Production Optimization

Introducing Quick Response Manufacturing to the Preprocessing Stage of Shipbuilding

T.F. Kreule

Delft University of Technology

Thesis for the degree of MSc in Marine Technology in the specialization of Ship Production

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Introducing Quick Response Manufacturing to the Preprocessing Stage of Shipbuilding

by

T.F. Kreule

performed at

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Company supervisor

Responsible supervisor:	B. Eng. C.F.D. Hoogendoorn	Damen Shipyards
E-mail:	don.hoogendoorn@damen.com	

University supervisor

Responsible supervisor:	Dr. ir. J.F.J. Pruyn	TU Delft
E-mail:	j.f.j.pruyn@tudelft.nl	

Thesis exam committee

Chairman/Responsible Professor:	Prof. ir. J.J. Hopman	TU Delft
Staff Member:	Dr. ir. J.F.J. Pruyn	TU Delft
Staff Member:	Dr. W.W.A. Beelaerts van Blokland	TU Delft
Company Member:	B. Eng. C.F.D. Hoogendoorn	Damen Shipyards

Author Details

Study number:	4009959
Author contact e-mail:	timokreule@gmail.com

TU Delft

Abstract

Damen Shipyards Group is a family-owned shipbuilding company active since 1927. Damen's unique shipbuilding concept is based on what the customers want: the best quality, proven designs, short delivery times, low maintenance and excellent resale value. To accomplish this, a decent production process is expected. In recent studies it is observed that the production process of Damen lags behind those of other companies. This research topic takes a look into the preprocessing department Damen Shipyards Galati, where the first step in the shipbuilding process takes place: steel plates are cut into parts, that are then ground and sorted to build stiffened panels and ships' sections. The steel preprocessing department of Damen Shipyards Galati currently consists of two separate facilities, sections 1 and 1A. It is examined whether the processes in section 1A can be adjusted to process the current portfolio of the two facilities together, without making a capital investment. Quick Response Manufacturing is introduced to this department to find whether this is a feasible method to achieve this elevation.

Quick Response Manufacturing is a management strategy with the aim of reducing the time from the moment a customer creates an order, along the critical path until the delivery of that order to the customer. The theory proposes a number of key points, of which the most eye-catching one is the organizational structure with a cellular organization instead of functional departments.

The initial step of the improvement is to find out whether the currently available resources are capable of generating a higher throughput based on their own characteristics, this indeed seems to be the case. The preprocessing of shipbuilding is a dynamic process and a numerical simulation model is constructed to resemble the processes in the department. This simulation is validated, verified and analyzed to define the critical path of the process and to quantify its current performance. It is found that the critical path in the current preprocessing department is defined by parts that are both ground and flanged and that on average, steel parts spend more than ten working days in the preprocessing facility. This is quite a lot as grinding and flanging usually take less than half an hour and forming of a plate also generally takes no more than two hours.

To find where this long time comes from a list of pain points is gathered, both as experienced by employees of the yard and as observed in the numerical model. The key points of Quick Response Manufacturing are then deployed to mitigate the delays due to these pain points. It is found that with these methods, the time in the process can be decreased by up to 88%. A major part of this decrease is due to the fact that a major sorting step after cutting is eliminated. This decrease leads to an increase in annual throughput of 73%, which does indeed elevate the throughput to that of the complete current portfolio of sections 1 and 1A together.

It is concluded that Quick Response Manufacturing can make a substantial difference for the preprocessing stage of shipbuilding. A reschedule of the processes taking place in the department can mean a lot for the lead times and annual throughput of the shipyard. To make full use of this theory however, it is recommended not to restrict the analysis to the preprocessing stage. Quick Response Manufacturing is a company-wide strategy so major benefits for the throughput of a shipyard could probably be achieved by expanding the scope of the application of Quick Response Manufacturing.

Preface

Dear reader,

Before you lies a Master's Thesis that is the key to unlock the door to the civilized world after finishing my time as a student.

First of all, I am of course very grateful for my parents and sister who have supported me massively during my studies and encouraged me to broaden my horizon and to focus on more than only studying.

Already at a young age I was infected with the virus called a passion for boats. Therefore I would like to show my massive gratitude to Age Hoekstra for hiring this young boy at Boat rental company "De Schakel" and so introducing me in the world of working with boats, which is a world I will probably never leave again.

This project could not have taken place without the help of Jeroen Pruyn and Don Hoogendoorn, who provided me with the right directions to go to and correcting me whenever I made some propositions that actually turned out to be complete nonsense. Also I would like to thank Hans Hopman and Wouter Beelaerts van Blokland for taking the time and effort to be part of my graduation committee.

Furthermore I would like to thank Joost van der Weiden for introducing me into Damen Shipyards and Kees van Ekeren, Jack Teuben, Bas Damman, Jing Zhuang and Nicusor Dimofte for providing a lot of necessary data, information and input for this project and Dirk Steinhauer for the massive support with the software.

Sitting still for more than five minutes is not really in my nature. Therefore I want to show some massive props to all the boys and girls who always want to go biking/running/pumping iron whenever I have spent a whole day being stationary behind a computer.

And of course, last but definitely not least, I would like to thank my lovely girlfriend Frederiek for her support and helping me escape from nights behind the computer.

Finally, as I believe there is a habit to include an inspirational quote in the preface of a scientific report, I will conclude with the following applicable one: "All models are wrong, but some are useful." *(George E.P. Box)*

Challas

T.F. Kreule
Delft, August 2018

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List of Abbreviations

ASD	Azimuth Stern Drive
AV	Average Variability
CMMI	Capability Maturity Model Integration
DES	Discrete Event Simulation
DSGa	Damen Shipyards Galati
FB	Flat Bar
FTMS	Focused Target Market Segment
HP	Holland Profile
KPI	Key Performance Indicator
MCT	Manufacturing Critical-path Time
MP	Main Panel
OT	Order Time
PMM	Project Management Maturity
POLCA	Paired-cell Overlapping Loops of Cards with Authorization
PSV	Platform Supply Vessel
Q-ROC	Quick Response Office Cell
QRM	Quick Response Manufacturing
S1	Section 1 of Damen Shipyards Galati
S1A	Section 1A of Damen Shipyards Galati
STS	Simulation Toolkit Shipbuilding
TMS	Target Market Segment
TT	Touch Time
WIP	Work In Progress
WT	Waiting Time

Glossary

2D-forming	Shaping a plate into a single curved plate.
3D-forming	Shaping a plate into a double curved plate.
Abkant	Press Brake
Entry-Control Method	A function of code that is called when a moving object enters an area or a fixed object such as a machine.
Exit-Control Method	A function of code that is called when a moving object leaves an area or a fixed object such as a machine.
Line Heating	Method used to give metal plates a 3D curve with a repetitive process. Marked lines on the plate indicate where the plate is heated using blowtorches. After heating it is cooled with water to obtain the correct shape.
Plate Roller	Machine used for rolling metal plates into a 2D shape, for e.g. shell plates, sheer strakes and derrick posts. It can also be used for flanging bulkhead corrugations. The plate is formed by rolling it between three hydraulically pressed rolls.
Preprocessing	The first stage of the ship production process. Parts are cut out of metal plates, formed, ground, tapered and/or flanged and then sorted to be used for assembly.
Press Brake	Machine used for flanging metal parts, using a hydraulic down stroking press.
Quick Response Manufacturing	A management strategy with the aim of improving business results by reducing lead times in all stages of production.
Roller Press	Machine used for rolling metal plates into a 3D shape using the process of stretching by rolling. This is generally a faster method than line heating.
Stamp Press	Machine used for give metal plates a 2D curve, using a hydraulic down stroking press. The plate is formed by pressing it into a die multiple times.

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Introduction

1.1. Background

To be an ever competitive shipbuilding company, Damen Shipyards Group feels the need to continuously reduce costs, improve quality and shorten the time to market. In the past decades Damen Shipyards Group changed their shipbuilding strategy by producing complete ships at their own yards, rather than subcontracting production of the hull at third-party yards, finishing the build at Damen yards. (Damen, n.d.a)
For this to be a feasible method of achieving Damen's objectives, production of the hulls should be a far optimized process concerning lead times, quality and costs.
Recent studies however show a different situation. According to these studies, production at Damen lags behind the production process at similar companies in the market and Damen's strategy of keeping hulls in stock is not a strategic advantage but is a needed mean for production to keep up with the competition. (Zevenhoven, 2017)

1.1.1. Shipbuilding Process

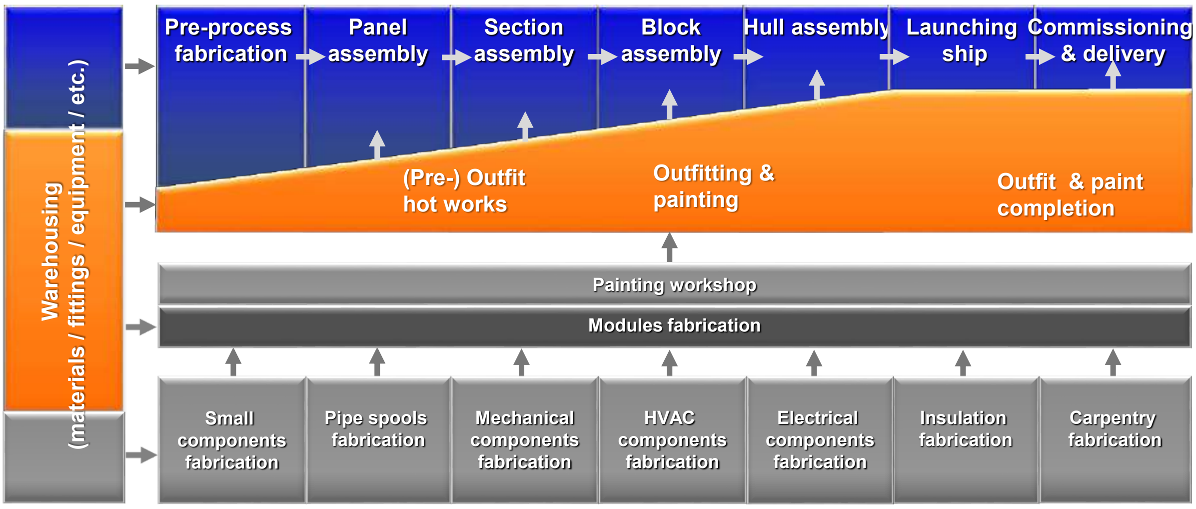


Figure 1.1: Shipbuilding process (Teuben and Damman, 2017)

In figure 1.1, the general overview of the shipbuilding process at Damen can be found. The process starts with raw materials in the warehousing, to be transformed into separate parts at the preprocessing stage. With these parts, panels are built and these are joined together to make a section. Several ship's sections are combined into a block, which is then fitted together with other blocks in hull assembly. When the ship is complete it is launched and delivered. An example of this structure of sections and blocks can be seen in figure 1.2, where for example sections 101, 201 and 303 together make up block 2.

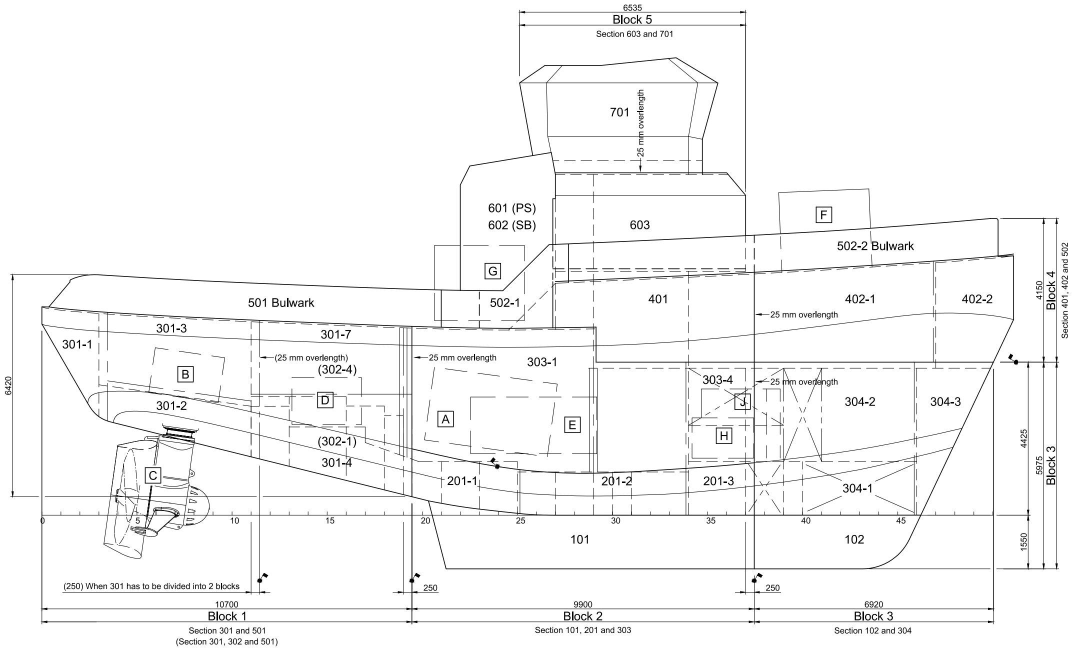


Figure 1.2: Section plan of a Damen ASD2913 Tugboat (Damen, 2015)

From this description, it is clear that the preprocessing stage can be quite a chaotic stage of the process. During plate cutting, one single plate can be transformed into several dozens of parts. Therefore the preprocessing stage is where the 'Material explosion' takes place, the event where a big number of parts arises at once.

1.1.2. Damen Shipyards Galati

To find the performance at this stage, it is a starting point to have a look at the annual turnover of the preprocessing facility of a Damen yard and those of other, similar companies.
At the time of writing, Damen Shipyards Galati (DSGa) is the largest yard of the Damen Shipyards Group. "Santierul Naval Fernic Galati"(Fernic Shipyard Galati) was established in 1893 and was a major shipbuilder in Romania for over a century. The presence of the Institute of Naval Architecture meant a big contribution to the shipyard's progress, transforming the city into a major shipbuilding pole. From 1994, Damen Shipyards Group started cooperating with the yard by subcontracting the build of cargo vessels to Galati. In 1999, Damen Shipyards Group acquired the yard and began streamlining the organization. An investment plan focused on improving efficiency and working conditions was introduced. This also caused a significant decrease in the number of employees. In 2006, still about 10,000 employees were present at the yard, while currently this number is around 2,500. Between the acquisition of the yard in 1999 and the end of 2017, 401 vessels were delivered of which 233 tugs. (Damen, n.d.a)
It seems however, that there still is plenty of room for improvement around the premises. Zevenhoven (2017) states there is a productivity gap with its well-performing competitors of around 25%, meaning that it should be able to improve up to 25% at least. Furthermore, it is stated that the section building department of DSGa currently lacks the space to perform its tasks efficiently and some sections are now built outside or on different locations within the yard. There are plans to erect a new building to increase the section building capacity (Gaibar, 2017). If the working methods the employees use were to be modernized and as a result, the space they use is decreased, it might be feasible to increase the space for section building without the need for an extra shed.

When looking at the layout map of Damen Shipyards Galati in figure 1.3, it is seen that the yard consists of two separate sub-yards Section 1 and Section 1A and supporting facility Section 1B. The colours in this map coincide with the colours in table 1.1 that states the same order as figure 1.1. It seems that in these facilities the working methods are still unchanged compared to what they used to be decades ago, as illustrated in section 1.1.3.

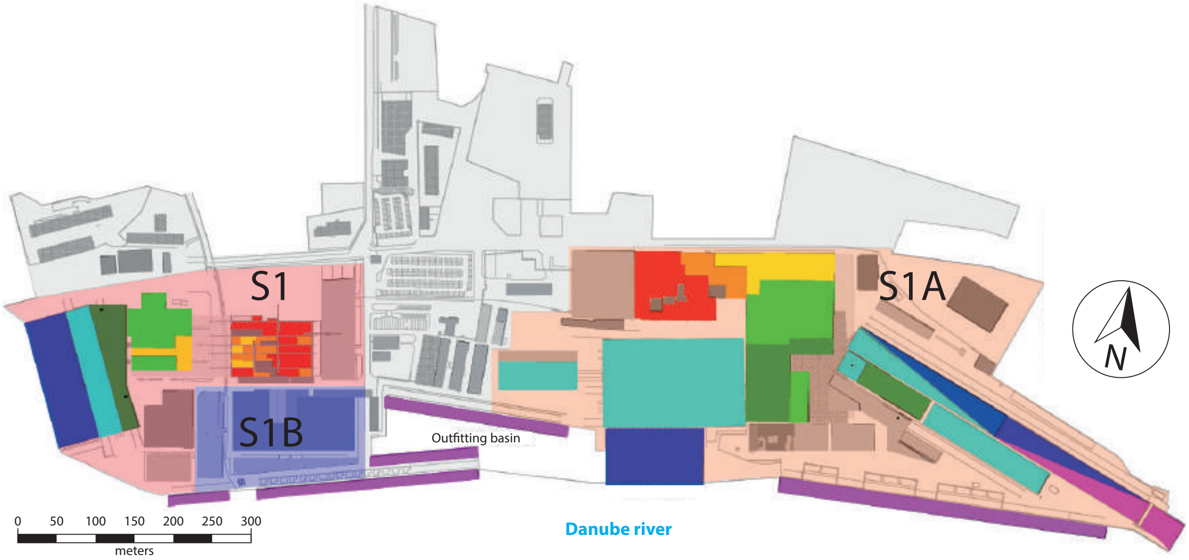


Figure 1.3: Layout of Damen Shipyards Galati

Table 1.1: Production steps defined by colours

Colours	**Process**
Red	Preprocessing
Orange	Subpanel assembly
Yellow	Mainpanel assembly
Light green	Section assembly
Dark green	Block assembly
Light blue	Hull assembly
Dark blue	Launching
Purple	Outfitting, painting, commissioning and delivery

1.1.3. Benchmark

At DSGa, the preprocessing is stretched out over two separate sheds in Section 1 and Section 1A, as can be seen in figure 1.3 and appendix B. When comparing this department to similar departments at other companies, it seems that a big gain in efficiency could be achieved. Figure 1.4 compares the preprocessing department of DSGa to that of "247TailorSteel", situated in Varsseveld, The Netherlands. In this company the same operations are performed. From plates of steel, parts are cut, bent, packed and shipped. The figure gives a clear image of what is happening in two similar facilities. It is seen that at DSGa a lot of work in progress is present in very large batches and the floor is scattered with material. The pictures of 247TailorSteel however tell a different story. Materials are stacked in a tidy manner, the place is clean and uncluttered.
To roughly quantify the performance of the preprocessing stage, the yearly output of DSGa, IHC Metalix and 247Tailorsteel are compared in appendix B. The results are stated in table 1.2.

Table 1.2: Benchmark of DSGa, IHC Metalix and 247TailorSteel

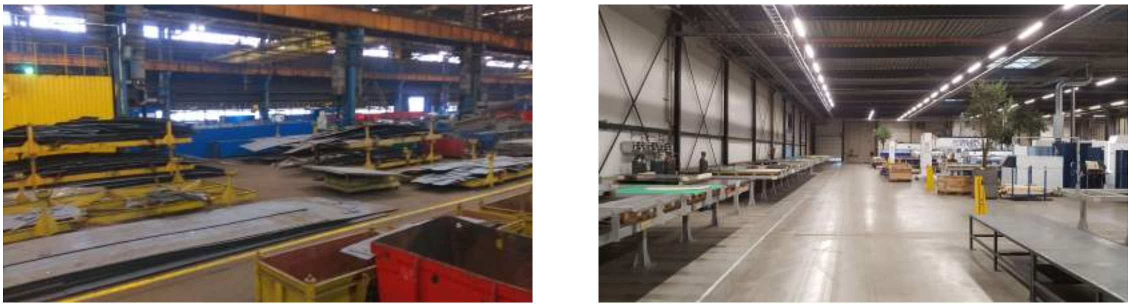
Facility	**Floor area [m^2]**	**Output per area [T/m^2/year]**	**Output per area [Normalized w.r.t. DSGa]**
DSGa	13000	1.92	1
IHC Metalix	6000	8.33 (5.55*)	2.89
247TailorSteel	3500	12.86 (6.12*)	3.19

*number of working hours decreased to double shifts for a fair comparison.

The values for DSGa and IHC Metalix were obtained from the Damen Yard Support Department.

The value for 247TailorSteel was obtained from 247TailorSteel.

As seen in table 1.2, the productivity of the preprocessing of DSGa lags behind those of similar companies.



(a) DSGa

(b) 247TailorSteel

(c) DSGa

(d) 247TailorSteel

Figure 1.4: A visual representation of the preprocessing departments of DSGa and 247TailorSteel (own pictures)

Looking at these pictures, it is not hard to imagine that the number in table 1.2 could be improved when using a proper strategy. To make a proposal for this, existing and proven theories are explored. First, a brief insight is taken into the motivation for process improvement, based on the Capability Maturity Model Integration in section 1.2. After this, several existing and proven management strategies are explored based on their characteristics and applications. One of them is chosen and on the basis of this, the main research question and sub-questions are presented.

1.2. Process Maturity

To determine what to focus on when trying to improve the preprocessing at DSGa, first an investigation will take place on the maturity of the process. A mature process is a process that is operating at a level that helps the company reach its business objectives. The idea of the Capability Maturity Model Integration is creating a path to consistency (Persse, 2007). This demands a commitment to process as well as a commitment to time.

Commitment to Process

Commitment to a process is key in achieving consistency in a company. The value of process can easily be seen when looking at obviously successful companies such as Coca-Cola or Heineken. When buying a cola at a supermarket in Gorinchem, it will have the exact same fizz as one bought in a bar in Sydney. Quality, consistency and control are essential to achieving this. With Damen having multiple new-building shipyards, this is a major future goal to keep in mind. In this sense, a spot on the horizon is having an order for any type of new ship and let its overhead system automatically determine where to buy this vessel based on availability, costs, distance to owner etc. while guaranteeing constant quality and specifications.

Commitment to Time

The discussed commitment to process will never realize its full benefits without a commitment to using the program over time. Process success takes time and the key to generating an effective program is to use it over time, observe where it performs well and where there is room for improvement, adjust and change it where needed so that step by step it takes on the desired qualities of efficiency and effectiveness. Many companies nowadays try to improve themselves by making a commitment to process. However, sometimes they do so without appreciating the required commitment to time. Newly introduced programs may not always show instant benefits. They may cause a disruption to work streams, but given the right amount of time, one may find that the program begins to unify the workplace and adds stability (Persse, 2007).

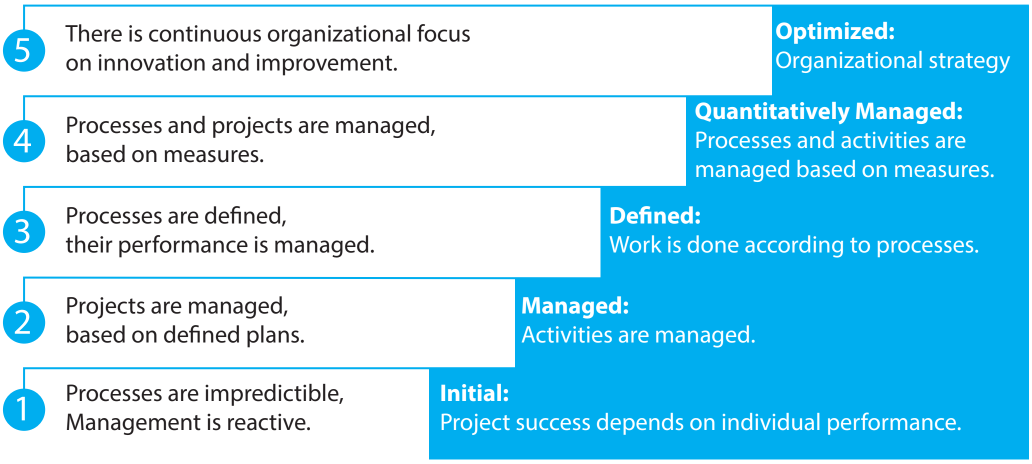


Figure 1.5: Capability Maturity Model Integration (Consulting, 2006)

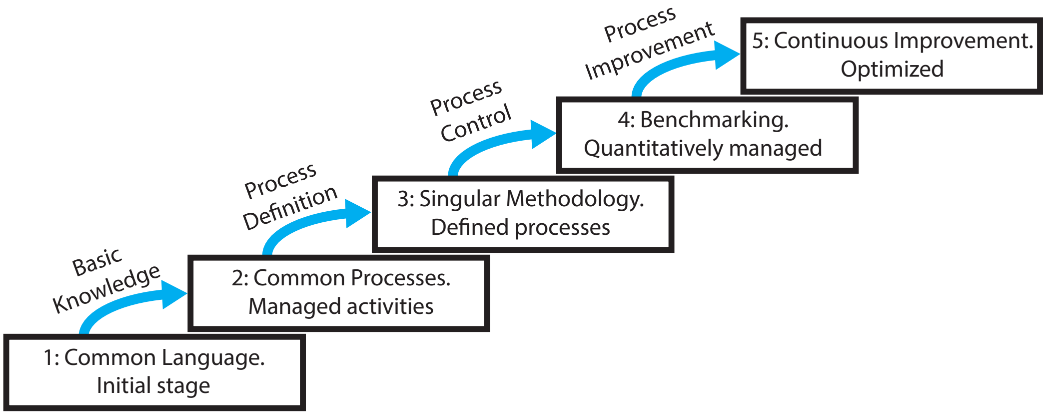


Figure 1.6: Project management maturity

Together, a commitment to process and a commitment to time will help the company realize the full value of the mission to boost project management maturity. The levels of maturity of the Capability Maturity Model Integration (CMMI) are shown in figure 1.5. It is estimated that the preprocessing at Damen Shipyards Galati is currently between level 1 and 2. This is confirmed on page 52. For the shipyard to be competitive, it should perform at least at level 3, with the work done according to clear processes, not dependent on individual performance.

To grow in CMMI, project management maturity (PMM) is used. PMM is a strategy of helping the company climb through the levels of CMMI. The two models are combined, yielding a clear guide to the processes and steps needed to improve the maturity of the company. The project management maturity model is shown in figure 1.6. The texts at the arrows are the steps to be taken, to gain a respective level.

1.3. Operations Management

For climbing on the CMMI and thus improving the preprocessing at Damen Shipyards Galati , a management process improvement approach is applied. Several of these approaches were already invented and sometimes combined. These different strategies have different backgrounds and perspectives. These theories can be subdivided into three perspectives of decision making:

- Operations management, focusing on logistic chains and improving the efficiency of processes.
- Quality management, focusing on constant quality of products and therefore avoiding rework.
- Asset management, focusing on improving reliability of equipment.

For Damen Shipyards Galati, the focus will be on Operations management, as it is the logistic chain, controls and large amount of non-value adding work steps that could make a major difference. Currently there are several wellestablished theories that make use of this approach. These can be seen in figure 1.7, where the type of output (Product Mix) is presented versus the method of manufacturing (Process Type). The presented concepts show some similarities but are all different strategies. In this figure, four process types are distinguished. A job shop is a system where the flow of material is determined by the location of the resources. The machines are often arranged by function. In a flow shop, the locations of resources are determined by the flow of material. In a flow shop large amounts of standardized products are produced. This is also the case in a line flow, where subsequent tasks are usually subject to a tact-time and the production resembles a production line. Lastly the continuous flow production takes this production line even further by emphasizing on moving the product through the process without stopping. In this situation, the lead time of the process is equal to the cycle time so the product never waits in a queue for an operation.

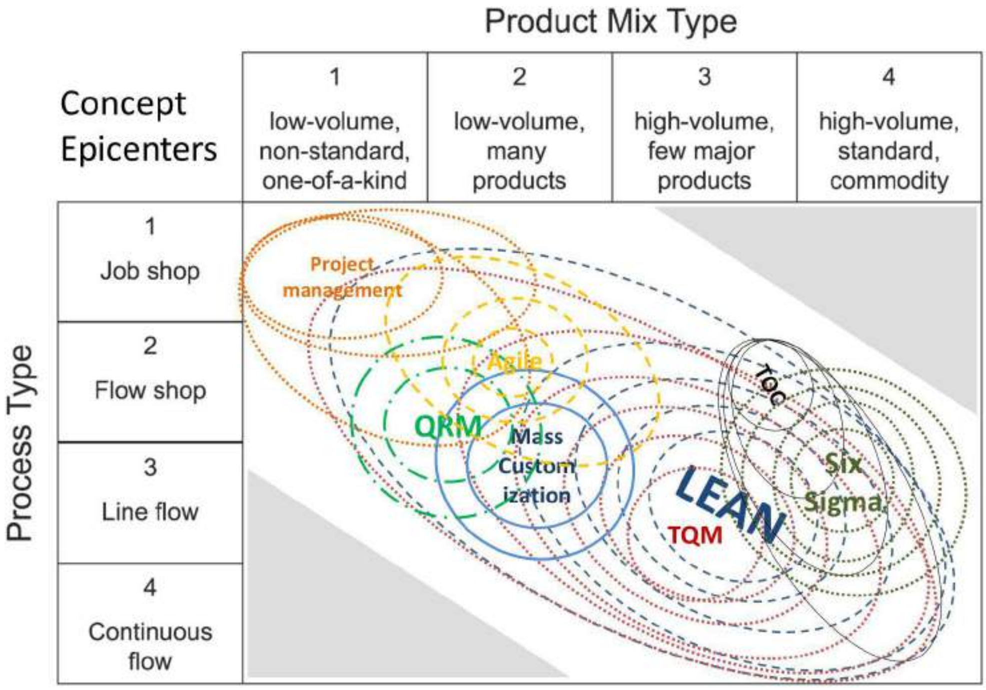


Figure 1.7: The Concept Epicenter Map (Netland, 2014)

A ship is generally a low-volume, non-standard, one-of-a-kind product built with a Job shop process. When looking at the preprocessing stage however, the process has a bigger volume, still with great variety. The vast majority of the parts travel through the process in a more or less logical order although small amounts of parts have to travel through back-and-forth through the hall as seen in a job shop process. It is estimated that the preprocessing stage resembles a flow shop process with significant variety (Roser, 2017). Therefore Quick Response Manufacturing may be a useful strategy to improve this department. It is a strategy yet hardly applied to the process of shipbuilding so as a pilot it is chosen to implement it at the preprocessing department.

Quick Response Manufacturing is about shortening the time from the order of a product to its delivery. Some costs in the manufacturing process are accepted to reach this goal if they lead to big advantages at an other place in the process, such as decreased logistic handling or decrease of inventory.
An organization based on Quick Response Manufacturing shows four key principles:

1. Cellular organization.
2. Team Ownership instead of top-down control.
3. Cross-trained team members instead
4. Focus on time reduction.

This is further elaborated upon in section 1.4. The fundamentals of Quick Response Manufacturing are explained in chapter 2.

1.4. Project Description

To make a contribution to Damen's shared objectives (reducing costs, improving quality and shortening time to market), the goal of the DCR - production optimization project, of which this particular project is the first step, is to improve the production process taking place at every new building yard of Damen Shipyards Group. (Bender and Hoogendoorn, 2017)

As a pilot, first the focus will be on Damen Shipyards Galati. At this yard, a large number of different ship types is built so it is a good representative of the production methods of Damen. The topic regards the preprocessing department, the very first phase of the shipbuilding process.

The main objective for the topic is to find out what order of investment should be used to raise the output of DSGa preprocessing to match or even transcend similar processes taking place at other companies in the market.

To find the answer to this main objective, the goal of this project is improving the preprocessing department at DSGa with only minor financial investments. The focus is on the process flow based on Quick Response Manufacturing. In the report the preprocessing department of DSGa is examined and its current situation is modeled. Using Quick Response Manufacturing, the potential methods of improvements are identified and applied to the model with the constraint of keeping financial investment low. The aim is to save space that is currently used for preprocessing, to be used for section building.

This minor investment sets the following boundary conditions:

- New equipment:
  - If needed, small hand tools can be purchased.
  - Other equipment is limited to what is currently present.
- Moving equipment is allowed, except for resources with a fixed foundation, or resources fixed to the building:
  - All cutting machines,
  - Hugh Smith Plate Roller,
  - Overhead crane rails,
  - Carriage rails.

Therefore, the main question of this report is:

> **Can Quick Response Manufacturing in combination with a minimal financial investment elevate the output of preprocessing department Section 1A of Damen Shipyards Galati to the current output of sections 1 and 1A combined?**

To answer this main question, the topic is split up into four phases with four sub-questions:

1. *What are the relevant insights about Quick Response Manufacturing?*
2. *Does the currently available steel processing equipment allow the output to be elevated to the desired quantity?*
3. *What method is used to analyze the performance of the preprocessing department?*
4. *What are the specifications of the preprocessing department at DSGa in the current situation?*
5. *What are the specifications of the preprocessing department in the proposed situation?*
6. *What are the potential improvements for the preprocessing department, based on Quick Response Manufacturing and what benefits do they bring?*

All these phases carry their own question or objective and in the next section, these are addressed.

1.5. Phases of the Project

This research project consists of six separate phases. In this section, these six phases will be elaborated upon.

1.5.1. Literature study

What are the relevant insights about Quick Response Manufacturing?

As the objective of this project is to apply Quick Response Manufacturing to a part of the process of shipbuilding, it is important to find out what the key points about this theory are, so when pain points are identified after examining the processes it can be determined what factors of this theory are applicable for the shipyard. In chapter 2, Quick Response Manufacturing is explained.

1.5.2. Estimation of utilization

Does the currently available steel processing equipment allow the output to be elevated to the desired quantity?

The second step of the project is to execute a background study about what is happening at the preprocessing department at Damen Shipyards Galati, what equipment there is and find out what the current output is and whether it is even feasible to propose to elevate the throughput of section 1A. Based on the information about the equipment, the organization and the product portfolio an estimation is made for the utilization in the current and desired situation.

1.5.3. Method of analysis

What method is used to analyze the performance of the preprocessing department?

If it turns out the equipment potentially has the capacity to indeed increase the throughput of section 1A sufficiently using the currently available equipment, a method is picked to analyze the performance of the preprocessing department.

1.5.4. Modeling the current situation of the preprocessing at DSGa

What are the specifications of the preprocessing department at DSGa in the current situation?

Using all information gathered during the previous phase, the preprocessing department of DSGa is modeled in its current state and layout. This analysis yields quantitative information about the preprocessing department, to be able to quantify benefits of improvement suggestions.

1.5.5. Proposing an improved situation for the preprocessing department

What are the specifications of the preprocessing department in the proposed situation?

Quick Response Manufacturing has a clear vision regarding the layout and structure of an organization. In the previous stage, the performance of the preprocessing department in the current situation is quantified. In this stage a cellular organizational structure is proposed and its performance is computed and compared to the current situation.

1.5.6. Identifying and implementing separate potential improvement strategies

What are the potential improvements for the preprocessing department, based on Quick Response Manufacturing and what benefits do they bring?

The model of the preprocessing facility in its current situation yields an overview of the key figures of the department. From this overview, issues might be found that form one side of the basis of the improvement ideas. The other side is based on Quick Response Manufacturing in chapter 2. The objective of this phase is to find which factors of QRM will help resolve these issues. Of course the improvement suggestions are not limited to currently perceived issues.

These possible improvement suggestions are implemented in the model to quantify the improvement they bring.

2

Quick Response Manufacturing

What are the relevant insights about Quick Response Manufacturing?

Quick Response Manufacturing (QRM) is a management strategy developed by professor of Industrial and Systems Engineering Rajan Suri, explained extensively in his book "It's about Time" (Suri, 2011). Suri developed Quick Response Manufacturing as a strategy for modern companies making high-variety products with low volume. Currently, there is a trend of demand for products with high variety, lots of options and full-custom products. This asks for a different management strategy than Lean Manufacturing, as this strategy is not in accordance with this trend but it is focused on products with a (more or less) constant throughput, such as the automotive industry. QRM is about shortening the lead times with three distinctive goals: Improving quality, lowering costs and eliminating waste. As read on page 1, this is exactly what Damen's shared objectives are about. It is clear that Quick Response Manufacturing shows some similarities to other management strategies.

QRM is a strategy based on four pillars: The power of time, organizational structure, system dynamics and the enterprise-wide application. In this chapter, these four pillars will be treated extensively, as devised by Suri (Suri, 2011).

2.1. The Power of Time

As stated before, QRM is all about time. Reducing time in a process can have a major impact on a company. It can reduce the lead time of the products, making it possible to ship the products to the client earlier, enabling the client to make money faster. Also it can improve the quality of the products and the cost it takes to make it. However the focus of QRM is never on minimizing costs, it is a strategy of time-based competition, aimed at a single target with the goal of reducing lead times. The difference between cost-based thinking and QRM can easily be seen in figure 2.1. In this figure of a fictive company, there is a clear distinction between touch time (green) and waiting time (white). The touch time is the sum of the directly measured working hours. The waiting time is the time spent between processes so it includes waiting and transport time. It can easily be seen that in this particular example the touch time, which is the focus point of cost-based thinking, makes up a total of only 19.5 hours within a total time of 34 days, just over 7%, assuming an eight-hour working day. If the company in this example wants to shorten its lead time, it is easy to imagine that making the work steps work harder or more efficient might save a few hours at most. A manager may state a boost in efficiency of 20%, while it only saves less than 4 hours on a project of 34 days, or about 1.5%! This is a time reduction the client will not even notice. In a lot of companies the touch time in a process is less than 5% of the total time, in some cases even less than 1% (Suri, 2011).

Manufacturing Critical-path Time

To be able to improve the total lead time of a process, it is important to define what lead time actually is. In production, several lead times are defined, of which the most important two are:

- External lead time - time experienced by the customer,
- Internal lead time - the time it takes to put orders through the organization.

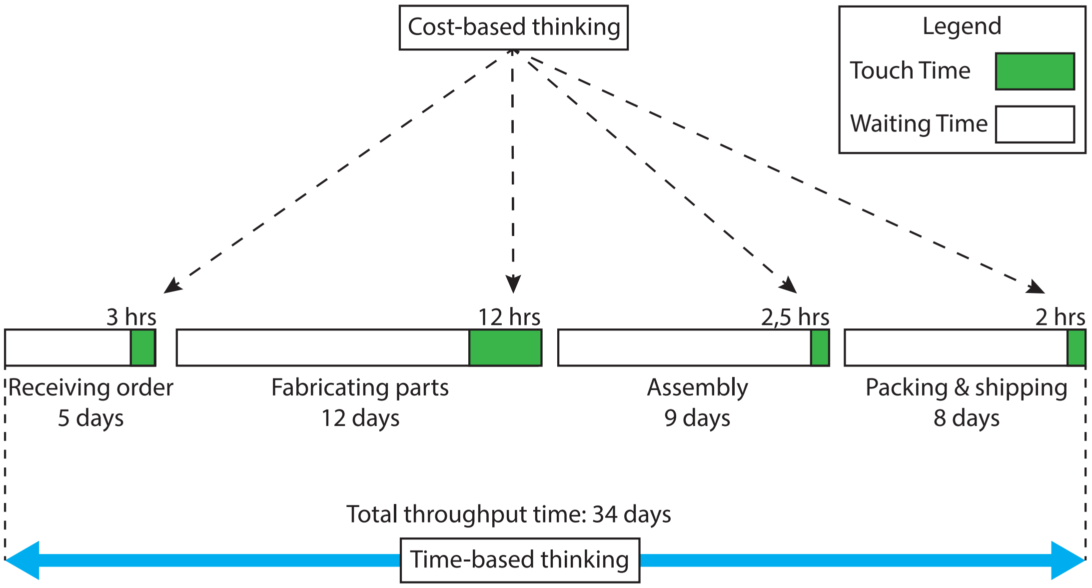


Figure 2.1: The difference between cost-based strategy and QRM (Suri, 2011)

Several other lead times are defined, such as offered lead time and supplier's lead time (Suri, 2011). In some cases, it is not clear which lead time should be used. Therefore, in collaboration with several industrial partners, a lead time measuring method is developed that gives a clear image of what QRM is about. This lead time is called *Manufacturing Critical-path time (MCT)*. The MCT is defined as:

> "A representative amount of calendar time from the moment a customer creates an order, through the critical path until the first (partial) delivery of that order to the customer." (Suri, 2011)

This definition demands some explanation to make exactly clear what the MCT is about. MCT should be a representative amount of time, without requesting too much data-analyses. Gathering detailed data is exactly contrary to what QRM tries to achieve, as it may take a lot of effort to do this. The goal of MCT is gaining a global view on the process, showing the main points of improvement. Also, as seen in figure 2.1, the touch time only represents a very small part of the total time. It is the waiting time that is used to convince management and employees and motivates them to take action, using QRM-methodology. It is not needed to exactly know the MCT, as long as it is clear that there is a lot of waiting time in figure 2.1. A global MCT is sufficient and relatively easy to compute.

Overhead Cost Reduction

Although not being the focus point, cost reduction is of course an important goal when applying QRM. One of the main advantages of reducing the MCT, is reducing overhead costs simultaneously. A lot of waste is associated with overhead, which disappears with reducing the MCT. Often overhead costs are distributed over direct labour and machine hours, giving some kind of justified cost figure. As the high volume of course demands the major portion of these expenses, a big fraction of overhead costs is associated with these high volume products. However, in reality the low-volume products carry the major portion of the overhead costs, as they need significantly more time and energy from the company. Engineering may need to modify an existing concept, the purchasing department may need to purchase a special material or component and maybe a whole new production management system needs to be developed. It is the waiting time per product that ends in the overhead costs, not the touch time (Suri, 2011). As seen in figure 2.1, the touch time accounts for less than 10% of total time. So optimizing the touch time has a marginal effect, while the overhead costs can account for up to 50% of the value of sold products. In the case a 30% cut from overhead costs is possible with overhead costs making up 50% of a company's costs, this means 15% of the total cost of the sold products. Meanwhile, the big benefit is that these savings are not at the expense of other KPI's but the contrary is true: while reducing the MCT by up to 90%, a big improvement is made on product quality (Suri, 2011)! This is in big contrast to conventional methods, trying to save costs based on reducing the touch time.

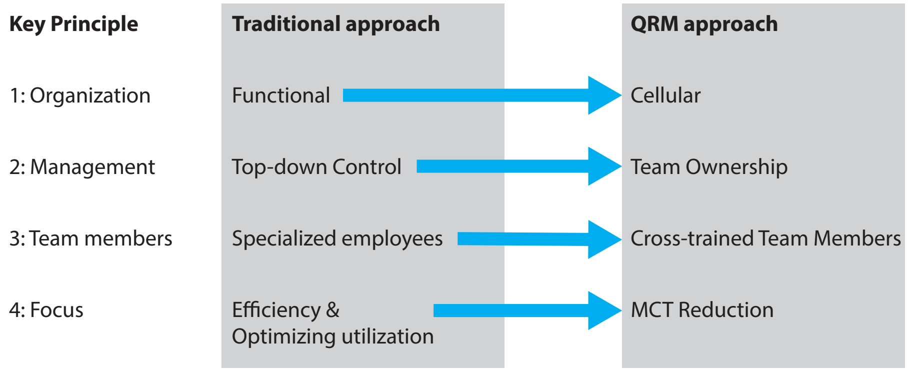
In some cases, it is even recommended to increase the touch time (Suri, 2011). In a production environment where assembling a product is done in three different departments, each of which executing a different task, every department will try to minimize its labour costs per product. This is also seen in the way the assembly is divided. Often big batches of products undergo one operation and production employees are specifically trained to perform this particular operation. Although every product is produced quite fast, a lot of work-in-progress is present in the system. Products will be parked in a buffer until the batch is complete before undergoing the succeeding workstep. In this case it is recommended to construct a QRM-cell (explained in section 2.2), with multifunctional employees so every workstep can be executed within this cell. As the employees need to perform multiple operations and will have to use more tools, the touch time (green blocks in figure 2.1) will increase. As the touch time is increased and the multifunctional employees may demand (and deserve) higher wages because of their higher competences, while simultaneously applying the overhead costs to the touch time, a conventional accounting system may find that the costs are increasing. On the other hand, the batch will be finished within mere hours, instead of several days, so the MCT will be reduced drastically (Suri, 2011).

