. The method is used to add a value to the different criteria that are important for a choice. The possible solutions can then be calculated and established. The result is ultimately the scenario that best meets the criteria.

In Chapter 4, criteria have been established which are used in the AHP model. These criteria test the scenarios that have also been mentioned in Chapter 4. Normally, in an AHP model 7 criteria are used to test the results. We have chosen, however, to include 20 criteria in our model. Below a list is shown of the criteria we used:

- Designed for growth
- Status of each part must be traceable
- Operating on 70-80% of production capacity
- Paperless production
- Minimal fiber technique (laser)
- Cutting capacity up to 25 mm thick (laser)
- Can produce great variance of products
- Easy design changes
- High level of automation
- High level of flexibility
- Low change over time
- Easy/predictive maintenance
- Status info from machines
- Standard machines
- Machines need to be connected sharing info
- Laser needs to load and unload automatically
- Press brake can be equipped with bending aid

- Press brake equipped with angle measurement
- Modular and autonomous (Storage system)
- Compatible with different lasers (Storage)

To test these criteria, an AHP Priority Calculator was used. This software from bpmsg.com allows to enter 20 criteria and compare them. This leads to 190 comparisons where it should be indicated which criteria are more important with respect to the other and a score (1-9) should match it that indicates how much more important one criterion is. There is also a possibility to score a criterion as equally important. After completing this information, a consistency check is performed. This Consistency Ratio should score below 10%.

In the table below, table 5-1, the results of the AHP are shown, where the criteria are ranked.

Figure 5-1 Outcome AHP

Criteria		
Category	**Priority**	**Rank**
High level of automation	23,5%	1
Press brake equipped with angle measurement	11,3%	2
High level of flexibility	9,3%	3
Laser needs to load and unload automatically	7,3%	4
Can produce great variance of products	6,3%	5
Minimal the fiber technique (laser)	6,2%	6
Status of each part must be traceable	5,3%	7
Easy design changes	4,9%	8
Cutting capacity up to 25 mm thick (laser)	4,7%	9
Operating on 70-80% of production capacity	4,0%	10
Easy/predictive maintenance	2,5%	11
Machines need to be connected sharing info	2,2%	12
Standard machines	2,0%	13
Status info from machines	1,9%	14
Low change over time	1,9%	15
Designed for growth	1,6%	16
Modular and autonomous (storage system)	1,5%	17
Compatible with different lasers (storage system)	1,5%	18
Press brake can be equipped with bending aid	1,4%	19
Paperless production	0,8%	20

The scenarios outlined in Chapter 4 must then be tested against the criteria. For each scenario, each criterion is scored from 1 to 10. The results are shown in Table 5-2 below.

Figure 5-2 Scenario review

Criteria									
AHP Priorities	**AHP score**	**Scenario 1: Continue outsourcing**		**Scenario 2: Laser cutting up to 3 x 1,5 meter and bending**		**Scenario 3: Laser cutting up to 6 x 2 meter and bending**		**Scenario 4: Laser cutting, bending and cutting up to 16 meters**	
		Score 1-10	Weight score	Score 1-10	Weight score	Score 1-10	Weight score	Score 1-10	Weight score
High level of automation	0,016055	5	0,080275	6	0,09633	8	0,12844	9	0,144495
Press brake equipped with angle measurement	0,053063	4	0,212252	8	0,424504	8	0,424504	7	0,371441
High level of flexibility	0,039502	2	0,079004	7	0,276514	8	0,316016	8	0,316016
Laser needs to load and unload automatically	0,00758	5	0,0379	7	0,05306	8	0,06064	7	0,05306
Can produce great variance of products	0,061845	5	0,309225	7	0,432915	9	0,556605	7	0,432915
Minimal the fiber technique (laser)	0,047375	10	0,47375	10	0,47375	10	0,47375	10	0,47375
Status of each part must be traceable	0,063086	9	0,567774	6	0,378516	8	0,504688	9	0,567774
Easy design changes	0,049347	2	0,098694	6	0,296082	7	0,345429	8	0,394776
Cutting capacity up to 25 mm thick (laser)	0,23507	4	0,94028	8	1,88056	7	1,64549	6	1,41042
Operating on 70-80% of production capacity	0,092823	4	0,371292	7	0,649761	8	0,742584	9	0,835407
Easy/predictive maintenance	0,019002	0	0	9	0,171018	8	0,152016	6	0,114012
Machines need to be connected sharing info	0,02537	0	0	8	0,20296	8	0,20296	7	0,17759
Standard machines	0,019151	0	0	9	0,172359	9	0,172359	9	0,172359
Status info from machines	0,019912	0	0	8	0,159296	7	0,139384	6	0,119472
Low change over time	0,021613	0	0	9	0,194517	8	0,172904	7	0,151291
Designed for growth	0,072519	0	0	10	0,72519	10	0,72519	6	0,435114
Modular and autonomous (storage system)	0,014181	0	0	10	0,14181	10	0,14181	10	0,14181
Compatible with different lasers (storage system)	0,112696	0	0	10	1,12696	10	1,12696	10	1,12696
Press brake can be equipped with bending aid	0,01525	0	0	9	0,13725	8	0,122	6	0,0915
Paperless production	0,014559	0	0	9	0,131031	8	0,116472	6	0,087354
Subtotal for scenario 1:		50	3,170446	72	4,961992	81	5,198146	80	5,000054
Total score:				163	8,124383	167	8,270201	153	7,617516