Also an important measure is reducing the batch size. QRM recommends to make this change, which may be a counter-intuitive step for conventional managers to take. As smaller batches are subject to more operations, also here the green blocks from figure 2.1 will get bigger so the conventional accountants will notice the costs are increasing. However, as will be explained in section 2.2, using smaller batches will reduce the MCT significantly (Suri, 2011).

By now it should be clear that the main point is making a shift from cost-based thinking to time-based thinking, which the entire company should make. Not only management, not only production. One of the main points of QRM is that reducing the MCT should be the main measure of performance and will in the end reduce the company's costs. In the next three sections, the method used to achieve the MCT reduction will be explained.

2.2. Organizational Structure

Applying QRM demands an unconventional organizational structure, making sure the MCT can be reduced massively, up to 90%. In this section the four key principles of the QRM organization are explored. These four principles are of utmost importance for guaranteeing a short response time of an organization (Suri, 2011). They can be seen in figure 2.2. The first one indicates the organizational layout of the 'new' property while the other three principles make sure this layout can be maintained.



Key Principle	**Traditional approach**	**QRM approach**
1: Organization	Functional	Cellular
2: Management	Top-down Control	Team Ownership
3: Team members	Specialized employees	Cross-trained Team Members
4: Focus	Efficiency & Optimizing utilization	MCT Reduction

Figure 2.2: The four key principles of QRM

Changing from Functional to Cellular Organization

A QRM-cell is a set of dedicated, collocated, multifunctional resources selected so that this set can complete a sequence of operations for all jobs belonging to a specified focused target market segment. This demands some clarifications:

Market segment: It can for example occur that the demand for a certain type of tug is growing. In that case it can be interesting to reduce the lead time for this specific product and this is the Target Market Segment (TMS). The market can however also be an internal client such as, for example, the assembly department of a shipyard in Romania. If the assembly department is often waiting for specific parts of the ship that are delayed in production, the TMS will be these parts. The next step is to refine and focus the Target Market Segment, yielding the *Focused Target Market Segment* (FTMS), the main focus point of a QRM-cell.

Dedicated resources: The resources assigned to a particular QRM-cell, are completely dedicated to this cell. Suri (2011) states that if a milling machine is assigned to a QRM-cell, this machine can only be used for orders belonging to the FTMS of this cell. Even if the QRM-cell is idle at any point in time, the machine cannot be used for other orders to improve utilization, as could be a strategy with conventional management. These orders do not fit the usual pattern of the cell and will probably demand a lot of setup times, messing up the rhythm of the cell immediately.

Collocated resources: The resources in a QRM-cell should be located close to each other, with the boundaries of the cell clearly indicated. This may require some relocation of personnel or equipment to this cell.

Multifunctional resources: This means that the resources should be capable of executing multiple work steps. There should never be something such as a ’Plate forming cell’ or a ’grinding cell’. QRM means that the group of resources can execute different functional operations for a part within its boundaries.

Sequence of operations: When a part arrives at a QRM-cell, a number of operations will be done to this part. The product will not leave and return to the cell. The part can however be subjected to an operation of a certain machine multiple times if required. The main point is that these operations all occur within this same cell and once the part has left the QRM-cell, it will never return.

So the resources in a QRM-cell should be dedicated to the FTMS, have to be combined within the boundaries of the cell and have to execute different operations on one product. It may take a lot of analyses to determine which resources should be assigned to which cells. To limit the risk of unexpected bottlenecks due to crossing flows within the cells, the three other key principles (Team Ownership, Cross-training, focus on MCT-reduction) are needed, as well as System Dynamics, which will be discussed in section 2.3. Employing these principles will enable the cell to be an effectively operating, flexible cell, even with different types of orders with different routings within the cell.

Changing from Top-down Control to Team Ownership

When changing the approach of a company to QRM, the second key principle is not having managers or supervisors tell their people what to do. Teams have complete control over what happens in their cell. They are completely responsible for every operation taking place in the cell and decide themselves how orders are processed for a certain delivery date. The team decides if production should be terminated in the case of a quality issue and whether a meeting needs to take place.

If the team members are not only responsible for the work they are doing, but also can control what they are doing, they will most probably feel more dedicated and may exceed the expectations management has of them. This is a clear example of why the dedication of a cell may never be objected. Once management decides to make the cell work on products that are not part of the FTMS to improve utilization, the team will lose its ownership. The team then has no control over how to use their resources and it may happen that they do not reach their goals anymore.

Changing from Specialized Employees to Cross-trained Team Members

Cross-trained team members are of utmost importance for the success of implementing QRM in a company, with a number of reasons. As stated earlier, different types of orders will enter the QRM-cell from time to time. This means that bottlenecks may shift daily or even more often. A different order may require different machines and cross-training of team members creates a very flexible employability, enabling the team to shift capacities to where it is needed at any moment.

Furthermore, having cross-trained team members within physical reach of each other will result in a continuously improving production process. If two different machines demand a similar type of setup method and the team members experience this, they might find that just milling two slots in the material might make for easy alignment of the material in the machine. An improvement like this would not occur if these two machines and their dedicated employees were still on different sites within the production facility.

Changing focus from Efficiency/Utilization to MCT reduction
The last key principle of QRM is focusing on the right way of monitoring the performance of the cells. When employing QRM, it is of course nonsense to measure efficient machine occupation of a certain operator. In that case he/she will never leave the machine for team meetings, quality improvements and cross-training.

With QRM, the right focus point for monitoring performance is simple: MCT. As long as the MCT is being reduced, it does not matter who is operating which machine, whether the team spends a lot of time on meetings or a machine being idle from time to time. As long as the MCT is reduced, the team is operating right, according to Suri (2011). If the MCT is increasing however, it is clear that the team needs help to solve their issue and make the team work efficiently once again. As already seen on page 10, several benefits arise simultaneously when reducing the MCT. Therefore it is of utmost importance to monitor the improvement and encourage the team to continue on this approach. Suri (2011) therefore initiated the ’QRM-number’.

Measuring the throughput time using the MCT is a good start, however this does not include past improvements and may not really be inspiring for the team members. The QRM-number is a method of monitoring the MCT reduction effectively and therefore can be used to show the MCT reduction to the team members and is exactly what management needs in this situation according to Suri (2011).

To find the QRM-number of a cell, the MCT of this newly implemented QRM-cell is measured as a benchmark period. This is then repeated for several succeeding periods. The QRM-number is then computed with equation 2.1.

$$Current\ QRM-number = \frac{MCT\ of\ benchmark\ period}{MCT\ of\ current\ period} * 100\% \tag{2.1}$$

This equation gives a clear figure of the improvement accomplished by the cell. if the QRM-number is bigger than 100%, it is easy to see the cell has improved their work. Computing the QRM-number on a regular basis and sharing the result with the team, will challenge and motivate the team to improve even further.

2.3. System Dynamics

Suri (2011) states that simply changing the structure of an organization to a cellular one of course does not guarantee reduced MCT. When implementing QRM, the cells require support from other management strategies as well. In this section, it will be discussed how system dynamics influence the MCT and how a company should deal with this to reduce the MCT substantially. The interaction between machines, team members and products are of utmost importance in improving the MCT.

Utilizing the principles of system dynamics is a unique feature of QRM, other management strategies often ignore this, according to Suri (2011), important methodology.

When there is a peak in demand for products, the waiting time usually increases if there is no spare capacity of resources. If a cell has a utilization of 100%, the cell may perform optimally with normal demand, but this cell is not capable of dealing with an unexpected extra order and in that case the lead time increases dramatically. Therefore, an important aspect of QRM is to decrease utilization of a company’s resources during usual business.

Utilization
The utilization is computed as the ratio of all time a machine is occupied (including during break down, setups etc.) over the total time the cell should be active, as seen in equation 2.2. In this equation, u is the utilization. M denotes the "Magnifying effect of utilization".

$$M = \frac{u}{1-u} \tag{2.2}$$

This equation shows the increase in waiting time as a function of utilization. If a certain resource has a utilization of 75% (so u=0.75), M has a value of 3. If for some reason the utilization the utilization climbs to 90%, the value of M climbs to 9, showing that an increase of utilization of a certain resource by 15%, leads to a waiting time of 300% of the original value! It is clear that this can have a disastrous effect on the MCT.

In the same way, the desired spare capacity of a resource can be computed in a similar method, found in equation 2.3. In this equation, R indicates the spare capacity of a resource, leading to M, now defined as the "Miraculous effect of spare capacity".

$$M = \frac{1-R}{R} \tag{2.3}$$

This equation makes clear that an increase in spare capacity from 10% to 20%, the waiting times will decrease by more than 50%! This can also easily be seen in figure 2.3, showing that decreasing utilization a bit, has quite a big influence on the flow time.

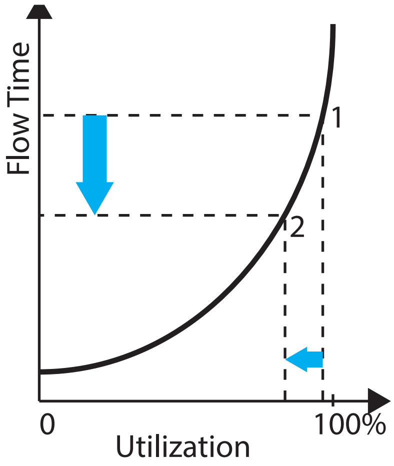


Figure 2.3: The effect of decreasing utilization

Variability

With the impact of utilization clear, it can be seen that variability also has a major impact on the performance of a cell. In the QRM-context, variability is always related to time. This can be variability in arrival times of orders to a cell, or variability in the throughput time of an order on a resource. These two types of variability have a major influence on the waiting time of a product before and in a cell. According to Suri (2011), the average variability is calculated with equation 2.4. In this equation V_A denotes the variability in arrival times and V_T indicates the variability of the throughput times.

$$Average\ Variability\ (AV) = \frac{(V_A)^2 + (V_T)^2}{2} \tag{2.4}$$

This average variability is used to compute the average waiting time for an order before it can enter the process in a cell. This waiting time is computed with equation 2.5. The waiting time is a function of the *Average Variability* (AV) as seen in equation 2.4, the utilization M from equation 2.2 and the *Order Time* (OT), being the sum of the setup time and the time required to process all products in an order.

$$WT = AV * M * OT \tag{2.5}$$

With this waiting time known, it is easy to find that the total flow time an order on this resource is simply equal to the sum of this waiting time and the time it takes to process this order: *OT*. This is seen in equation 2.6.

$$Flow\ Time = (AV * M * OT) + OT \tag{2.6}$$

This equation gives an easy insight into system dynamics. This flow time is defined as the amount of time the arrival of this order contributes to the MCT. There are clearly three factors in there increasing the MCT. To reduce the MCT, it is therefore easy to see that reducing these numbers is key.

Reducing the variability

The average variability, utilization and order time all have their own useful methods of being reduced. The average variability in arrivals can be reduced by reducing the interval in which orders are being generated. If for example all orders of a whole week are released to planning once a week, this gives quite an unsteady demand. It would be beneficial to release these orders daily or even directly. The variability in throughput time can be reduced by standardizing routines for setups and working procedures.

The miraculous effect of utilization can be reduced by simply reducing the utilization or in other words, increase the capacity. This requires a change in mindset of the management to make sure the resources are only utilized for less than 80% of time. This can be done by for example investing in preventive maintenance of machines or if needed, purchasing extra capacity.

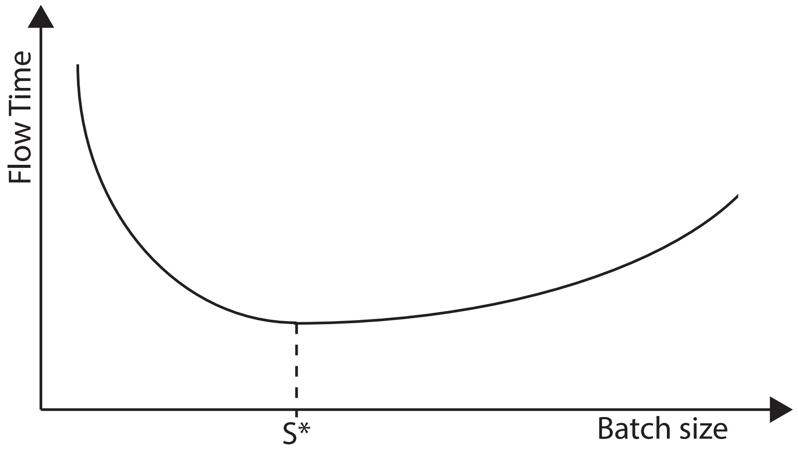


Figure 2.4: The influence of batch sizes on flow time

To reduce the order time, a simple method can be used: reducing batch sizes. Conventional cost-based thinking would be opposed to doing this, as cutting batch sizes will increase setup times. Suri (2011) however shows the influence of reducing batch sizes on the flow time of an order. Of course small batches require relatively much setup times, that is why the function never reaches zero. It is seen that there certainly is an optimal batch size S*, which carries both the smallest flow time as well as the smallest overhead costs (Suri, 2011).

The combined impact of these strategies can be seen in figure 2.5. This shows that just as in figure 2.3 the flow time is decreased by decreasing the utilization (going from point 1 to 2 on the graph). If however the average variability can be reduced as well, the flow time even is reduced even more (going from point 2 to 3 on the graph), also indicated by the blue arrow.

2.4. Enterprise-wide Application

Quick Response Manufacturing is no strategy for solely the production floor. It reaches to within the head office, planning department, purchasing and even sales. Usually, the office operations are not in the scope of resources to be improved, while in reality this department might carry over 25% of the total overhead costs of the company and take up more than half of the total throughput time of an order.

Figure 2.6 shows that, just as in the production floor (figure 2.1), a lot of time is being wasted as for the same example, the order spends more than two weeks in the office while the actual work done for the order takes

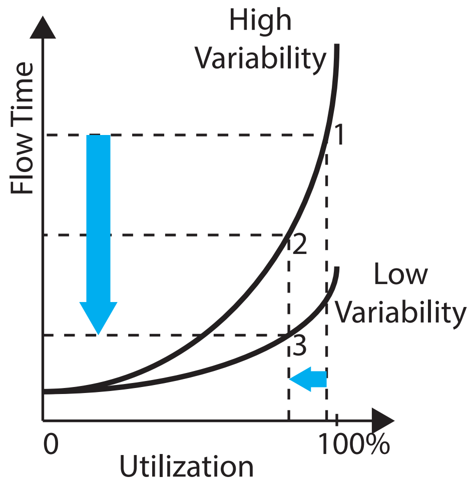


Figure 2.5: The combined impact of utilization and variability on the flow time

less than one hour (Suri, 2011). So in this sense, there is not so much difference between the production floor and the office and implementing QRM in the office environment also could make a huge difference. The office should therefore also be changed to a cellular structure with so-called *Quick Response Office Cells (Q-ROC's)*. The four key principles of QRM also apply here:

- Changing from functional office departments to Quick Response Office Cells.
- Changing from top-down control to team ownership by the Q-ROC's.
- Changing from specialized employees to cross-trained team members in the Q-ROC's.
- Changing focus from efficiency and utilization to MCT reduction for the Q-ROC's, measured by the QRM-number of every cell.

The principles of using system dynamics can also be applied when implementing the Q-ROC's:

- Make a strategic plan to ensure spare capacity in the office.
- Reduce the variability, both in the arrival of the orders as well as the time it takes to execute each task.
- Execute tasks in parallel instead of end-to-end.
- Make use of standard templates and forms to make sure orders will be executed right away instead of in big batches.

2.5. POLCA

Apart from these four principles, it is important not to let the workload of all resources escalate. In a continuous flow system, this is done with a fairly straightforward pull-system such as KANBAN. In the case of special orders or one-of-a-kind products, this will not work, however. To manage the workload effectively and keep the flow of materials on the shop floor within limits in a QRM-organization, Suri (2011) developed a system that fits the Cellular organization.

This system is called *Paired-cell Overlapping Loops of Cards with Authorization*, or simply 'POLCA'. POLCA is useful for companies making complex products, or products that require a lot of operations, resulting in the inability of producing final products in one single cell. Such a cell would be far too large, both in physical terms as well as the size of the team working in it. That is why a lot of these companies implement multiple cells, feeding each other. There can for example be multiple fabricating cells for multiple types of components.

When material flows from one cell to another, these two cells are connected by means of a POLCA-loop. This loop contains a number of so-called POLCA-cards, circulating along the loop. These cards state the simple message that the second sub-cell has finished its job and the first cell can send a new batch of work. The main

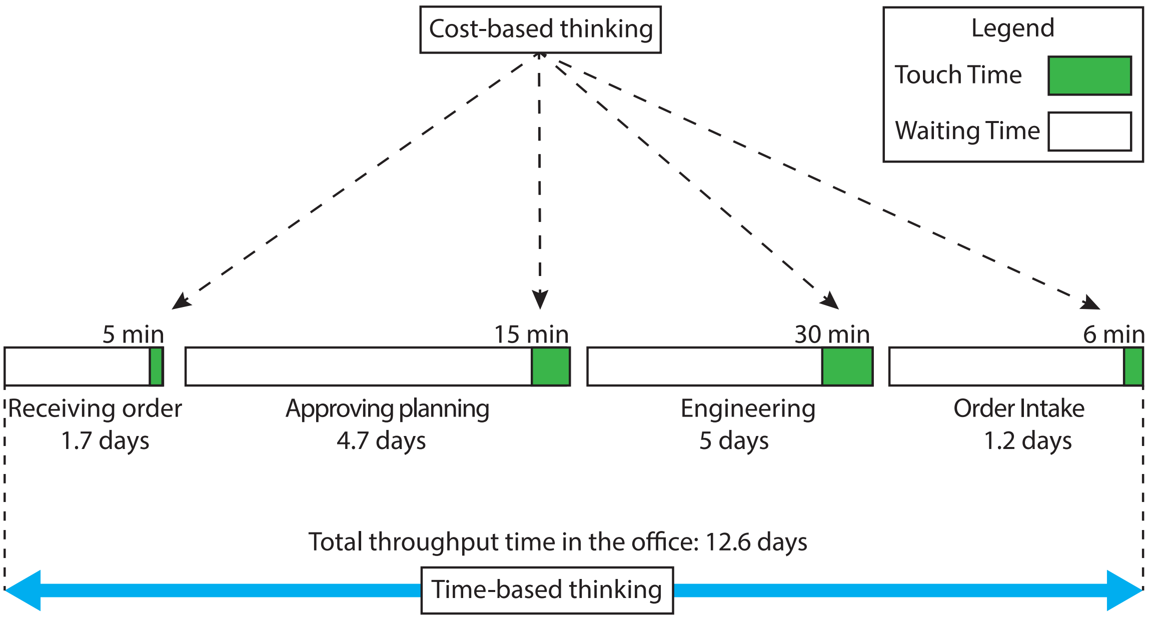


Figure 2.6: The difference between cost-based thinking and QRM for the office environment

difference between KANBAN and this POLCA-system is that POLCA is not an inventory-system, stating that the inventory of components is empty. POLCA is a capacity-signal. This signal arrives at the first cell when an order is finished and this cell can send a new order.

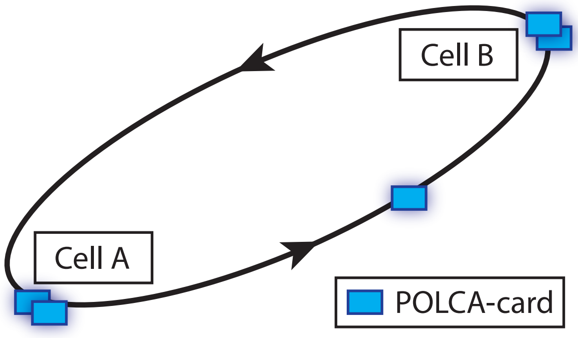


Figure 2.7: A POLCA-loop between cells A and B.

It can occur that one cell is incorporated in multiple loops, as seen in figure 2.8. An important aspect of the POLCA-system is then how to determine on which order a cell should start working if there are multiple of them. To make this decision, the 'Authorization list' is utilized. This list shows all orders that the cell has not started working on yet, on chronological order. An example can be seen in table 2.1. In this table, the grey area indicates the orders that are not authorized yet. The cell is authorized only to work on orders with their authorization date in the past or present. Now the decision on which order to start working is based on a simple rule: the top one goes first. However, this can only occur if a corresponding POLCA-card is present in the cell. If there is no A/D card present, this means that all A/D cards are at cell D and this cell probably already has a lot to work on. Sending another order to this cell would only increase the work-in-progress and the MCT.

In this case, the second order on the list is the first priority. So the team will start working on order 513005-302 if an A/B card is present. If this is not the case, the first priority will be the fourth order. However, as the authorization date of this order is in the future, the team cannot start working on this order, even if an A/F

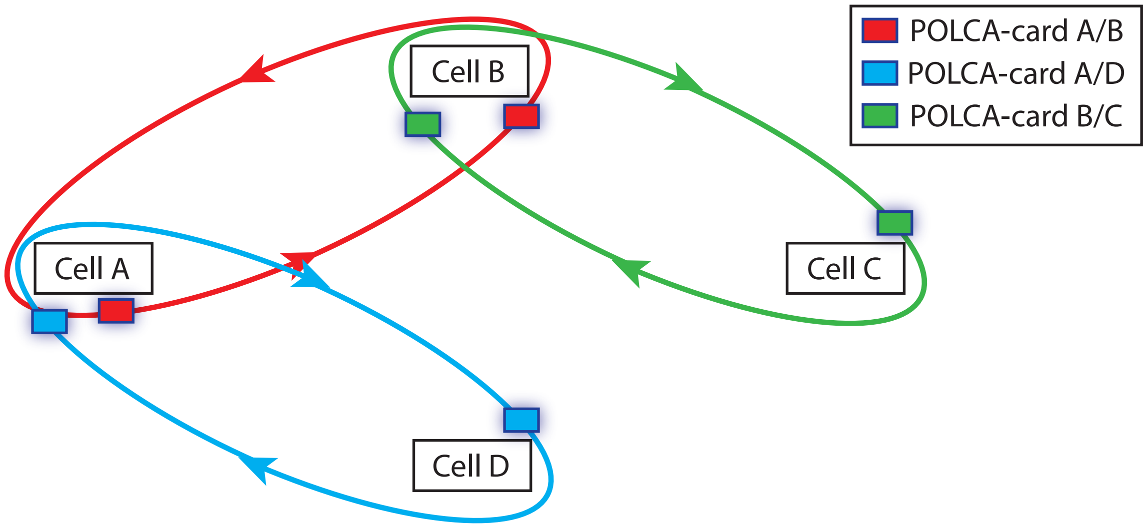


Figure 2.8: Overlapping POLCA-loops

Table 2.1: POLCA Authorization List

POLCA Authorization List			
Cell A		**Date: 03/02/2018**	
Order no.	**Authorization date**	**Next Cell**	**Remarks**
513005-201	01/02/2018	D	...
513005-302	03/02/2018	B	...
510629-101	03/02/2018	D	...
513006-101	04/02/2018	F	...
513006-102	05/02/2018	B	...
...	...	...	...
...	...	...	...

card is present. If they start working on this order and an A/D card arrives in the cell, the team should then quit their work and start on the first order, causing delays, partially finished orders, repeating of setups and an increased MCT.

QRM states that a better way to use this waiting time is to invest this in themselves: analyzing setups to reduce future setup times, some preventive maintenance, do some cross-training or clean the place up. If there is never a moment a team member does not need to be producing, there never will be a moment this team member will improve the team of course.

By now, a brief insight is given into the thinking process of QRM. It is clear that implementing this strategy can help the entire company strive for the same goal. The message QRM tries to tell is fairly simple. The focus is clear and applicable for every part of an organization. Everyone in the company can simply recognize the shared objective: reducing the MCT.

2.6. Conclusion

What are the relevant insights about Quick Response Manufacturing?

Quick Response Manufacturing is a management strategy revolving solely about reducing lead times in a company. This lead time is defined with the ’MCT’ (Manufacturing Critical-path Time): The representative amount of calendar time from the moment a customer creates an order, through the critical path until the first (partial) delivery for that order to the customer. The theory proposes an organizational structure that differs from most conventional approaches. The key principles of this structure is a cellular organization instead of functional departments. These cells are managed by the team working in the respective cell instead of a top-down control management. This team consists of cross-trained team members instead of specialized employees and their focus is completely on reducing the MCT instead of increasing efficiency and utilization. Results of improvement suggestions are measured with the QRM-number, that compares the MCT of a suggestion to the MCT of the initial situation.

A proposed QRM-cell requires support from the appropriate system dynamics. QRM emphasizes the importance of reducing utilization and variability. The interaction between two succeeding cells is done using the ’POLCA’-system: a system of cards travelling with orders in a loop of two succeeding cells.
The competitive force of QRM states that being responsive can help a company gain market share. Reducing MCT reduces costs as well and helps increase the quality of manufactured products. The organization brings new energy to the team members. With this in mind, it could be possible for anyone to strive ahead of other competitors in the market and to become a market leader in shipbuilding (or any other market for that matter).

3

Process description

Does the currently available steel processing equipment allow the output to be elevated to the desired quantity?

The first step in improving the preprocessing department without a major investment is to find out whether the currently available preprocessing equipment even allows the output to be elevated to that of section 1 and section 1A together. For this, an estimate is used to check whether it is actually any useful to proceed.
A background study about Damen Shipyards Galati and the processes taking place in the preprocessing stage is executed. The layout of DSGa can be seen in appendix A and figure 1.3. To start analyzing the (part of the) shipyard, the main requirement is to have a set of information regarding the processes taking place, describing the work steps. This yields an understanding of the processes happening at the yard. A summary of the steps taking place in the preprocessing department of DSGa is stated in section 3.1.

Apart from the information about these process steps, three more types of information are needed. The technical information includes information about the available equipment and is stated in section 3.2. The product data are a set of information about the ships built at the yard and all separate parts these ships consist of. This is stated in section 3.3. Lastly, the organizational data provide information about the employees working at the yard, the shift times they work in and the skills they have. The organizational data can be found in section 3.4. An estimation of the utilization is made in section 3.5.

3.1. Process Steps

A map of Damen Shipyards Galati can be seen in appendix A. As already stated in chapter 1, the preprocessing department of DSGa takes place in two separate facilities: section 1 (S1) and section 1A (S1A).

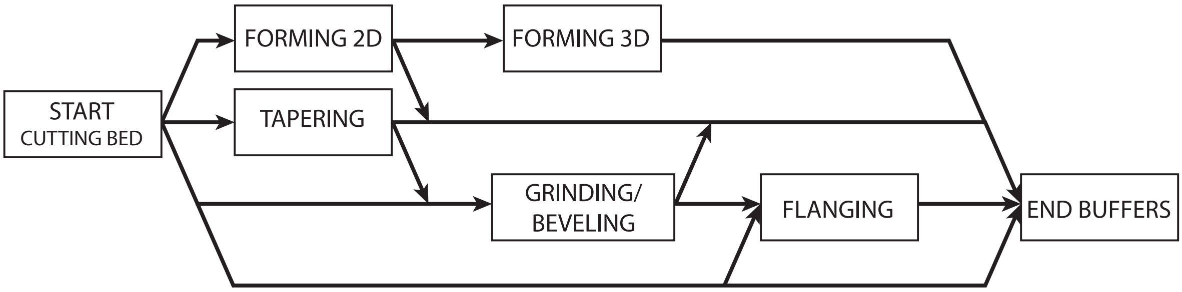


Figure 3.1: Possible paths of parts taking place at the preprocessing.

'Preprocessing' in a shipyard concerns the steps from parts being cut until, but not including, assembly. Figure 3.1 shows the different routings that take place in the preprocessing department of DSGa. This figure shows the routes a part can take so as seen in the figure, the material storage and infeed of plates are excluded.

This section gives an overview of these different steps. Appendices C and D give a more extensive explanation of these processes for Section 1 and 1A, respectively.

3.1.1. Material Storage

The raw material storage is located near preprocessing facility S1A. In this stock, four types of material are stored:

- Black (uncoated) plates of all sizes used in S1A and S1,
- Shot blasted, primered plates ready to be cut,
- Purchased profiles of all sizes used in S1A and S1,
- Leftover plates with rest material.

As a starting point for this analysis, primered plates are stacked, sorted per cutting group. A cutting group is a group of sections, nested together to minimize scrap. From this storage, stacks of plates enter preprocessing hall S1A per conveyor rail. Plates used in S1 are then transported from S1A to S1 per section transporter.

3.1.2. Cutting of Plates

A plate arriving on a conveyor rail to be cut, is picked up by a crane and placed on the assigned cutting bed. On the cutting bed, the plate is cut into separate parts. These parts are provided with marked lines for future joints and signed part numbers and routings.

After these plates are cut into parts, these parts are sorted per section for their next destinations. Seven sorting alternatives are distinguished:

- Small parts, sorted by hand into small containers.
- Main panels, brought to the panel line.
- To-be-formed parts, brought to the forming area.
- To-be-tapered parts, brought to the tapering area.
- Scrap, thrown into scrap containers by hand.
- Leftover plates, brought back outside to the material stock.
- All other parts, sorted into containers by crane.

3.1.3. Tapering, Beveling

(a) Tapered plate edge

(b) Beveled plate edge

Figure 3.2: The distinction between beveling and tapering

Tapering and beveling are steps that are applied before two plates are joined together. The difference between the two can be seen in figure 3.2.

If, between the plates, there is a difference in plate thickness, it is important to make a smooth transition on the edge and to prevent stress concentrations, material from the thicker plate of the two is removed by tapering as seen in figure 3.2a. This is done with an oxyfuel torch on a carriage, riding along the edge of the plate.

As prescribed by class, before welding, a bevel is to be made to the edge of one or both of the plates as seen in figure **??**, as otherwise the weld will not penetrate through the material. The gap that then exists is filled with the filler metal. The beveling operation is performed with a grinder.

3.1.4. Plate Forming

Figure 3.3: Process of plate forming

As a ship's hull is usually curved in some way, shell plates often need to be formed to match this curve. Due to the available equipment at DSGa, any plate that is formed first is formed along one axis using a big plate roller, so generating a 2D curve (single curve).

Some plates however require a curve along two different axes. These, already 2D-formed plates, are then brought into their final 3D curve (double curve) on a separate station, either with a roller press or with line heating.

3.1.5. Grinding

Figure 3.4: Process of grinding

After cutting, the edges of the parts are not treated yet. Parts that are coated or welded, therefore need to be ground along their edges. This is usually just simply done with an angle grinder or a stand belt grinder. An impression of this work step can be seen in figure 3.4.

3.1.6. Flanging

Figure 3.5: Process of flanging

Flanging is the process of creating a rim on a steel part. This is done for e.g. hatches on ships' decks or for girders and to execute this, a press brake is used. This process is expressed in figure 3.5.

3.1.7. End Sorting

After these operations, the parts have finished the preprocessing and the last step is to bring each part to its next location to be built into sub-panels, main panels or other structures. For the currently observed process, these next locations are the end buffers of the system. All parts are packed in containers with equal end buffer. These various end buffers can be seen in table 3.1.

Table 3.1: End buffers of the preprocessing stage

End Buffer	Destination	Location
910	Sub panel assembly	Parts processing area
920	T-beam assembly	Parts processing area
930	Main panel assembly	Panel line
940	Section assembly	Section building hall
950	Block assembly	Section building hall
960	Hull assembly	Outside
970	Small steel workshop	Outside
980	Mechanical workshop	Outside
990	Subcontractor	Outside

3.2. Available Equipment

The technical data are a list of all available equipment for preprocessing. This list can be found in appendix E. Table 3.2 states the available steel processing equipment in section 1A. The available material transporting equipment can be found in table 3.3. Section 1A is separated into three lanes, these lanes are stated as the locations of the various pieces of equipment. The division of section 1A into these lanes can be seen in figure 3.6.

Table 3.2: Steel processing equipment in preprocessing section 1A

Equipment	Location	Specifications	Tasks
Cutting Machines			
Plasma cutting machine 1+2	Lane 2	3 Cutting beds 2 ESAB Cutting Portals	Cutting plates Marking lines Beveling V-Seams Signing parts
Plasma cutting machine 3	Lane 3	4 Cutting beds 1 ESAB Cutting Portal	Cutting plates Marking lines Beveling V-Seams
Forming Equipment			
Plate Roller	Lane 2	Hugh Smith Plate Roller	2D-forming parts
Line Heating Platform	Lane 2		3D-forming parts, by blowtorch
Flanging Equipment			
Press brake	Lane 2	Hugh Smith Press Brake	Flanging parts
Tapering Equipment			
Tapering Table	Lane 3	Table, with tapering torch on tractor	Tapering Edges
Grinding equipment			
Fixed Grinder	Lane 3 Parts Processing Area 1	Stand Belt grinder	Grinding Beveling
Fixed Grinder	Lane 2 Parts Processing Area 2	Stand Belt grinder	Grinding Beveling
Fixed Grinder	Lane 2 Parts Processing Area 3	Two Stand Belt grinders	Grinding Beveling

Table 3.3: Transporting equipment in preprocessing section 1A

Equipment	Location	Remarks
Cranes		
Crane system lane 1	Lane 1	2 crane portals
Crane system lane 2	Lane 2	4 crane portals
Crane system lane 3	Lane 3	3 crane portals
Conveyor rails		
Infeed conveyor 1	Lane 2	
Infeed conveyor 2	Lane 3	
Transverse conveyor	Lane 2-3	
Carriages		
Profile infeed carriage	Lane 1	
Rest plates outfeed carriage	Lane 3	
Transverse Carriage	Lane 1-2-3	
Forklift		
Electic Forklift	n/a	

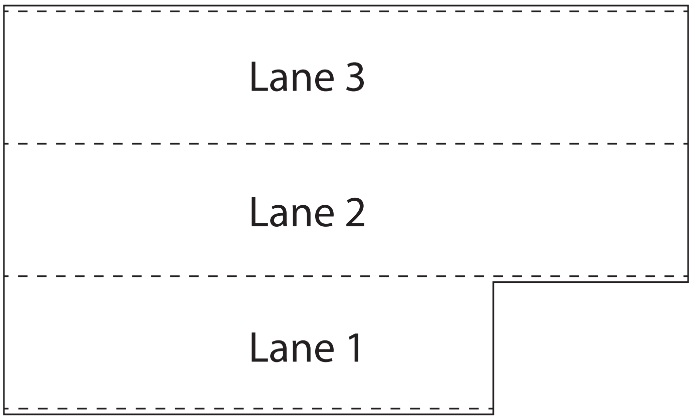


Figure 3.6: The division of section 1A into three lanes

3.3. Product Portfolio

Between 1999, when Damen acquired the shipyard, and 2017, DSGa has delivered 401 ships with the following distribution: (Damen, n.d.a)

- Cargo vessels: 85
- Tugs, workboats, barges & pontoons: 233
- Offshore: 65
- Others: 18

In 2017, 17 ships were delivered in total, of which:

- Tugs & workboats: 11
- Offshore vessels: 6

The figures of 2017 will be used for this analysis.

At Damen, the capacity of generating representative product data is very limited. Therefore it is chosen to represent the product portfolio by two ship types: one tugboat and one offshore vessel. To obtain a representative product portfolio for the analysis, an insight is given in the product portfolio of DSGa. Tugs are built

in various sizes, ranging from a variety of tugs with a length under 30 meters, up to the largest vessel with a length of 51 meters (Damen, n.d.b). Within this portfolio, a representative tug, based on length, beam and mass is the Damen ASD2913. Based also on availability of data, this is the analyzed vessel type.
The majority of offshore vessels that are built at DSGa, are Platform Supply Vessels (PSV). The PSV product range consists of six vessels with lengths ranging from 60 to 90 meters (Damen, n.d.b). To find a representative vessel, when looking at the actual sales of DSGa in 2017 and comparing them to the simplified assumption of only two vessel types, it is found that the majority of the PSVs are PSVs 3300. It is assumed that of set of 11 ASD2913 tugs and 6 PSVs 3300 form a representative product portfolio.

(a) ASD 2913 Tug

(b) PSV 3300

Figure 3.7: Two representative ship types

An overview of the product data can be seen in appendix G. These data show all plate parts these vessels consist of, their specifications and work steps they all have to endure, what ship's section they belong to, their end buffers, information on the nesting they originate from and information about the cutting groups of the two vessel types. The number of plate parts, the number of steel plates they originate from and the total mass of these parts are stated in table 3.4.

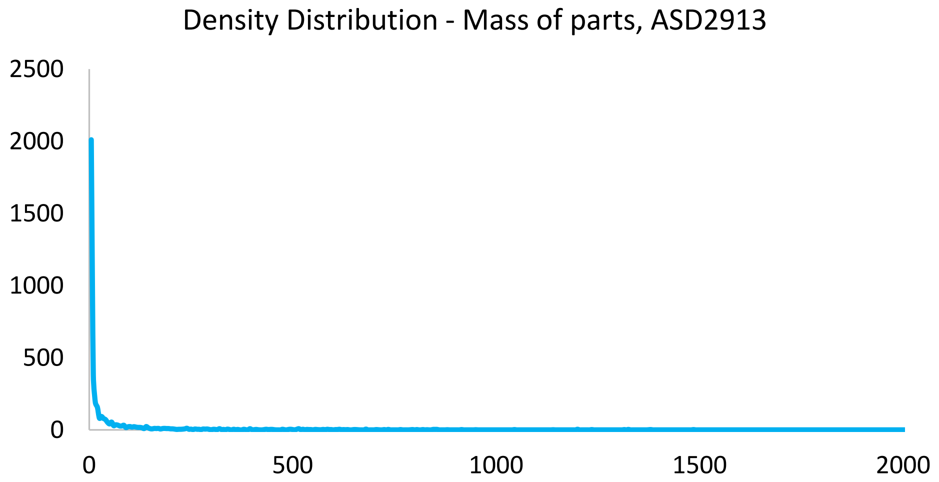
Table 3.4: Total numbers of parts of the two ship types.

Ship Type	Number of parts	Number of steel plates	Total mass of parts [T]	Total mass of plates [T]
ASD2913	4002	128	228	311
PSV3300	18117	661	1088	1455

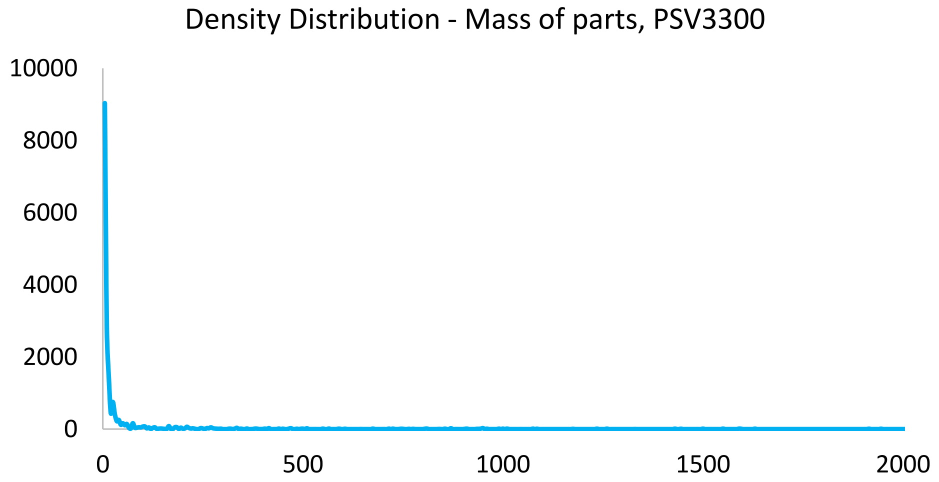
Based on the available data, it is found that the vast majority of all parts are small parts with a mass less than 10 kg. This is also illustrated in figure 3.8, where the number of parts is displayed with respect to their mass, in bins of 5 kg. For both ships these small parts however only make up less than 3% of the total mass.

The organizational data in appendix F show that in Section 1, 71 employees are active for cutting plates and preprocessing. In section 1A, these are in total 126, for not only cutting plates and processing them but also for cutting and processing profiles. One of the crews is responsible for this latter task, as well as for the plate forming station. From the 31 people in this crew, ten are responsible for the plate forming and 21 for the profile processing part. Therefore it is stated that in section 1A, 106 employees are available for the plate processing operations, a little over 1.5 times as much as in section 1. From this figure, it is estimated that the division of the workload is also around 40% for section 1 and 60% for section 1A.

With the known product portfolio, this yields an annual delivery of around 2.4 PSV's and 4.4 tugboats in section 1, versus 3.6 PSV's and 6.6 tugboats in section 1A. The masses of these two ship types are stated in table 3.4, so this yields an annual throughput of 3600 tons of parts for section 1 and a throughput of 5400 tons of parts for section 1A.



(a) Mass Distribution ASD2913



(b) Mass Distribution PSV3300

Figure 3.8: Distribution of masses of a Damen ASD2913 Tug (a) and a Damen PSV3300 (b)

3.4. Available Work Forces

The total number of employees at the preprocessing of DSGa is stated in appendix F. However, these employees are not always working simultaneously. Usually 10% of the employees in the yard are on holiday, the rest of them is divided into one, two or three shifts depending on the load of the workshop. When the workload at the yard is low, the standard shift is used so the employees work from seven o'clock in the morning until quarter to four in the afternoon. When the load is higher, two or three of the normal shifts are used. The 'turnus' shifts are hardly ever used.

Per preprocessing facility, three foremen are responsible for parts processing and sorting. From each of the parts processing crews, half of the employees should be capable of sorting parts for preprocessing and panel assembly. As in the observed situation shifts I and II of the normal shifts are used, about ten employees are present at each of the parts processing areas. With the foremen responsible for cutting and plate forming, respectively, these numbers are different.

3.5. Estimating the Utilization of Processing Equipment

By now, an insight is given into the processes taking place at the preprocessing department of DSGa. With this information, an insight can be obtained of whether the preprocessing department is working up to par and whether it could be able to handle bigger throughput.

Average processing times and setup times are provided by Damen and are stated in appendix H. In appendix I, an estimation is made for the utilization of the various pieces of equipment in section 1A, for an ASD2913 tugboat and a PSV3300. The overview of these times and utilization can be seen in table 3.5. It is seen that for the current situation (3.6 PSVs and 6.6 tugs) the utilization of processing equipment is not bigger than 37%. This indicates that more ships could be processed indeed. The table also shows the figures for the situation where the whole year's product portfolio (currently processed in sections 1 and 1A together) is processed in section 1A, this shows that the utilization of all machines is not bigger than 62%. Therefore it might indeed be possible to transfer all steel preprocessing to section 1A.