In Table 5-2 the 4 scenarios from Chapter 4 have been tested. It shows that scenario 1 cannot be scored for a number of criteria. Therefore, the choice was made to compare the first scenario with the other scenarios for the first 10 criteria. The subtotals in which scenario 1 can be compared, are listed in Table 5-2 as "Subtotal for scenario 1". For the first 10 criteria, the scenarios score as listed below:

- Scenario 1: 3.17
- Scenario 2: 4.96
- Scenario 3: 5.19
- Scenario 4: 5.00

The results clearly indicate that scenario 1, continue outsourcing, scores worse with regard to the other scenarios. Therefore, the scenario "continue outsourcing" is not investigated any further.

The remaining 3 scenarios can be compared with the full 20 criteria. The scenarios score as listed below:

- Scenario 2: 8.12
- Scenario 3: 8.27
- Scenario 4: 7.62

This demonstrates that scenario 2, cutting up to 3 x 1,5 meters and bending, and scenario 3, cutting up to 6 x 2 meters and bending differ little in terms of score. This AHP ultimately shows that scenario 3 is the scenario that best meets the criteria. Also due to the fact that Broshuis management intends to produce almost all steel parts inhouse in the future, it was decided to further develop scenario 3.

In scenario 3 2 lasers are purchased of 3 x 1.5 meters and one laser of 6 x 2 meters. The latter can be equipped with a 2.5D head which makes it possible to cut at an angle. A drill and tap unit can also be added to this laser, which means that rework can be kept to a minimum. The 3 lasers have the possibility to cut through sheets up to 25 mm thick. Furthermore, in this scenario a 4 meter press brake of 320 tons with bending aid was chosen. With this scenario approximately 85% of the outsourced work is produced.

5.2 Machines

Broshuis expressed a preference for brands that serve the top of the market. That is why only the most prominent brands were approached and invited for an interview. Following these interviews, a shortlist was created of the suppliers and the product they offer. These suppliers are briefly discussed below.

5.2.1 Lasers

5.2.1.1 Mazak

Yamazaki Mazak Corporation (Mazak) is a Japanese manufacturer of metalworking machines. The company was founded in 1919 as a manufacturer of pots and pans but has grown into a multinational with 10 factories and 7200 employees around the world. Mazak is known for its advanced, innovative, high-quality machines and the comprehensive service they offer.

Machine selection

Mazak is currently the only supplier to market a Direct Diode Laser. This machine can be delivered in the dimensions 3 x 1.5 meters. Broshuis desires to be a pioneer in technology and therefore has expressed its wish to purchase the latest techniques in the field of laser cutting. However, the DDL laser has only recently been launched and has not yet been used in the Benelux. To spread the risks, a 2nd fiber laser machine is recommended. These machines already have proven themselves in the market.

The following setup was chosen:

- Processing surface: 3000 mm x 1500 mm
- Technology: 4 kW DDL and 6 kW Fiber

These machines are connected to a central supply which is automatically loaded and unloaded.

5.2.1.2 MicroStep

Microstep has been on the market of CNC cutting machines since 1991. They sell their machines around the world and have dealers in 44 countries now. For the Netherlands this is Wouters Cutting & Welding.

Machine selection

The MicroStep fiber laser cutting machine MSF is a powerful machine for cutting different types of material with a fiber laser. The machine is designed for the production of high-precision parts at high cutting speeds with low maintenance and operation costs. The cabin combines a good accessibility to the machine while maintaining the necessary protection. For loading and unloading material, the machines is equipped with a MicroStep shuttle table that significantly reduces downtime during loading and unloading and increases the productivity of the machine.

The following setup was chosen:

- Processing surface: 6000 mm X 2000 mm
- Technology: 6 kW Fiber possibility for bevel cutting, drilling and tapping.

5.2.2 Sheet metal storage

5.2.2.1 Remmert

Remmert is a German family business that was founded in 1945. In 1972 it built its first fully automatic storage of goods followed by the fully automatic sheet metal storage in 1982. It has since grown into an international company that sells its systems worldwide.