Table 3.5: Estimations of the utilization of steel processing equipment

Equipment	**1 Tug**	**1 PSV**	**3.6 PSVs + 6.6 Tugs**		**6 PSVs + 11 Tugs**	
	Hours	**Hours**	**Hours**	**Utilization**	**Hours**	**Utilization**
Cutting machine lane 2 - 1	42	233	1117	28%	1861	47%
Cutting machine lane 2 - 2	42	233	1117	28%	1861	47%
Cutting machine lane 3	56	311	1489	37%	2482	62%
2D Plate Roller	146	149	1498	37%	2497	62%
Line Heating Platform	155	54	1213	30%	2022	51%
Press Brake	68	166	1045	26%	1742	44%
Grinder	30	163	784	20%	1307	33%
Tapering	37	0	243	6%	405	10%

The utilization and key figures of the transport equipment are not very straightforward to obtain. The usage of transport equipment is heavily dependent on the allocation of batches at the cutting machines and parts processing areas. Also it is dependent on timing and interdependencies between various parts. So to find these figures for the transport equipment, a more elaborate analysis is needed.

Furthermore, these numbers neglect an important factor: interdependencies between parts, batches and equipment. Table 3.5 shows numbers for only the processing and setup times but assumes these processes do not interfere and can all be executed separately. This issue is illustrated in figures 3.9 to 3.11. Figure 3.9 shows a situation that orders are all equal in size and arrive at equal intervals so this can be considered as a Utopian situation. In reality however, orders are not of equal size at all but there is a great variability between them. Figure 3.10 shows this situation and does not necessarily form a problem if the orders are sufficiently spaced apart in time. In the real world however, batches are not equal in size, nor equally spaced apart. Orders may arrive while the previous order is still being processed, inducing waiting time as shown in figure 3.11.

To take this phenomenon into account and to compute other QRM-figures such as flow time and variability, a more extensive analysis is needed. To give an accurate set of figures for the performance of the yard, a quantitative analysis is chosen to be performed, that incorporates interdependencies between transport equipment and other objects. In chapter 4, the way of analyzing the process is elaborated upon.

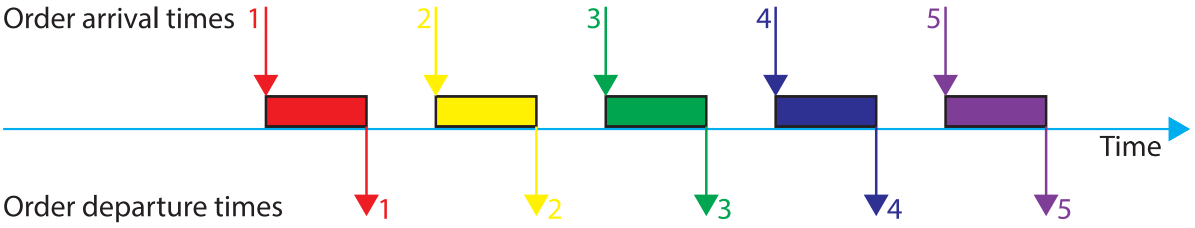


Figure 3.9: Deterministic orders: equal length and arrival intervals

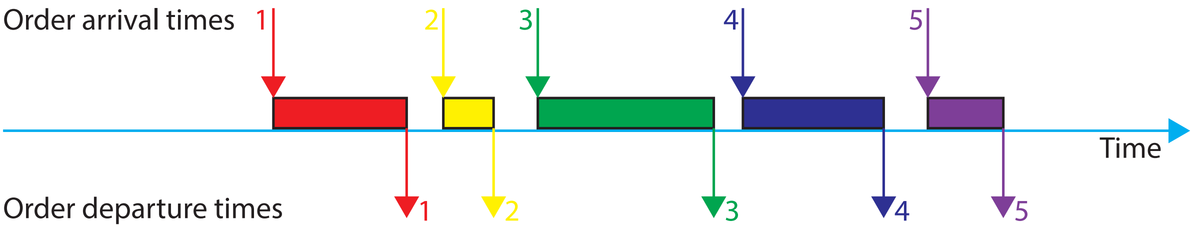


Figure 3.10: Variable orders but spaced apart

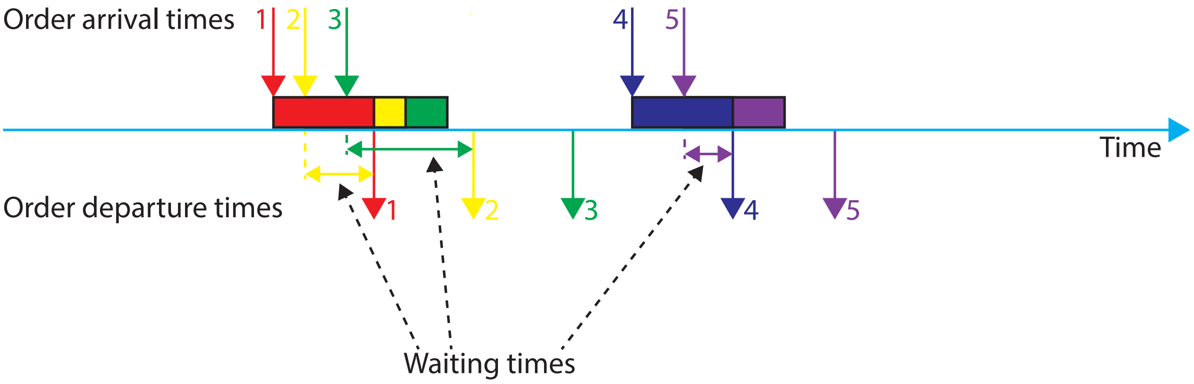


Figure 3.11: Bursts of orders

3.6. Conclusion

Does the currently available steel processing equipment allow the output to be elevated to the desired quantity?
A study about the preprocessing department at Damen Shipyards Galati was performed.
To make a detailed analysis of the preprocessing, four types of information are required:

First, the process data are required. This is information related to the operations and processes that take place in the preprocessing facility of the shipyard. In the process data, the information is stated about the routines and operations that cut steel parts are applied to. Per operation, this information includes all , their sequence and sorting criteria.

The technical data are a set of information about the yard itself. It includes the relevant equipment that is present in the facility, such as cutting machines, forming equipment and also transporting equipment such as cranes and conveyors.

The organizational data shows information regarding the employees working in the observed section of the shipyard. A list of these employees is provided as well as the skills they have and the crew they belong to. It also states information about the working times of the yard.

The product data show the product portfolio the observed part of the shipyard works on. The portfolio consists of tugboats and platform supply vessels. One ASD2913 tug consists of 4002 separate parts cut from steel plates, one PSV3300 consists of 18117 separate parts cut from steel plates, these parts have different routines and operations they require.

The preprocessing phase of shipbuilding is a process that starts by cutting plates into parts, performing various operations on these parts and sorting them for various assembly steps. Based on these processes, the yearly portfolio, the available equipment and the available number of personnel, it is found that it could indeed be possible to perform all steel preprocessing in section 1A. This information however does not yet incorporate interdependencies between equipment nor any dynamics. In the next chapter, a method of analysis is chosen to be able to incorporate these phenomena.

4

Method of Analysis

What method is used to analyze the performance of the preprocessing department?

As seen in the previous chapter, a static analysis is not sufficient to generate an accurate image of the performance of the yard. To quantify the performance of a process with factors that depend on each other, a quantitative analysis is a useful method and a process simulation is the most popular and widely supported method for quantitative analyses of processes (Dumas, 2015). According to the Oxford English Dictionary, simulation is defined as *"To assume falsely the appearance or signs of (anything); to feign, pretend, counterfeit, imitate; to profess or suggest (anything) falsely"*.

More modern definitions might however seem more appropriate: VDI (2000) defines simulation as *"the reproduction of a real system with its dynamic processes in a model. The aim is to achieve transferable findings for reality."* So this is exactly what is done with the yard in Galati. In this chapter the motivation for using simulation is explained and the choice is made for the software package that is used for simulating the yard at DSGa. A look is taken into what simulation and its applications are and what the benefits of simulation are. After this, relevant existing software options are examined, from which a choice is made for the software used for this project.

4.1. Motivation

Anyone can perform a simple analysis, as shown in section 3.5. As the complexity of the observed system increases however, a simple analysis or a spreadsheet does not suffice anymore. Simulation however, can incorporate randomness and interdependencies characterizing the behavior of the system in the real world. Simulation can solve real-world problems in a safe and efficient way. It is used when executing experiments on a real system is not possible or practical because of cost or time (ProModel, 2017). To convince management boards to invest in certain improvement suggestions, clear results from a simulation study can be of utmost importance.

Simulation offers an accurate depiction of reality. As already stated, compared to an analytical model, a simulation model can capture great detail providing increased accuracy. Events are tracked as they occur and all time-related data is gathered. With static analysis methods such as the queuing theory the data examination is limited and could assume that production orders move unconstrained while in fact e.g. an operator is required, yielding a very inaccurate capacity estimate. Static analyses such as spreadsheets are limited to providing quantitative results for one moment in time. Simulation can however replicate a dynamic business realistically. With simulation, running future orders through a company is possible quite easily, contrary to a stationary spreadsheet. One of the major perks for this particular analysis is the interdependence in businesses. When two or more events occur simultaneously, requiring one single resource, this creates competition between them and may cause delays further in the process, which are hard to account for by a spreadsheet. Simulation also shows bottlenecks that are caused by system interdependencies before implementing changes. Also money and time can be saved as a virtual experiment with a simulation model is far less expensive and time-consuming than experiments with real assets. Simulation also offers a safe method of testing and exploring different scenarios. Resources can be relocated or changed without interrupting the actual work so the right decisions can be made before making changes in the real world. Lastly, animating simulation models in 2D or 3D allows concepts and ideas to easily be verified and understood (ProModel, 2017).

The above statements give a clear insight into the background of simulation. For this project, the simulation has clear benefits: It results in hard-money savings, as it requires only a small capital expenditure. Proper labor assignments prevent unnecessary new hires and new building of facilities. Accurate and clear planning of the facility also eliminates rework costs. Another result is seen in soft-money savings: Productivity is increased due to facility rearrangement or reassignment of tasks, customer satisfaction is improved by reduced waiting times and valid decision-making information is ensured by an accurate depiction of the system. Furthermore, there are some intangible benefits. Employee education is improved by an increased understanding of the process that is actually taking place and teamwork and communication are improved by coordinated simulation projects (ProModel, 2017).

4.2. Simulation Study

According to Garrido (2009), a simulation study is built up of nine stages. To perform the analysis on the preprocessing department, these stages form the backbone of the process. The nine steps of a simulation study concern the following:

1. *Problem Statement*
   A simulation starts with stating the problem, it describes the purpose of building the model, the questions it helps to answer and the performance needed to answer these questions. This problem is stated in chapter 1.
2. *Data Collection*
   A simulation study requires four types of data: process data, technical data, product data and organizational data. In chapter 3, the data collection is elaborated upon.
3. *Conceptual model*
   The conceptual model is a description of the simulation model in a concise but understandable manner. The description includes a list of relevant components and their interactions and relationships. This model description is stated in appendix D.
4. *Design of the model*
   In this stage, the details of the data structures are stated as well as the details of the algorithms for the dynamic behavior of the model. The principles of the model are stated in chapter 5.
5. *Implementation of the model*
   This concerns the actual programming of the model in a suited software. The stage mainly consists of coding, debugging and testing the model. The suited type of software is chosen in this chapter, the model itself can be seen in section 5.1.
6. *Verification of the model*
   Verification of the model is important as it shows that the model is implemented correctly with respect to the conceptual model. It checks if the specifications of the model match the conceptual specifications and the assumptions are acceptable for the modelling purpose. The verification is done in section 5.1.3.
7. *Validation of the model*
   The output of the verified model are compared with outputs of the real scenario, so the model is compared to reality in this stage. The validation is performed in section 5.1.4.
8. *Design of experiments*
   In this stage the goal is to determine which factors and their levels have the greatest effects on the response. This can be seen in chapters 6 and 7.
9. *Analysis of the results*
   In the last stage, the results of the previous stage are analyzed and interpreted, so that they can be used for implementations in the real system. This also takes place in chapters 6 and 7.

In the next sections, the process of simulation is further described, stating different and relevant types of simulation.

4.3. Simulation Dynamics

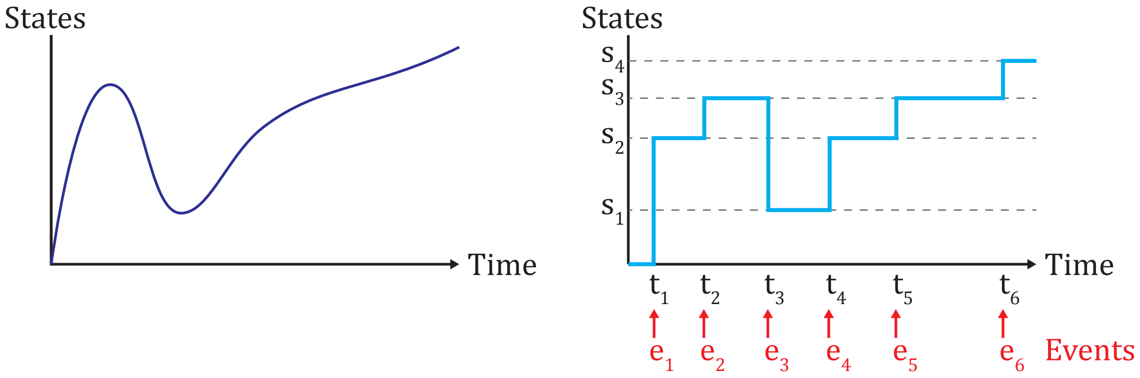
Simulations rely on a model of a real-world process to imitate time-dependent behavior. For modeling a system, two alternative simulation dynamics are distinguished: Continuous simulation and Discrete event simulation.

4.3.1. Continuous Simulation

In a continuous simulation a variable is observed in a continuous way, so the state variables change continuously over time such as the continuous function in figure 4.1a. Continuous simulations are often used to answer problems with wetlands or hydromodification. Examples of observed systems can be water quality over time or groundwater levels and its interaction with surface water (Kuch, 2014). It is typically used in such systems as variations are small over time. In these cases continuous simulation gives a well-detailed solution to the problem. The disadvantage however is that this well-detailed solution results in quite a long run time for the model and the amounts of data can be very large. The amount of data can be far bigger than what is needed from the solution, therefore a suited time step needs to be chosen.

4.3.2. Discrete Event Simulation

The discrete event approach models the process as a series of instantaneous occurrences, or *discrete events*. Inbetween these events, the system is approximated as fixed and not changing. The behavior of a dynamic system is analyzed by approximating it as a sequence of instantaneous occurrences (MathWorks, n.d.).



(a) Continuous

(b) Discrete

Figure 4.1: A continuous function (a) expressed with discrete event simulation (b)

The discrete event approach can be seen in figure 4.1. Figure 4.1a shows a continuous function, so the state space spans $\mathbb{R}$. In figure 4.1b this same function is expressed by six discrete events, it can be seen that the state space consists of $\{s_1, s_2, s_3, s_4\}$. Decreasing the time step would of course improve the accuracy of the discrete event approach, but increase the computing difficulty.

The process of manufacturing (parts of) a ship is very much suited for using discrete event simulation, as the nature of this process is event-driven. In this case, an event is for example a container being placed on the floor by a crane. Discrete event simulation is usually used to solve issues concerning scheduling, capacity planning and resource allocation (MathWorks, n.d.).

4.4. Programming Paradigms

A variety of programming paradigms (styles of programming languages) have been invented up until now. The paradigms are aspects that define the differences between these programming languages. Every paradigm uses its own concepts and characteristics to represent computer programs so for every programming objective (or for every user), there is one paradigm that is preferred over others, based on its distinctive features. In this section the appropriate paradigm is chosen from a variety of options to make a quantified analysis of the preprocessing of DSGa. There are two types of paradigms commonly used in programming, as seen in the following paragraphs.

4.4.1. Imperative Paradigms

An imperative paradigm is a paradigm that executes a computation by means of a state change of the programmed system, for example the state change at time t_5 in figure 4.1b. The two main forms of imperative programming are block-structured paradigms and object-oriented paradigms.

Block-structured Programming

A block-structured paradigm is an exemplar that features nested blocks, procedures and recursion. In this sense, a block is a piece of code where variables are localized. These local variables are used exclusively within this block. This phenomenon is beneficial as this localizes changes that might be made in the future. The block structure refers to nested blocks of code, so that procedures are nested within procedures. The state of the system is represented by a stack with a reference to the procedure block that is currently active on top of the stack (Paauwe, 2012).

Object-oriented Programming

An object-oriented paradigm is a paradigm of languages that make use of interacting objects. In this sense, an object is a group of procedures that share a state. Data is also part of a state, so data and all the procedures or functions that apply to the data can be captured as attributes of an object. Objects are independent of each other and can be as simple as an integer value, or as complex as an airplane (Paauwe, 2012).

4.4.2. Declarative Paradigms

Declarative languages are programming languages in which a program specifies a function or relation. The declarative paradigm makes no assignments to variables of programs. Contrary to imperative paradigms that focus on *how* a computer should solve a problem, the declarative paradigms focus mainly on *what* the computer should do. Therefore the declarative paradigms generally have a higher level of programming.

Logic Programming

Logic programming is a paradigm that is derived from predicate logic. It revolves around deduction as devised by Aristotle. One of its key features is its declarative semantics, that state that there is a simple method to determine the meaning of a statement and it does not depend on how this particular statement is used to solve a problem. Logic programming is often used in rapid prototyping and exploratory programming (Paauwe, 2012).

Functional Programming

Functional programming relies on mathematical functions. It relies on functions returning a single value based on a list of parameters. A program is a function call where parameters call other functions to generate the used parameter values. Functions themselves are values that can be passed on to other functions, so functional programming is used for programs that modify themselves, such as in the phenomenon of 'Machine Learning' (Paauwe, 2012).

4.5. Used Method

As stated in section 4.3, the manufacturing process is an event-driven process, with the events called by the moving or processing of objects such as steel parts or containers. As a result of this, a discrete event, object-oriented simulation package is very much suited and therefore the logical choice. Based also on a preference of Damen, the discrete-event, object-oriented program *Siemens Plant Simulation* is used with the additional toolkit *Simulation Toolkit Shipbuilding*, to make a quantitative analysis of the parts preprocessing department at DSGa.

4.5.1. Siemens Plant Simulation

Siemens Plant Simulation is a package established as part of the Siemens PLM Software, to show the characteristics of production systems and processes and to optimize them. It is a discrete-event package that shows throughput statistics, dependencies between objects and orders and is often used to run experiments and improvement scenarios without interfering with an existing production system. It helps to make reliable decisions in early stages of planning. Due to the availability of the software and extensive documentation of it, this is a very suited package to be used for this project.

4.5.2. Simulation Toolkit Shipbuilding

The *Simulation Toolkit Shipbuilding* (STS) is a toolkit that can be added to existing simulation packages such as Siemens Plant Simulation. It was established by a team of Flensburger Shipyard to support decisions in the production planning because it was found that existing simulation tools were not sufficient to be used in shipbuilding. Therefore, STS was developed to be especially suited for the process of shipbuilding at Flensburger Shipyard. To be suited for other shipyards with other specifications as well, this package is constantly under development, currently by the German company SimPlan. To visualize the shipbuilding process and show accurate behavior of shipbuilding-related equipment, STS is a very suited method.

4.6. Conclusion

What method is used to analyze the performance of the preprocessing department?
In the previous chapter it was determined that it could be possible to elevate the output of preprocessing section 1A. This was determined by a static analysis that does not incorporate interdependencies between equipment or any dynamics.

To incorporate these interdependencies and dynamics a simulation study is performed. A discrete-event, object-oriented method is chosen to model the preprocessing department in section 1A of Damen Shipyards Galati. This is done using the software package *Siemens Plant Simulation* with the additional toolkit *Simulation Toolkit Shipbuilding*.

5

Setup of the Preprocessing Model

What are the specifications of the preprocessing department at DSGa in the current situation?

This chapter shows the current setup of the preprocessing facility of DSGa and gives a brief insight of the issues already present.

5.1. Model of the Current Situation

The layout of DSGa can be seen in appendix A. Descriptions of the preprocessing department can be seen in appendices C and D. Using the software package Tecnomatix Plant Simulation by Siemens with the additional library of the Simulation Toolkit Shipbuilding by Simplan, a discrete-event, object-oriented simulation model is constructed. Figure 5.1 shows an overview of the model of the current situation of section 1A, with the same structure as seen in figures A.3 and F.1 and the procedures as stated in appendix D.

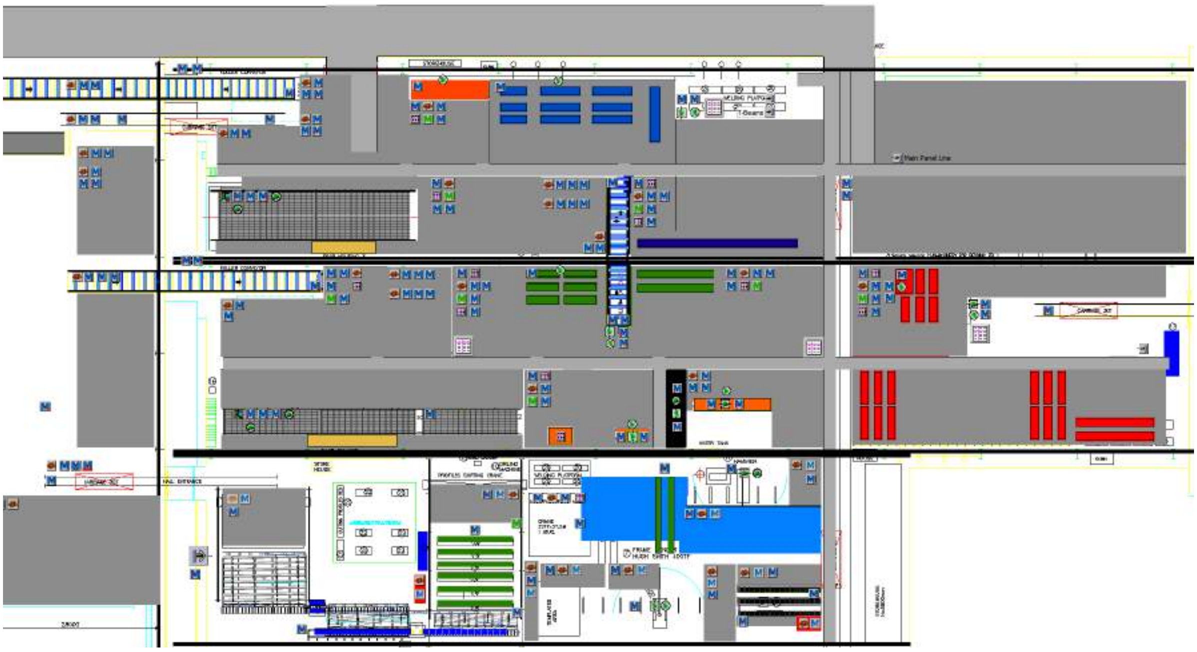


Figure 5.1: Model of the current situation of preprocessing section 1A

A few assumptions were made to be able to build this model. As no information is present about which cutting group is cut at which cutting machine, these cutting groups are allocated randomly at the two cutting machines. The same is the case for the allocation of sections (batches) to the foremen. These batches were allocated randomly at the three foremen in section 1A.

5.1.1. Methodology of the model

To give an insight into the procedures taking place within the model of the preprocessing department of section 1A, the methodologies of programming are shown in this section. As seen in section 3.1, there is a variety of routes a part can take through the preprocessing department, based on the operations it requires. This leads to ten different operations' scenarios, as seen in figure 5.2. At the preprocessing department of DSGa, formed parts are separated from the other parts directly after cutting, this is also seen in the figure.

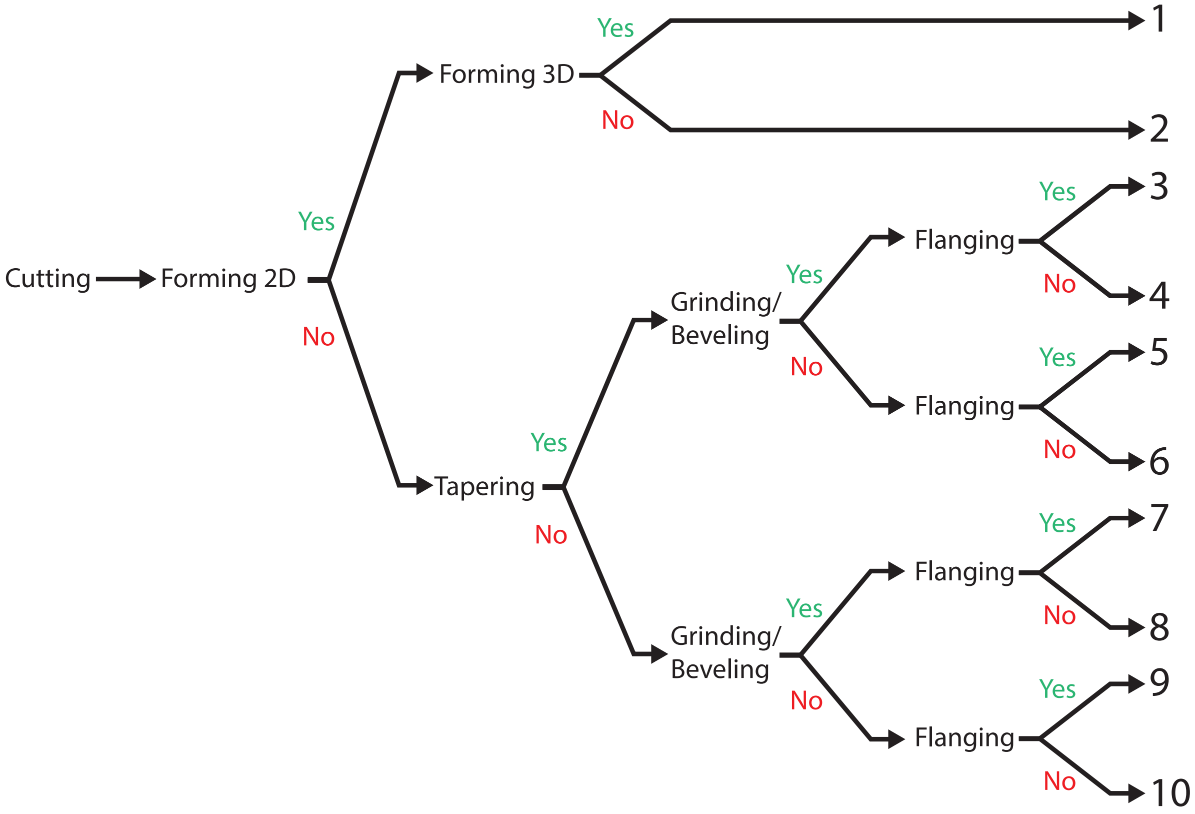


Figure 5.2: The combinations of operations that can occur to any part in preprocessing

These ten operations' scenarios, with their frequency of occurring for an ASD2913 and PSV3300 are stated in table 5.1. These percentages are derived from the product data stated in appendix G. It is seen that the combination of tapering and flanging does not occur for the observed ship types. From the Damen Yard Support Department it is learned that this combination per definition never occurs.

Table 5.1: Operations' scenarios with percentages of parts of the ASD2913 and PSV3300

Operations' scenario		Parts ASD2913	Parts PSV3300
1.	Forming 2D + Forming 3D	2.5%	0.2%
2.	Forming 2D	1.9%	0.7%
3.	Tapering + Grinding/Beveling + Flanging	0.0%	0.0%
4.	Tapering + Grinding/Beveling	0.4%	0.0%
5.	Tapering + Flanging	0.0%	0.0%
6.	Tapering	0.1%	0.0%
7.	Grinding/Beveling + Flanging	4.7%	3.2%
8.	Grinding/Beveling	75.6%	91.3%
9.	Flanging	1.3%	0.0%
10.	No operations	13.4%	4.5%

The next paragraphs give an overview of the procedures taking place at the various stations in the preprocessing model.

Infeed and Cutting of Plates

The numbers in these paragraphs correspond to the numbers in figure 5.3.
At the plate storage (1), plates are stacked per cutting group, per plate thickness. When such a stack appears at the storage, it is checked at which cutting station this cutting group is allocated.

If the cutting group is cut in lane 2 and the infeed conveyor in lane 2 (2) is available, plates from the cutting group with equal thickness are stacked onto the conveyor, up to its maximum capacity. When this stack is complete, the stack rolls inside and triggers the 'exit control method' of the conveyor. This exit control method investigates which of three cutting beds (3) is available if any, and requests the overhead crane to place the top plate of the stack onto this cutting bed. When the plate is placed on the cutting bed, the cutting portal is requested. A potential changeover of ten minutes is executed if the plate thickness is unequal to that of the previous plate. After this the plate is cut according to the available nesting information.

If the cutting group is cut in lane 3 and the infeed conveyor in lane 3 (4) is available, plates from the cutting group with equal thickness are stacked onto the conveyor, with a height of maximum two plates. This latter condition is used not to keep this conveyor occupied with a large stack of plates, as this conveyor is also used for another route. When the stack of two plates is complete, the stack rolls inside and the exit control investigates which of the cutting beds (5) is available. The overhead crane is requested to place the plate onto the cutting bed after which the cutting portal is requested. A potential changeover of ten minutes is executed if the plate thickness is unequal to that of the previous plate. After this the plate is cut according to the available nesting information.

Plates with a thickness bigger than 20mm are not cut in section 1A but on an oxy-fuel machine in section 1. For these plates, as well as complete cutting groups cut in section 1, the infeed conveyor of lane 3 is used as well. In these cases, the plates are stacked onto the conveyor up to its maximum capacity and the stack rolls inside. The exit control stacks the plates onto a section rack and a section transporter is requested to bring the plates to section 1.

Figure 5.3: Plate storage and cutting department of the model of section 1A

Sorting After Cutting

The numbers in this paragraph correspond to the numbers in figure 5.4.
After cutting, the cut parts are sorted per section into seven divisions. Main panel plates are stacked on a stack on the packing space (1). When all plates of the cutting group are cut, these plates are brought to the main panel line, east in lane 3. Plates in lane 3 are transported directly by crane, plates in lane 2 are first brought to

lane 3 on the transverse conveyor (4*). From here the plates are transported by crane.

Parts that are processed at one of the parts processing areas are placed per section in containers or boxes on the sorting space (2). When the box or container is full, and the parts processing area is waiting for this section, the container is transported there. If the parts processing area is busy processing another section, the containers are stacked on the sorting space, with a maximum height of three containers. When the container is placed on the stack, a check is performed again if the container is demanded at one of the parts processing areas (the parts processing crew might finish the previous batch while this container is hanging in the crane). If not, the containers remain on this stack until the section is indeed requested by the appropriate parts processing area.

To-be-formed parts are stacked on a stack on the packing space (3). When all plates of the cutting group are cut, these plates are transported to the forming area in lane 2. Parts that are cut in lane 2 are transported directly by crane, one by one. Parts that are cut in lane 3 are first brought to lane 2 on the transverse conveyor (4*) and then transported to the forming area by crane.

To-be-tapered parts are transported directly from the cutting bed to the tapering area in lane 3 (4). Parts that are cut in lane 2 are first brought to lane 3 on the transverse conveyor (4*), after which they are picked up by a crane and transported to the tapering area.

Scrap is deposited in one of the scrap containers (5), these are emptied twice a week.

Leftover plates are brought back outside to be placed back in the storage. In lane 2, these plates are placed on the infeed conveyor to bring them back outside again. In lane 3, these plates are placed on the outfeed carriage, driving them outside.

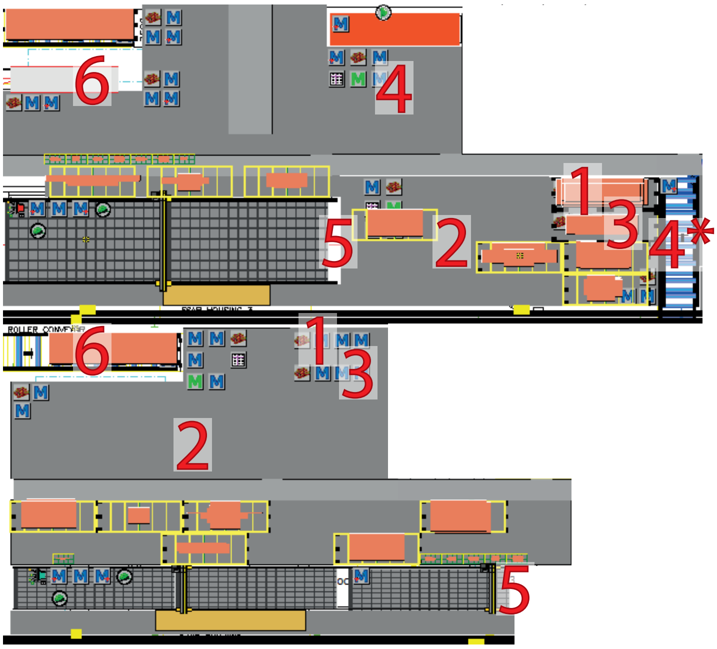


Figure 5.4: Sorting area in the model of section 1A

Tapering Area

The numbers in this paragraph correspond to the numbers in figure 5.5.

At the tapering area, parts arrive one by one. When the plate is discharged from the crane that brought it, the entry control method of the space (1) checks whether the section the part belongs to, is currently processed at one of the parts processing areas. If this is the case, one of the employees of that parts processing area has the skill to perform the tapering action. The part is brought onto the tapering table (2) and the time it takes to perform the tapering operation is computed. The employee of the parts processing area is requested to perform this operation for all parts of this section. When the operation is finished, an overhead crane is requested to pack the part(s) onto a container as seen in figure 5.5. When all to-be-tapered parts of the section are tapered, the container is checked out and transported to the appropriate parts processing area.

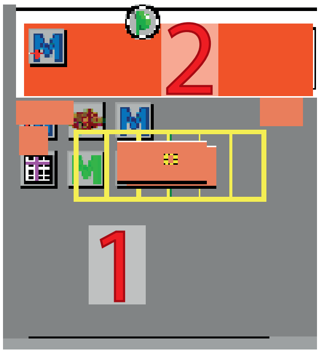


Figure 5.5: Tapering area in the model of section 1A

Forming Area

The numbers in this paragraph correspond to the numbers in figure 5.6.

As stated earlier, parts arrive at the forming area one by one. These parts are stacked on the floor of the forming area (1). When the plate roller is available, the top plate of the stack is picked up by the overhead crane and placed on the plate roller (2). During the setup time, the crane hook stays attached to the part. On the plate roller the part is formed into a 2D-shape. Three employees are requested to perform this operation. After this operation, the part is either placed back on the floor if a 3D curve is also required, or packed on a container if this is not required.

If the part is placed at the floor after the 2D-shape is obtained at the plate roller, it waits here until the line heating platform (3) is available. The crane requested again to place the part onto the line heating platform, where a 3D-curve is realized by two employees. After forming, the part is packed onto a container.

As these are formed parts, they are not stacked easily. Therefore the following conditions are applied:

- Formed parts are packed per section
- 2D-formed and 3D-formed items are not mixed
- Maximum five formed parts are packed together.

All formed parts are destined to go to section building, so when either a container is full (five parts) or all parts of a section are formed, the container is picked up and brought to the section building hall.

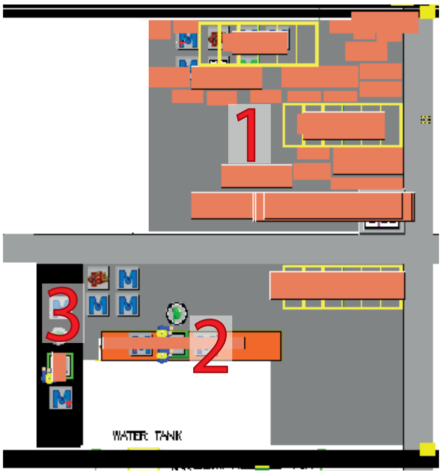


Figure 5.6: Forming area in the model of Section 1A

Parts Processing Areas

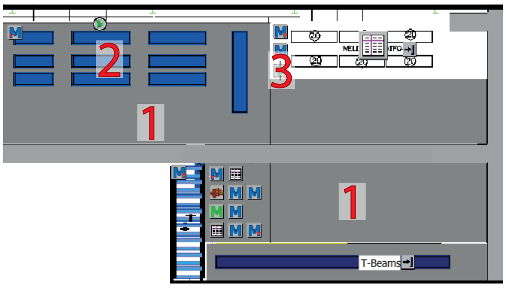
The numbers in this paragraph correspond to the numbers in figures 5.7a through 5.7c.

The three parts processing areas are similar facilities, so these are addressed together.

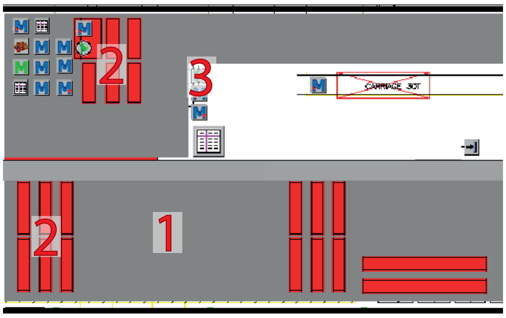
At each of the parts processing areas, parts arrive from either one of two packing spaces, or from the tapering area. Once the container is placed on the floor (1), it is unpacked. If the part does not need to be ground, it is placed on the floor. A part that needs to be ground is placed on a grinding table (2) if its mass is bigger than 10 kg or on a stand belt grinder (3) otherwise. After grinding, it is checked whether the part needs flanging and if so, it is packed on a europallet if the part is smaller than this pallet. If it is bigger, the part is transported to the flanging area directly. If the europallet is packed with all small parts that need to be flanged, it is transported to the flanging area by a forklift. The parts are flanged at the flanging area and return back to the parts processing area. All parts are then sorted per end buffer and packed in containers. When all parts are packed, the containers are transported to their end buffers.

In reality, the parts processing areas are also used to assemble sub-panels and T-beams. In this model however, these processes are not included. The parts are packed in containers (parts for the same subpanel/T-beam are packed together) and this container is transported to the end bufer.

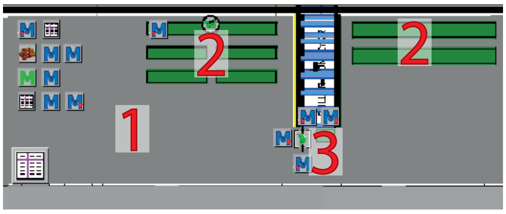
After the batch is processed, the planning of the foreman shows which section is due to be processed next and a method is called to fetch this section. First it is examined whether the containers of this section are placed on the sorting space in lane 3 and if so, all containers of that section are transported to the parts processing area. If not, it is examined whether the containers of the section are on the sorting space of lane 2 and if so, they are transported to the parts processing area. If the containers are not there either, the parts of the section are apparently not cut yet. This latter option however does never occur as the sorting spaces of lanes 2 and 3 are emptied alternately.



(a) Foreman Area 1



(b) Foreman Area 2



(c) Foreman Area 3

Figure 5.7: Three parts processing areas

Flanging Area

The numbers in this paragraph correspond to the numbers in figure 5.8.

At the flanging area, small parts arrive on a europallet by forklift and big parts arrive one-by-one. Once a europallet is placed it is unpacked. All to-be-flanged parts are brought onto the press brake (2). In one or more repetitions, the part is flanged. After flanging the part is packed on the same europallet it came from if it is smaller than this pallet, or stacked on the floor (1) otherwise. Once all to-be-flanged parts of a section are flanged, the europallet is brought back to the parts processing area it came from by forklift and the stacked parts are brought back to the parts processing area by crane and/or transverse carriage.

Figure 5.8: Flanging area in the model of Section 1A

5.1.2. Uncertainty

With the building of a model like this, a substantial uncertainty is introduced, as any model is a simplification of reality and there is no model in the world that is a 100% match to the real-world situation. For the model-building, four types of uncertainties are defined (van 't Klooster, 2018):

- **Theory uncertainty**
  The first type of uncertainty is a theoretical uncertainty. To construct the model, a process description is written that describes the processes taking place at the preprocessing department. This document is checked extensively by the Yard Support Team of Damen. It however seems that there are always uncertainties in a description that follows strict rules. Employees may want to smoke now and then, if it is cold outside processes are handled in a different way than when it is sunny and things may change when an employee is ill. It is stated that the process description regards the major flows and that very rare exceptions are excluded. In this way, it is possible to construct a model according to the process description.

- **Model uncertainty**
  For the simulation, the model relies on the software as provided by Siemens and SimPlan. It is found that the Simulation Toolkit Shipbuilding was originally developed for one particular shipyard. To broaden the possibilities of the software it is still constantly under development and not every desired option is possible yet. To overcome these struggles, some situations are modelled in a slightly different way. An example of this is the cutting machine in lane 2 of section 1A, where two portals serve the plates on three cutting beds. In the software, it is not possible to have two portals assigned to one cutting bed. In this situation therefore, a simplification is made where one portal serves two of the cutting beds and the other portal serves the third.

- **Parametric uncertainty**
  To find the behavior of the preprocessing department, input data such as sorting time and crane speed is required. As the capacity of collecting these data is limited, values are provided by the Yard Support team. In many cases however, these are average values. An example of this is the sorting time of a small part. The model states that every manual sorting action takes 30 seconds, while in reality this depends on much more. This therefore is related to the theory uncertainty. As the process description regards the major flows and Quick Response Manufacturing is a theory that depends on average values, it is determined that these average values sufficient in this stage of the simulation process.

- **Measurement uncertainty**
  Times are measured in the model to compare its behavior to the real-world situation. It is assumed that the measurement of times in the model is right, so that uncertainty is small. Measurements in the real-world situation to compare them with are often done by stopwatch so this may cause some uncertainties. As stated in the paragraph of the parametric uncertainty, it is assumed that by lack of better values, the average values suffice. For this analysis it is assumed that the measurements carried out in the real-world situation are also done correctly.

5.1.3. Verification of the Model

Verification of the model is defined as *"The process of evaluating software to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase"* (Sharma, 2017). This is a static practice to verify whether the model behaves in the way the specifications say it should. The verification is performed with an inspection of the model using the verification checklist in appendix J and a walkthrough of the model with experts about the preprocessing at DSGa. To verify whether the model behaves as it should, five verification methods are used:

Visual Inspection
For some simple situations a visual inspection suffices, to check whether for example never more than two stacks of plates are present on one infeed conveyor system simultaneously.

Cumulative Plate Number Test
To check whether stacks in e.g. the raw material storage are stacks of cutting groups, stacked on order of thickness, the numbers of plates on each stack is monitored. With a sample test it is found out that the stacks are indeed stacked per thickness and that they belong to the appropriate cutting group. The same procedure is used to check whether parts are correctly stacked per section at the cutting and forming departments.

Track and Trace
Using a track-and-trace method, parts are followed throughout the several processes. It is verified whether the parts indeed follow the routes they are supposed to.

New Call Chain Analysis
A new call chain is the subsequent calling of multiple methods that trigger each other. A new call chain is analyzed by inserting break points in these methods at appropriate locations to check whether these methods are indeed called by the right method at the right time with the right statements.

Timing of Processes
To verify whether certain steps of the preprocessing indeed take as long as they should, break points are added to the source code right before and after the execution of the work step. With this information, it is checked that the processes indeed take as much time as they should.