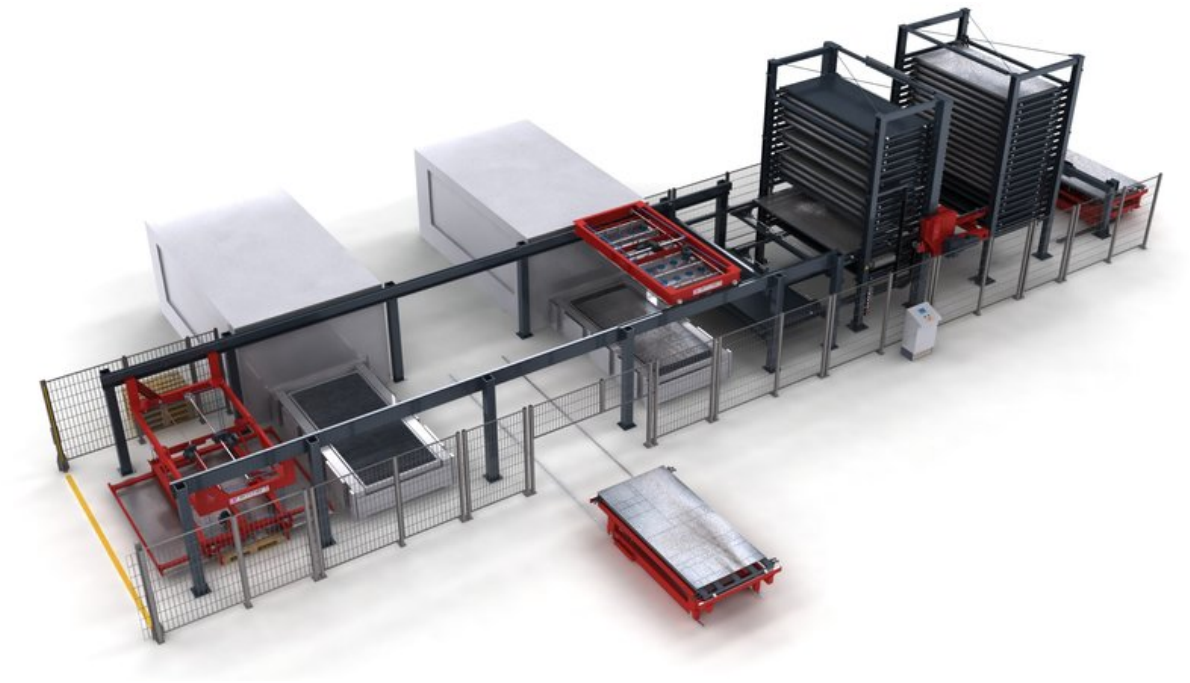
Machine selection

The aim is to load and unload the 3 x 1.5 fully automatically. Even in the future a fully automatic sorting unit is desired. The laser is provided with unprocessed sheets that are stored in a tower with trays. Once the products to be cut have been completely nested in the background and the order is ready for the laser, the storage unit receives a signal and transports the correct sheet to the laser.

The storage unit needs to be flexible in nature and must be suitable in the future for connecting the different laser brands. This is the reason why Remmert was chosen. It is an independent storage builder that can be connected to any laser.

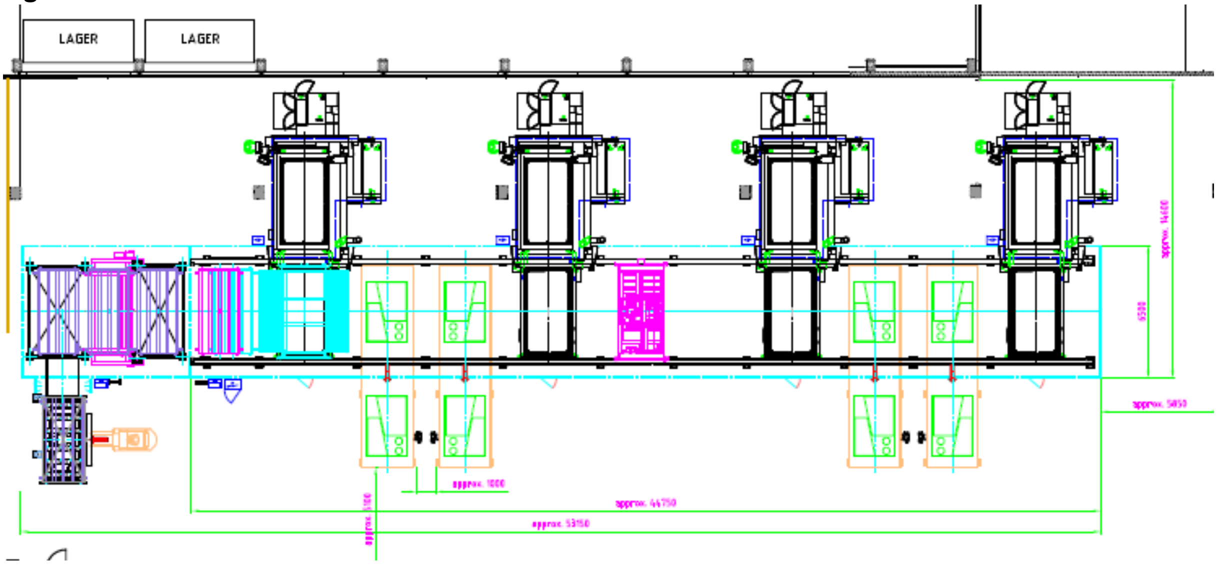
The sheet metal storage Remmert is offering, is the LaserFLEX 4.0 with a BASIC Tower 4.0 is shown in figure 5-1. This is a completely modular storage and therefore easy to expand with an additional laser or tower. The setup is ideally produced with two towers. The additional tower provides more storage space and the possibility to put residual sheets in the thicker range back in storage instead of scrapping them. The software of Remmert keeps track of the number sheets that are in stock, which certificates accompany the sheets and flawlessly communicates with the laser. The input and output of the laser cutter is automated with the LaserFLEX 4.0. This unit loads and unloads the laser cutter with a cycle of less than 60 seconds. This makes it currently the fastest system in the market and therefore the ultimate automation solution.

Figure 5-1 Remmert Laser-Flex



After the laser cutting process, the products need to be taken out of the sheet. The conservative way is to knock them out. This means that employees are bent over the sheet to knock out parts with a hammer or magnet. Then the parts have to be sorted and placed on the appropriate pallets or carts. However, Remmert also offers a solution for sorting out the products. This is, however, still under development and will be launched on the market in October 2018. During the visit at Remmert it appeared that they are still looking for a partner in the Netherlands for its development. Mutual goodwill has been expressed for this cooperation. At the moment, little is known about this system but needs to be further investigated. In figure 5-2 a possible future state is shown.

Figure 5-2 Future state: 4 lasers



5.2.3 Press brakes

5.2.4 LVD

LVD is named after its founders, Jacques Lefebvre, Marc Vanneste and Robert Dewulf. Founded in 1950, LVD established itself in the market by producing press brakes. Since 1998, they have also been producing laser cutters and have grown into an international company that is active in 45 countries with more than 2000 employees.

Machine selection

The LVD press brakes are known as the best in the industry. In addition, LVD has the biggest advantage in terms of software. Therefore, we chose LVD as the supplier of the press brakes.
The analysis has shown that there are quite a number of products that require a bending operation over the full 3 meters. This is also the reason that we implement the press brakes in the 4-meter version as the 3-meter version only has 2850 mm between the sidewalls and is therefore insufficient. We opted for the PPEB press brake, which has a patented Easy-Form laser system. This system measures the bevelled edges and ensures that the maximum deviation is only 0.5 degrees. The software and interface of these press brakes are very easy to use and provide the operator with 2D and 3D instructions and simulations. Three press brakes have been selected to create enough production capacity.

Taking into account the QRM idea, the press brakes are all built the same. A changing product mix therefore has no effect on the production.
The press brakes are equipped with the following specifications:

- 2 X PPEB press brake with working length of 4000 millimetres and 320 tons of compression force
- 1 X PPEB press brake with working length of 4000 millimetres, 320 tons of compression force and 2 X bending aid of 200 kg.

To bend particularly heavy or large products, one press brake is equipped with two bending aids. These relive the employee and the press brake and increase production speed.

5.3 QRM

One of the most important pillars of QRM and actually one of the few real conditions set by QRM is the use of a maximum of 70-85% of the capacity. As this is one of the most important conditions, it was decided to calculate the capacity utilization of the machines in scenario 3. It concerns the following machines: 6 x 2 m laser, 3 x 1.5 m laser (2x), press brakes (3x).

5.3.1 Production capacity per machine tool

The production capacity per day is checked per machine tool. This is done by using the information provided by the machine suppliers.

Laser cutting machines

For the laser cutting machines (3 x 1.5 meter), the cutting tables supplied by Mazak were used. Different speeds are achieved for different sheet thicknesses. Furthermore, the used cutting gas affects the cutting speeds. Nitrogen obtains higher speeds than oxygen for sheets up to 8 mm thick. Cutting with nitrogen is considerably more expensive than with oxygen, though.

The calculation of the capacity utilization of the laser cutting machines is difficult, because it produces a large variety of products. These products vary in size and number of inserts. It has been decided to take the number of lineal millimetres per minute to make a comparison between the speeds for oxygen and nitrogen. These are speeds for 1 machine. Where no value is entered, the cutting with nitrogen has no added value anymore as the speeds are lower than for oxygen and the costs are higher.

Table 5-3 Cutting speeds

Cutting speeds		
Sheet thickness in mm	**Cutting speed with Oxygen (O_2) in mm/min**	**Cutting speed with Nitrogen (N_2) in mm/min**
2	3500	3600
3	3500	18000
4	3500	10000
5	3300	7200
6	3200	5200
8	2600	2300
10	2300	1000
12	1900	X
15	1600	X
20	1100	X
25	830	X

These speeds are obtained during the cutting of the outlines of the product. However, when you start cutting, it is necessary to make an insert. This insert is not included in the cutting speeds and is also dependent on whether or not common cutting lines are used. To calculate the capacity utilization, it is essential to take the number of inserts into account, but due to the large variety of products it is impossible to include this in the calculation.