5.1.4. Validation of the Model

Validation is defined as *"The process of evaluating software during or at the end of the development process to determine whether it satisfies specified requirements"* (Sharma, 2017). Validation is a dynamic procedure to check whether the model behaves according to the expectations and requirements by the client. The validation is performed using the process data files in appendices C and D. These files are checked by the Damen Yard Support team in the Netherlands as well as employees of DSGa.

Furthermore, a validation is executed to check whether the time the processes take in the preprocessing are in the same order as stated by the actual figures.

As stated in section 3.3, the portfolio for one year consists of eleven ASD 2913 tugboats and six PSV's 3300, processed in section 1 and 1A together.
The organizational data in appendix F show that in Section 1, 71 employees are active for cutting plates and preprocessing. In section 1A, these are in total 126, for not only cutting plates and processing them, but also for cutting and processing profiles. The crew headed by Poalelungi is responsible for this latter task, as well as for the plate forming station. From the 31 people in this crew, ten are responsible for the plate forming and

21 for the profile processing part. Therefore it is stated that in section 1A, 106 employees are available for the plate processing operations, a little over 1.5 times as much as in section 1. From this figure, it is estimated that the division of the workload is also around 40% for section 1 and 60% for section 1A.

This yields an annual delivery of around 2.4 PSV's and 4.4 tugboats in section 1, versus 3.6 PSV's and 6.6 tugboats in section 1A. The masses of parts of these two ship types are stated in table 3.4, so this yields an annual throughput of about 3600 tons for section 1 and a throughput of 5400 tons for section 1A.

The simulation yields a yearly throughput of 5482 tons as seen in figure 5.9. It is assumed that this value is in the right order of magnitude to resemble the current preprocessing situation. During this period, 271 sections were completed.

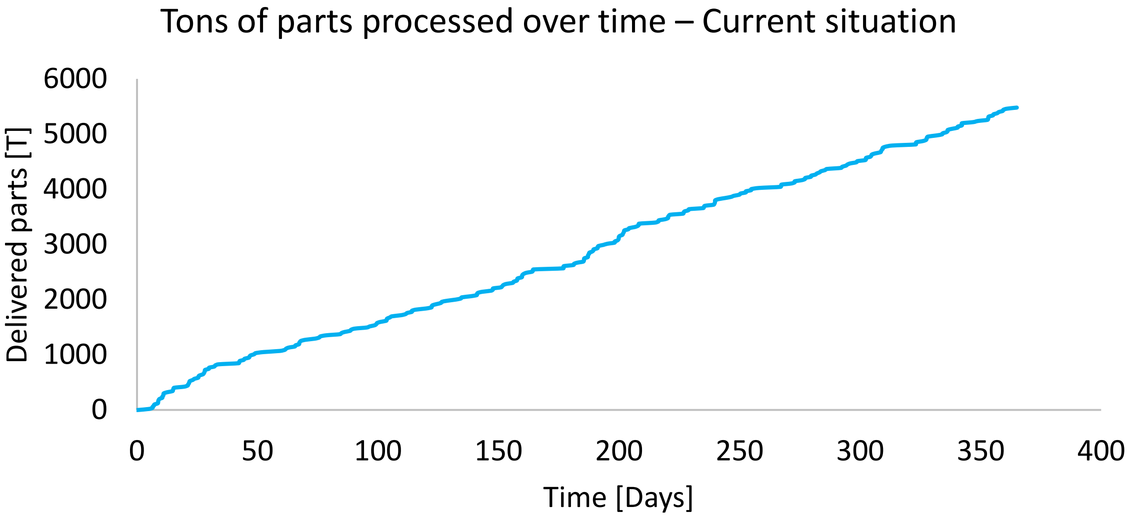


Figure 5.9: Deliveries of tons of parts over the year in the preprocessing department

5.2. Key figures of the Current Situation

The distribution of sections over the foremen was not available. At DSGa, this distribution is made by the production manager of the relevant preprocessing hall. This schedule is written on a chalkboard within the hall and is not documented well. Therefore for the model this distribution is made randomly multiple times. In this section the key figures of the preprocessing are computed. As stated in chapter 2, Quick Response Manufacturing is all about time, so important factors are the flow time and the MCT.

As stated in chapter 2, the definition of the MCT is "a representative amount of calendar time from the moment a customer creates an order, through the critical path until the first (partial) delivery of that order to the customer". Suri (2011) uses calendar time as calendar time is what the customer experiences, instead of the working hours of the company. To improve the process at the preprocessing however, this calendar time is not the most useful. As seen in appendix B, the working routine of DSGa is 16 hours per day for five days per week. The lead times can be influenced massively in the potential situation that a batch is only one hour from finished when the employees stop working on Friday night. In this case, the batch is finished on Monday morning, adding two days to the lead time of the batch. This might lead to inaccurate improvement situations. Furthermore, the customers of the preprocessing department are internal clients and these particular clients also work at the same shift times. Time is basically at a standstill during the weekends and nights. Therefore it is decided not to use calendar time to quantify improvements, but use working times instead. The MCT in working hours is denoted as MCT*.

In sections 5.2.2 and 5.2.3 the flow time and MCT* of the current situation of the preprocessing department, are computed, respectively.

5.2.1. Total Time in the System

To validate the MCT*, first simply the time is computed that every part spends in the preprocessing. Figure 5.10 shows the time parts spend in the preprocessing department, in bins of 20 hours. This shows that the most parts spend around 160 hours in preprocessing. Figure 5.11 shows the cumulative function of the time the parts spend in preprocessing, from this figure the median of times of all parts is extracted with the green line. This shows that the median lies at 145 hours. When taking the average of the times of all parts in preprocessing, a value of 147 hours is found. It is expected that the MCT* is in the same order of magnitude.

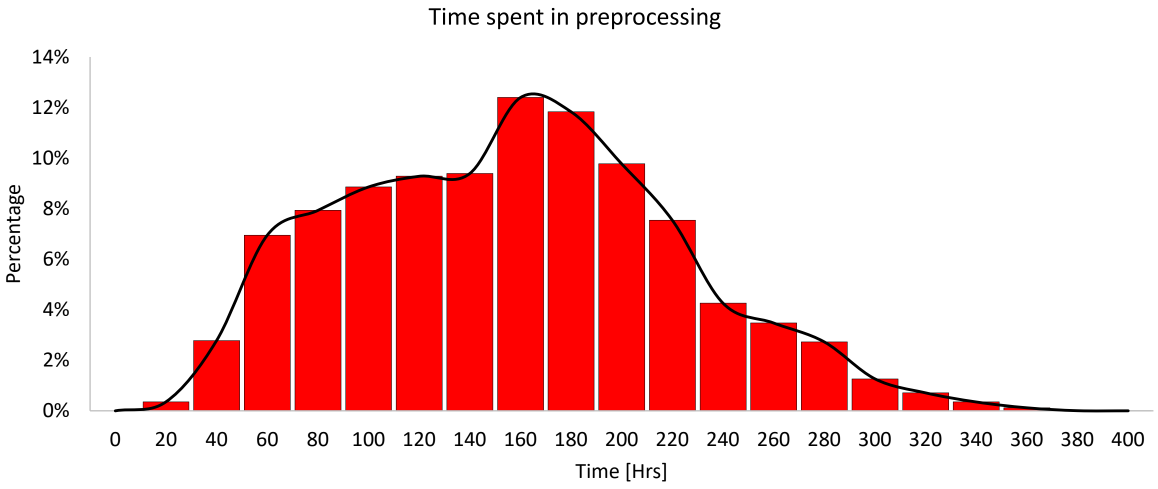


Figure 5.10: Time spent by parts in preprocessing, in bins of 20 hours.

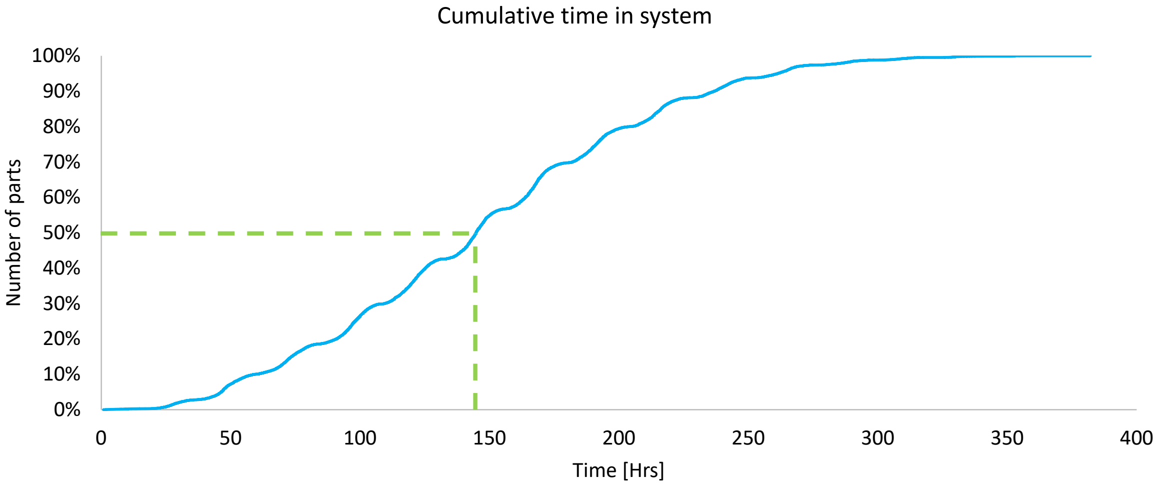


Figure 5.11: Cumulative time spent in preprocessing

5.2.2. Flow Time

As stated in section 2.3, the flow time of the system is a function of the average variability, the magnifying effect of utilization and the order time of the batches passing through this system. These batches are in this case defined as the sections that the preprocessing department works on.

The **average variability** (AV) is computed in equation 2.4 as a function of the variability of arrivals (V_A) and the variability of throughput (V_T). The first of these two is computed in equation 5.1.

$$V_A = \frac{S_A}{T_A} \tag{5.1}$$

In this equation, T_A is the average time between arrivals. In the case of the preprocessing model, this is defined as the average of the inter-arrival times: the time between the moment a section arrives to be processed at a parts processing area, until the moment the next section arrives at this area. For reference, the inter-arrival times can be found in appendix K. Based on these times, T_A is found to be equal to 45 hours and 20 minutes.

S_A is the standard deviation of these inter-arrival times. S_A has a value of 39 hours.
With S_A and T_A known, V_A is found to be equal to 0.86.

The variability of throughput V_T is obtained using equation 5.2.

$$V_T = \frac{S_O}{T_O} \tag{5.2}$$

T_O is the order time, also denoted as OT in chapter 2. This defined as the average of job times: the time between the moment a section arrives to be processed at a parts processing area, until the moment this section is finished. For reference, the job times can also be found in appendix K. Based on these times, T_O is equal to 38 hours.

S_O is the standard deviation of the job times, for the current situation of the preprocessing department this has a value of 34 and a half hour as derived in appendix K. With S_O and T_O known, V_T is computed with equation 5.2 and is equal to 0.91.

With the values for the variability of arrivals and the variability of throughput, the average variability is computed with equation 2.4 and is found to be:

$$AV = \frac{{V_A}^2 + {V_T}^2}{2} = \frac{0.86^2 + 0.91^2}{2} = 0.78$$

The **magnifying effect of utilization** (M) was already seen in chapter 2 and equation 2.2. According to Suri (2011), all the time that a processing area is occupied by a section and therefore cannot start working at an other (unexpected) batch, is counted in the utilization. Therefore the utilization of the parts processing areas is computed by taking the ratio of the sum of all job times on a parts processing area in a year and the total time in the same year. The combined utilization for the parts processing areas is therefore found to be equal to 80% as stated in appendix K, yielding a value for M of:

$$M = \frac{u}{1-u} = \frac{0.80}{1-0.80} = 3.9$$

The third input for the flow time is the **order time** (T_O). It was already seen that T_O has a value of 38 hours. With the three input values known, the flow time of the system can be with equation 2.6. It is seen that the flow time is equal to:

$$Flow\ Time = (AV * M * T_O) + T_O = (0.78 * 3.9 * 38) + 38 = 153\ hours$$

It is found that the flow time for a batch of cut parts in the preprocessing model has a value of 153 hours or almost ten working days, while the touch time for the average batch is only around four hours.

5.2.3. MCT*

As already seen in section 5.1.1, the ten operations' scenarios are:

1. Forming 2D + Forming 3D
2. Forming 2D
3. Tapering + Grinding/Beveling + Flanging
4. Tapering + Grinding/Beveling
5. Tapering + Flanging
6. Tapering
7. Grinding/Beveling + Flanging
8. Grinding/Beveling
9. Flanging
10. No operations

To calculate the MCT*, one sub-scenario is added. The main panels do fall within the ten scenarios but are separated from the process as stated in section 5.1.1 and appendix D. To prevent inaccurate results, the main panels are therefore separated. Furthermore, it was already stated that one part is never both tapered and flanged. Therefore, scenarios 3 and 5 are excluded.

Figure 5.12 shows the representative times spent in the preprocessing department, for each of these operations' scenarios. The largest value of these times, is the MCT*. It is seen that scenarios 4, 6, 7, 8, 9 and 10 all have similar values. This is due to the fact that after grinding, the parts that are flanged go to the press brake to be flanged and return to be reunited with the other parts. The other parts simply keep waiting in the parts processing area because they are exported to their end buffers together with the flanged parts. The MCT* for the preprocessing department at DSGa is equal to 157 hours, as indicated by the blue dashed line in figure 5.12. This value is very close to the average time in the system that was found in section 5.2.1. This has to do with the fact that the majority of the parts travel along operations' scenarios 4, 6, 7, 8, 9 or 10, that are all dependent on each other.

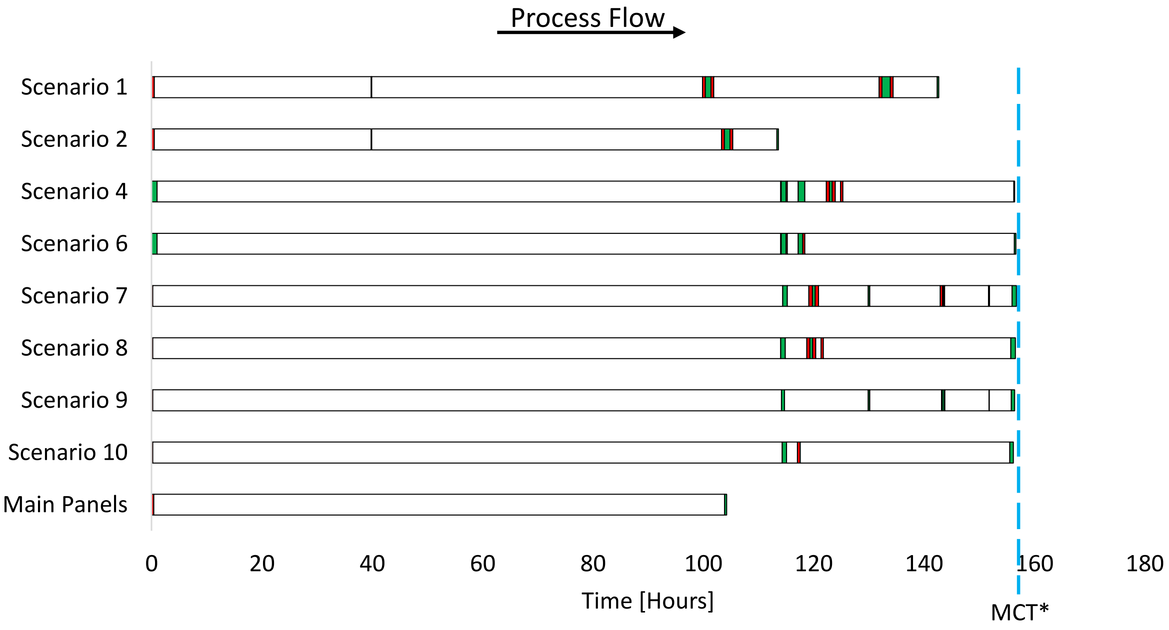


Figure 5.12: Determination of the MCT* of the current preprocessing department of section 1A.

It is seen that per scenario, there are quite a lot of small increments making up the touch time together. An explanation of these increments (which piece of touch time is which process) can be found in appendix L. From this figure, it is determined that scenario 7 is the critical path. It is due to the fact that the to-be-flanged parts are transported to the press brake together, leaving all other parts waiting at the parts processing area.

If this step could be eliminated by bringing the press brake to the parts and perform the flanging operation directly after grinding, instead of bringing the parts to the press brake in a batch, this will probably shorten the MCT*. Another option is changing the route of the flanged parts. If the flanged parts are separated from the other parts directly after cutting and brought to the press brake directly from the sorting space, flanged and brought to the parts processing area as soon as the section is being worked on at this parts processing area, they can then be ground and packed for their end buffers directly. The behavior of these parts will then resemble the situation in operations' scenarios 4 and 6, where in the current situation the to-be-tapered parts are brought to the tapering station directly after cutting and stay here waiting until the section they belong to is processed by one of the parts processing areas.

If this change indeed makes the process faster, the MCT* will probably be determined by scenario 1, as this is only marginally shorter than the other processes. The fact that scenario 1 (2D forming + 3D forming) is a lot slower than scenario 2 (only 2D forming), probably has to do with the fact that the current method of 3D forming (line heating) is a very slow process, leading to a lot of waiting times. If this could be changed, for example by using the roller press that is currently located in section 1, this process could already be accelerated.

5.3. Conclusion

What are the specifications of the preprocessing department at DSGa in the current situation?

To make a quantified analysis of the preprocessing at DSGa a discrete-event, object-oriented simulation model is constructed. This model is verified and validated according to the procedures described by Sharma (2017). Using this model, it is found that in section 1A, a yearly throughput is achieved of 5482 tons of parts and that the critical path is followed by parts that are ground and flanged. This critical path leads to an MCT* of 157 hours.

6

Cellular Structure

What are the specifications of the preprocessing department in the proposed situation?

In this chapter a cellular structure is introduced for the preprocessing department in section 1A, as prescribed by Suri (2011) and explained in section 2.2 of this report.
QRM, in a lot of cases, is contrary to traditional beliefs. This may cause some doubts about the theory in all sections of the organization. Therefore it is useful to prove the concept using some projects with low costs or cheap investments. This can be a Q-ROC for a section of the office operations, a small cell on the shop floor that does not demand new machines or costly repositioning of machines, or a numerical model simulating the behavior of the process. When these small projects yield the first results regarding MCT-reduction as well as enthusiasm, this may overcome these doubts and make people convinced to start projects that do need investments. (Suri, 2011)

First, the methodology is described and some qualitative pain points are described. The improvement suggestions are based on these pain points. The layout proposition is also partially based on this.

6.1. Methodology

Suri (2011) challenges anyone who aims to implement QRM to think outside the box when creating QRM-cells, possibly experiencing some resistance from cost-based visions. His methodology of implementing the cellular structure is defined in the following way:

- Rethink everything with the goal of minimizing MCT.
    - Create an initial list of pain points leading to wastes due to a long MCT.
    - Give rough initial measurements of the MCT of some important products, particularly waiting times.
- Rethink the sequence in which operations are performed.
- Exploit cross-training to eliminate steps.
- Find a smaller-scale process implementation.
- Question the need for the operation.
- If the operation can't be brought into the cell, use time-slicing at the shared resource.
- Use a combination of strategies for maximum effect.
- If no workable strategy can be found, consider splitting the cell in two.

6.2. Pain Points

The first step in determining improvement suggestions, is creating a list of pain points leading to a long MCT. These pain points are further explained in appendix M.

6.2.1. Experienced Pain Points

As QRM is not a top-down management philosophy but for a major part based on team-ownership, it is important to find out what issues are experienced by the employees on the spot as these are the people who are practically on top of the problem. A study on this was performed by Buwalda (2017). Buwalda found that the local employees experienced quite a number of issues, such as:

- In each preprocessing hall, only one press brake is present for flanging. This causes a lot of queues and waiting times. On this one press brake, the parts are handled per section, not per process. Big parts and small parts continuously succeed each other.
- At the press brake machine, the employee sometimes cannot handle the big supply of parts. Parts from three foremen arrive simultaneously, it can be hard to keep it all apart.
- The operator of the press brake does not receive information for the flanging on the part. He has to check what needs to be done based on drawing and write it on the parts.
- The operator of the forming station makes own molds based on drawings. This should not be the case, a list with dimensions is sufficient to pick the correct template from the stack and form the part.
- Information for grinding is not printed onto the parts. The edges to be ground are checked from a drawing and chalked onto the material by the foreman.
- A forklift is present, but it is hardly ever used.
- No specific order for processing a pallet is dictated to the foremen, therefore they just do what they want. Usually there is no target and orders are random. The foremen follow their own strategy. Here it can be seen that the performance is in accordance with CMMI level 1, as stated on page 5.
- Plannings are usually not accurate and do not conform to reality. The foremen experience that too many projects are active simultaneously.
- Often profiles from the profile line do not arrive in time, causing waiting times and an accumulation of parts in the workshop.

It is seen that Buwalda (2017) states multiple issues about the capacity of the press brake. Also a very flexible and valuable mean of transportation is hardly ever used. Foremen need to do a lot of research themselves on section drawings, which could also be dictated by job processing.

6.2.2. Analyzed Pain Points

With the initial situation a qualitative analysis can already be done yielding a number of pain points, partially coinciding with the experienced pain points.

- Virtually all inter-lane transports are executed by the fixed-rail carriage, each time demanding three operations:
    - Bringing an item onto the carriage by crane in the first lane,
    - Driving the carriage to the second lane,
    - Unloading an item from the carriage in the second lane and bringing it to its destination.
- Virtually every section includes to-be-flanged parts. These parts all have to be transported to the flanging station and return back to the parts processing area after flanging.
- All to-be-formed parts are stacked at the sorting space after cutting, until the entire cutting group is finished. After this, the plates are transported to the forming area one by one.
- At the forming area, the 3D Line heating station lacks capacity, as this is quite a slow process. The line heating station is a bottleneck in the forming process.
- All mainpanels are stacked at the sorting space after cutting, until the entire cutting group is finished. After this, the plates are transported to the other end of the hall in lane 3.
- Materials are handled in very big batches:
    - At the cutting department and the forming department, the batch size is one cutting group (4-7 sections),
    - At all other departments, the batch size is one section.
    - A section can consist of up to 1000 separate parts.
- Within these batches, a substantial variability is present between the parts, concerning market, scantlings and operations.
- The three parts processing areas all have similar crews, they are not specialized for certain types of operations.
- At the parts processing areas, arriving containers are unpacked onto the floor.

6.3. Starting Point

Currently the preprocessing in Section 1 handles aluminium as well as steel. One of the consequences is that when these two metals touch, galvanic corrosion occurs. Galvanic corrosion occurs when two different metals, with different potentials, connect in the presence of an electrolyte. This electrolyte can just be condensation or moist present in the air. When the two metals connect, the metal with the lower potential will act as an anode and will corrode, while the metal with the higher potential stays intact. This phenomenon is often used to protect a ship's hull from corroding by placing a sacrificial anode.

In a preprocessing hall however, tiny bits of steel flying around from a cutting or grinding station, touching an aluminium plate is enough for the aluminium to start corroding. Therefore the employees are constantly busy protecting the sheets of aluminium with plastic covers. As the shipyard is planning on increasing its aluminium throughput (Brugge, 2017), the desire is to physically separate the processes of steel and aluminium handling. The desire is to shift all steel processing to S1A, while keeping the aluminium processing in S1.

This immediately is contrary to one of the boundary conditions. The oxy-fuel cutting machine in S1 is the only machine capable of cutting thick steel plates. The boundary conditions show that moving this machine to section 1A is not possible. Therefore it is decided to keep the oxy-fuel cutting machine in its current location, with the consequence of still having to transport cut steel parts from S1 to S1A. As S1 consists of separate buildings separated by physical walls, this will not have a negative effect for the galvanic corrosion.

As stated in chapter 2, an organization that is in accordance with Quick Response Manufacturing has a cellular organizational structure.

To find the optimal layout for the given challenge, a solution is found from two the combination of different perspectives: an operations-based perspective and a client-based perspective. In the next sections, these two perspectives are shown.

6.4. Operations-based Perspective

QRM-cells are per definition set up for a defined market segment: the Focused Target Market Segment as mentioned in chapter 2. This FTMS can be based on the required operations of all processed parts. Based on the process data in section 3.1 and figure 3.1, all possible combinations of operations taking place can be defined. This overview is presented in figure 5.2. These combinations of operations of course do not take place an equal amount of times across all parts of the ships. The number of times they occur are presented in table 6.1.

It is seen that, according to figure 5.2, the forming operations are totally excluded from all other operations. This is contrary to common sense, as of course a formed part could e.g. still be beveled as multiple formed parts are joined together to make a ship's hull. At DSGa however, the formed parts are indeed excluded from further preprocessing operations. After forming these parts are packed together. The small operations they need to endure are then executed in the section building department. Grinding and beveling are stated together as they are executed together. This is not necessarily a preferred situation of course. It could be a better option to execute beveling with another tool instead of an angle grinder. A separate study on this method is performed by Damen. (Zhuang, 2018)

From table 6.1 it can be concluded that ten cells are demanded of which three can already be scrapped instantly. Operations scenario's 3 and 5 do not ever occur for the observed tugboat and the observed PSV. As already stated in chapter 5, the combination of tapering and flanging for one plate part per definition does not occur so these are no target market segments. Operations scenario 10 requires no operations at all. By far the most parts go through operations scenario 7: only grinding and/or beveling. These two operations do not require heavy machinery and can be executed virtually anywhere.

After the operations, the parts are sorted for their next destination and packed together in containers.

Table 6.1: The different types of operations taking place

		ASD2913 Tug (Flatbars included)		ASD2913 Tug (Flatbars excluded)	
1	Forming 2D + Forming 3D	99	2%	99	3%
2	Forming 2D	78	2%	78	2%
3	Tapering + Grinding/Beveling + Flanging	0	0%	0	0%
4	Tapering + Grinding/Beveling	18	0%	18	1%
5	Tapering + Flanging	0	0%	0	0%
6	Tapering	3	0%	3	0%
7	Grinding/Beveling + Flanging	188	5%	113	3%
8	Grinding/Beveling	3027	76%	2383	73%
9	Flanging	51	1%	51	2%
10	No operations	538	13%	538	16%
		4002		3283	
		PSV 3300 (Flatbars included)		PSV 3300 (Flatbars excluded)	
1	Forming 2D + Forming 3D	34	0%	34	0%
2	Forming 2D	146	1%	146	1%
3	Tapering + Grinding/Beveling + Flanging	0	0%	0	0%
4	Tapering + Grinding/Beveling	0	0%	0	0%
5	Tapering + Flanging	0	0%	0	0%
6	Tapering	0	0%	0	0%
7	Grinding/Beveling + Flanging	582	3%	582	4%
8	Grinding/Beveling	16528	91%	12532	89%
9	Flanging	5	0%	5	0%
10	No operations	822	5%	814	6%
		18117		14113	

6.5. Client-based Perspective

The Target Market Segment can also be based on the clients of the process. For the preprocessing there are nine internal clients, mentioned in table 3.1 on page 24. When introducing a shift from a functional organization to a cellular one, these internal clients will act as the targeted market segments.
So, ideally, nine cells would be present in the organization, with the following requirements:

- The cells are all team-owned,
- The cells all have dedicated resources. So for the whole sequence of operations in preprocessing this means:
  - A cutting machine,
  - A tapering station,
  - A forming station,
  - A flanging station,
  - A grinding station,
  - At least one crane or other suitable method of transportation.
- Every employee in the cell can operate either of these mentioned resources,
- These resources are placed close together.

Making nine cells with these characteristics is of course easily done. This particular project however introduces some extra requirements. First, the cells should fit within the preprocessing building of S1A. The objective is to modify the preprocessing department without big investments, so a cellular structure is proposed that meets the boundary conditions in section 1.4. To meet these conditions, the overview of technical data stated in section 3.2 is important. The starting point of this option is based on the product data in section 3.3. Table 6.2 shows the different internal clients (already known from section 3.1) and the numbers of parts with these respective clients

Table 6.2: Internal clients with the number of parts per ship type

Internal Client	ASD2913 Tug (Flatbars included)		ASD2913 Tug (Flatbars excluded)	
910	837	21%	488	15%
920	459	11%	237	7%
930	128	3%	65	2%
940	2262	57%	2208	67%
950	79	2%	72	2%
960	162	4%	140	4%
970	31	1%	29	1%
980	44	1%	44	1%
990	0	0%	0	0%
	4002		3283	

Internal Client	PSV3300 (Flatbars included)		PSV3300 (Flatbars excluded)	
910	5030	28%	1829	13%
920	766	6%	372	3%
930	884	3%	739	5%
940	8621	29%	8511	60%
950	45	0%	45	0%
960	2650	13%	2496	18%
970	0	0%	0	0%
980	121	1%	121	1%
990	0	0%	0	0%
	18117		14113	

As seen in table 6.2, for both the ASD2913 tug and the PSV3300 the biggest number of parts have end buffer 940. In fact, with the flatbar parts excluded, these parts make up well over half of all parts. There are few parts for internal client 930. This is due to the fact that these parts make up the main panels. These parts are relatively big, but there are of course relatively few of them.

In the table it can also be seen that there are no parts at all for internal clients 990. This internal client is only used for profile parts. Internal clients 960, 970, 980 and 990 are located elsewhere on the premises of DSGa and demand unprocessed parts. Therefore these end buffers are excluded from the cellular structure and the numbers do not add up to the same totals as in table 6.2.

Table 6.3: Equipment needed for number of parts with different internal clients

ASD2913 Tug

Internal Client	Cut parts	Flanging	Forming	Tapering
910	488	25	0	9
920	237	0	0	1
930	65	0	0	6
940	2208	138	177	1
950	72	0	0	0
Total:	3070	163	177	17

PSV3300

Internal Client	Cut parts	Flanging	Forming	Tapering
910	1829	121	0	0
920	372	0	0	0
930	739	0	0	0
940	8511	310	180	0
950	45	0	0	0
Total:	11496	431	180	0

So what remains, are cells with FTMS 910, 920, 930, 940 and 950, still requiring the resources stated earlier in this section. However, due to the boundary conditions in section 1.4 and the available equipment from section 3.2, the number of resources is limited. Table 6.3 shows the number of different operations that are required per FTMS. Beveling and grinding are not included in this table, since these two operations do not require any special equipment other than an angle grinder.

It can be seen that all parts that require forming have end buffer 940, so only the cell with FTMS 940 needs a forming station. This is beneficial, as this means that the roller press currently in section 1 and the plate roller in section 1A can be collocated to make up this forming station.

Furthermore it is seen that only internal clients 910 and 940 require parts that are flanged. As two press brakes are available, these pieces of equipment shall be located in these two cells.

Four of the five internal clients demand parts that require tapering. In appendix E, it can be seen that currently two tapering tables are present, however the tapering tractors themselves are not necessarily fixed to the tapering tables but can also be used remotely, anywhere in the hall. Due to the layout of the facility, to prevent large waiting times from occurring due to transport to and from the tapering station, one tapering table is placed in lane 2, the other is placed in lane 3.

6.6. Proposal

To make a proposal for the cellular structure, the operations-based perspective and the client-based perspective are combined. The combination of parts going through the various operations scenarios to the various internal clients can be found in tables 6.4 and 6.5 for the ASD2913 tugboat and the PSV3300, respectively.

Table 6.4: The number of plate parts of an ASD2913 for internal clients 910 - 950, per operations scenario (flatbars excluded)

	ASD2913	Internal Clients					
	Operations scenarios	910	920	930	940	950	Total
1	Forming 2D + Forming 3D	0	0	0	99	0	99
2	Forming 2D	0	0	0	78	0	78
3	Tapering + Grinding/Beveling + Flanging	0	0	0	0	0	0
4	Tapering + Grinding/Beveling	9	1	5	1	0	16
5	Tapering + Flanging	0	0	0	0	0	0
6	Tapering	0	0	1	0	0	1
7	Grinding/Beveling + Flanging	23	0	0	90	0	113
8	Grinding/Beveling	352	83	0	1725	32	2192
9	Flanging	2	0	0	48	0	50
10	No operations	102	153	59	167	40	521
	Total	488	237	65	2208	72	**3070**

Table 6.5: The number of plate parts of a PSV3300 for internal clients 910 - 950, per operations scenario (flatbars excluded)

	PSV3300	Internal Clients					
	Operations scenarios	910	920	930	940	950	Total
1	Forming 2D + Forming 3D	0	0	10	24	0	34
2	Forming 2D	10	0	134	2	0	146
3	Tapering + Grinding/Beveling + Flanging	0	0	0	0	0	0
4	Tapering + Grinding/Beveling	0	0	0	0	0	0
5	Tapering + Flanging	0	0	0	0	0	0
6	Tapering	0	0	0	0	0	0
7	Grinding/Beveling + Flanging	116	0	0	310	0	426
8	Grinding/Beveling	1495	333	199	8021	45	10093
9	Flanging	5	0	0	0	0	5
10	No operations	203	39	396	154	0	792
	Total	1829	372	739	8511	45	**11496**

These tables show that by far the most parts require only grinding and/or beveling and go to internal client 940. It is therefore decided that a dedicated cell will be constructed for these parts. The other internal clients

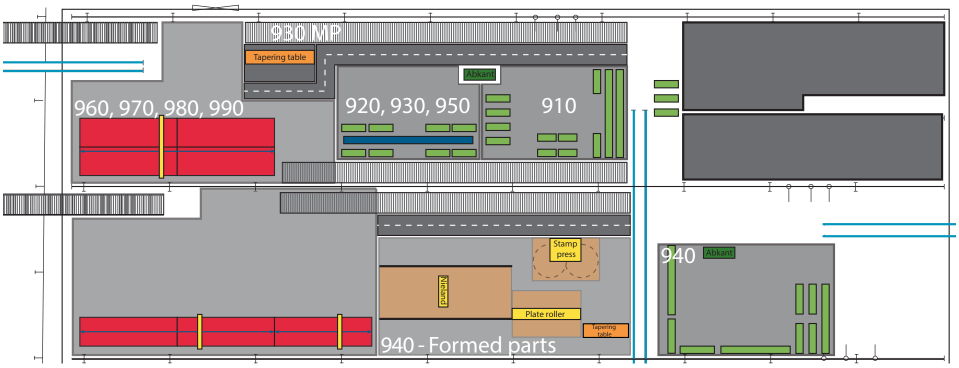


Figure 6.1: Proposed cellular structure

require less parts so these could be combined into an FTMS.

As the boundary conditions of this research state that relocating of cutting machines and the plate roller will not take place. As the cutting machine in lane 2 of section 1A has a higher capacity than the one in lane 3 and the plate roller (used for parts for internal client 940 only) is also located in this lane, it is determined that a cell with FTMS "940" is assigned to lane 2. As the number of parts for this cell exceeds all other parts together, it is determined to have lane 2 dedicated for these parts. the parts for all other internal clients are cut on the cutting machine in lane 3. This lane can of course be subdivided, respecting the boundary conditions and the requirement of dedicated resources as stated by Suri (2011). As three crane portals are available in this lane for preprocessing and one of them is used at the cutting station, two cells can be constructed in lane 3.

The cells with FTMS "910", "940" and "920,930,950" all require the equipment and skills to flange parts. To decrease inter-lane transports it is decided to place one press brake in cell "940" and one on the border between the two cells in lane 3. The press brake in lane 3 makes use of "Time-slicing", a QRM-method for usage of one piece of equipment by two different cells. For this model, it is simply assumed that cell "920,930,950" can use this press brake during the first work shift of each day, cell "910" uses it during the second shift.

From improvement suggestion 2 it was derived that changing the line-heating station to a roller press has a major impact on the throughput of 3D-formed cells. This change is therefore applied. With this situation, the idea arises that with increased throughput the 3D-forming machine is no bottleneck but the plate roller is. Therefore it is decided also to add the stamp press from section 1, to be able to subdivide the formed parts for their 2D-shape.

The overview of this proposed cellular layout can be seen in figure 6.1, the model can be found in figure 6.2.

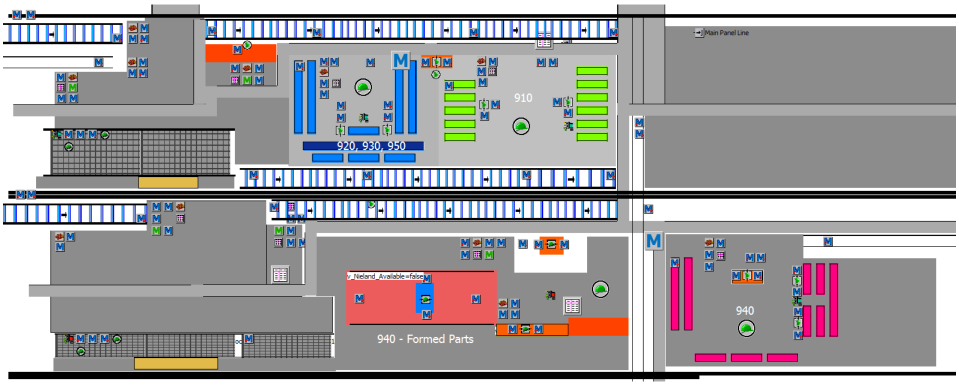


Figure 6.2: Model with the proposed layout

6.6.1. Nesting

As seen in figure 5.2.3, it is seen that sorting after cutting is a very time-intensive step, due to the big batches that are used to process steel parts. To reduce both the time of this sorting step and eliminate inter-lane transports, a new nesting procedure is obtained. The nestings are divided into two sets:

- A set with all parts for 940,
- A set with all other parts.

This was done by taking the original plates and parts and incorporating the right thickness and material grade, check if a plate has sufficient free surface for this part. If this is the case, the part is nested onto this plate. If it is not the case, the same procedure is done with the next plate. Another constraint is added that parts for the same panel with the same thickness, are nested on the same plate together. With this method all parts still fit on the number of plates that is used in the current situation and an average plate utility factor (the ratio to the sum of the surface of the nested parts to the surface the plate itself) of 80% is obtained, which is comparable to that of the provided nesting documentation. This is however not an optimized situation, nor an accurate one. Regarding the dimensions of the parts, only the length, width, thickness and mass are known. Therefore with the density of steel the surface can be computed but if a part has an odd shape, this is not accounted for in this made-up nesting procedure. Also it is assumed that the cutting time of the plates is equal to the average cutting time of the plates in the current situation. Therefore it is recommended to perform studies to optimize the nesting in the future.

With the generated nesting and implying that the batches for the preprocessing department are equal to one plate, the step of sorting after cutting is simplified and the time of this step is decreased massively. This is also shown in figure 6.3. The process time after the sorting step is not much shorter than the process time of the situation with reduced batch sizes in suggestion 4, but the time of the sorting step has a major impact on the MCT*.

6.6.2. Methodology of the model

This paragraph describes the methodology of the preprocessing model with the proposed cellular structure. The model itself can be seen in figure 6.2.

Lane 2

On the infeed conveyor in lane 2, all nested plates with the parts for cell "940" enter the building. From the conveyor, the plate is picked up by crane portal 60572 and placed on either of the available cutting beds. The plate is cut and parts that are formed and/or tapered are placed in the "Formed-parts" cell one by one, as there is usually only 0 or 1 of these parts per plate. The other parts are placed in a container together. After these parts are placed in the container, it is transported to the cell "940". Here each part is ground on the grinding tables or fixed grinder. After grinding the part is either flanged at the press brake in the cell or packed directly. This flanging method therefore resembles improvement suggestion 1A. After flanging these parts are also packed in a box per section. When this is done, the boxes are placed on the outfeed carriage and the carriage drives into the section building hall, where the internal client is located. When the containers have left the cell, a POLCA-card is sent to the cutting machine so a new batch can be sent.

The formed parts are placed on either the plate roller or the stamp press, depending on which of these two machines is available. On one of these machines, the part is formed into a 2D-shape. If the part does not require a 3D-shape, it is placed on a container.
If the part does require a 3D-shape however, it is placed within reach of the working crane of the roller press. If the roller press is available the part is picked up by the crane gantry and placed on the roller press. The part is formed into the required shape and afterwards it is placed in a container as well. In this case, the restriction of keeping 2D-formed parts and 3D-formed parts apart is removed, as a batch of these parts only consists of 1, 2 or 3 parts. When the batch from one plate is finished these plates are also transported to the section building hall. The formed-parts cell does not send a POLCA-card to the cutting machine, but these formed parts are brought to the formed-parts cell based on the POLCA-card of the "940"-cell.

Lane 3

On the infeed conveyor in lane 3, all nested plates with the parts for internal clients 910, 920, 930, 950, 960, 970 and 980 enter the building. From the conveyor, the plate is picked up by crane portal 60598 and placed on either of the available cutting beds. The plate is cut and the parts are sorted per next destination. Parts for internal clients 960, 970, 980 and 990 are sorted in containers per client. When a container is full, it is picked up by a transporter and brought to the client outside. The batch sizes in these containers are bigger than the set of parts from one plate.

Mainpanels are transported to the mainpanel line via the conveyor North in lane 3, so these transports do not interfere with the dedicated cranes of the cells. From this conveyor it is picked up and placed in the buffer for the mainpanel line. If the main panel requires to be tapered, this is done before it is placed on the conveyor.

Small parts for cell "910" are placed in a box together, just as the parts for cell "920,930,950". When the batch is completed, this box is transported to their cell by forklift. Big parts are transported via the conveyor South in lane 3, so these transports do not interfere with the dedicated cranes of the cell. From the conveyor, these parts are picked up by the crane and placed directly onto the grinding tables in the appropriate cell. On these tables the part is ground. If it needs to be flanged, the part is brought to the press brake when the time-slice of the press brake is dedicated to the cell. If it does not need to be flanged the part is packed onto a container. In cell "920,930,950" the parts are separated per client.

The small box arriving per forklift is placed on the floor of the cell and the parts are ground at the grinding tables or the fixed grinders. If the part needs to be flanged it is placed at the press brake in the time-slice of the cell. If it does not need to be flanged the part is packed onto a container. In cell "920,930,950" the parts are separated per client.

After flanging, these parts are also packed onto the appropriate container.

After all parts that do not need to be flanged are packed, a POLCA-card is sent to the cutting machine so a new batch can be sent before the flanged parts are packed. This mitigates the risk that when the this happens in the time slice of the press brake for the other cell, production comes to a halt for ten hours.

When all parts in a cell for an internal client is packed, the container is brought to the client. In the case of clients "910" and "920", these clients are in the same cells. The internal client "930" is located at the main panel line so these containers are transported there. The client "950" is located in the block building department. The containers for this internal client are picked up by a transporter and drive outside to this department.

6.6.3. MCT*

In figure 6.3 the MCT* of the preprocessing department with the proposed cellular structure is determined. It is seen that while the time spent in the cells is not a lot smaller than in the situation with the reduced batch sizes in suggestion 4, the MCT* is decreased dramatically by changing the method of sorting after cutting. The critical path is determined by the flanged parts and an MCT* of 18 hours and 11 minutes is obtained, leading to a QRM-number of 863. With this method, in total 9372 tons of parts are processed over the course of the year, which is in fact more than the current throughput of sections 1 and 1A together, that was stated in chapter 3.