In Table 5-4 the capacity is displayed of 2 laser cutters for 8 hours.

Table 5-4 Capacity per shift (8 hours)

Capacity per shift (8 hours)		
Sheet thickness in mm	**Cutting length with Oxygen (O_2) in meters/shift**	**Cutting length with Nitrogen (N_2) in meters/shift**
2	3360	3456
3	3360	17280
4	3360	9600
5	3168	6912
6	3072	4992
8	2496	2208
10	2208	960
12	1824	X
15	1536	X
20	1056	X
25	796,8	X

For the 6 x 2 meter laser the production capacity / cutting speed are the same as for the 3 x 1.5 meter laser, because it uses the same technique. This laser can be used for cutting bevelled edges or drilling and tapping. These operations are not included in the calculation of the capacity utilization.

Press brakes

Calculating the capacity and capacity utilization of the press brake is difficult. Broshuis does not produce large series or batches. Every bend is different and has its own set time and processing time. However, it was decided to convert the press brakes as little as possible. This means that 1 press brake is used for the same thickness as much as possible. To be able to calculate the capacity utilization, a number of assumptions have been made based on the expertise and experience with the bending process. It is assumed that a simple chamfering of small products takes 10-20 seconds. With large products this can be up to 1 minute or longer. It has been decided to combine all additional work required for chamfering up to an average time per chamfer. It was decided to keep the total time of 1 chamfer at 1.5 minutes.

This results in the following calculation where assume an 8-hour workday:

$$\frac{(8\ hours\ \cdot 60\ minutes)}{1.5\ minute} = 320\ settings\ per\ day\ per\ pressbrake$$

$$320\ settings\ \cdot 3\ press\ brakes = 960\ settings\ per\ day$$

This is a generous estimate, as not every product requires the same work (setting, etc.)

5.3.2 Production volume

The production volume is the quantity of goods a company produces in a certain time period. This is compared with the capacity. The current production is 5 trailers per day. For the calculation an average mix is used and 2 scenarios have been drawn up.

Scenario 1
Scenario 1 consists of three container chassis, one semi low loader and one low loader.

Scenario 2
Scenario 2 consists of two container chassis, two semi low loader and one low loader.

6 x 2 m laser

The processing times of the three trailers are known for the parts that are produced on the 6 x 2 m laser. These processing times are generated by a software program that uses the cutting tables that have been made available and are shown in table 5-5. This information is further used to determine the capacity utilization for the two scenarios.

Table 5-5 Cutting time per trailer type

Cutting time per trailer type	
Trailer type	**Cutting time in hours**
Container chassis	0.9970394
Semi low loader	0.629673632
Low loader	0.6329732

Scenario 1
The total cutting time for scenario 1 is:

$$(3 \cdot 0.99703\ hours) + (1 \cdot 0.629673\ hours) + (\ 1 \cdot 0.63297\ hours) = \ \ 4.25376\ hours$$

This means that if these cutting programs are all cut sequentially, the 6 x 2 meter laser would take more than 4 hours and 15 minutes to finish it.

$$\frac{4.25376\ hours}{8\ hour\ shift} \cdot 100\ \% = 53{,}17\ \%$$

The capacity utilization for the 6 x 2 m laser for this scenario is 53,17% compared to the capacity per day with a shift of 8 hours.

Scenario 2
The total cutting time for scenario 2 is:

$$(2 \cdot 0.99703\ hours) + (2 \cdot 0.62967\ hours) + (\ 1 \cdot 0.63297\ hours) = \ \ 3.88639\ hours$$

This means that if these cutting programs are all cut sequentially, the 6 x 2 meter laser would take more than 3 hours and 53 minutes to finish it.

$$\frac{3.88639\ uur}{8\ hour\ shift} \cdot 100\ \% = 48{,}58\ \%$$

The capacity utilization for the 6 x 2 m laser for this scenario is 48,58% compared to the capacity per day with a shift of 8 hours.

3 x 1.5 m laser
The same is done for the 3 x 1.5 lasers. Two laser cutting machines are available now, for which the capacity utilization is calculated. The processing times of the different trailers are found in table 5-6.

Table 5-6 Cutting time per trailer

Cutting time per trailer type	
Trailer type	**Cutting time in hours**
Container chassis	1.076
Semi low loader	3.244192599
Low loader	3.88446464

Scenario 1

The total cutting time for scenario 1 is:

$$\frac{(3 \cdot 1.076\ hours) + (1 \cdot 3.244192\ hours) + (\ 1 \cdot 3.88446\ hours)}{2\ lasers} = \ 5.17833\ hours$$

This shows that when using two 3 x 1.5 m laser cutting machines, the total cutting time of scenario 1 takes a little more than 5 hours and 10 minutes of the capacity.

$$\frac{5.17833\ hours}{8\ hour\ shift} \cdot 100\ \% = 64{,}73\ \%$$

For scenario 1 this means a capacity utilization of 64,73% on the total capacity of the two 3 x 1.5 m lasers per day with a shift of 8 hours.