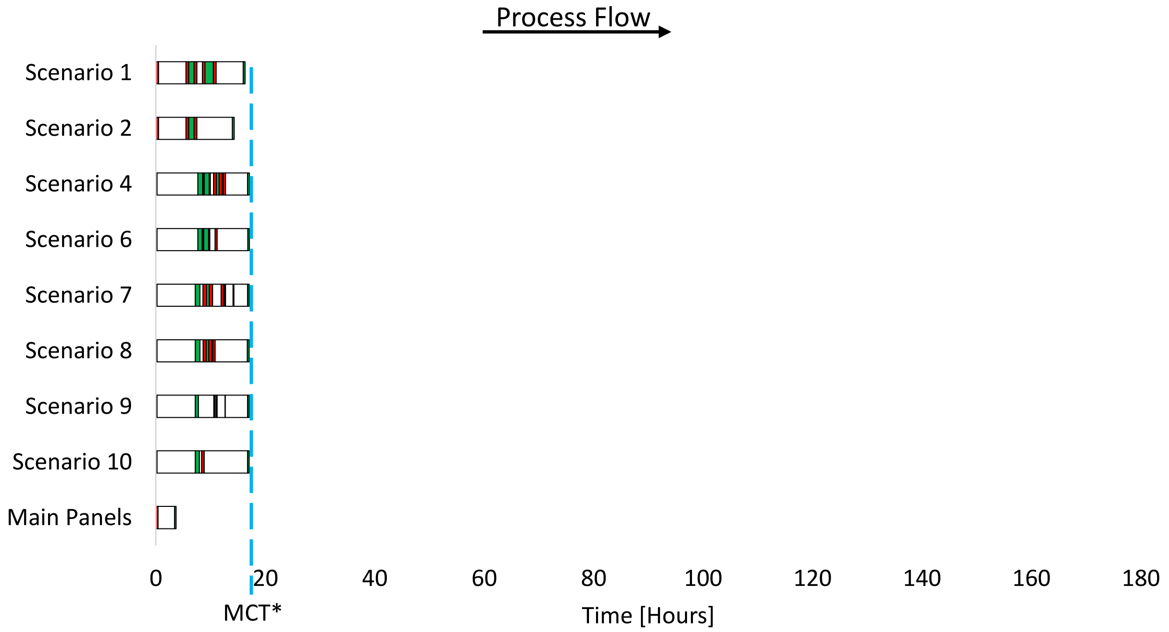


Figure 6.3: Determination of the MCT* of the preprocessing stage with modified nesting and a cellular organization

6.7. Conclusion

What are the specifications of the preprocessing department in the proposed situation?

It was tested if a cellular structure in combination with an altered nesting makes a substantial difference. First the methodology of improvement as stated by Suri (2011) is presented. Based on experience of the employees at DSGa and an analysis of the simulation model a number of pain points are listed, used as the starting point for the improvement suggestion and for constructing the cellular structure. It is shown that the rate at which a batch of parts is processed is a lot smaller compared to the initial situation, partly due to the fact that the batches are a lot smaller. The number of transports is however decreased drastically and a nesting that enables batches to be formed per cut plate leads to a substantial decrease in waiting time in the sorting step after cutting. With this suggestion implemented, an MCT* of little over 18 hours is achieved, yielding a QRM-number of 863 and an annual throughput of 9372 tons. This shows that applying Quick Response Manufacturing can indeed have a significant impact on the preprocessing stage of shipbuilding. However there are a lot more improvement strategies, as seen in figure 1.7. Before implementing Quick Response Manufacturing, it may be wise to compare it to other strategies. In the meantime, it can be beneficial to make some smaller-scale changes. A few of these are seen in the next chapter.

7

Small-Scale Improvement Suggestions and Their Benefits

> *What are the potential improvements for the preprocessing department, based on Quick Response Manufacturing and what benefits do they bring?*

As stated in the previous chapter, Quick Response Manufacturing can make a significant change to the preprocessing stage of shipbuilding. Before implementing this strategy however, it may be beneficial to have a look at other strategies as well to determine the best outcome.

In the meantime, it is beneficial to have a look at some small-scale process improvements to already make a slight improvement to the preprocessing department. A few of them are already proposed in this chapter, based on the pain points stated in section 6.2.In the next sections, these investigated improvement suggestions and the benefits they bring are stated.

7.1. Suggestion 1: Flanging

As seen in section 6.2.1, the foremen at DSGa experience quite some issues with the press brake. Section 5.2.3 confirms that there are in fact some serious issues with this process. Small parts are moved on a europallet so this pallet waits at the parts processing area until all to-be-flanged parts are packed onto this pallet after they are ground. After this, the parts are transported to the flanging area, so three pallets of to-be-flanged parts can be present at the flanging area simultaneously, with parts of three different sections, this is a situation that happens quite often as seen in appendix K and this situation is stated as one of the pain points in section 6.2.1. This situation could of course be improved by avoiding this time-consuming transport after grinding.

This idea is worked out in two sub-suggestions as already briefly explained in section 5.2.3.

Suggestion 1A: Bringing the press brake to the parts

This suggestion aims at avoiding all these time-consuming transports and takes a first step towards team-ownership and cross-trained team members. Although not in line with the boundary condition of not spending any money, it is interesting to observe what the effect is when the flanging operations of parts from the three parts processing areas are separated and each of the parts processing areas have their own press brake. This introduces a few demands:

- All three of the parts processing areas require a press brake,
- All three of the crews at the parts processing areas require the skills to operate the press brake.

In this situation, the to-be-flanged parts are not packed onto containers anymore, but are directly brought from the grinding tables or fixed belt grinder onto the press brake that is now present in the parts processing area. From the press brake, the flanged part is then directly packed onto the appropriate container to go to its end buffer.

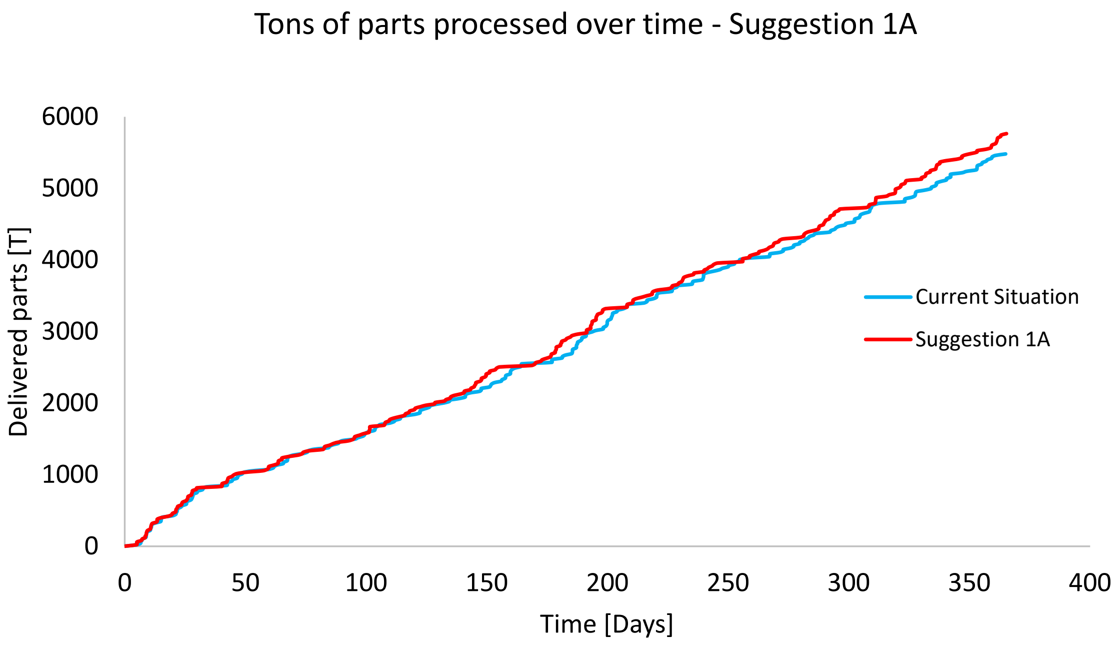


Figure 7.1: Deliveries of tons of parts over the year in the preprocessing department, with suggestion 1A applied

Figure 7.1 shows the throughput of this solution. It is seen that in with the implementation of this suggestion, 5763 ton of parts is processed. This is an elevation of 5% compared to the current situation. Figure 7.2 shows the determination of the MCT*. It can be seen that the MCT* of this suggestion is equal to 142 hours, so this yields a QRM-number of $\frac{157}{142} * 100 = 111$. Although the process times are reduced drastically, this is not reflected entirely in the MCT* and the QRM-number, as the critical path is now determined by scenario 1 due to the relatively slow process of 3D-forming. At a later stage in this chapter, the 3D-forming process is regarded.

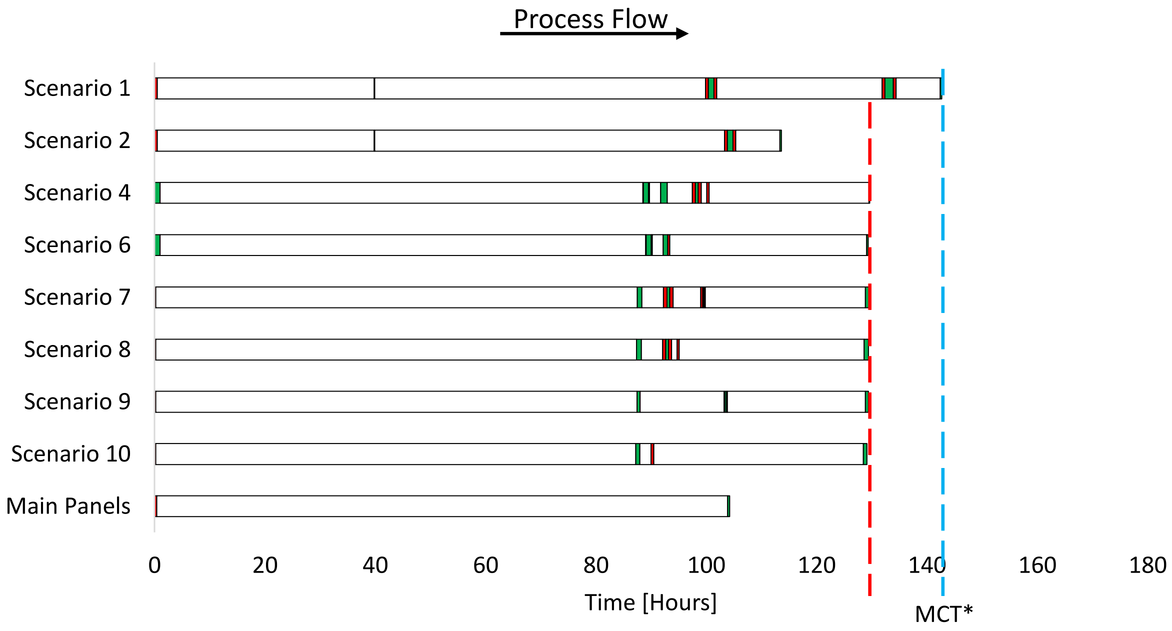


Figure 7.2: Determination of the MCT* of the preprocessing department with suggestion 1A implemented.

Suggestion 1B: Separating flanged parts after cutting

The second option is an option that resembles the flow that tapered parts currently endure after cutting, is in line with the boundary conditions and is a first step towards using the POLCA-system proposed by QRM in chapter 2. After cutting, the to-be flanged parts are separated from the other parts. Small parts are placed on a europallet. Parts that do not fit on a europallet are transported directly to the flanging area and stacked here per section. When all parts of the cutting group are cut, the pallet is transported to the flanging area as well. When a parts processing area starts working on a section that has flanged parts, a POLCA-card is sent to the foreman of the press brake and the employees of the flanging area start processing the parts of this section. Once this batch of flanged parts is finished, they are transported to the parts processing area to be ground and join the other parts.

In this situation, the flanged parts are processed at the flanging area a lot earlier than in the current situation. Apparently it is not necessarily required to perform grinding before flanging, this can also be done the other way round (Damman, 2018).

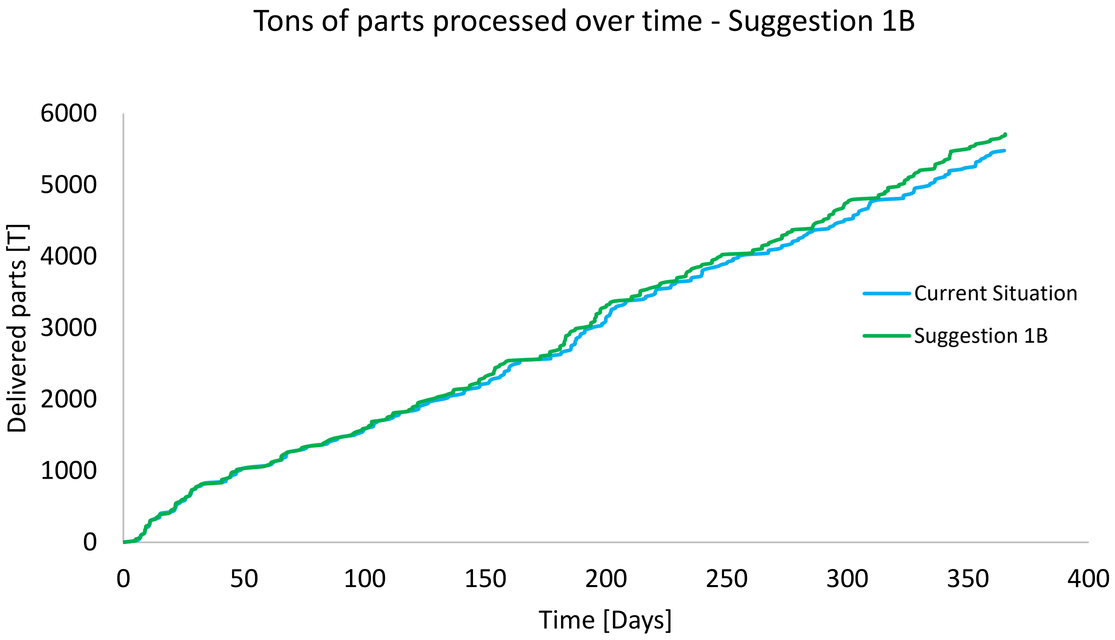


Figure 7.3: Deliveries of tons of parts over the year in the preprocessing department, with suggestion 1B applied

Figure 7.3 shows the throughput of this solution in a year. With the implementation of this suggestion, 5714 tons of parts are processed so this is an elevation of 4% compared to the current situation. In figure 7.4 the determination of the MCT* is shown. Just as with the implementation of suggestion 1A, the critical path is now defined by operations' scenario 1, yielding an MCT* of 142 hours, resulting in a QRM-number of 111.

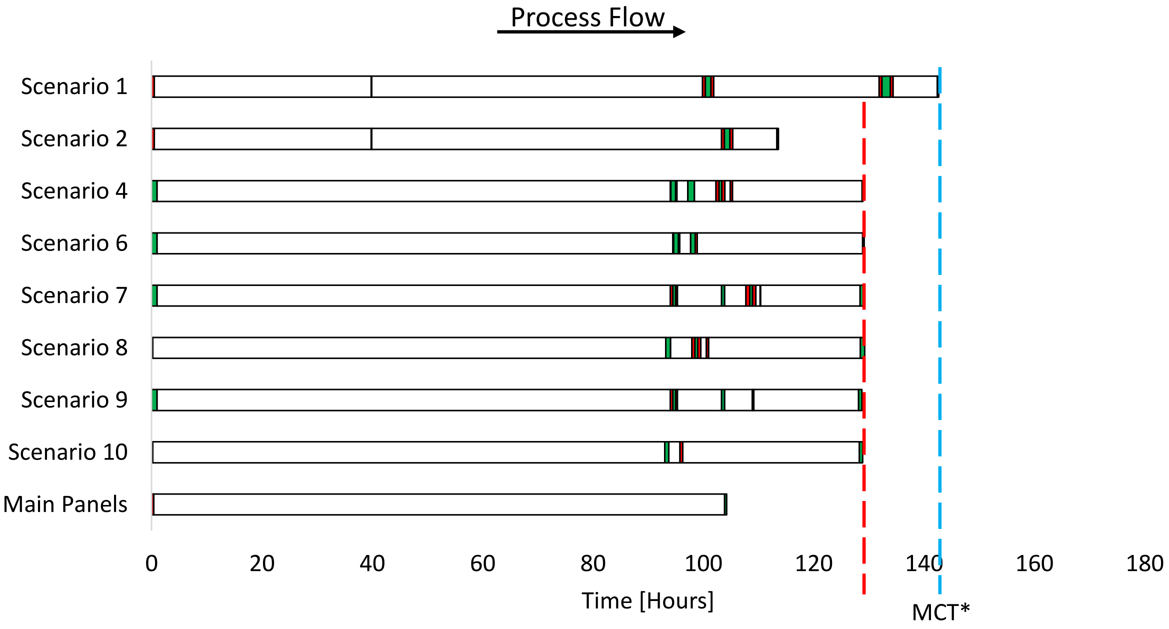


Figure 7.4: Determination of the MCT* of the preprocessing department with suggestion 1B implemented.

7.2. Suggestion 2: 3D-forming

As stated in section 6.2.2, the 3D Line heating station lacks capacity, as this is quite a slow process. The line heating station is a bottleneck in the forming process as explained in appendix M. Therefore it is interesting to have a look at the 3D-forming method. In section 1 of DSGa, the 3D-forming is done using a roller press. This achieves the same result, only this process is a lot faster. Therefore it is decided to investigate what happens when the line heating station in section 1A is replaced by the roller press currently in section 1. To find this the line heating station in the simulation model is replaced by the roller press from section 1. Basically it is also a workstation with a processing time three times as fast compared to the line heating station. In appendix M the number of objects on the forming area is shown as a function of elapsed time. Figure 7.5 shows this same function in blue. It also shows the situation with the faster 3D-forming process in red. It is clear that this gives a different result. The number of objects is a lot lower and it does not exceed ten objects anymore, where in the situation at some points more than 40 objects were present.

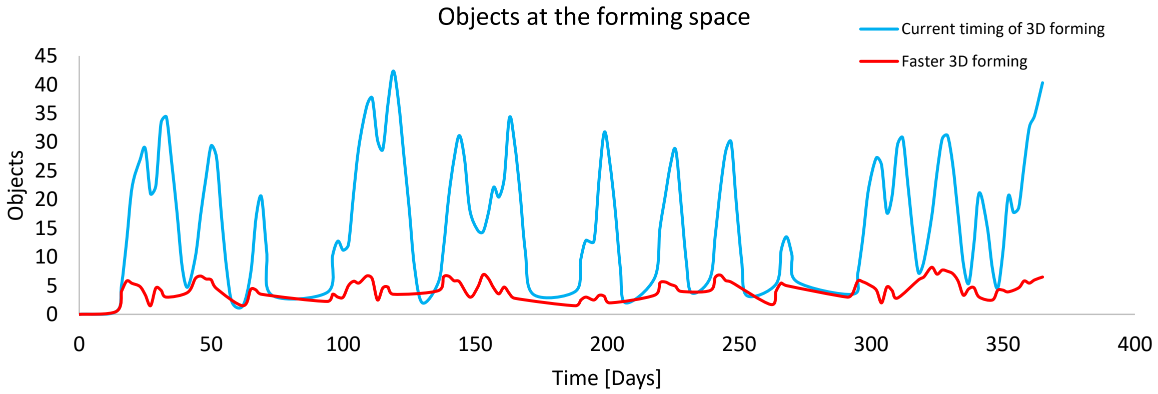
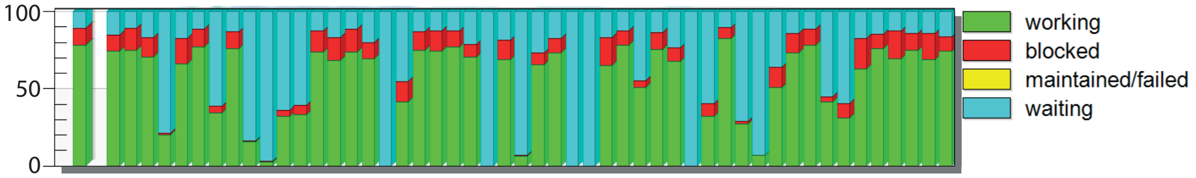
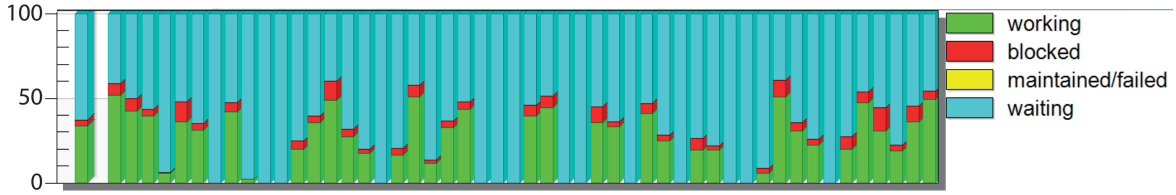


Figure 7.5: Indication of space utilization of the forming space.

This difference is also seen in the utilization of the forming equipment, shown in figure 7.6. It shows that the utilization of the 2D-forming plate roller is more or less unchanged compared to the utilization of that machine in the current situation, shown in appendix M. The utilization of the 3D-forming station however is a lot smaller. It still shows the same bursts of order that are shown in the current situation, only the 3D-forming station can handle the orders a lot faster.



(a) Utilization of the Plate Roller



(b) Utilization of the accelerated 3D-forming station

Figure 7.6: Utilization of the forming equipment in section 1A, with accelerated 3D-forming process

For this situation, the MCT* is also computed of course, this can be seen in figure 7.7. As already known from figure 5.12, scenario 1 is not the critical path in the current preprocessing department, so this actually does not change the MCT*. Section 7.1 however shows that with the implementation of suggestions 1A and 1B, the critical path does shift to operations' scenario 1. When combining suggestions 1A and 1B with the accelerated 3D-forming procedure, this does have an influence on the MCT* as seen in figures 7.8 and 7.9, respectively. Figure 7.8 shows that the suggestion of bringing the press brake to the parts combined with the accelerated 3D-forming method leads to an MCT* of 129 hours and 36 minutes, yielding a QRM-number of 121. The suggestion of separating the flanged parts from the other parts directly after cutting yields an MCT* of 129 hours and 45 minutes as seen in figure 7.9. This value also yields a QRM-number of 121. The number of tons that are processed does not really change compared to the situation with only the altered flanging procedure, as after forming, no new batch of formed parts enters the forming area but this happens when the next cutting group is cut. This cutting depends on the processing of parts at the parts processing areas.

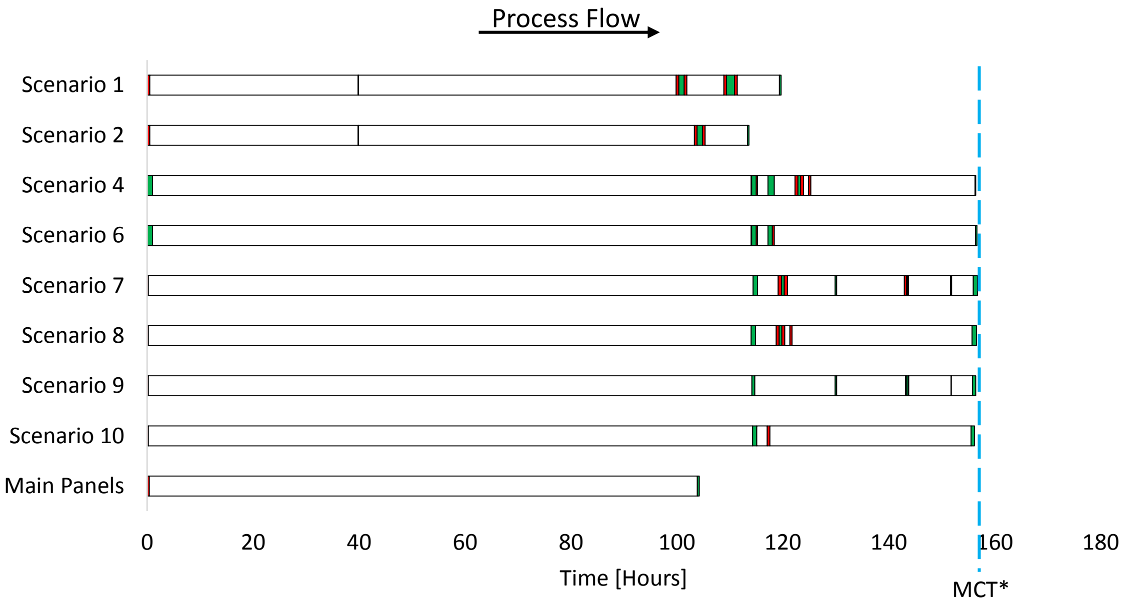


Figure 7.7: Determination of the MCT* of the preprocessing department with accelerated 3D-forming

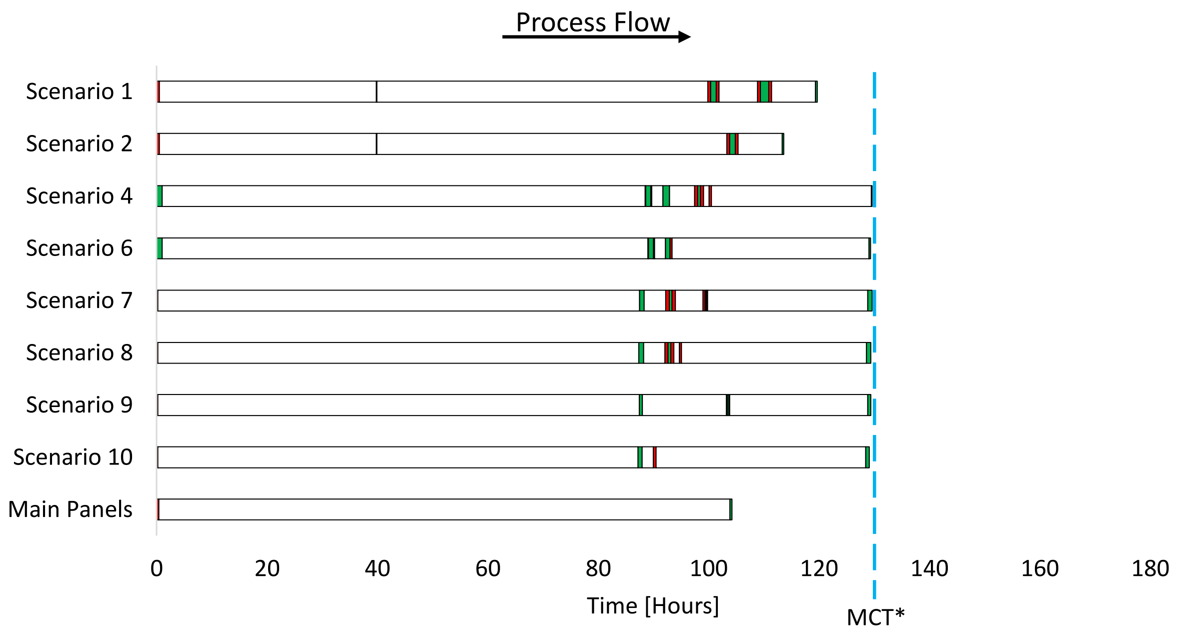


Figure 7.8: Determination of the MCT* of the preprocessing department with suggestion 1A and accelerated 3D-forming

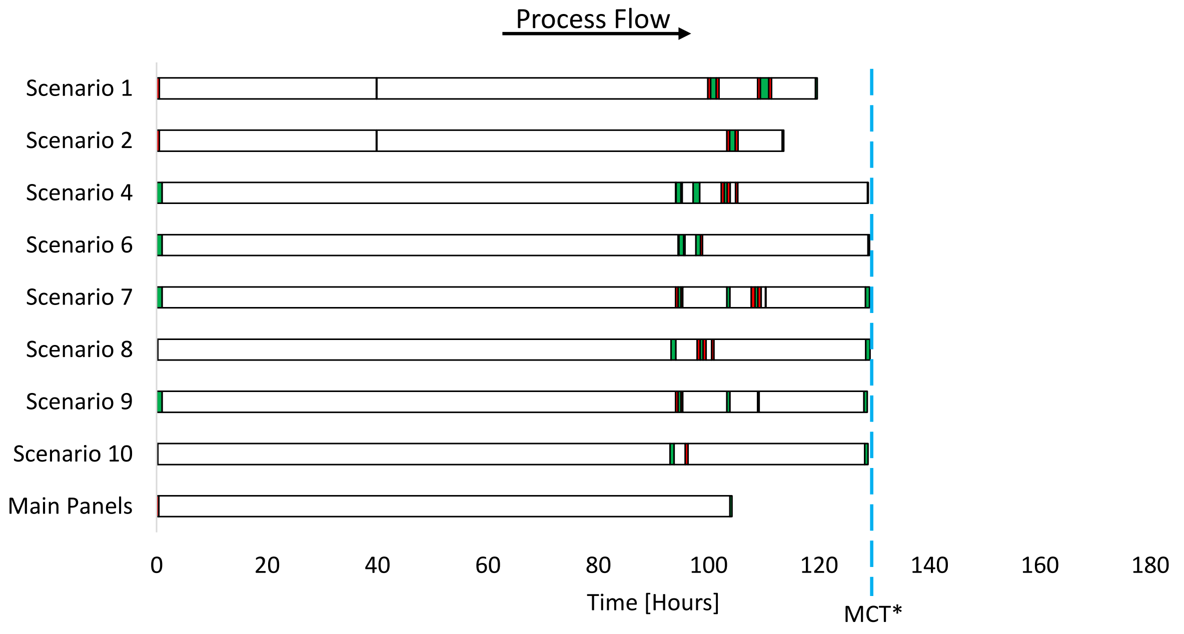


Figure 7.9: Determination of the MCT* of the preprocessing department with suggestion 1B and accelerated 3D-forming

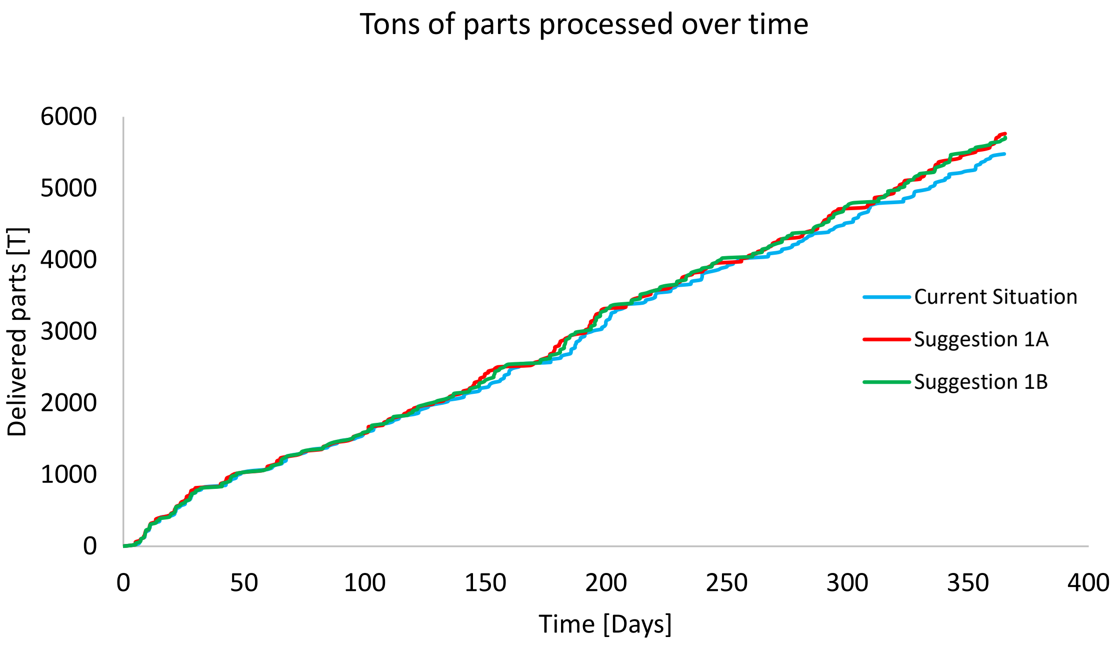


Figure 7.10: Deliveries of tons of parts over the year in the preprocessing department with suggestions 1A and 1B applied and accelarted 3D-forming

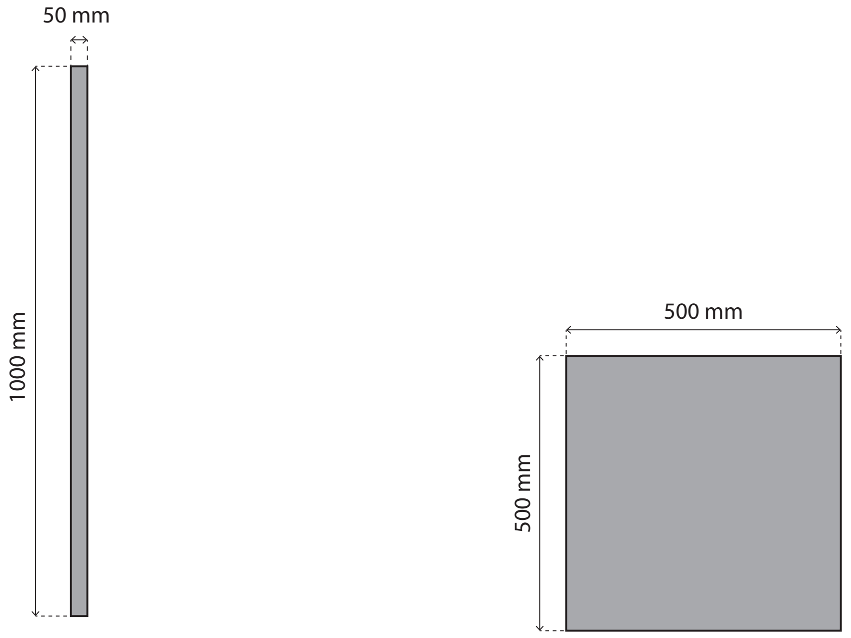
7.3. Suggestion 3: Flat Bar profiles

- *Flatbars to be processed at the profile line to reduce variability.*

As stated in chapter 2, two important factors of Quick Response Manufacturing are the size of handled batches and variability. Flat bar parts are currently cut out of steel plates just as the other plate parts, although they function as profile parts. Compared to profile parts cut from profiles, these parts demand a great amount of work as their edges always need to be ground. This induces a great variability in processes. For a long and narrow part such as a flat bar profile part, this is of course an extensive process as these parts have a large edge length compared to their area, compared to plate parts with a lower aspect ratio as seen in figure 7.11. The benefit of obtaining flatbar parts from flatbar profiles is that these parts require less grinding, as only the cut (short) edges need to be ground.

This change would mean that all flatbar parts are handled by the robot profile line in lane 1. Unfortunately no detailed data is present about this profile line. Therefore the provided data in appendix H is used. In table H.1 it can be seen that generally it takes eleven minutes for one profile bar to be cut into separate parts.

Table 7.1 shows the number of HP and FB profile parts needed for one ASD2913 tug, Table 7.2 shows the same information for one PSV3300. These ships also demand other types of profile parts (e.g. round bars, half round bars and square bars), these types of profile profile parts are not included, as Holland Profiles and Flat bars are the only profile types that are cut on the profile cutting robot.



(a) Flatbar part.
Area: 0.05m^2
Grinding length when cut from plate: 2.10m
Grinding length when cut from profile: 0.10m

(b) Square plate part.
Area: 0.25m^2
Grinding length: 2m

Figure 7.11: A flatbar part and a square plate part.

Table 7.2: The number of HP and FB profiles needed for one PSV 3300.

Holland profiles				Flat bar profiles			
Profile type	# parts	Total length [m]	# profile bars	Profile type	# parts	Total length [m]	# profile bars
HP100x6	619	1603.57	146	FB100x10	363	416.24	44
HP120x7	628	1197.96	115	FB100x12	154	497.05	44
HP140x7	1502	3746.84	327	FB100x6	55	106.32	11
HP160x8	978	2223.48	200	FB100x8	88	49.50	11
HP180x8	378	1219.40	130	FB105x15	22	31.72	11
HP200x10	88	229.92	29	FB120x10	913	1135.12	99
HP220x10	104	313.39	39	FB120x12	55	121.94	11
HP240x10	156	482.95	52	FB120x15	110	256.73	22
HP300x11	78	256.91	26	FB130x10	2926	2603.67	220
				FB130x15	264	475.11	44
				FB140x10	242	141.12	22
				FB140x8	33	27.12	11
				FB150x10	66	156.86	22
				FB150x12	1529	2258.08	198
				FB180x15	33	6.53	11
				FB200x12	11	35.28	11
				FB200x20	22	107.04	11
				FB50x10	99	61.17	11
				FB50x8	55	79.56	11
				FB60x10	44	16.57	11
				FB80x10	1067	1267.84	110
				FB80x8	77	81.38	11
Total	4531	11274.42	1064	Total	8228	9931.93	957

Table 7.1: The number of HP and FB profiles needed for one ASD2913 Tug.

Holland profiles				Flat bars			
Profile type	# parts	Total length [m]	# profile bars	Profile type	# parts	Total length [m]	# profile bars
HP80x6	593	813	68	FB80x8	83	101.374	9
HP80x6	439	556	47	FB120x10	26	28.484	3
HP100x7	68	168	15	FB60x8	255	258.098	22
HP100x7	201	273	23	FB100x10	52	31.59	3
HP120x7	97	146	13	FB130x12	56	94.521	8
HP160x8	6	7	1	FB80x6	80	99.188	9
HP200x10	55	83	7	FB200x15	8	18.867	2
HP240x10	11	24	2	FB100x8	2	2.42	1
HP140x8	31	80	7	FB150x15	28	74.839	7
HP240x10	48	72	6	FB50x6	11	5.733	1
HP120x7	17	32	3	FB44x6	2	4.258	1
HP160x8	13	13	2	FB250x20	2	7.426	1
				FB200x20	32	55.963	5
				FB100x7	3	0.782	1
				FB30x8	8	8.172	1
				FB110x6	56	109.654	10
				FB100x6	15	9.548	1
Total	1579	2266.262	194	Total	719	910.917	85

It can be seen that currently for one ASD tug, 194 Holland profile bars are cut, so this takes about 36 hours to cut on the profile line. For one PSV 3300, 1064 Holland profile bars are cut as seen in table 7.2, taking about 195 hours.

So when building 11 tugs and 6 PSV's per year, the total cutting time for the cutting robot is (11 * 36) + (6 * 195) = 1562 hours. With 4000 working hours per year this yields a utilization of only 39%. Therefore it could be feasible to cut the flatbars on the profile line as well.

For one ASD 2913 tug, 85 flatbar profiles are cut, taking about 16 hours. For one PSV 3300, 957 flatbar profiles are demanded, taking 175 hours to cut. So for 11 tugs and 6 PSV's, this results in an extra cutting time of (11 * 16) + (6 * 175) = 1224 hours. This gives a total cutting time of 2786 hours and a utilization of 70%. This shows that in fact the profile cutting robot is capable of handling these extra profile bars.

This extra number of cut profiles of course demands more effort by the employees in the profile lane, as they have to handle more profiles compared to the current situation. It is assumed that this is no issue, as still the same number of parts needs to be handled in total. It will might cause some relocation of workers.

Figure 7.12 shows the determination of the MCT* of the preprocessing department with this suggestion implemented. It is seen that the processes indeed are accelerated as seen by the red dashed line. However this is not reflected entirely in the MCT* as in this case, just as seen before, the critical path is now determined by the forming procedure. A MCT* of 142 hours is achieved, yielding a QRM-number of 111.
These estimates are still quite conservative. As stated in paragraph 5.1.2, average values for processing times are used as provided by Damen. These do not incorporate the big difference in grinding length as shown in figure 7.11. Therefore it can safely be assumed that this suggestion makes an even bigger difference.

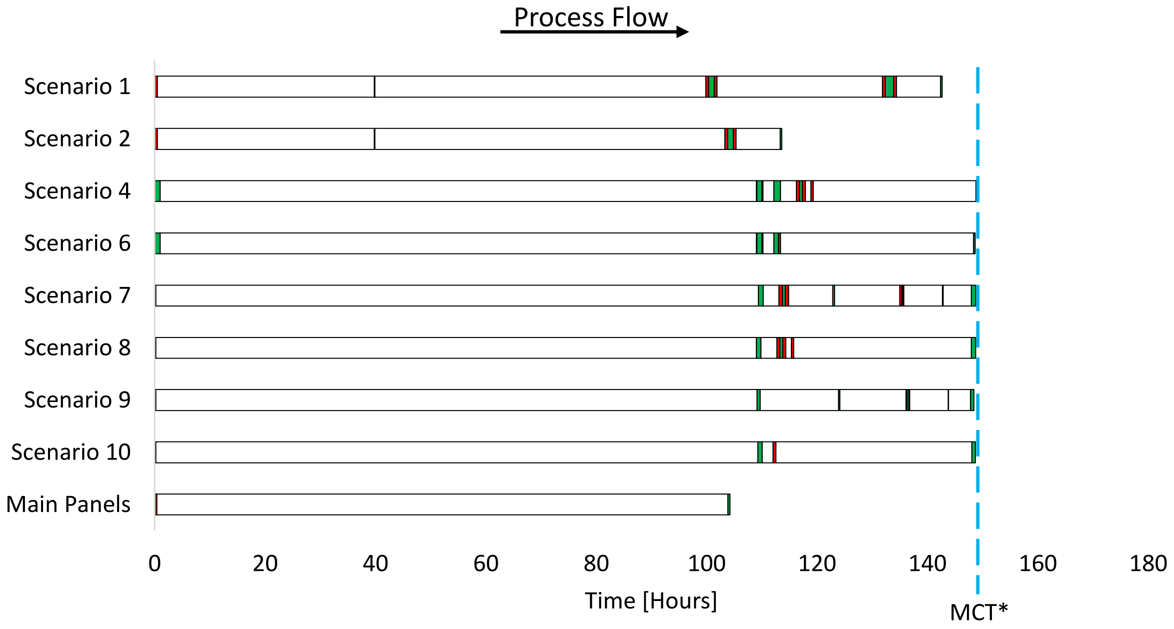


Figure 7.12: Determination of the MCT* of the preprocessing department with suggestion 3 implemented

7.4. Suggestion 4: Batch Sizes

As stated in section 6.2.2, currently the parts in the preprocessing department are processed in batches with the size of one section, this ranges between 23 parts for the keel section of a tug and 1235 for the aft section of a PSV. As seen in section 5.2.2, the flow time currently is quite large and it is interesting to see what the influence of the batch size is on this flow time. To isolate the influence of this batch size only, two options are examined:

- A: Reduce batch size of processing to third of current situation
- B: Reduce batch size of processing to third of scenario 4A

Apart from this, every other parameters are kept the same so this reduction does not account for the fact that parts for one panel can be in multiple batches

The MCT* of the first of these two suggestions is stated in figure 7.13. From this figure, it is observed that the initial time spent at the parts processing areas is decreased significantly. The batch sizes are still spread apart quite substantially, an order time T_O is obtained of 5 hours and 10 minutes, with a substantial standard deviation S_O of 7 hours and 45 minutes. The inter-arrival time T_A is decreased to 10 hours and 15 minutes with a standard deviation of 10 hours and 10 minutes. These values lead to an average variability AV of 1.62. Due to the smaller batch sizes, a relatively big number of transportation takes place. This leads to a lower utilization of the parts processing areas, as this is defined in section 5.2.2. This utilization is equal to 54%, leading to a value for M of 1.18. With the parameters for the flow time known, a flow time is obtained of 15 hours. The MCT* equal to 142 hours as seen in figure 7.13.
It is seen that the critical path is again defined by the formed parts. When the faster 3D-forming from improvement suggestion 2 is applied the MCT* is defined by the red dashed line in figure 7.13 and is equal to 120 hours. This yields a QRM-number of 131.

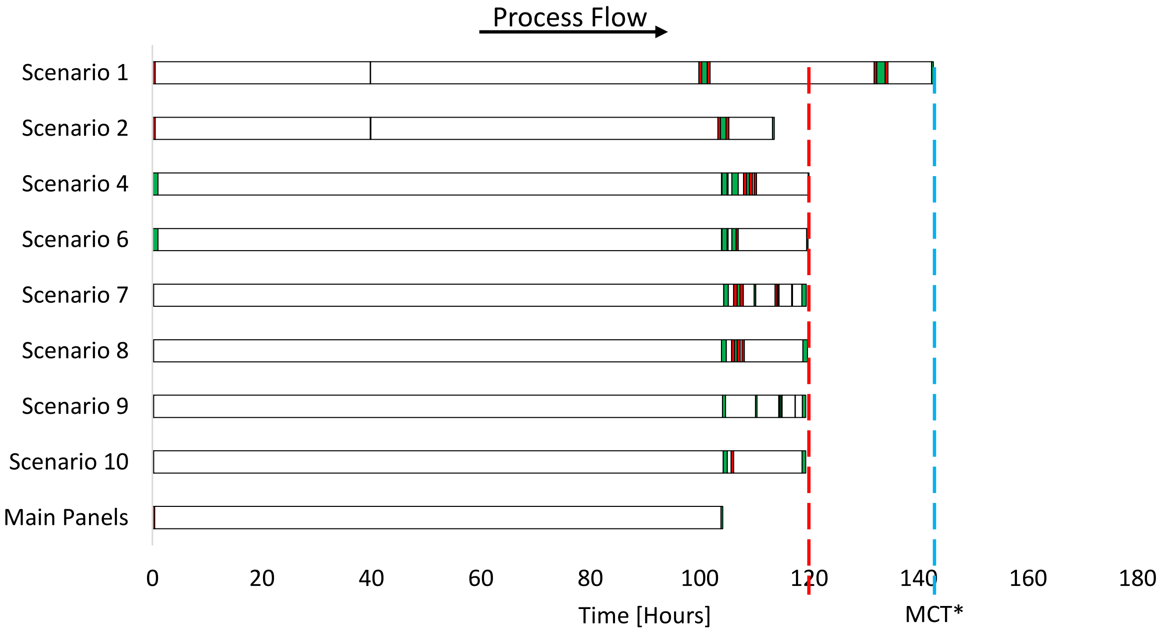


Figure 7.13: Determination of the MCT* of the preprocessing department with decreased batch sizes

When the batches are then reduced by a factor three again, a process flow as seen in figure 7.14 is obtained. It is clearly seen that the step of sorting after cutting does not change that much. In this situation, 9 times as much batches arise after cutting, but the number of parts processing areas does not change. Furthermore, from every plate in the cutting group, parts still go to virtually every batch. This still leads to substantial waiting time at the step of sorting after cutting. The time spent at the parts processing area is of course decreased again. It is also seen that the touch time of the flanging steps is actually increased in this situation, as the smaller batches lead to an increase in changeovers.

The ordertime T_O of the processing areas with this improvement suggestion implemented is decreased to 2 hours and 21 minutes, with a standard deviation S_O of 4 hours, as some of the batches still take almost a full working day. The inter-arrival time T_A is equal to 1 hour and 16 minutes with a standard deviation of 3 hours and 34 minutes, due to the same reason. From these parameters, an average variability is obtained of 5.4. The utilization of the parts processing areas is decreased even further as with this situation, the influence of the transports increases. This utilization is equal to 30% leading to a value of M of 0.43. The average variability, utilization and order time lead to a flow time of seven hours and four minutes.

The MCT* is derived in figure 7.14. It is seen that the MCT is influenced by the new critical path of the formed parts again and is equal to 142 hours. When regarding the option of the accelerated 3D-forming method again, the MCT* is defined by the red dashed line in figure 7.14 and is equal to 110 hours, leading to a QRM-number of 143.

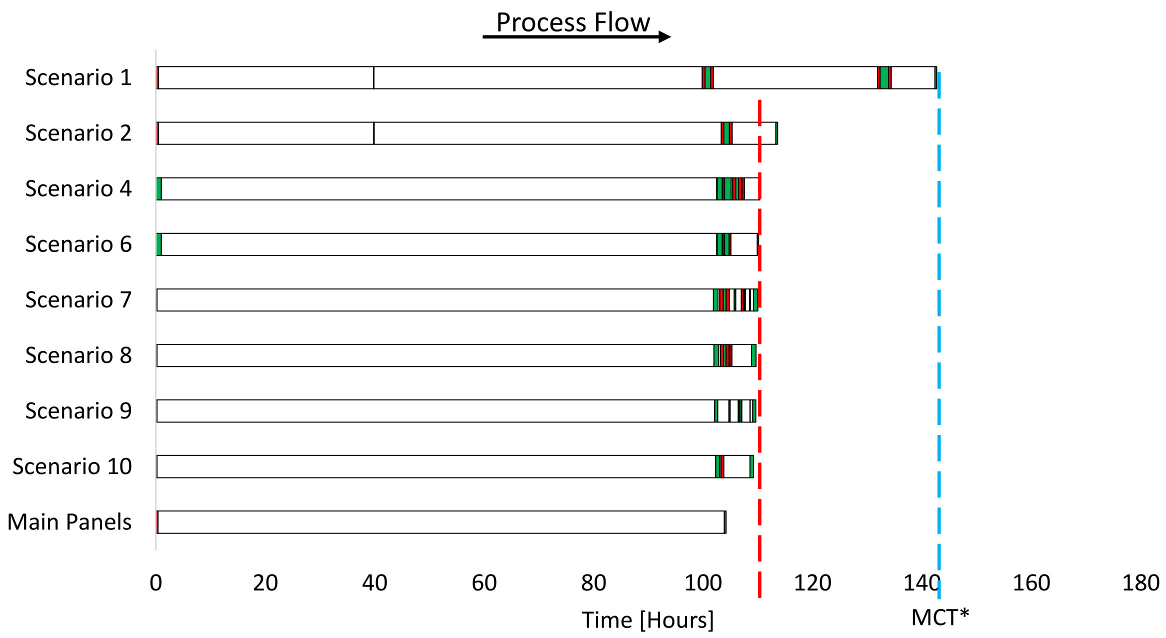


Figure 7.14: Determination of the MCT* of the preprocessing department with further decreased batch sizes

7.5. Conclusion

What are the potential improvements for the preprocessing department, based on Quick Response Manufacturing and what benefits do they bring?

Before implementing a cellular structure, more research should be executed on alternative improvement measures. In the meantime, it can be beneficial to apply some changes to current pain points seen in the preprocessing department. The pain points as stated in chapter 6 are used as the starting point for the improvement suggestions. Various key points of Quick Response Manufacturing are deployed to mitigate these issues. The first suggestion aims at reducing waiting times by changing the policy of the flanging department in two different ways. This leads to a QRM-number of 111 and a change in the critical path to the forming department. Making a change in this department by replacing the line-heating station to a roller press the MCT* is reduced even further to 129 hours, yielding a QRM-number of 121.

To decrease the grinding time, an option is suggested to cut flat bar parts out of profiles instead of plates. This decreases the batch sizes simultaneously. When keeping all other parameters constant, a MCT* is obtained of 142 hours, with a QRM-number of 111. The relation of batch sizes on the MCT* is then further examined by changing these. It is seen that as batch sizes are decreased, the flow times at the parts processing areas are decreased as well but the transport times increase as the amount of batches is now increased. The same counts for the touch time of the press brake as with more batches, more changeovers are carried out. A reduced MCT* is achieved of 110 hours, leading to a QRM-number of 143.

8

Conclusion and Recommendations

This research is setup to find the answer to the question: "Can Quick Response Manufacturing in combination with a minimal financial investment elevate the output of preprocessing department Section 1A of Damen Shipyards Galati to the current output of sections 1 and 1A combined?" To find the answer to this question, the production process at Damen Shipyards Galati is analyzed, a study about Quick Response Manufacturing is performed and a numerical simulation model of the preprocessing department is built, analyzed and modified according to key points of Quick Response Manufacturing. Measurements of timing in the model quantify the effect of these modifications on the lead time and provides insight in the most important parameters.

8.1. Answers to the Research Questions

In the introduction of this thesis a number of sub-questions and a main research question were defined. The answers to these questions yield:

- **What are the relevant insights about Quick Response Manufacturing?**
  Quick Response Manufacturing is a management strategy revolving solely about reducing lead times in a company. This lead time is defined with the 'MCT' (Manufacturing Critical-path Time): The representative amount of calendar time from the moment a customer creates an order, through the critical path until the first (partial) delivery for that order to the customer. The theory proposes an organizational structure that differs from most conventional approaches. The key principles of this structure is a cellular organization instead of functional departments. These cells are managed by the team working in the respective cell instead of a top-down control management. This team consists of cross-trained team members instead of specialized employees and their focus is completely on reducing the MCT instead of increasing efficiency and utilization. Results of improvement suggestions are measured with the QRM-number, that compares the MCT of a suggestion to the MCT of the initial situation.

  A QRM-cell requires support from the appropriate system dynamics. QRM emphasizes the importance of reducing utilization and variability. The interaction between two succeeding cells is done using the 'POLCA'-system: a system of cards travelling with orders in a loop of two succeeding cells.

  The competitive force of QRM states that being responsive can help a company gain market share. Reducing MCT reduces costs as well and helps increase quality of manufactured products. The organization brings new energy to the team members. With this in mind, it could be possible for anyone to strive ahead of other competitors in the market and to become a market leader in shipbuilding (or any other market for that matter).

- **Does the steel processing equipment allow the output to be elevated to the desired quantity?**
  A study about the preprocessing department at Damen Shipyards Galati was performed. The preprocessing phase of shipbuilding is a process that starts by cutting plates into parts, performing various operations on these parts and sorting them for various assembly steps. Based on these processes, a simplified yearly portfolio, the available equipment and the available number of personnel, is found that it could be possible to perform all steel preprocessing in section 1A. This information however does not yet incorporate interdependencies between equipment nor any dynamics.

- **What method is used to analyze the performnce of the preprocessing department?**
  In the previous answer it was determined that it could be possible to elevate the output of preprocessing section 1A. This was determined by a static analysis that does not incorporate interdependencies between equipment or any dynamics.

  To incorporate these interdependencies and dynamics a simulation study is performed. A discrete-event, object-oriented method is chosen to model the preprocessing department in section 1A of Damen Shipyards Galati. This is done using the software package *Siemens Plant Simulation* with the additional toolkit *Simulation Toolkit Shipbuilding*.

- **What are the specifications of the preprocessing department at DSGa in the current situation?**
  To make a quantified analysis of the preprocessing at DSGa a discrete-event, object-oriented simulation model is constructed. This model is verified and validated according to the procedures described by Sharma (2017). Using this model, it is found that the critical path is followed by parts that are ground and flanged. This critical path leads to a an MCT* of 157 hours.

- **What are the specifications of the preprocessing department at DSGa in the proposed situation?**
  It was tested if a cellular structure in combination with an altered nesting makes a substantial difference. First the methodology of improvement as stated by Suri (2011) is presented. Based on experience of the employees at DSGa and an analysis of the simulation model a number of pain points are listed, used as the starting point for the improvement suggestion and for constructing the cellular structure. It is shown that the rate at which a batch of parts is processed is a lot smaller compared to the initial situation, partly due to the fact that the batches are a lot smaller. The number of transports is however decreased drastically and a nesting that enables batches to be formed per cut plate leads to a substantial decrease in waiting time in the sorting step after cutting. With this suggestion implemented, an MCT* of little over 18 hours is achieved, yielding a QRM-number of 863 and an annual throughput of 9372 tons.

- **What are the potential improvements for the preprocessing, based on Quick Response Manufacturing and what benefits do they bring?**
  Before implementing a cellular structure, more research should be executed on alternative improvement measures. In the meantime, it can be beneficial to apply some changes to current pain points seen in the preprocessing department. The pain points as experienced by employees of DSGa and as analyzed from the simulation model are used as the starting point for the improvement suggestions. Various key points of Quick Response Manufacturing are deployed to mitigate these issues. The first suggestion aims at reducing waiting times by changing the policy of the flanging department in two different ways. This leads to a QRM-number of 111 and a change in the critical path to the forming department. Making a change in this department by replacing the line-heating station to a roller press the MCT* is reduced even further to 129 hours, yielding a QRM-number of 121.

  To decrease the grinding time, an option is suggested to cut flat bar parts out of profiles instead of plates. This decreases the batch sizes simultaneously. When keeping all other parameters constant, a MCT* is obtained of 142 hours, with a QRM-number of 111. The relation of batch sizes on the MCT* is then further examined by changing these. It is seen that as batch sizes are decreased, the flow times at the parts processing areas are decreased as well but the transport times increase as the amount of batches is now increased. The same counts for the touch time of the press brake as with more batches, more changeovers are carried out. A reduced MCT* is achieved of 110 hours, leading to a QRM-number of 143.

The conclusion of the literature study on Quick Response Manufacturing and analysis of the current situation of the preprocessing department of Damen Shipyards Galati shows that this department has a lot of potential compared to the way it is currently used. It is shown that the throughput can be elevated by even implementing relatively small changes proposed by QRM. A simple re-routing of parts is sufficient to make a substantial gain in the MCT* without even spending a single Euro. Big gains are achieved by introducing a cellular structure with a modified nesting of plate parts. With these changes implemented, a QRM-number of 863 was achieved with the throughput exceeding the original throughput of sections 1 and 1A together. The simple answer to the main research question therefore is **yes**. Quick Response Manufacturing can indeed make a substantial change for the preprocessing stage of shipbuilding. However, it is not stated that Quick Response Manufacturing is the very best method to improve this department. To find the best method, some further investigations need to take place. Therefore, some recommendations are proposed in the next section.

8.2. General Recommendations

In this section, recommendations for further research are presented.

- **Harvest full benefits by applying QRM to the whole enterprise**
  Quick Response Manufacturing typically is a company-wide approach. In a way, the complete shipbuilding process resembles a QRM-flow, with orders going from preprocessing, to panel-assembly, section-assembly to blockbuilding and hull-assembly. It could very much be beneficial to implement QRM to the whole process, instead of only a relatively small portion such as the preprocessing. As stated in chapter 1, there is a desire to increase the space for section building. Therefore it could also be beneficial to improve the working methods of the section building process itself, instead of only generating more space by improving the preprocessing department. Substantial gains can also be made by restructuring the office environment to achieve short response times, supporting the shop floor in an optimal manner.

- **Optimize the nesting**
  Within the scope of this thesis, the actual nesting of the parts on steel plates was only addressed briefly. For future research it can very much be beneficial to optimize this nesting to be able to feed the preprocessing the parts exactly where they need them, when they need them.

- **Investigate whether it is beneficial to also process parts for 960, 970, 980 and 990 in the preprocessing department**
  Currently these parts are processed elsewhere, which is of course beneficial for the MCT of the preprocessing on its own. When expanding the scope of the research however, it may be found that it is beneficial to process these parts in the preprocessing hall as well.

- **Investigate other improvement strategies than Quick Response Manufacturing**
  This thesis gives an indication that QRM can make a substantial difference for the preprocessing department of a shipyard. It is however not stated that QRM is in fact the best method of all management strategies available. Therefore it is interesting to investigate the influence of other strategies as well, with and without the boundary constraints of a low investment. A first step into this investigation is already made by Kees van Ekeren in his Master's thesis: "Process improvement of Damen Shipyards Galati pre-processing: Merging two pre-processing facilities by implementing Lean Manufacturing" (2018).

Bibliography

Paul Bender and Don Hoogendoorn. Dcr program - production optimisation, 2017.

Jip Buwalda. S1 pre-processing, presentation on value stream mapping and data gathering for process improvement, 2017.

Cynertia Consulting. It processes audit and improvement, 2006. URL `www.cynertiaconsulting.com`.

Damen. Section plan asd2913, 2015.

Damen. Damen shipyards galati - history, n.d.a. URL `https://www.damen.com/en/companies/damen-shipyards-galati/history`.

Damen. Damen shipyards galati - product portfolio, n.d.b. URL `https://www.damen.com/en/companies/damen-shipyards-galati#products`.

Damen. Section plan psv3300, n.d.c.

Marlon Dumas. Business process management - quantitative process analysis, 2015.

José M. Garrido. *Object Oriented Simulation.* Springer, 2009.

Tony Kuch. Continuous simulation modeling webinar, 2014.

MathWorks. Understanding discrete-event simulation, n.d. URL `https://nl.mathworks.com/videos/series/understanding-discrete-event-simulation.html`.

Torbjørn Netland. The concept epicenters of lean, tqm, six sigma & co, 2014. URL `http://better-operations.com/2014/01/17/concept-epicenters-lean-tqm-six-sigma/`.

Robert Paauwe. *Programming for Interaction Designers - Bridging the gap between design idea and code implementation.* 2012.

James Persse. *Project management success with CMMI.* Pearson Education, 2007.

ProModel. Justifying simulation, 2017.

Cristoph Roser. All about lean - organize your industry, 2017. URL `https://www.allaboutlean.com/`.

Lakshay Sharma. Difference between verification and validation, 2017. URL `http://toolsqa.com/software-testing/difference-between-verification-and-validation/`.

Rajan Suri. *It's about Time.* LeanTeam, 2011.

Jack Teuben and Bas Damman. Blueprint production, 2017.

Steven van 't Klooster. *How good is good enough in DP calculations?* 2018.

VDI. Simulation von logistik-, materialfluss- und produktionssystemen. *VDI-Richtlinie 3633 Blatt 9*, 2000.

Tom Zevenhoven. Damen yard performance. Master's thesis, 2017.

Jing Zhuang. Beveling tool vs grinder, 2018.

A

Layout of DSGa

This appendix shows the layout of Damen Shipyards Galati and the location of the two physically separate preprocessing facilities. Figure A.1 shows an overview of the yard of DSGa. It can be seen that this yard is split up into two separate, autonomous facilities:

- Section 1, on the left, marked in pink.
- Section 1A, on the right, marked in orange.

Furthermore Section 1B on the left is marked in blue, this is not a complete sub-yard but a collocation of workshops serving both sections 1 and 1A. It includes a pipe shop, a module-skids workshop, a mechanical workshop and a small-steel workshop.

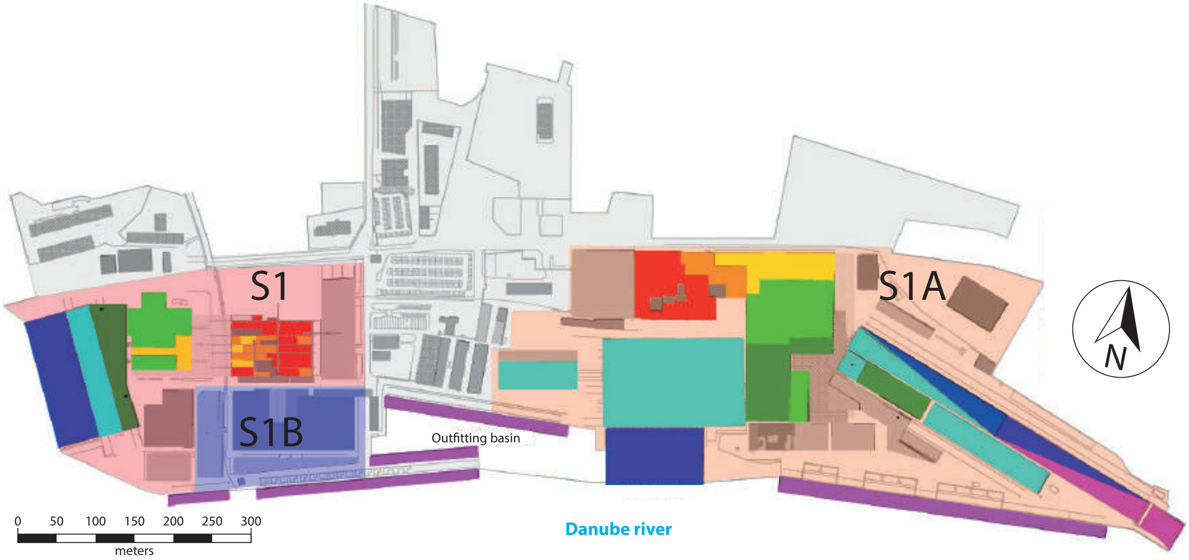


Figure A.1: Overview of the premises of DSGa

The various colours on this map indicate the step in the shipbuilding process taking place at the particular location. Table A.1 shows these colour codes, as devised by Jack Teuben. It is seen that parts in the shipbuilding follow the 'rainbow': from preprocessing in red, up to launching in blue and delivery in purple.

Table A.1: Production steps defined by colours

Colours	Process
Red	Preprocessing
Orange	Subpanel assembly
Yellow	Mainpanel assembly
Light green	Section assembly
Dark green	Block assembly
Light blue	Hull assembly
Dark blue	Launching
Purple	Outfitting, painting, commissioning and delivery

This division in S1 and S1A obviously means that there are also two separate preprocessing departments. Maps of the preprocessing departments of S1 and S1A can be seen in figures A.2 and A.3, respectively. Obviously the colours on these two maps do not coincide with the colours stated in table A.1, although the parts still follow a rainbow within preprocessing.

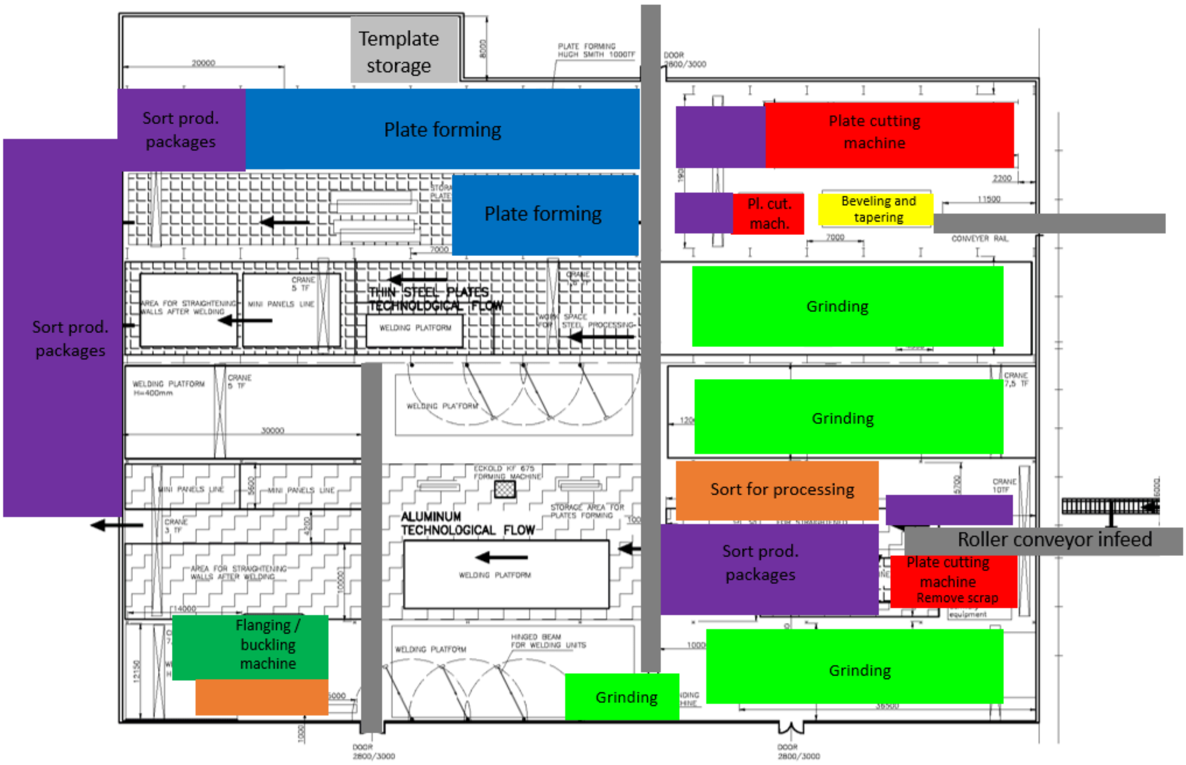


Figure A.2: Preprocessing department S1

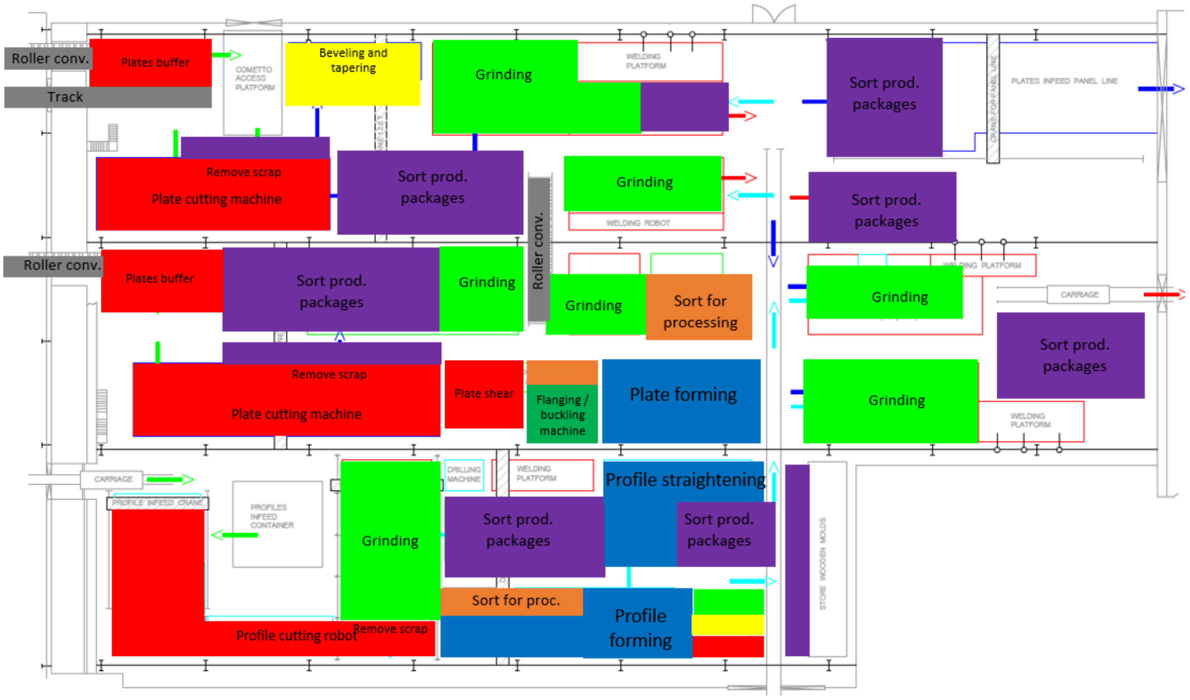


Figure A.3: Preprocessing department S1A

B

Benchmark

This appendix shows the computation of the productivity of DSGa, IHC Metalix and 247TailorSteel. The results are the following:

Table B.1: Benchmark of DSGa, IHC Metalix and 247TailorSteel

Facility	Floor area [m^2]	Output per area [T/m^2/year]	Output per area [Normalized w.r.t. DSGa]
DSGa	13000	1.92	1
IHC Metalix	6000	8.33 (5.55*)	2.89
247TailorSteel	3500	12.86 (6.12*)	3.19

*number of working hours decreased to double shifts for a fair comparison.

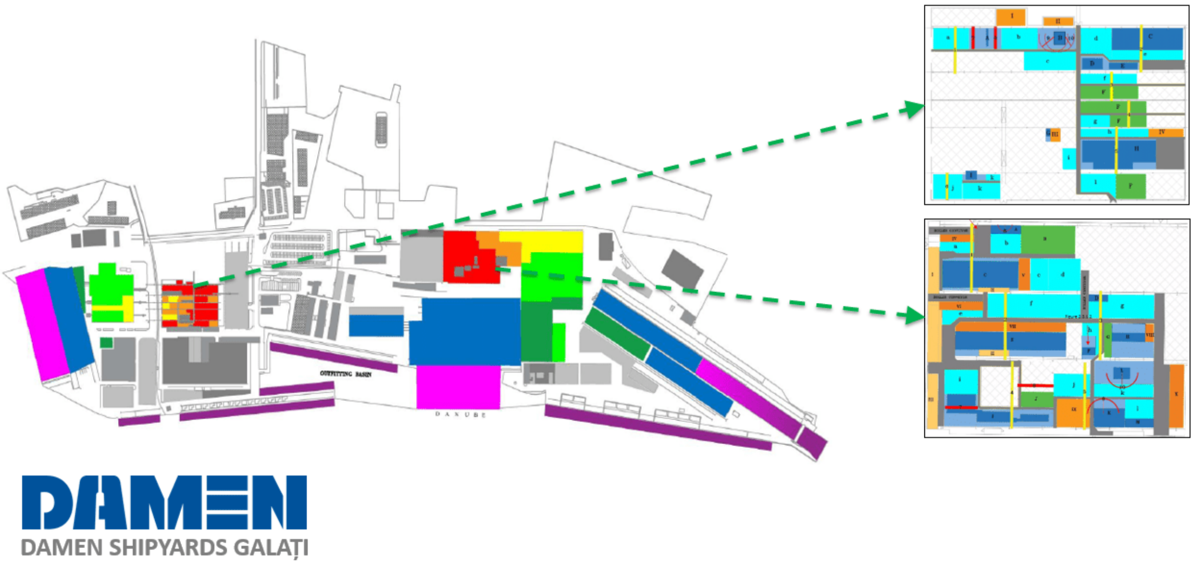
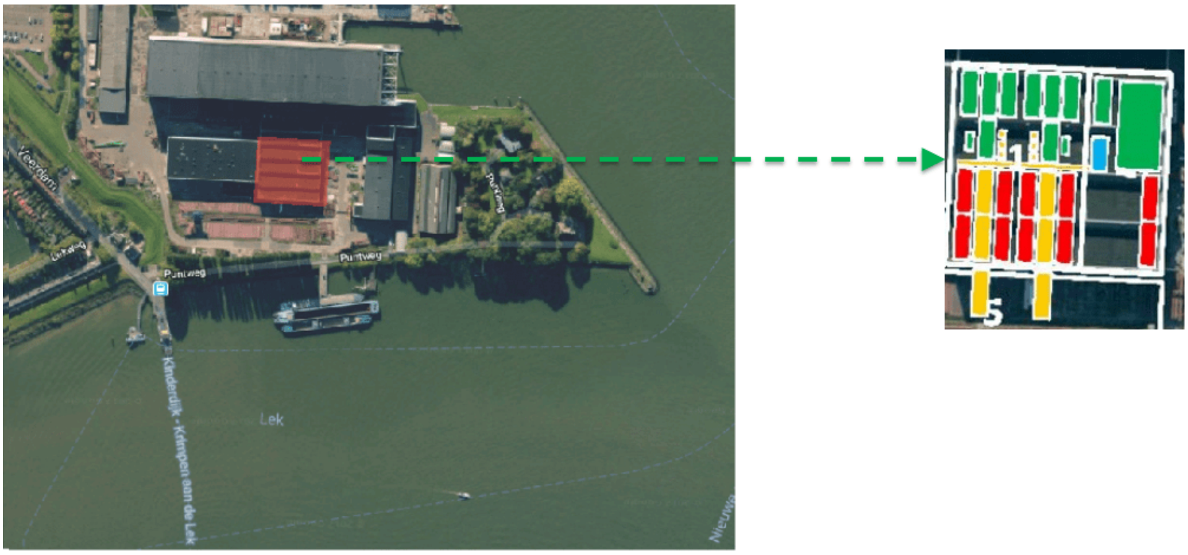


Figure B.1: Preprocessing department DSGa

Figure B.1 shows the preprocessing department of Damen Shipyards Galati. It has the following characteristics:

Floor area:	13000 m^2
Yearly output:	25000 tons
Productivity:	1.92 ton/m^2/year
Working regime:	'Double' shifts: 16/5



IHC METALIX THE TECHNOLOGY INNOVATOR.

Figure B.2: Preprocessing department IHC Metalix

Figure B.2 shows the preprocessing department of IHC Metalix in Kinderdijk. It has the following characteristics:

Floor area:	6000 m^2
Yearly output:	50000 tons
Productivity:	8.333 ton/m^2/year
Working regime:	'Triple' shifts: 24/5

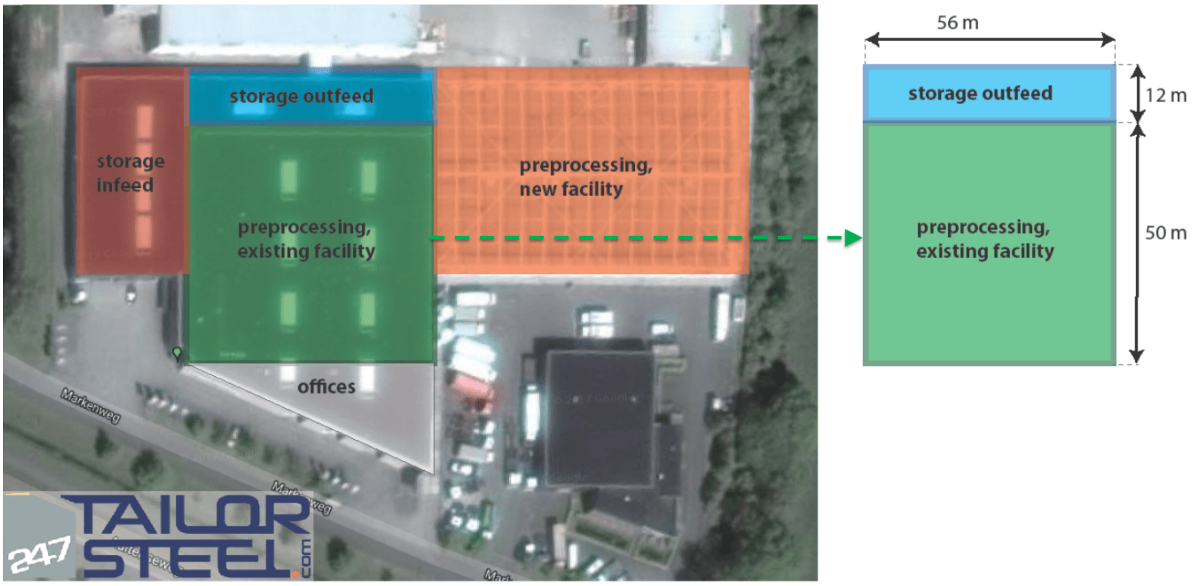


Figure B.3: PreProcessing department 247TailorSteel

Figure B.3 shows the preprocessing department of 247TailorSteel in Varsseveld. It has the following characteristics:

Floor area:	3500 m^2
Yearly output:	45000 tons
Productivity:	12.86 ton/m^2/year
Working regime:	24/7

C

Process Description of Preprocessing Section 1

They are structured as follows. The processes are described based on the layout delineations. Per part of the map the processes are described. The following topics are recognised: They are linked to the map presented in figure C.1.

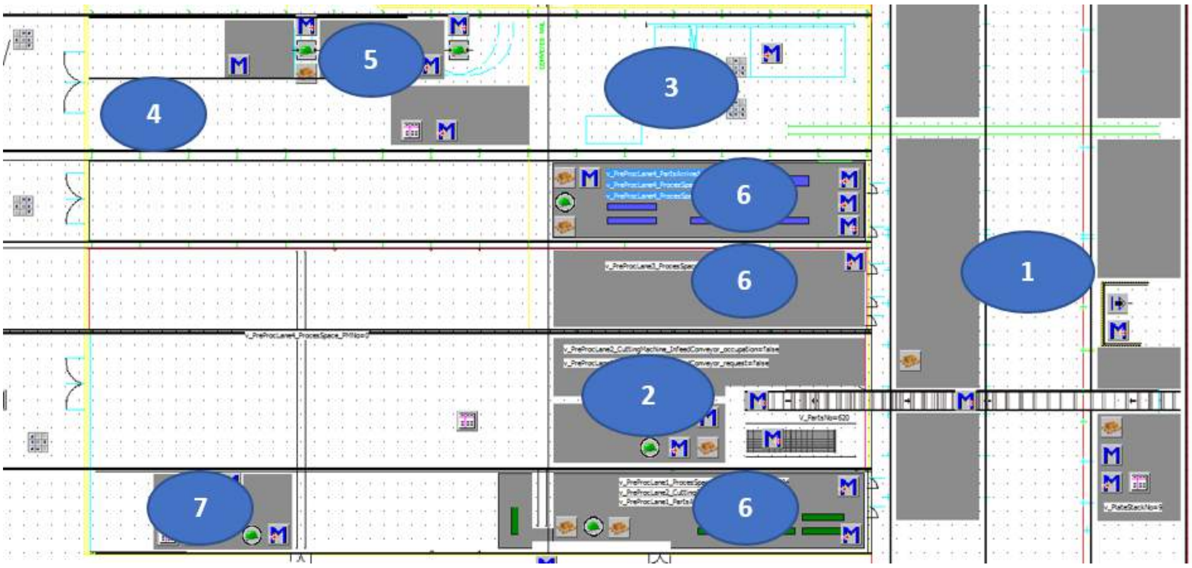


Figure C.1: Overall figure S1 facility

1. Outside plate storage
2. Plasma cutting machine
3. Oxy acetylene cutting machine
4. Beveling/tapering station
5. Forming station
6. Parts processing station
7. Flanging station

For each of these areas the process is described. The sorting for end buffers is described whenever applicable to the operations of the areas. This is done as follows.

1. General information: General information about the area is described. This includes the layout and general statements about logistics. Whenever applicable the following topics are dealt with:
    - Flow
    - Logistics
    - Machines/tooling
    - Personnel
2. Current situation: Each individual process is described, namely infeed, processing, outfeed/sorting. Sorting for end buffers is described whenever applicable. The description is done twofold:
    - Related to the layout: by means of arrows the flows are depicted. Each flow is then described under a sub header.
    - Related to flow diagram: a flow diagram is drawn. Each block is then described under a sub header.

All information in this document is reviewed by the Damen Yard Support department and the DSGa support team. As discussed in Chapter 4.

1. Outside plate storage

A. General information

In this section the outside plate storage is concerned. The input/output/internal flows are described. There are drawn in the Figure below, figure C.2.

1. A rack with plates arrive from S1A.
    - Thin plates (t<=30mm) per cutting group, batch size (max). approx. 100t.
    - Thick plates (t>30mm) joint transport for multiple cutting groups.
2. Plate output flows to cutting machines.
3. Left overs input flow.
4. Input flow of cut main panels which do not require forming.

These flows are described in more detail below.

B. Current situation

Plate entrance process:

Plates enter the steel storage in lane 3 and are unloaded onto the space.

Flow:

- The plates enter Section 1 from S1A, on a rack by means of a multi-wheeler / section transporter.
- The rack is emptied on the space by the crane
    - There is not specific need to let the section transporter waiting.
    - The plates are stored on stacks per thickness and cutting group.
    - Thickness <= 30mm are stored left.
    - Thickness > 30mm are stored right.

Logistics:

- The section transporter is able to carry approximately 100ton, and has its own driver, speed 2m/s.
- The crane can carry 10ton, with yoke.

People:

- Crane driver: belongs to cutting department pool.

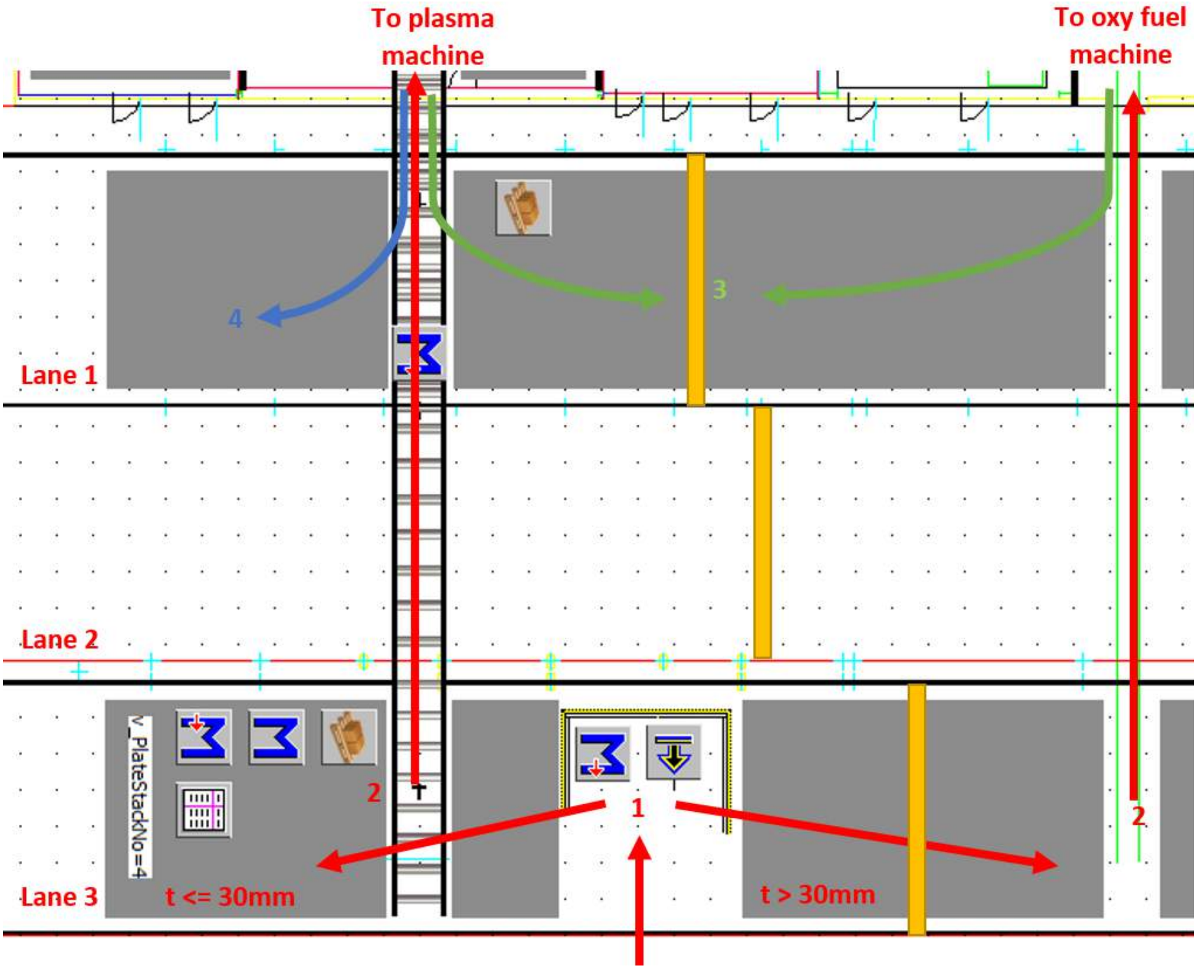


Figure C.2: Overall Figure S1 facility

Plates are loaded onto conveyor

Plates are moved inside the building to the cutting machine by either the conveyor (t<=30mm) or the carriage (t>30mm).