Scenario 2

The total cutting time for scenario 2 is:

$$\frac{(2 \cdot 1.076\ hours) + (2 \cdot 3.24419\ hours) + (\ 1 \cdot 3.88446\ hours)}{2\ lasers} = \ 6.26242\ \ hours$$

This shows that when using two 3 x 1.5 m laser cutting machines, the total cutting time of scenario 2 takes a little more than 6 hours and 15 minutes of the capacity.

$$\frac{6.26242\ hours}{8\ hour\ shift} \cdot 100\ \% = 78{,}28\ \%$$

For scenario 2 this means a capacity utilization of 78,28% on the total capacity of the two 3 x 1.5 m lasers per day with a shift of 8 hours.

Press brakes

The capacity utilization for the press brakes is divided between three available press brakes. This operation takes place in parallel and per trailer. Table 5-7 displays the number of settings per trailer.

Table 5-7 Total settings per trailer

Cutting time per trailer type	
Trailer type	**Number of settings**
Container chassis	76
Semi low loader	242
Low loader	135

Broshuis has indicated that it wants to convert as little as possible, which is why it was decided to cluster the thicknesses. In table 5-8 is the distribution over press brakes show.

Table 5-8 Distribution over the press brakes

Distribution over the press brake				
Press brake	**Sheet thickness in mm**	**Number of settings in container chassis**	**Number of settings in semi low loader**	**Number of settings in low loader**
Number 1	2 -5 mm	35	138	41
Number 2	6 mm	17	54	49
Number 3	8 – 20 mm	24	50	45

This distribution was obtained as a result of the analysis in Chapter 3.

Scenario 1
The processing time is calculated per press brake and per trailer.

Press brake 1 container chassis:

$$35\ settings \cdot 1.5\ minutes \cdot 3\ trailers\ = 157.5\ minutes$$

Press brake 2 container chassis:

$$17\ settings \cdot 1.5\ minutes \cdot 3\ trailers = 76.5\ minutes$$

Press brake 3 container chassis:

$$24\ settings \cdot 1.5\ minutes \cdot 3\ trailers = 108\ minutes$$

Press brake 1 Semi low loader:

$$138\ settings \cdot 1.5\ minuut \cdot 1\ trailer\ = 207\ minutes$$

Press brake 2 Semi low loader:

$$54\ settings \cdot 1.5\ minuut \cdot 1\ trailer\ = 81\ minutes$$

Press brake 3 Semi low loader:

$$50\ settings \cdot 1.5\ minuut \cdot 1\ trailer\ = 75\ minutes$$

Press brake 1 Low loader:

$$41\ settings \cdot 1.5\ minuut \cdot 1\ trailer\ = 61.5\ minutes$$

Press brake 2 Low loader:

$$49\ settings \cdot 1.5\ minuut \cdot 1\ trailer\ =\ 73.5\ minutes$$

Press brake 3 Low loader:

$$46\ settings \cdot 1.5\ minuut \cdot 1\ trailer\ =\ 69\ minutes$$

The capacity utilization per press brake for scenario 1 is shown in hours in table 5-9.

Table 5-9 utilization per press brake in hours for scenario 1

Capacity utilization per press brake		
Press brake	**Total time in minutes**	**Total time in hours**
Number 1	(157.5 + 207 + 61.5) = 426 min	7.1
Number 2	(76.5 + 81 + 73.5) = 231 min	3.85
Number 3	(108 + 75 + 69) = 252 min	4.2

The capacity utilization per press brake for scenario 1:

$$Press\ brake\ 1: \frac{7.1\ hours}{8\ hour\ shift} \cdot 100\% = 88{,}75\%$$

$$Press\ brake\ 2: \frac{3.85\ hours}{8\ hour\ shift} \cdot 100\% = 48{,}13\%$$

$$Press\ brake\ 3: \frac{4.2\ hours}{8\ hour\ shift} \cdot 100\% = 52{,}5\%$$

Scenario 2
The processing time is calculated per press brake and per trailer.

Press brake 1 container chassis:

$$35\ settings \cdot 1.5\ minuut\ \cdot\ 2\ trailers\ =\ 105\ minutes$$

Press brake 2 container chassis:

$$17\ settings \cdot 1.5\ minuut\ \cdot\ 2\ trailers = 51\ minutes$$

Press brake 3 container chassis:

$$24\ settings \cdot 1.5\ minuut \cdot\ 2\ trailers = 72\ minutes$$

Press brake 1 Semi low loader:

$$138\ settings \cdot 1.5\ minuut\ \cdot\ 2\ trailer\ =\ 414\ minutes$$

Press brake 2 Semi low loader:

$$54\ settings \cdot 1.5\ minuut\ \cdot\ 2\ trailer\ = 162\ minutes$$

Press brake 3 Semi low loader:

$$50\ settings \cdot 1.5\ minuut\ \cdot\ 2\ trailer\ = 150\ minutes$$

Press brake 1 Low loader:

$$41\ settings \cdot 1.5\ minuut\ \cdot\ 1\ trailer\ = 61.5\ minutes$$

Press brake 2 Low loader:

$$49\ settings \cdot 1.5\ minuut\ \cdot\ 1\ trailer\ =\ 73.5\ minutes$$

Press brake 3 Low loader:

$$46\ settings \cdot 1.5\ minuut\ \cdot\ 1\ trailer\ =\ 69\ minutes$$

The capacity utilization per press brake for scenario 2 is shown in hours in table 5-10.

Table 5-10 utilization per press brake in hours for scenario 2

Capacity utilization per press brake		
Press brake	**Total time in minutes**	**Total time in hours**
Number 1	(105 + 414 + 61.5) = 580.5 min	9.675
Number 2	(51 + 162 + 73.5) = 286.5 min	4.775
Number 3	(72 + 150 + 69) = 291 min	4.85

The capacity utilization per press brake for scenario 2:

$$Press\ brake\ 1: \frac{9.675\ hours}{8\ hour\ shift} \cdot 100\% = 120{,}94\%$$

$$Press\ brake\ 2: \frac{4.775\ hours}{8\ hour\ shift} \cdot 100\% = 59{,}69\%$$

$$Press\ brake\ 3: \frac{4.85\ hours}{8\ hour\ shift} \cdot 100\% = 60{,}62\%$$

5.3.3 Conclusion

The capacity for some machine tools exceeds the recommended 70-85%. However, in this calculation an 8-hour workday is taken into account and Broshuis has decided to work in two shifts. This solves the capacity problems. For this calculation it should be considered that assumptions are made.

5.4 Summary

In Chapter 5 an answer was given to the question: *"Which approach should be chosen, taking the conditions set by QRM, Smart Industry and the requirements and wishes of the project team into account?".* In the first section the results of the AHP were discussed. The AHP has shown that scenarios 2 and 3 differ little from each other. Scenario 3, however, appears to be the most suitable scenario for Broshuis. Due to the fact that the management intends to produce all steel parts in the future, it was decided to further develop this scenario.
In section 5.2 the choices for the machines were presented. The capacity and the capacity utilization of the different machine tools were calculated in section 5.3. The results were that in an 8-hour workday, capacity problems arise for some machine tools. Broshuis Parts Production, however, works in 2 shifts of 8 hours.

6. Discussion and final assessment

In Chapter 5 the results of this research were discussed. It appeared that scenario 3 best fits the requirements and wishes of Broshuis. In this chapter a number of observations are made about this result and some recommendations follow. An overview of the investments also included and discussed.

In section 6.1 the consideration to phase the purchase of the machines is addressed. This section is followed by the financial part in section 6.2.

6.1 Phasing

The research has shown that scenario 3 is the most suitable scenario for Broshuis. This scenario consists of two 3 x 1.5 meter lasers (connected to an automated supply), a 6 x 2 meter laser with a 2.5D head and 3 press brakes up to 4 meters with 320 tons of bending force. These machines will be located in the new facility in which a completely new process will be started. Starting a new company requires a lot of energy and time. Setting up the new process according to QRM will also take time. New staff must be recruited, which need to be trained. This is the reason why it would be wise to phase the purchase of the machines.

It is recommended to purchase the two 3 x 1.5 meter lasers first together with the automated supply for loading and unloading and the 3 press brakes of 4 meters with 320 tons at the start-up of the new company. The main reason for this is the high level of automation within this 3 x 1.5 meter range. This format is standard within the industry and the different suppliers have obtained a high level of automation within these dimensions. Cutting and bending programs can be generated automatically and sent to the machine tools. The 6 x 2 meter laser is much more complicated to automate, as this laser is able to do chamfers and drilling operations. The software is not advanced enough yet that cutting programs are fully automated. Since the entire organization has to be built from scratch, it has been decided to purchase the 6 x 2 meter laser in a second phase. This gives the opportunity to gain experience with the limited process before proceeding with the more complex 6 x 2 meter process. The organization of the company according to QRM will also get more attention this way.

6.2 Financial

7. Conclusions and recommendations

This research is part of a project at Broshuis: Broshuis Parts Production, where cutting and bending of metal is insourced. Cutting and bending of metal is a completely new activity for Broshuis. This has advantages and disadvantages. The lack of experience of course involves risks. On the other hand, Broshuis is not affected by habits, holy temples and outdated methods that have slowly been shaped. Broshuis Parts Production is located in the newly built hall, hall 7.