Flow:

- Thin plates: the plates are loaded onto the conveyor as a stack, to plasma machine.
  - By overhead crane.
  - When all plates of a certain thickness per cutting group are arrived and cutting machine is available.
  - The stack is moved inside when it contains all plates of a certain thickness per cutting group or load capacity of the conveyor is reached.
  - The infeed conveyor maximum contains two stacks. (1 is being loaded, 1 is being unloaded.
- Thick plates: the plates are loaded onto the carriage as a stack, to oxy fuel machine.
  - By overhead crane.
  - When all plates of a certain cutting group are arrived and cutting machine is available.
  - Moves inside when all plates of a certain cutting group are loaded.

Logistics:

- Conveyor loading capacity: 25 tons, speed 4m/min.

- Carriage: loading capacity: 25 tons, speed 30m/min.

People:

- Both are operated by crane driver, belongs to cutting department pool.

Left overs storage
After cutting the left overs enter the steel storage again. This is done during the night shift. There is not specific storage strategy.

Flow:

- Left overs leave the cutting areas by conveyor or carriage, per batch.
- Loaded onto the space in lane 1.

Logistics:

- Conveyor/carriage see no. 2.
- The crane can carry 10ton, with yoke.
- Speeds see technical data document.

People:

- Operated by crane driver, belongs to cutting department pool.
- Two shifts per day are worked. This applies for the entire pre-processing organisation.

Cut main panels outfeed
Main panels are moved out via the conveyor. This is done at the end of each cutting group. They are stored on a rack per section. There is room for only one rack so if this is occupied the plates are stored on the space.

Flow:

- Cut main panels leave the cutting areas by conveyor, per stack.
- Loaded onto rack/space by overhead crane in lane1.
- Wait for transport to main panel line in S1a. or S1 end buffer.
- Loaded from the space onto a rack for transport.
- Moved when rack is full.
- S1 main panel end buffer is located at the end of the pre-processing shed.
- S1a buffer is indicated in the S1a process model description.

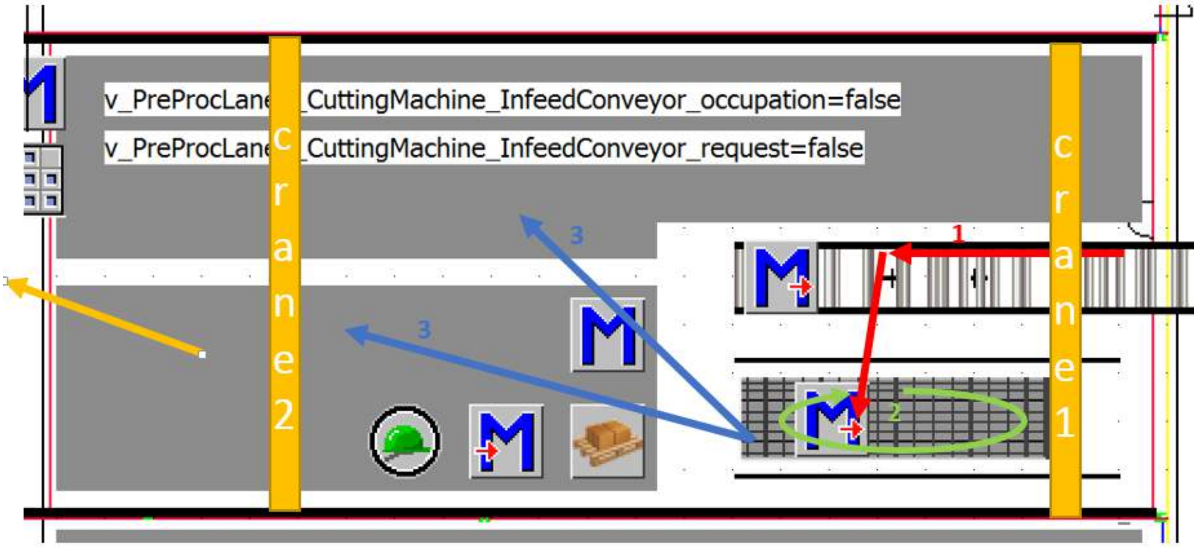
Logistics:

- Section transporter was already introduced

2. Plasma cutting machine station

A. general information

Here the second area, distinguished in the introduction, is described. First the layout is presented in figure C.3 and department general characteristics are described. Then the following arrows are described: Subsequent general notions are described, followed by notions concerning logistics and people.



v_PreProcLane_CuttingMachine_InfeedConveyor_occupation=false
v_PreProcLane_CuttingMachine_InfeedConveyor_request=false

Figure C.3: Overall figure S1 facility

- Infeed of plates
- Plate cutting process
- Sorting process
- Transport process

General:

- Part mass > 100kg, crane 1, time depends on crane speed
- Part mass >20 and <=100kg, crane 2, time depends on crane speed
- Part mass <= 20kg, by hand, takes on average 0.5min. per part.
- Big container: size 3m x 8m, loading capacity of 8t.
- Small container: size 1m x 2m, loading capacity of 2t.
- Small part: length and width < 0.5m.

Logistics:

- Characteristics crane 1: loading capacity 10t, equipped with yoke,
- Characteristics crane2: loading capacity 10t, equipped with small magnet
- Speeds see technical data document.

People:

- The cutting department pool consist out of 1 foreman and 5 workers.
- Foreman managing all cutting departments in S1.
- Five workers:
  - Worker 1: sorting, operate cutting machine (plasma)
  - Worker 2: sorting, operate cutting machine (oxy fuel)
  - Worker 3: sorting, can operate the conveyor, carriage and crane
  - Worker 4: sorting, can operate the conveyor, carriage and crane
  - Worker 5: sorting, can operate the conveyor, carriage and crane

B. Current situation

Now the arrows are described.

Plate infeed process

The plates are moved inside per thickness and per cutting group (nestings of 4-6 sections, ±100t.) and loaded onto the cutting bed.

Flow:

- A stack of plates with the same thickness arrives on the conveyor.
- The stack is unloaded one by one, by means of crane 1.
- Plates are directly loaded onto the cutting bed.
- When the stack is emptied a new stack can arrive.

Cutting process

Flow:

- When the plate is loaded on the cutting bed the cutting machine operator has to activate the machine.
  - When a new thickness is being cut a changeover time of 10min is required.
- Plate is marked.
- 50% of the parts is signed by inkjet tool.
- Plate is cut by means of plasma.
  - Automatically bevels V-seams
- 50% of the parts are signed by hand.
- Scrap cutting by hand
- Scrap removing by hand
  - Loaded in red containers
  - Container is moved every week on Tuesday, first shift.
- Sorting of parts.
  - Described in next paragraph.

Machines/tools/logistics:

- Cutting machine has one portal
  - Dry plasma marking and cutting tool
  - Inkjet torch
- Cutting machine characteristics: one cutting bed, tmax <= 30mm, aluminium cutting ability.
- Further cutting machine characteristics unknown, provide separately
- Red container: 1.5m x 2m, loading capacity of 5t.

People:

- Manual signing by cutting machine operator.
- Scrap cutting by cutting machine operator
- Sorting by all workers.

Sorting process

Here the sorting rules are described. First a general notion is made.

General:

- Logistic transportation rules as described in introduction of this paragraph.
- The parts are sorted per section.
  - Different containers or stacks for different destinations.

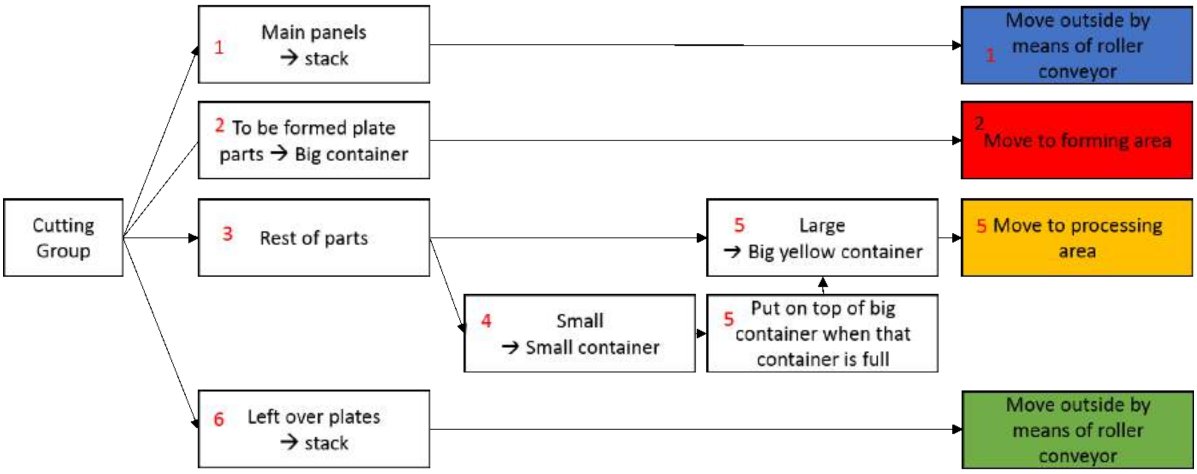


Figure C.4: Cutting sorting process diagram

Flow:
The letters refer to the letters in the flow diagram above.

1. Main panels. (end sort code 930, part type PL and panel name 1xx-4xx)
    - Put on a stack
    - Moved outside by the roller conveyor. Flow 4 in figure in chapter 1.
    - Moved after cutting group is finished.
2. To be formed plate parts (no profiles) are put in a big container
    - Container is full when load is maximum or cutting group is finished
3. Rest of the parts is sorted on weight/size.
4. Small parts
    - Empty container is picked up from outside (lane2.)
    - When the container is full another container is used.
5. Big parts
    - Empty container is picked up from outside (lane2.)
    - When container is full a small container is loaded on top.
        - Independently whether this container is full or not.
    - A carriage is requested to bring the joint combination of big and small container to the next destination, which is a part processing space.
    - Then a new empty container is used.
6. Left over plates are moved outside the same way as the main panel plates
    - They are stored conform the description at the ‘plate storage’ chapter
    - Minor flow, therefore not further considered.

Next station selection process
As described under the previous flow (no. 3) there are 3 destinations.

General:

- Main panels: flow to outside, described earlier in first section.
    - Temporary storage on sorting area after cutting.
    - Moved outside by roller conveyor.

  - Temporary storage on outside plate storage (described in first chapter),
  - Moved by truck to either S1a end buffer (main panel line) or S1a end buffer
- To be formed plate parts: flow to infeed/outfeed buffer for forming. This is a sorting area.
  - All containers of one cutting group are sent there.
- Rest of the parts: moved to parts processing spaces, illustrated on figure below.
  - Not per cutting group but per section.
  - Section is assigned to parts processing area in a planning.
  - Only one section processed at parts processing space at once.
  - When parts processing space is occupied containers are temporarily stored outside (green arrow). (Two containers can be temporarily stored at parts processing space too.)
    - ◇ A part processing space is occupied for all containers else than the ones belonging to the section under consideration.
    - ◇ When parts processing is available again the containers of a new section can enter.
    - ◇ A parts processing space is available when all parts of the processed section are processed and left.

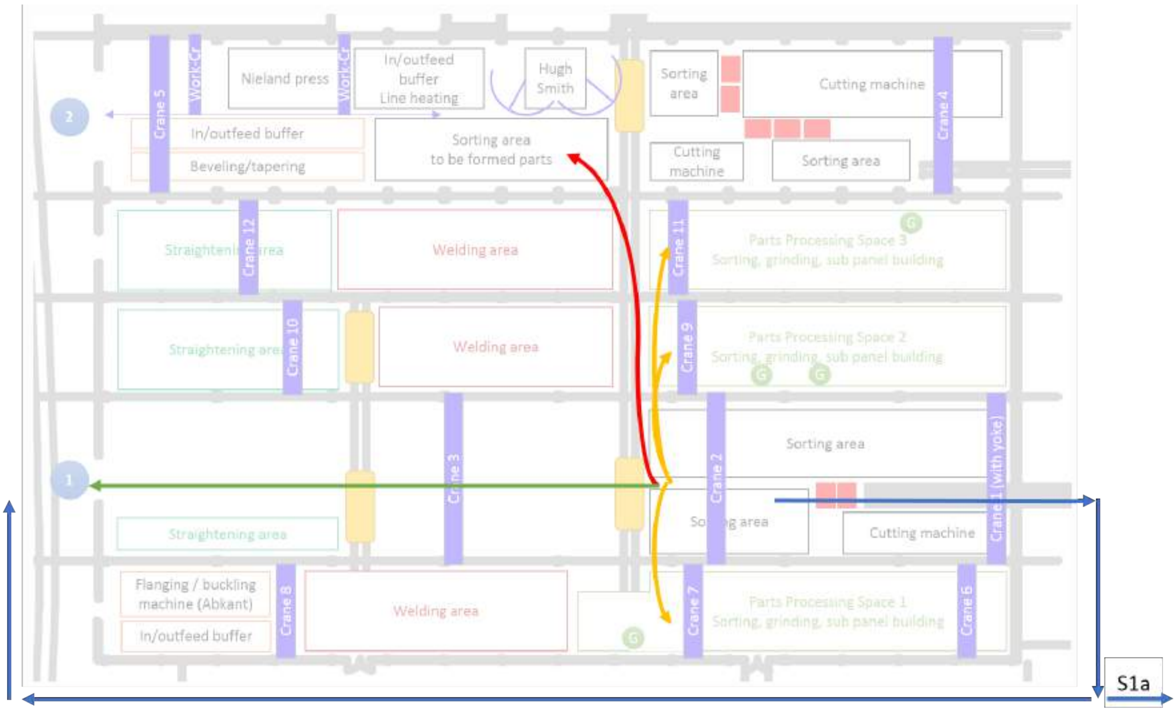


Figure C.5: Cutting transport overview

Flow:

- Container is put on carriage by crane 2.
- Carriage moves to next destination.

Logistics:

- Attaching a container to a crane takes 10minutes (time for attaching the slings).
- Carriage: loading capacity: 25 tons, speed 30m/min.
- Two carriages on the same track.

Beveling / Tapering station

A. General information

Here the third station, as introduced in the introduction, is described. Below the bevel station is indicated on a layout map. The input/output and internal flow will be described.

1. Input flows entering the infeed buffer

    - From sorting space of oxy fuel cutting machine, thick parts, transported part by part.
    - From part processing spaces, thin parts, transported on a container (only require tapering)

    [noitemsep]

2. Internal process: part processing

3. Output flow form the outfeed buffer

    - To outside buffer, thick parts, transported part by part.
    - To part processing spaces, thin parts, transported on a container.

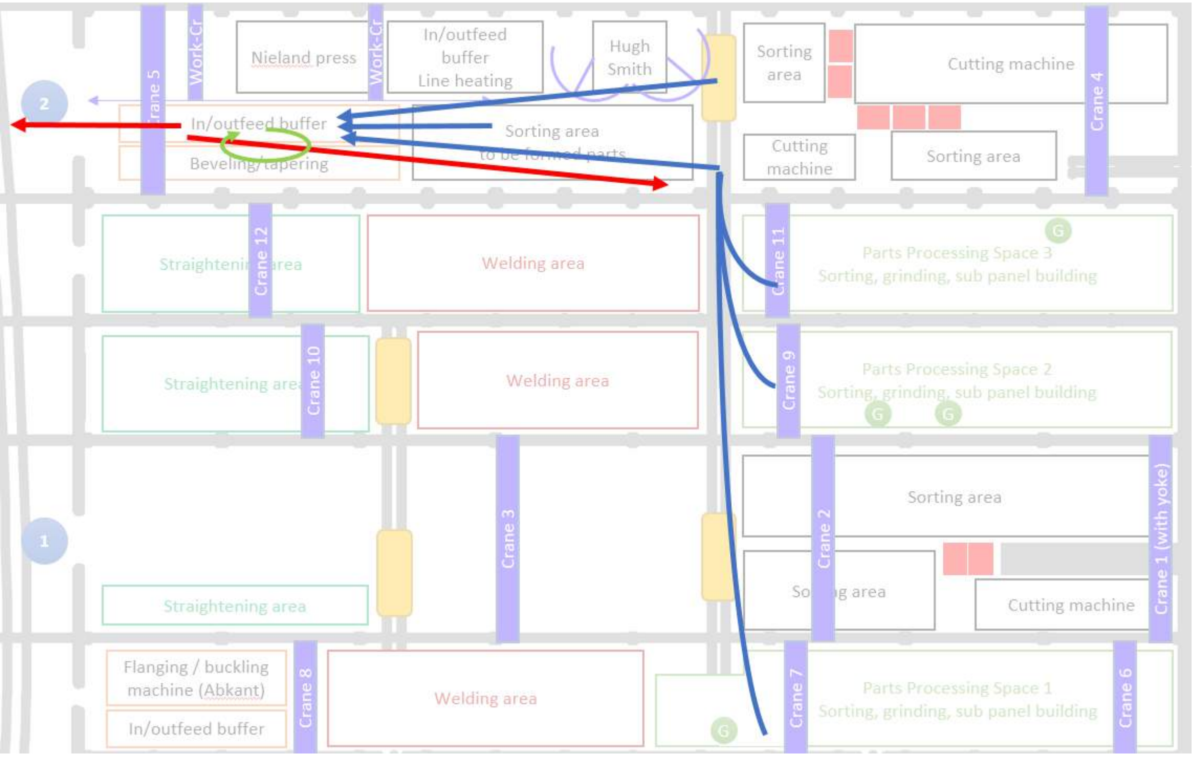


Figure C.6: Tapering station S1

Logistics:

- Crane 5 is used in the tapering station, loading capacity 10ton,
- Speeds see technical data document

People:

- Done by worker originating form part processing space where section is processed.
- Beveling skill, 2 workers per parts processing space.

B. Current Situation

Now the flows will be described individually. The colors of the flows match with the colors of the subtitles.

1. Infeed flow

Flow:

- Plates enter the infeed buffer on a container or single by means of crane 5 or crane 13.
- Container is offloaded on the space and then used again.

2. Internal process

Flow:

- A part is picked up by crane 5 and put a work bench. (there are 2 of them)
- If it requires tapering the semi-automatic tractor is setup for tapering, The part is tapered.
- If it requires beveling (only thick parts) the semi-automatic tractor is setup for beveling, The part is beveled.
- The part is picked up by crane 5 and put back in the outfeed buffer.
  - Thick part, on stack
  - Thin part, on container

Machines/tools:

- 2 workbenches (10m x 3m)
- Setup time for semi-automatic tractor is 5 minutes

People:

- Specific skills required.

3. Output process

Once the parts are processed and stored on a container or stacks they are moved to the next destination.

Flow:

- Thick parts, moved out to outside buffer by crane 5, one by one.
  - When main panel is built in S1a on main panel line the parts with end buffer code 930 move per section to S1a, else stored on end buffer space.
- Thin parts, moved back to part processing spaces, by crane 5 and carriage, on a container

B. Current situation

Containers with parts arrive

Once a container enters the parts are sorted. An overview is provided in figure C.7.

Flow:

- Containers with parts arrive at the parts processing spaces on a carriage.
- The containers are unpacked.
- Sorting is done as depicted below.
  - Parts which require tapering, container.
  - Plates size L<6m, stack 1
  - Plates size L=>6m, stack 2
  - Pallet full when approximately 750kg.

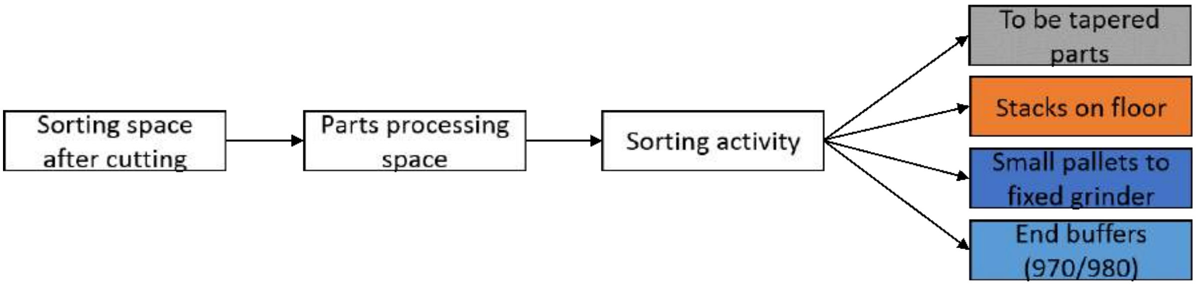


Figure C.7: Local grinding infeed sorting overview

Flow to tapering
Flow:

- When all parts which require tapering are collected they are moved on a carriage to the tapering station.
- When they come back they follow the same procedure as the other parts.
    - Stacks on floor.
    - Small pallets to fixed grinder.

Flows originating from stacks
An overview of the flow, depicted in figure C.8, is described in the following steps:

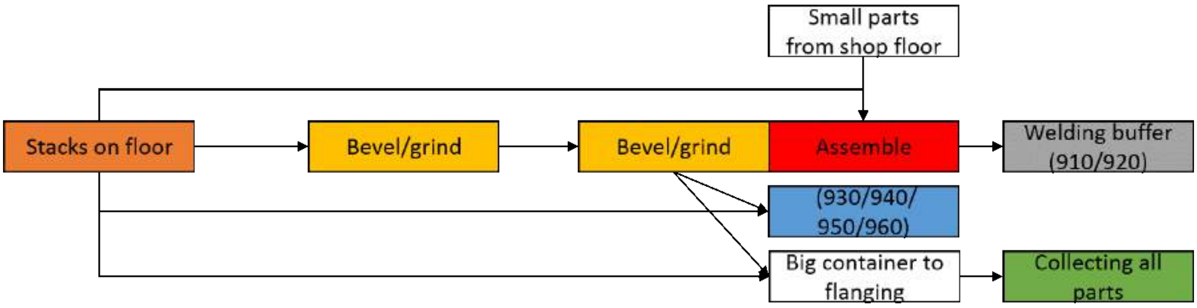


Figure C.8: Processing of large parts

Flow:

- Part is picked up from the stack and put on a work bench, by means of a crane.
- When all parts which are arrived at the parts processing area are unpacked and sorted
- Destination decision:
- If no grinding/bevelling is required and flanging is required, the part is put in a big container.
- If parts require no pre-processing and sub assembly, part is stored in a container for the end buffers. (main panel, section, block, hull assembly respectively)
- If parts require no pre-processing but sub assembly, part is put on a work bench.
    - 1 or 2 work benches depends on size of part.
- Else the part is bevelled and/or grinded on the table.

Processing
Flow:

- Part is bevelled and/or grinded.
- Part is rotated by means of the crane an put on the same spot on the workbench.
- Part is bevelled and/or grinded.
- Decision for next destination:

- If parts require flanging they are put in a container
- If parts are finished they are put in a container per end buffer.
    - The position of the end buffers is illustrated in the layout figure below.
- If parts require assembling they are assembled on the same spot on the work bench.
    - Once assembled the part is loaded onto a container for the welding end buffer.
    - Once all parts are assembled the container moves to the welding station.

Assembling

Assembling is not modelled, only until grinding/bevelling is modelled. Then the parts are stored in a container.

Flow:

- Part is put in a container with all parts for sub panels (910,920 codes)
- Container moves to welding station.

Flows originating from pallets

An overview of the flow, depicted in figure C.9, is described in the following steps:

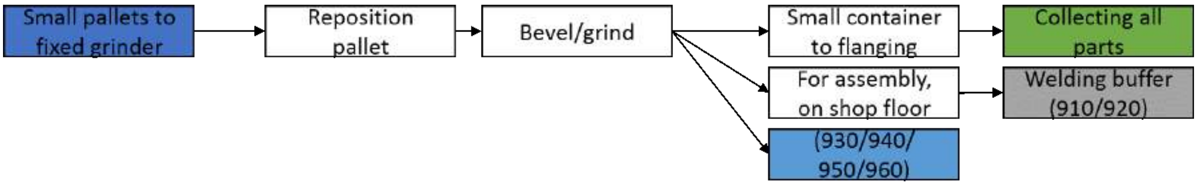


Figure C.9: Processing of small parts

Flow:

- Pallet is re-positioned near a small grinding station.
- Green bullet in overview figure at the start of chapter.
- Small grinding station, dedicated work bench and/or belt grinding machine.
- Parts are picked from the pallet by hand, grinded/bevelled.
    - When all parts which are arrived at the parts processing area are unpacked and sorted
- Destination of part is determined.
- Pallet for parts to flanging, pallet 1
- When required for sub panel building, put on the shop floor in the neighbourhood where assembly takes place.
    - Follows procedure as described under 'Assembling'
- For end buffers, pallet 2-5.
    - If there is a container and a pallet which have the same end buffer the pallet loaded onto the container. Else pallet is directly moved to end buffer.

Collection all parts for flanging

An overview of the flows is depicted in figure C.10. The flows are described below.

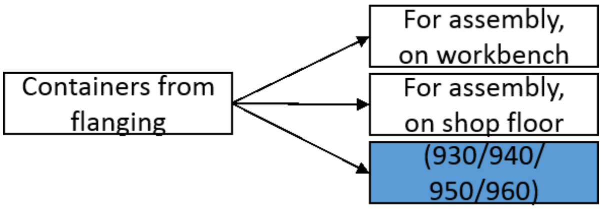


Figure C.10: Collection to be flanged parts

Flow:

- When all parts for flanging are collected the pallet is loaded upon a container by crane.
- Container moves to flanging
- At the flanging station one section is processed at the time.
    - In the infeed buffer there is room for storing 1 container temporarily.
- When flanged there arrive at the parts processing space again, the following step takes place.
    - End buffer parts are directly sorted in the right containers/pallets, by hand or crane
    - parts for sub panel building are put on the floor (small) or work benches (large).

Final transport
The parts which do not require not assembled to sub panels are moved to the outside buffers. An overview of the flow is presented in figure C.11.

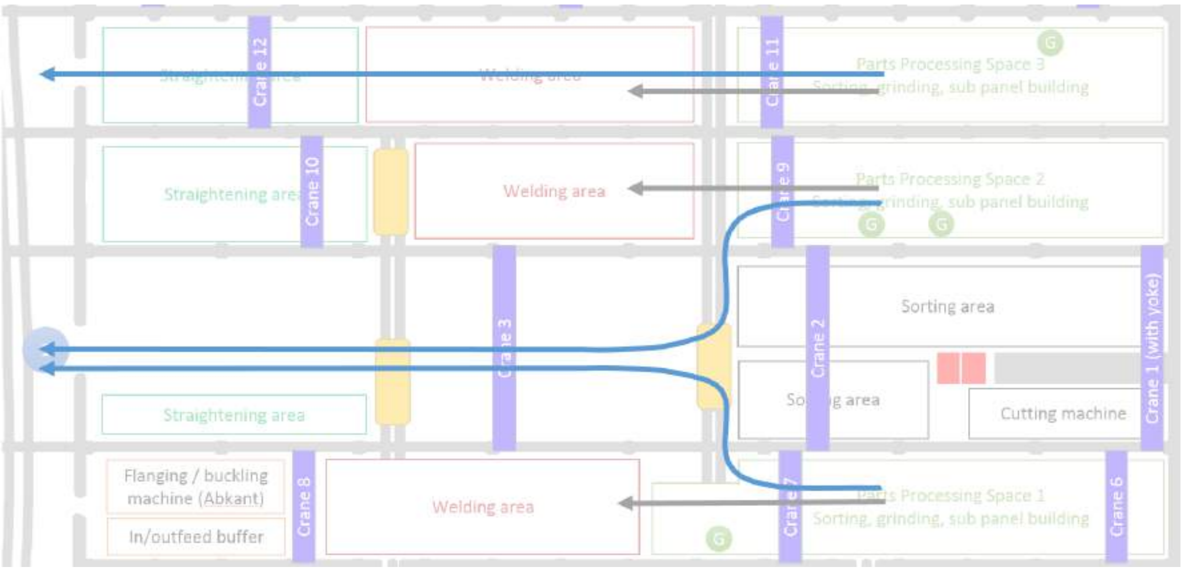


Figure C.11: Final transport from grinding stations

Flow:

- Buffer 940/950/960/970/980, moved to outside storage. See figure below.
- Buffer 930 moved to main panel line in S1a.

Flanging station

A. General information

In this part of the process model description the flanging station is described. First the overall layout of the station and the position in the S1 shed is presented. The parts which are processed in the flanging station originate from all three parts processing spaces in S1. When processed they parts move back to the parts processing spaces. These flows are drawn on the layout in figure C.12. First some general notions are made. Then the flows are described individually.

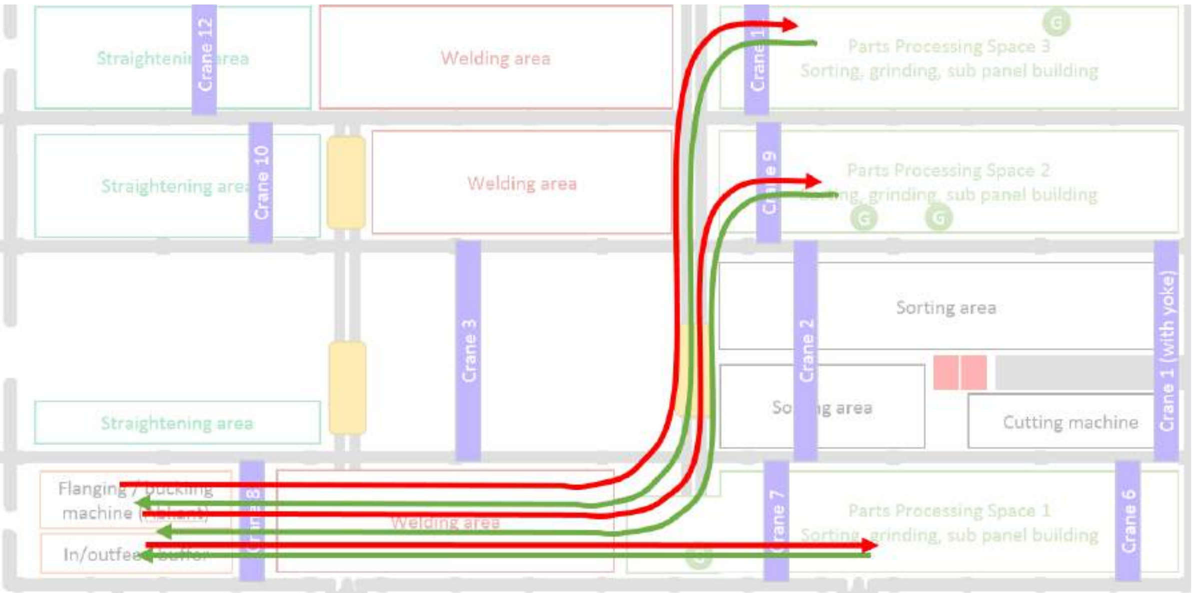


Figure C.12: Transport between grinding-flanging-grinding

General:

- Same handling rules as in parts processing.

Logistics:

- crane 8 is used in this area. Speeds see technical data document

machines/tooling

- press brake

People:

- Same foreman as the forming station
- 2 workers, highly skilled, 1 per shift.
- 2 workers, assistants, 1 per shift.

B. Current situation

Parts entrance

The parts enter the flanging station from the parts processing station.

Flow:

- Container with parts arrives.
- The pallet is offloaded and positioned close to the press brake.

  - The parts are picked up from the pallet and put on the flanging machine.
- The other parts are offloaded from the container and put on the space
  - When the container is offloaded the parts are picked up and put on the flanging machine.

Flanging process
Flow:

- A part is flanged, not necessarily in batches per thickness.
- After flanging:
- small part is put again on a pallet
- Large part is put again on a container
- Pallet is put on container and is sent back to the part processing area.
- By crane (and carriage)

Machine

- Setup time of machine is approximately 5min

People:

- One skilled operator required.
- One assistant required.

D

Process Description of Preprocessing Section 1A

This document contains Process-related information on facility S1A. It is possible to use this as a guideline for checking the procedures or for making another model.
The scope of this document contains:

- Material storage S1A
- Plate preprocessing S1A
- Plate parts preprocessing S1A

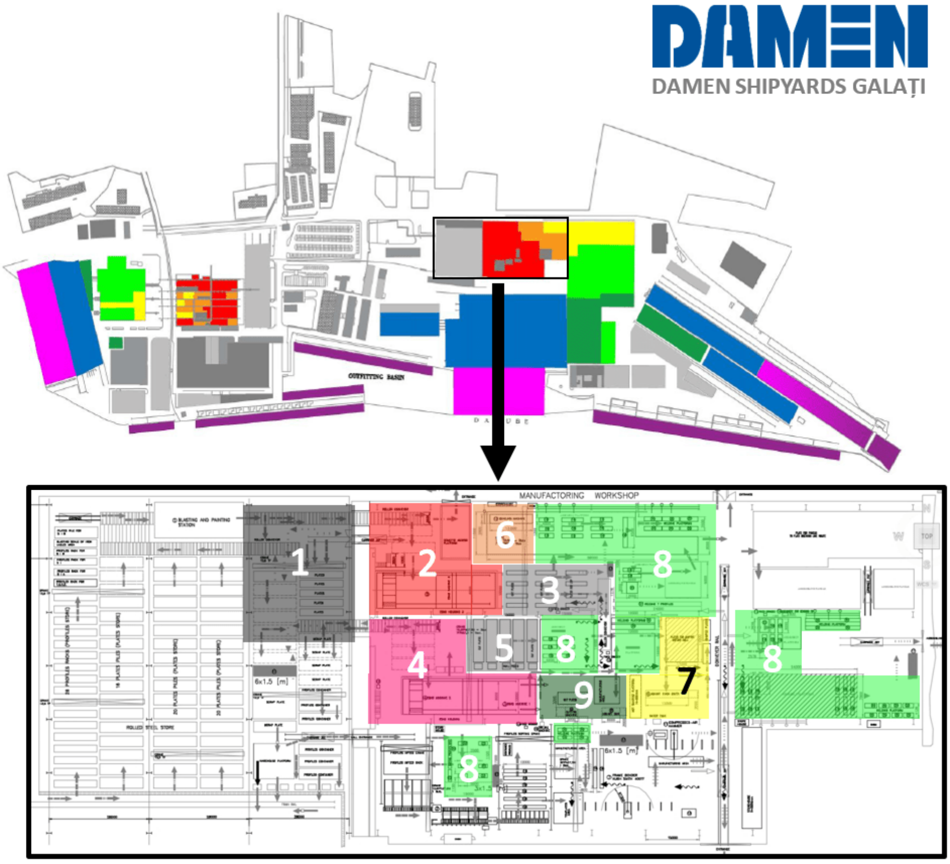


Figure D.1: Overview of various parts of the preprocessing department of section 1A.

This document contains information regarding the following processes and areas, corresponding to the map shown in figure figure D.1.

1. Plate storage
2. Infeed and cutting of plates - Lane 3
3. Sorting after cutting – Lane 3
4. Infeed and cutting of plates – Lane 2
5. Sorting after cutting – Lane 2
6. Tapering Station
7. Forming Area
8. Parts processing Area
9. Flanging Area

These sections are built up in the following structure:

A. Short description.
A short description showing the events taking place at this step.

B. Current situation.
A more extensive description, concerning:

- Flow details,
- Logistic equipment,
- Machines,
- Tools,
- Personnel.

The end sorting procedure is included in the chapters. All information in this document is information assumed by the writer, based on information obtained from DSGo, DSGa and own observations. The numbers of the foremen and their crews correspond to the foremen stated in appendix F. The numbers of cranes and other equipment correspond to the numbers in appendix E.

D.1. Plate Storage

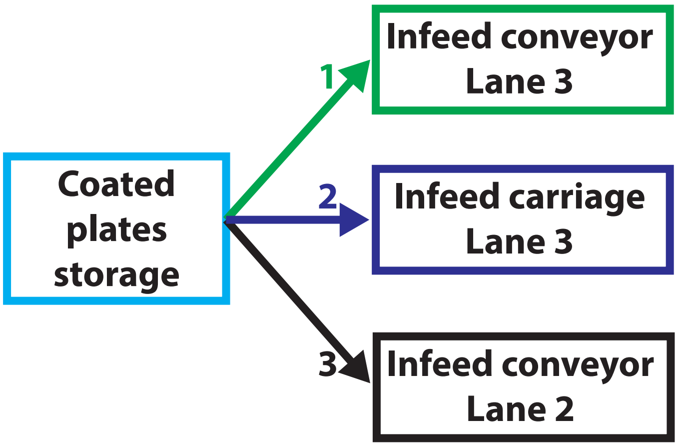


Figure D.2: Possible flows at the plate storage

A. Description of plate stock

This section describes the process taking places in the raw plates stock.
The starting point is the ‘coated plates storage’: intermediate storage after shot blasting shed.
As seen in figure figure D.2, there are three possible routes.

1. On the infeed conveyor of lane 3,
2. On the infeed carriage of lane 3,
3. On the infeed conveyor of lane 2.

These three possibilities are further explained in the next paragraphs.

B. Current situation

Flow Details

In the intermediate plates storage, the plates are stacked on stacks of the same cutting group, per thickness. As stated, the infeed of plates takes place with either of three routes. This decision is made based on the cutting group assignment.

- Infeed Conveyor Lane 3
  - Used for plates that are cut in section 1 and plates cut in lane 3 of section 1A.
  - For plates cut in S1:
    - ◇ Plates are stacked onto the conveyor, up to its max. capacity.
    - ◇ When this stack is complete, the stack rolls in to hall S1A.
  - For plates cut in lane 3 of S1A:
  - All plates of the same thickness are stacked right next to the conveyor.
    - ◇ Two plates are stacked onto the conveyor, so the conveyor is not occupied with stationary plates.
    - ◇ When this stack is complete, the stack rolls into hall S1A.
- Infeed Carriage Lane 3
  - Hardly used, as infeed sometimes for plates that are cut in lane 3.
  - Plates are stacked onto the carriage, up to its max. capacity.
  - When the stacking is complete, the carriage rolls into hall S1A.
- Infeed Conveyor Lane 2
  - Used for plates that are cut in lane 2.

  - Plates of the equal thickness are stacked onto the conveyor, up to its max. capacity.
  - When this stack is complete, the stack rolls in to hall S1A.

From the stack in the intermediate plate storage the crane takes the plates one by one and stacks them onto either of the conveyors or onto the carriage.

Logistics
In this step, the following equipment is utilized:

- Crane:
  - Crane type: 2 overhead cranes with a magnetized yoke.
  - The North portal is used to load plates onto the conveyor of lane 3 and the carriage of lane 3.
  - The South portal is used to load plates onto the conveyor of lane 2.
- Conveyors:
  Both conveyors have the following specifications:
  - Max. capacity: 25 tons.
  - Speed: 4 meters/min.
  - Width: 3.5m.
- Carriage:
  The infeed carriage has the following specifications:
  - Max. capacity: 30 tons.
  - Speed: 30 m/min
  - Width: 2.5m
  - Length: 9m.

Personnel
- Two employees are used for this step.
- Skills:
  - Crane Driving
- Crew:
  - Foreman 4
- The cranes, carriage and conveyors are all operated by the same team.

D.2. Infeed and Cutting of Plates

A. Description of the Cutting Department of Lane 3

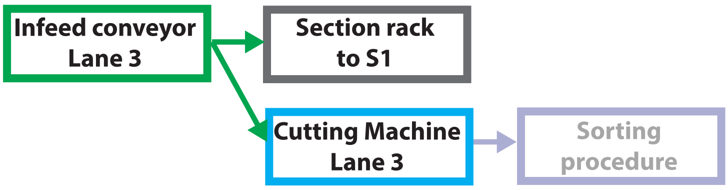


Figure D.3: Possible flows at the infeed of the cutting department of lane 3

In the cutting department, the following events take place:

- Plates are transported from the infeed conveyor in Lane 3, to a transporter driving to section 1.
- Plates on the infeed carriage in lane 3 are put on the cutting bed, cut into parts and then sorted for their next destination.

B. Current Situation

Flow
When a plate is entered on either of the transport means, there are several routes possible:

1. When a stack of plates due to be cut in section 1, enters on the infeed conveyor in Lane 3:
    - The plates leave the building to be cut in section 1.
    - Plates for a cutting group are stacked onto a section transport platform.
    - Up to 100 tons.
    - With the least amount of different thicknesses possible.
    - When this platform is full, it is brought to section 1.
2. When a stack of plates due to be cut in lane 3 of section 1A, enters on the infeed conveyor in Lane 3:
    - The plate is put on one of the cutting beds of the cutting machine.
    - The machine marks lines for future joints
    - The machine cuts the plates into separate parts
    - An employee takes a pressure washer and rinses the plates down
    - The operator drops by and writes the part number and routing on the parts.
    - The operator manually cuts the scrap into smaller pieces.

Logistics
In this step, the following equipment is utilized:

- Crane:
    - Crane portal 60598 is dedicated for the cutting department. The crane carries a magnetized yoke.

Machines
One cutting machine is utilized:
The machine:

- Has 4 cutting beds with water basins.
- Has 1 cutting portal.
- Is capable of doing parallel or mirrored cuts with two torches.
- Is capable of beveling V-seams.
- Is capable of marking lines for future joints on the parts.
- Is not capable of signing information on the parts.

Tools
In this step, the following tools are used:

- A manual oxyfuel torch to cut the scrap into small pieces.
- A white marker for signing

Personnel
Two employees are present to operate the cutting machine, perform the scrap cutting, signing and sorting of parts.

- Crew:
  - Foreman 4
- Skills:
  - Operating ESAB-machine
  - Crane driving

D.3. Sorting after cutting - Lane 3

A. Description of Sorting

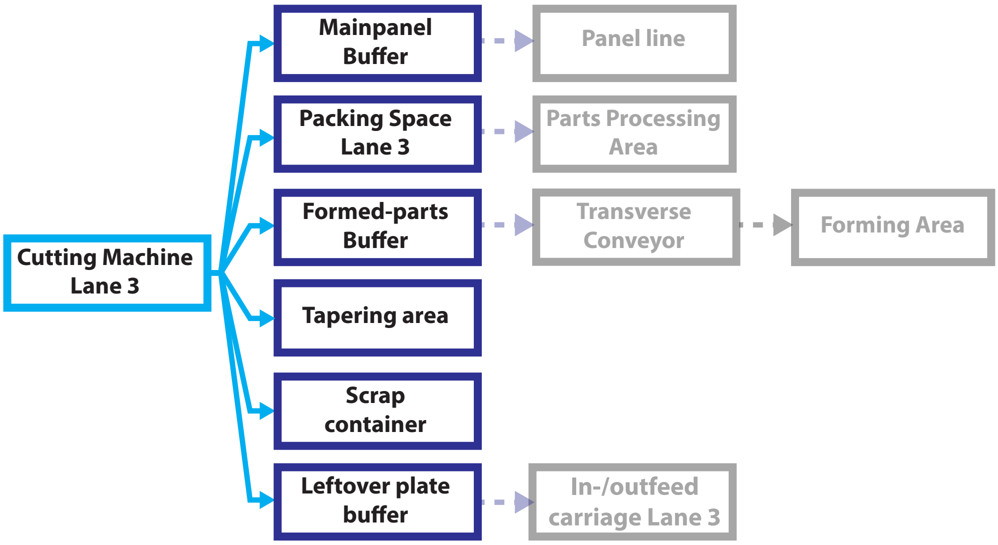


Figure D.4: Possible flows after cutting at the cutting department of lane 3

After Cutting, the cut parts are sorted for six different next destinations.