Setting up a new company also involves purchasing new machines. This research was therefore aimed at making recommendations for the purchase of cutting and bending machines. Broshuis has opted to have QRM business philosophy as its guiding principle, as well as the Smart Industry idea. The objective of this research therefore can be formulated as below:

The purpose of this research is to give advice on the machines to be purchased for the production department of Broshuis Parts Production B.V. based on QRM and the Smart Industry concept.

The theoretical framework has shown that research into QRM is only in its early stages. As a result, QRM does not provide many preconditions for the choice of machines. QRM focuses on lead time and all the actions and investments must lead in this direction. The conditions that could be drawn up, are mainly filtered from the maturity model of Ten Hoonte (2012). Smart Industry also does not provide many concrete conditions. Smart Industry is mainly engaged in the automation of organizations. However, we have managed to filter a number of conditions that were used later to complete the list of conditions, requirements and wishes of the project team.

After establishing the theoretical framework, an analysis was made of the cutting and bending parts that are currently purchased. This analysis showed that Broshuis purchases a wide variety of steel parts. Therefore, it was examined which techniques are required to make these products. Broshuis has indicated that it wants to purchase standard machines and use the latest techniques. After the analysis of the current product portfolio, an analysis was performed on the current cutting techniques on the market and several suppliers were contacted. This resulted in various standard setups that could possibly produce the product portfolio. The current product portfolio was then distributed across these standard setups and provided insight into the distribution of the products and the required machines.

The analysis of the current product portfolio and the distribution across the available machines in the market resulted in new knowledge of the project team. This information was used to see what the requirements and wishes are for the machines to be purchased. Together with the conditions set in the theoretical framework, these constitute all the conditions, requirements and wishes. At the establishment of these conditions, 4 scenarios have been drawn up after a brainstorm session in which the pros and cons were described:

- Scenario 1: Continue outsourcing; represents 0% of the outsourced work
- Scenario 2: Insource laser cutting (3x1.5 meters) and bending; represents 60% of outsourced work
- Scenario 3: Insource laser cutting (up to 6x2 meters) and bending; represents 85% of outsourced work
- Scenario 4: Laser cutting, bending and cutting long items (up to 16 meters); represents 95% of outsourced work

These scenarios were tested against the set criteria according to the AHP method. This showed that scenario 2 and 3 both score about the same. Scenario 3, however, scores slightly higher than scenario 2. Due to the fact that the management of Broshuis wants to produce all steel parts inhouse in the future, scenario 3 has been chosen and further elaborated. For this scenario a shortlist of suppliers has been created.

The conclusion mentioned above answers the purpose of this research:
'The purpose of this research is to give advice on the machines to be purchased for the production department of Broshuis Parts Production B.V. based on QRM and the Smart Industry concept.' n scenario 3 2 lasers are purchased of 3 x 1.5 meters and one of 6 x 2 meters. The latter can be equipped with a 2.5D head, which makes it possible to cut at an angle. A drill and tap unit can also be added to this laser, which means that rework can be kept to a minimum. The 3 lasers can cut up to 25 mm thick. Furthermore, in this scenario we have opted for a 320-ton press brake of 4 meters with bending assistance. With this scenario approximately 85% of the outsourced work is produced.

After the choice between the different scenarios the capacity utilization was calculated for an average mix of trailers. This showed that for some machines the capacity is exceeded. In this calculation, however, a single shift of 8 hours has been used. Broshuis intends to run 2 shifts of 8 hours each. The capacity problem is thus tackled. This meets one of the main conditions set by QRM; nothing should be planned for more than 70 – 85% of the capacity.

It is recommended to divide the purchase and setting up of the new organization into 2 phases. In phase 1 two 3 x 1.5 meter lasers (connected to an automatic supply) and 3 press brakes (4 meters, 320 tons) are purchased. When these machines are running, it is recommended to purchase the 6 x 2 meter laser. The reason for this is that setting up a new organization and adapting to a new operation process is intensive enough. When the scope immediately gets too big, problems will arise and cannot as yet be fully evaluated. The choice to first purchase the 3 x 1.5 meter lasers, is because within this range a high level of automation can be achieved. For the 6 x 2 meter range, unfortunately, this is different. In addition, the investment of a 6 x 2 meter laser is considerable. For this reason, the purchase of the 6 x 2 meter laser will ultimately take place in phase 2.

The management board of Broshuis has chosen to implement QRM only in hall 7 for the time being. However, this does not produce the desired reduction in lead time Broshuis is looking for. To realize this, Broshuis needs to make the entire organization QRM. This results in the desired reduction in lead time. Therefore, it is recommended for Broshuis to investigate how they can introduce QRM within their entire organization. It is important to consider that support is created within the organization to introduce and ensure QRM in the right way within the organization.

Furthermore, Broshuis needs to carry out research into the steel parts currently outsourced. They need to look closely what the next step is to produce them their selves. Perhaps these are the sheet parts, but the turning and milling parts, for example.

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