B. Current Situation

Flow

The parts are sorted per section into seven divisions:

- Small parts, these are sorted by hand, into the boxes for small parts on the packing space.
- Main panels, these are moved by crane and put in the dedicated main panel stack at the sorting space
- Parts to be formed, these are moved by crane and put in the dedicated formed-part stack at the sorting space
- Parts to be tapered, these are moved by crane and put in the infeed buffer of the tapering table.
- Scrap containers. Scrap parts are placed in the scrap containers by hand.
- Leftover plates, these are removed by crane and brought outside via the carriage.
- All other parts, these are removed by crane and put on a big (10T) container on the packing space.

Logistics

- Cranes:
  - Crane 60598 is dedicated to the cutting department in lane 3. This crane carries a magnetized yoke.
- Conveyor:
  - To bring parts from Lane 3 to the forming area in Lane 2, the transverse conveyor is used.
- Containers:
  The following distinction is made to determine the type of container used for any part:
  - A small part
    - ⋄ Is a part where any dimension of the part is bigger than 1 meter
    - ⋄ Container type: big yellow container,
      - · Dimensions of container: 3x8 meter.
      - · Max. Capacity: 8 tons.
  - A big part

- ◇ Are all other parts.
- ◇ Container type: small box
    - · Dimensions of container: 2x1 meter.
    - · Max. Capacity: 2 tons.

Personnel
The worker pool of the cutting machine also takes care of this sorting procedure.

D.4. Infeed & Cutting of plates - Lane 2

A. Description of the Cutting Department of Lane 2

Figure D.5: Possible flows at the infeed of the cutting department of lane 2

Plates on the infeed conveyor in lane 2 are put on the cutting bed, cut into parts and then sorted for their next destination.

B. Current Situation

Flow

A plate entering on the infeed conveyor in Lane 2:

- The plate is put on one of the cutting beds of the cutting machine.
- The machine marks lines for future joints on the plate.
- The machine signs the future parts with their routing codes.
- The machine cuts the plates into separate parts.
- An employee takes a garden hose and rinses the plates down.
- The operator of the cutting drops by and writes the part number and routing on the parts.
- The operator manually cuts the scrap into smaller pieces.

Logistics

In this step, the following equipment is utilized:

- Crane:
  - Crane portal 60572 is dedicated for this cutting department. The crane carries a magnetized yoke.

Machines

The machine in Lane 2:

- Has 3 cutting beds in line with water basins.
- Has 2 cutting portals on the same rail.
- Is capable of beveling.
- Is capable of marking lines for future joints on the parts.
- Is capable of signing information on the parts, although it is also done manually afterwards.

Tools

The following tools are used:

- A manual oxyfuel torch is used to cut the scrap into small pieces.
- A white marker for signing.

Personnel

Three employees are present to operate the cutting machine, perform the scrap cutting, signing and sorting of parts.

- Crew:
  - Foreman 4
- Skills:
  - Operating ESAB-machine

D.5. Sorting after cutting - Lane 2

A. Description of Sorting

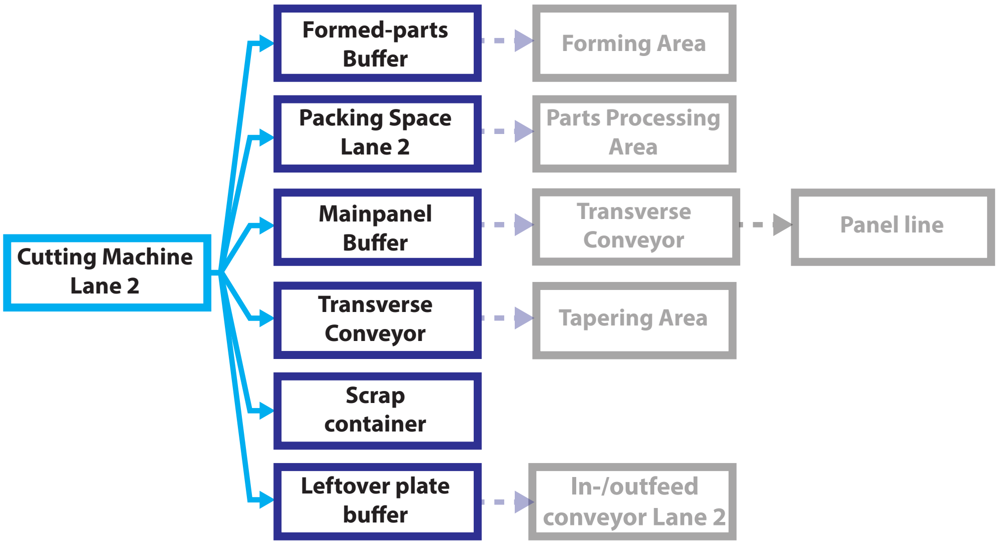


Figure D.6: Possible flows after cutting at the cutting department of lane 2

After Cutting, the cut parts are sorted for six different next destinations.

Flow
The parts are sorted per section into seven divisions:

- Small parts, these are sorted by hand, into the boxes for small parts on the packing space.
- Main panels, these are moved by crane and put in the dedicated main panel stack at the sorting space
- Parts to be formed, these are moved by crane and put in the dedicated formed-part stack at the sorting space
- Parts to be tapered, these are moved by crane and put on the transverse conveyor to lane 3.
- Scrap containers.
- Leftover plates
- All other parts, these are removed by crane and put on a big (10T) container on the packing space.

Logistics
- Cranes:
  - Crane 60572 is dedicated to the cutting department in lane 3. This crane carries a magnetized yoke.
- Conveyor:
  - To bring parts from Lane 2 to the tapering area, the transverse conveyor is used.
- Containers:
  The following distinction is made to determine the type of container used for any part:
  - A small part
    - ◇ Is a part where any dimension of the part is bigger than 1 meter
    - ◇ Container type: big yellow container,
      - · Dimensions of container: 3x8 meter.
      - · Max. Capacity: 8 tons.
  - A big part
    - ◇ Are all other parts.

- Container type: small box
  - Dimensions of container: 2x1 meter.
  - Max. Capacity: 2 tons.

Personnel
The worker pool of the cutting machine also takes care of this sorting procedure.

D.6. Tapering Station

A. Description of Tapering Station

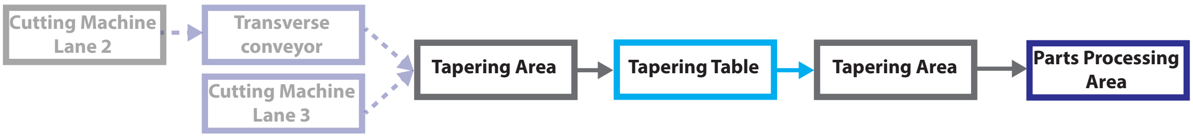


Figure D.7: Flow at the tapering station

- At the Tapering station, only tapering takes place, beveling does not take place here.
- To-be-tapered parts arrive one-by-one from the cutting department.
- These parts wait here until the section they belong to is handled by one of the foremen.
- Parts are tapered on the tapering table.
- From the table, parts are packed on a container
- The container is brought back to the parts processing area responsible for the section the part belongs to.

B. Current Situation

Flow

- Before tapering
  When a part arrives at the tapering area:
  - As soon as the section the part belongs to is in process in one of the parts processing areas, an employee of the foreman crew drops by to perform the tapering.
  - The parts are placed on the tapering table.
  - In turn, the parts are aligned on the tapering table.
  - The parts are not clamped to the table.
- Tapering
  - The required edge of each part is tapered in turn.
- After tapering
  - The tapered edge is smoothened with an angle grinder.
  - From the tapering table, the part is directly put on a container
  - When all parts of the section are tapered, the container is brought to the parts processing area where the relevant section is processed.

Logistics

In this step, the following logistic equipment is utilized to perform the stated operations, and their returns in exactly the same but opposite way.

- Cranes
  - Crane 60688 is used to bring big parts onto the tapering table and back on a container.
  - This crane is used to bring containers away to either parts processing area 1 (Foreman 1) or the transverse carriage.

Machines

- The tapering torch rides on a fixed rail attached to the tapering table.

Personnel
One employee from each foreman crew is capable of and responsible for tapering.

- Crew:
    - Foreman 1, Foreman 2 or Foreman 3
- Skills:
    - Tapering Semi-automatic

D.7. Forming Area

A. Description of Forming Area

Figure D.8: Flow at the forming area

- At the forming area, parts get either a 2D shape or a 3D shape.
- To-be-formed parts arrive at the forming area one by one.
- From the floor, all parts are 2D-formed in the roller press.
- Some parts receive an additional 3D shape on the line-heating station.
- Formed parts are brought to their next destination.

B. Current situation

Flow

- Before forming
  - All to-be-formed parts are brought to the forming area one by one.
  - One part at a time is brought onto the roller press.
  - If the thickness of the part is not equal to the previous part, the machine is changed over.
- Forming
  - On the roller press, the part is brought into its 2D shape.
  - The part is put back on the space.
  - If the parts requires an additional 3D shape:
    - ◇ The part is put on the line heating platform when it is available.
    - ◇ The part is brought into its 3D shape.
    - ◇ The part is put back on the space.
- After forming
  - The part is put onto a container.
  - The container of parts is brought to its next destination.

Logistics

For this step, the following transport means are used:

- Cranes
  Either of the available overhead cranes of lane 2 is used to:
  - Bring parts to the forming area,
  - Put parts onto the roller press and back,
  - Put parts onto the line heating platform and back,
  - Put parts onto a container,
  - Bring containers of parts away after forming.

Machines

- The Roller press is used to bring parts into their 2D shape.

Tools

- On the line heating platform, blow torches and water hoses are used.

Personnel
At the roller press, 3 employees are requested by the work place.

- Crew:
  - Foreman 5
- Skills:
  - Forming

At the Line heating platform, 2 employees are requested by the work place.

- Crew:
  - Foreman 5
- Skills:
  - Forming

D.8. Parts Processing Area

A. Description of Parts Processing Area

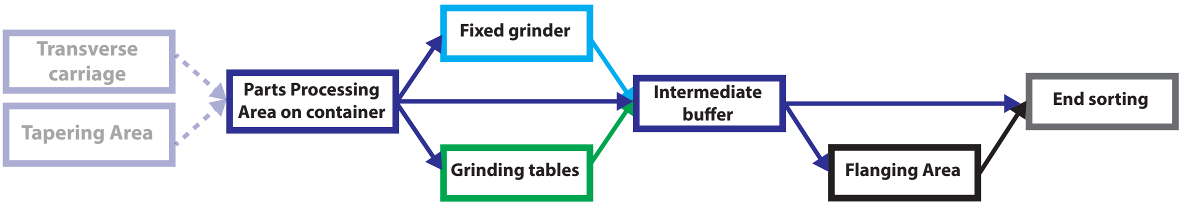


Figure D.9: Flow at the parts processing area

This description is applicable for all 3 of the parts processing areas.

- Containers with parts arrive.
- Parts that need to be ground are ground.
- Parts that need flanging are flanged at the Flanging area.
- All parts return and are sorted to go their next destination.

B. Current situation

Flow

- Before grinding
  - Containers of cut parts are brought from a cutting machine to a parts processing area.
  - When a container of big parts arrives, it is unpacked onto the grinding tables.
  - When a container of small parts arrives, it is unpacked onto the grinding tables or fixed grinder.
- Grinding.
  - Workers pick up the small parts in turn
  - The parts are ground on a table ($m>10$kg) or on the fixed grinder ($m<=10$kg).
  - Parts that need a beveled edge:
    - ◇ If thickness < 10 mm, edge type is v-seam, get their beveled edge by grinding.
    - ◇ Else, get their beveled edge by semi-automatic bevel machine.
  - The small parts are put back on the floor.
- After grinding
  - Small parts that need flanging are put on a europallet
  - Big parts that need flanging are put in a big container.
  - The container and/or europallet is transported to the flanging area and returns with flanged parts.
  - Parts that need tapering are placed together in a container.
  - The container is transported to the tapering area, tapered here and brought back.
  - Profile parts arrive, required for sub panel building.
  - A big part is placed on a grinding table.
  - If it needs to be ground, this is done on the table.
  - The corresponding small parts are searched for on the floor, and combined with the big part, making up a subpanel.
  - All parts are sorted for their next destination.
  - The parts are brought to this destination.
- Next Destinations (End buffers):
  - 910 and 920 are located in the parts processing area.
  - 930, 940 and 950 are located in the section building hall.
  - 960, 970 and 980 are located outside (south of the preprocessing hall).

Logistics

- Cranes:
  For parts processing area 1 (lane 3), crane portal 60688 is used to:
  - Unpack big parts from the containers,
  - Bring big parts onto the grinding tables and back on the floor,
  - Sort big parts for the profile lane, flanging and tapering.
  - Sort big parts for their end buffers.
  - Bring containers away for their respective destination.

  For parts processing area 2 (lane 2), crane portal 60687 is used for the same operations.
  For parts processing area 3 (lane 2), crane portal 60689 is used for the same operations.
- Carriage:
  - The transverse carriage is used for all transports between different lanes.
- Forklift:
  - The forklift is used to transport europallets of to-be-flanged parts to the flanging area and back.

Tools

- Hand held angle grinders are used for parts bigger than 10kg.
- A fixed belt grinder is used for smaller parts.

Personnel

In each of the parts processing areas, 10 people are employed.

- Crew:
  - Parts processing area 1: Foreman 1
  - Parts processing area 1: Foreman 2
  - Parts processing area 1: Foreman 3
- Skills:
  - Grinding,
  - Manual Bevelling,
  - Sorting

D.9. Flanging Area

A. Description of Flanging Area

Figure D.10: Flow at the parts flanging area

- From either of the parts processing areas, parts arrive at the flanging area.
- The parts are brought onto the Abkant in turn.
- The parts are processed on the Abkant.
- The parts are packed again and brought back to the parts processing area they came from.

B. Current situation

Flow

- Before flanging
  - From the parts processing area, europallets and containers of to-be-flanged parts are brought to the flanging area.
  - When a container arrives, the parts are unpacked and sorted on the floor.
  - The parts are brought to the Abkant in this order:
    - Parts of equal thickness succeed each other
      - Parts with similar bends succeed each other.
  - In between two parts of unequal thickness, the machine is changed over.
  - The parts are aligned on the dye of the Abkant.
- Flanging
- In one or more pressing repetitions, the parts are brought into shape.
- Big parts stay connected to the crane in the meanwhile.
- In between buckles, the part is repositioned on the Abkant.
- After flanging
- The parts are picked up from the dye of the Abkant.
- The parts are put back on the container they came with.
- When all flanging of a section is done, the container is transported back to the parts processing area it came from.

Logistics

- Cranes:
  - Either of the available cranes in lane 2 is used to:
    - Bring big containers of parts to the flanging area.
    - Handle big parts within the flanging area.
    - Reposition big parts on the Abkant.
    - Bring the container away.
  - Either of the available crane portals in lane 3 is used to:
    - Bring a container onto the transverse carriage if the parts come from parts processing area 1 in lane 3.
    - Bring the same container back after flanging.
- Carriage:
  - The transverse carriage is used to:
    - Bring containers coming from lane 3 (parts processing area 1) to lane 2.
    - Bring them back after flanging.
    - Forklift:
    - Small parts are transported on a europallet.
    - This pallet is brought to the flanging area by forklift and back.

Machines
The Abkant machine in lane 2 is used to perform the flanging.

Personnel
2 employees are employed in the workplace of the press brake to sort, pack and flange.

- Crew:
    - Foreman 5
- Skills:
    - Flanging

E

Technical Data

This document shows the technical data of the preprocessing department of DSGa, consisting of information of manufacturing equipment, cranes, carriages and conveyors.

E.1. Equipment

This section shows the available equipment for preprocessing. Tables E.1 and E.2 show the lists of all these pieces of equipment in section 1 and section 1A, respectively.

Table E.1: Equipment present in preprocessing S1

Equipment S1									
Equipment	**Foreman 6**		**Foreman 7**		**Foreman 8**		**Foreman 9**		**Total**
	No.	**Location**	**No.**	**Location**	**No.**	**Location**	**No.**	**Location**	
Fixed grinder			1	Lane 1	1	Lane 3	1	Lane 2	3
Fixed work bench			5	Lane 1	5	Lane 3	8	Lane 2	18
Pre-assembly bench			2	Lane 1	2	Lane 3	3	Lane 2	7
Pedestal			1	Lane 1	1	Lane 3	1	Lane 2	3
Welding Bench			6	Lane 1	6	Lane 3	6	Lane 2	18
Press Brake			1	Lane 1					1
Scissors			1	Lane 1					1
Battering Ram			1	Lane 1					1
Microstep cutting machine	1	Lane 1							1
Oxyfuel cutting machine	1	Lane 5							1
ESAB Combirex cutting machine	1	Lane 5							1
Hugh Smith press			1	Lane 5					1
Nieland roller press			1	Lane 5					1
Disposal bed	1	Lane 1							1
Roughing bed					1	Lane 5			1
Electric forklift	1	Variable							1

Table E.2: Equipment present in preprocessing S1A

Equipment S1A											
Equipment	**Foreman 1**		**Foreman 2**		**Foreman 3**		**Foreman 4**		**Foreman 5**		**Total**
	No.	**Location**	**No.**	**Location**	**No.**	**Location**	**No.**	**Location**	**No.**	**Location**	
Profile line									1	Lane 1	1
ESAB Cutting machine 1							1	Lane 2			1
ESAB Cutting machine 2							1	Lane 2			1
ESAB Cutting machine 3							1	Lane 3			1
Hugh Smith plate roller									1	Lane 2	1
Profile press									1	Lane 1	1
Press Brake									1	Lane 2	1
Shearing Guillotine					1	Lane 2					1
Drillling machine					1	Lane 1					1
Pneumatic hammer									1	Lane 1	1
Profile sawing machine									1	Lane 1	1
Fixed grinder	1	Lane 3	1	Lane 2	2	Lane 1					4
Lathe			1	Lane 2							1
Roughing machine	1	Lane 3									1
Electric Forklift					1	Lane 2					1
Assembly bed	12	Lane 3	17	Lane 2	6	Lane 1					34
Polishing bed									8	Lane 1	8
Welding bed	6	Lane 3	12	Lane 2	6	Lane 1					24
T-beam welding line	1	Lane 3									1
Pedestal	1	Lane 3	1	Lane 2	8	Lane 1					10
Electric forklift							1	Variable			1

E.2. Cranes

Tables E.3 and E.4 show the available overhead crane portals for section 1 and section 1A, respectively.

Table E.3: List of the overhead crane portals in section 1

Lane	**Crane ID**	**Max. Load [ton]**	**Lifting speed [m/min]**		**Lowering speed [m/min]**		**Driving speed [m/min]**		**Trolley speed [m/min]**
			min.	**max.**	**min.**	**max.**	**min.**	**max.**	
Lane 1	60104	7.5	2	8	2	8	25	100	20
	60288	5	2	8	2	8	25	100	20
	60093	5	2	8	2	8	25	100	20
Lane 2	60106	10	2	8	2	8	25	100	20
	60096	3	2	8	2	8	25	100	20
	60100	5	2	8	2	8	25	100	20
	27313	10	2	8	2	8	25	100	20
Lane 3	60305	5	2	8	2	8	25	100	20
	60103	7.5	2	8	2	8	25	100	20
Lane 4	60153	12.5	2	8	2	8	25	100	20
	60421	5	2	8	2	8	25	100	20
	60287	1.5	2	8	2	8	25	100	20
Lane 5	60434	12.5	2	8	2	8	25	100	20
	60237	5	2	8	2	8	25	100	20
	60103	15	2	8	2	8	25	100	20

Table E.4: List of the overhead crane portals in section 1A

Lane	Crane ID	Max. Load [ton]	Lifting speed [m/min]		Lowering speed [m/min]		Driving speed [m/min]		Trolley speed [m/min]
			min.	max.	min.	max.	min.	max.	
Lane 1	25912	12.5	0.83	5	0.83	5	16	100	20
	60573	12.5	0.83	10	0.83	10	16	100	20
Lane 2	60572	12.5	0.83	10	0.83	10	16	100	20
	60689	12.5	0.83	10	0.83	10	16	100	20
	27312	12.5	0.83	5	0.83	5	16	100	20
	60687	12.5	0.83	10	0.83	10	16	100	20
Lane 3	60598	12.5	0.83	10	0.83	10	16	100	20
	60688	12.5	0.83	10	0.83	10	16	100	20
	60691	12.5	0.83	10	0.83	10	16	100	20

For all cranes, the times for loading and discharging of parts are stated as:

- Loading and unloading of a container (Attaching chains): 5 minutes.
- Loading and unloading a small plate on a magnet: 30 seconds.
- Loading and unloading a plate on a yoke: 1 minute.
- Changing a crane over from a magnet to a yoke: 30 minutes.

E.3. Conveyors

In section 1, two conveyors are present as stated in appendix E. They are both used as infeed for the cutting machines. In section 1A, both cutting machines also have a conveyor for the infeed of plates. There is one extra conveyor with three purposes:

- Bringing to-be-tapered parts from the sorting space in lane 2 to lane 3 to be carried to the tapering area,
- Bringing main panels from the same sorting space to lane 3 to be carried to the panel line,
- Bringing to-be-formed parts from the sorting space in lane 3 to lane 2 to be carried to the forming area.

These three routes can be seen in figure E.1. This carriage has a maximum load of 25 tons and a velocity of 2.5 meters per minute.

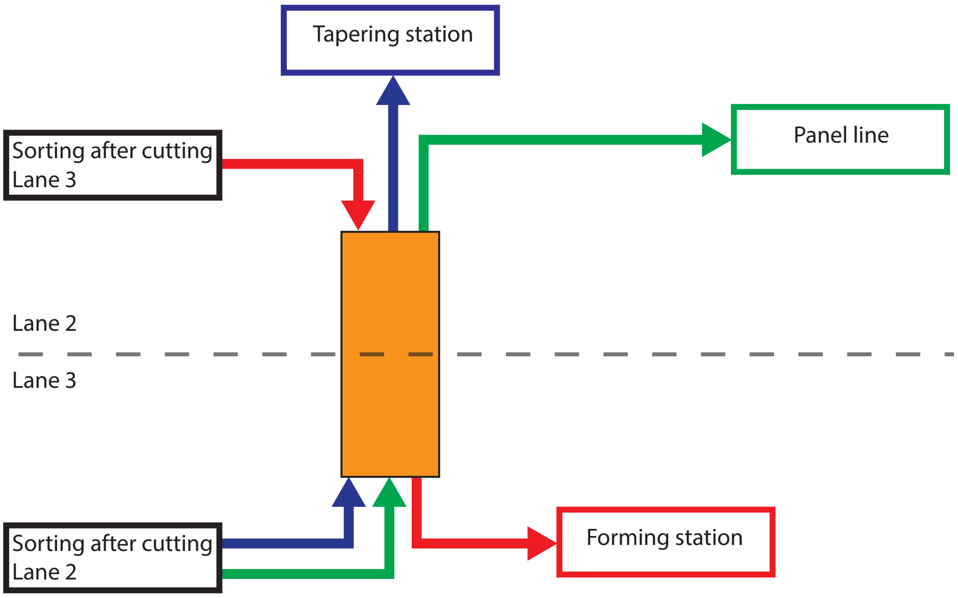


Figure E.1: Three routes on the transverse conveyor in section 1A

E.4. Carriage

In both section 1 and section 1A, a set of straight rails is placed on the floor with a carriage driving on these rails. This carriage is used for all inter-lane transports that are not stated in figure E.1. This carriage has a length of 9 meters, a width of 2.5 meters, a maximum load of 30 tons and it drives with a velocity of 30 meters per minute.

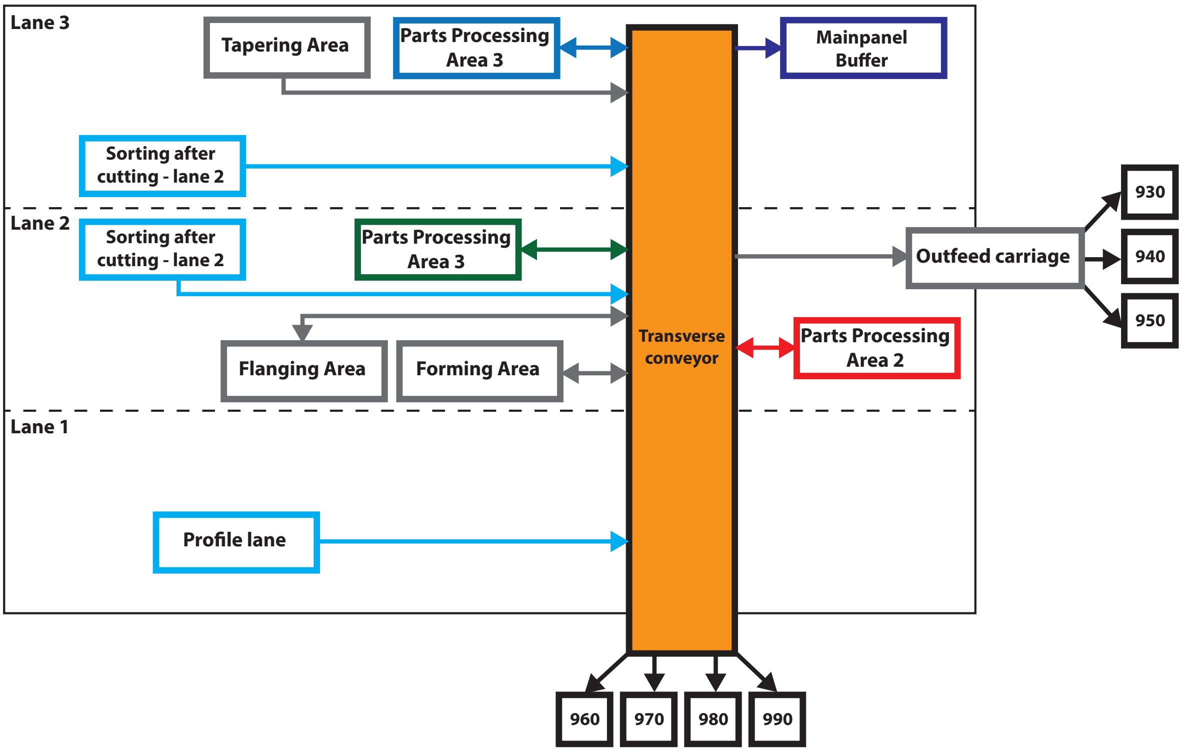


Figure E.2: Overview of the interactions with the transverse carriage in section 1A

F

Organizational Data

This document shows the organizational data of the preprocessing at DSGa.

Section F.1 shows the employees of the preprocessing at DSGa. In section F.2, the times of the shifts are stated.

F.1. Workers at DSGa Preprocessing

This section shows an overview of the workers in the preprocessing at DSGa. For the preprocessing department, in total nine foremen are responsible: four in section 1 and five in section 1A. Figures F.1 and F.2 show the areas the foremen are responsible for in section 1A and section 1, respectively. The numbers belonging to the respective foremen are

Tables F.1 and F.3 show the amount of workers in the foreman crews of section 1A and section 1, respectively. Tables F.2 and F.4 show the tasks of these crews.

From the people in tables F.1 and F.3, usually 10% are on vacation according to regulations. The rest are divided in one, two or three shifts depending on the load of the workshop.

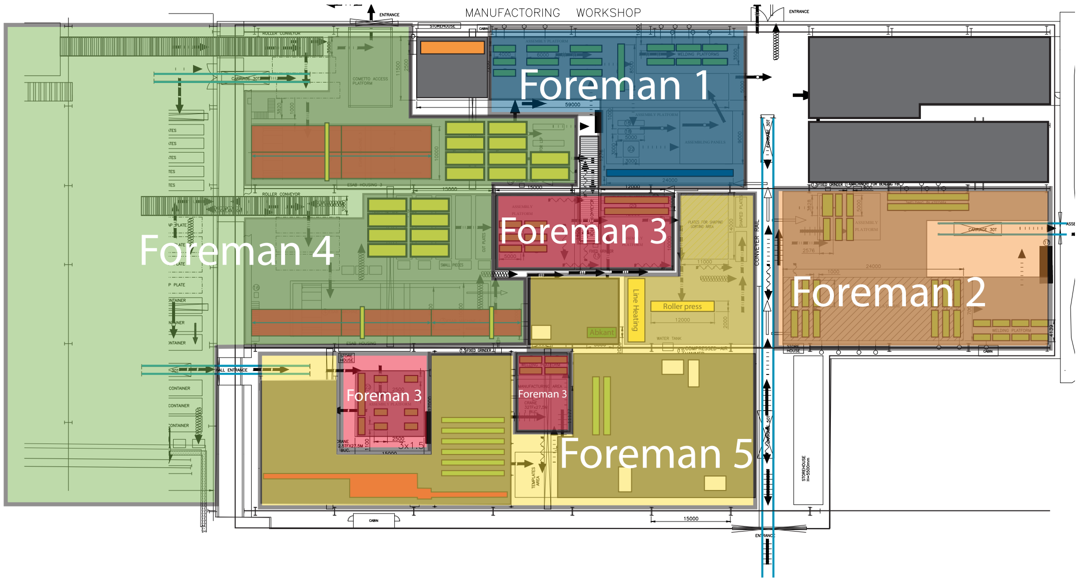


Figure F.1: Map of S1A preprocessing, with the division of the foremen

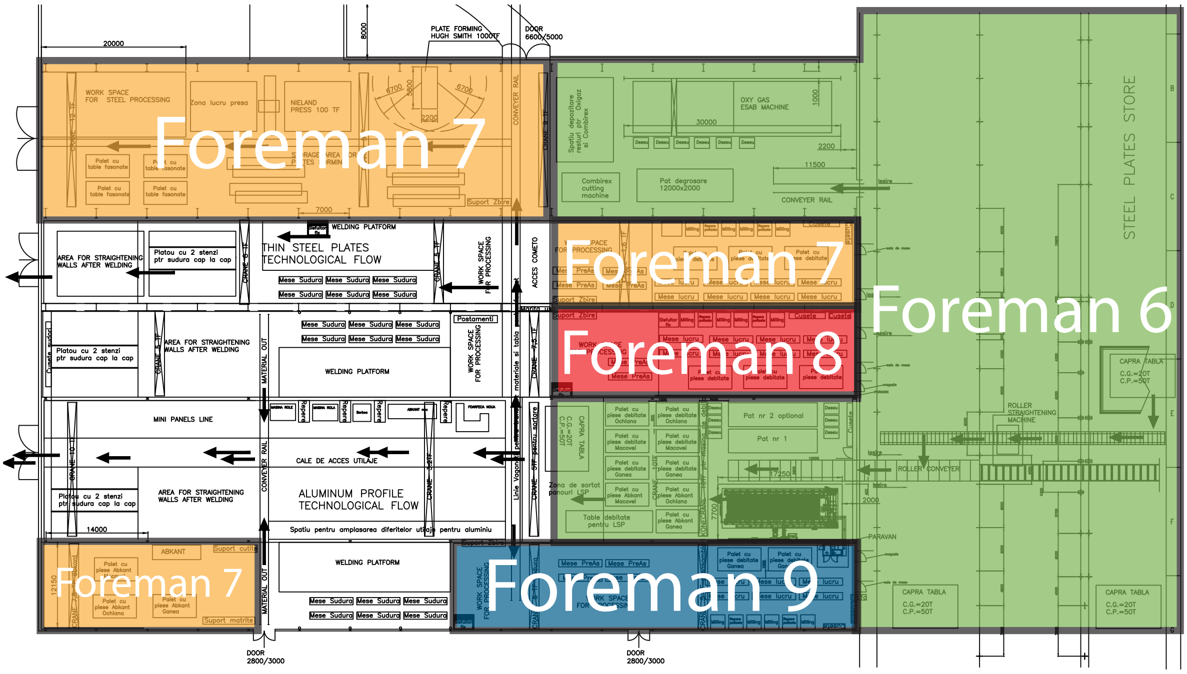


Figure F.2: Map of S1 preprocessing, with the division of the foremen

Table F.1: Total amount of workers in Section 1A, per foreman.

	100% load of workshop							
Foreman	**Slingers**	**Craners**	**Sorting parts**	**Beveling manually**	**Beveling semi-automatic**	**Tapering Semi-automatic**	**Straightening, finalizing**	**Total**
Foreman 1	22	14	~10	3	2	2	2	**23**
Foreman 2	28	10	~14	2	2	2	1	**28**
Foreman 3	19	11	~10	2	2	2	3	**20**
Foreman 4	23	20	20	-	2	2	-	**24**
Foreman 5	31	16	4	4	-	-	-	**31**

Table F.2: The responsibilities of the foreman crews in S1A preprocessing.

Foreman	**Tasks**
Foreman 1	Beveling, Tapering, Grinding edge, Subpanel assembly, T-beam assembly, Main panel assembly, Outfitting assembly.
Foreman 2	Beveling, Tapering, Grinding edge, Subpanel assembly, T-beam assembly, Main panel assembly, Outfitting assembly.
Foreman 3	Beveling, Tapering, Grinding edge, Subpanel assembly, T-beam assembly, Main panel assembly, Outfitting assembly.
Foreman 4	Cutting, Sorting, Shotblasting, Priming.
Foreman 5	Flanging, Forming, Preprocessing of profiles.

Table F.3: Total amount of workers in Section 1, per foreman.

	100% load of workshop							
Foreman	**Slingers**	**Craners**	**Sorting parts**	**Beveling manually**	**Beveling semi-automatic**	**Tapering Semi-automatic**	**Straightening, finalizing**	**Total**
Foreman 6	12	12	12	0	2	0	0	**12**
Foreman 7	22	16	10	2	2	2	2	**23**
Foreman 8	16	10	10	4	2	2	2	**17**
Foreman 9	18	14	10	4	3	3	3	**19**

Table F.4: The responsibilities of the foreman crews in S1 preprocessing.

Foreman	**Tasks**
Foreman 6	Cutting, Sorting.
Foreman 7	Beveling Tapering Grinding Subpanel assembly T-beam assembly Mini panel assembly Outfitting assembly Flanging Forming plates
Foreman 8	Beveling Tapering Grinding Subpanel assembly T-beam assembly Mini panel assembly Outfitting assembly
Foreman 9	Beveling Tapering Grinding Subpanel assembly T-beam assembly Mini panel assembly Outfitting assembly

F.2. Shift Times

The shift times that are used at DSGa are stated in table F.5. When the load of the yard is low, the standard shift is used. In normal operations, shifts I and II of the normal shifts are used.

Table F.5: Diferent shift types at DSGa, depending on the load of the yard.

Shift type		**Start**	**End**	**Remarks**
Normal	Shift I	06:00	14:00	(Usually for sandblasting and cutting plates or profiles)
	Shift II	14:00	22:00	(Usually for sandblasting and cutting plates or profiles)
	Shift III	22:00	06:00	(Usually for sandblasting and cutting plates or profiles)
Turnus	Shift I	06:00	18:00	(Rarely used)
	Shift II	18:00	06:00	(Rarely used)
Standard		07:00	15:45	(Usually for section building, hull assembly)

G

Product Data

This document shows the product data for the analysis of the preprocessing of DSGa. The product data consists of two ship types: the Damen ASD2913 tugboat and the Damen PSV3300. These ships are shown in figures G.1 and G.2, respectively (Not on the same scale, obviously).

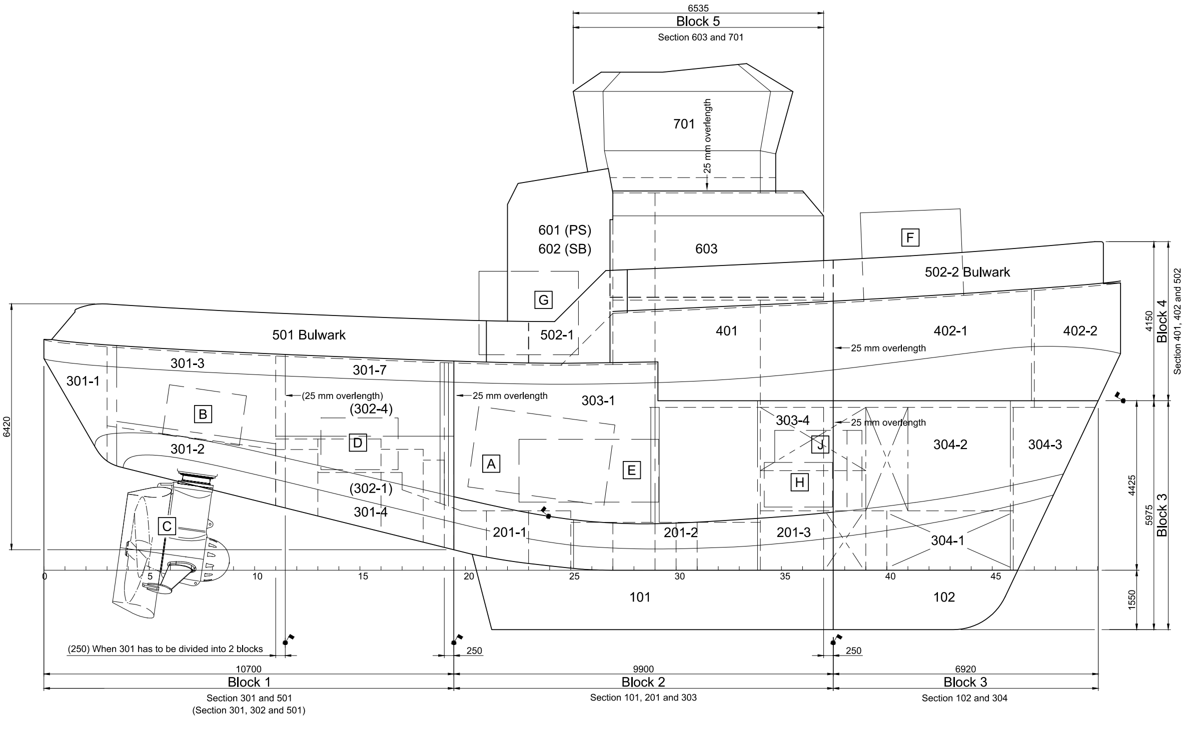


Figure G.1: Section plan of a Damen ASD2913 Tugboat (Damen, 2015)

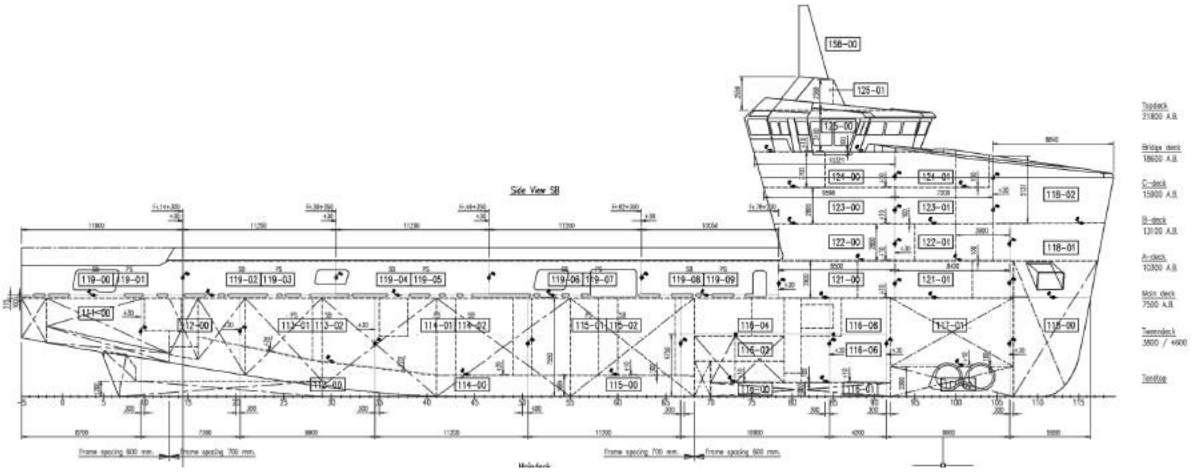


Figure G.2: Section plan of a Damen PSV 3300 (Damen, n.d.c)

Table G.1 shows the sections of an ASD2913 tugboat. It is seen that such a vessel is divided into two cutting groups and the number of plate parts per section varies between from 23 to 993. The table also shows the number of tapered, formed, ground and flanged parts and the number of main panel parts and thick parts. Table G.2 shows the same information for the PSV3300. It is seen that a PSV consists of a bigger number of sections. It is seen that there are a lot of 'identical' sections: sections that have the exact same number of parts that endure the same operations. This is due to the limited capacity of data-collection by Damen. Table G.3 shows that information of only seven sections is available, these sections are representative for the other sections. To make a decent analysis about this ship, the other sections are stated to be equal to either of these seven.

Lastly, tables G.4 and G.5 show the number of parts per section for the various end buffers, for the ASD2913 tug and the PSV3300, respectively.

Table G.1: The number of plate parts in an ASD2913 tug, per section

Section	Cutting group	Number of plate parts	Tapering	Forming	Grinding	Flanging	Main panels	Thick parts
101	1	40	0	2	0	0	0	0
102	1	23	0	1	0	0	0	0
201	1	428	4	15	237	22	14	0
301	1	993	2	45	571	25	5	18
303	1	734	0	19	519	59	13	2
304	1	504	0	24	265	4	15	0
401	2	279	0	6	211	11	11	0
402	2	394	3	22	238	12	2	5
501	1	94	0	9	60	5	0	0
601	2	30	0	0	15	10	0	0
602	2	27	0	0	10	9	0	2
603	2	164	0	0	116	10	0	0
701	2	122	0	0	53	56	0	0

Table G.2: The number of plate parts in a PSV3300, per section.

Section	Cutting group	Number of plate parts	Tapering	Forming	Grinding	Flanging	Main panels	Thick parts
11100	1	1235	0	14	826	34	43	5
11102	5	117	0	0	99	0	2	0
11200	1	1235	0	14	826	34	43	5
11300	3	720	0	8	473	16	17	0
11301	3	515	0	6	353	18	26	5
11302	3	515	0	6	353	18	26	5
11400	3	720	0	8	473	16	17	0
11401	3	515	0	6	353	18	26	5
11402	3	515	0	6	353	18	26	5
11500	3	720	0	8	473	16	17	0
11501	3	515	0	6	353	18	26	5
11502	3	515	0	6	353	18	26	5
11600	4	720	0	8	473	16	17	0
11601	4	720	0	8	473	16	17	0
11602	4	515	0	6	353	18	26	5
11604	4	515	0	6	353	18	26	5
11606	4	515	0	6	353	18	26	5
11608	4	515	0	6	353	18	26	5
11700	2	651	0	23	477	0	4	0
11701	2	515	0	6	353	18	26	5
11800	2	446	0	23	291	0	20	0
11801	6A	341	0	0	262	22	8	0
11802	6B	341	0	0	262	22	8	0
11900	5	117	0	0	99	0	2	0
11901	5	117	0	0	99	0	2	0
11902	5	117	0	0	99	0	2	0
11903	5	117	0	0	99	0	2	0
11904	5	117	0	0	99	0	2	0
11905	5	117	0	0	99	0	2	0
11906	5	117	0	0	99	0	2	0
11907	5	117	0	0	99	0	2	0
11908	5	117	0	0	99	0	2	0
11909	5	117	0	0	99	0	2	0
12100	6A	341	0	0	262	22	8	0
12101	6A	341	0	0	262	22	8	0
12200	6A	341	0	0	262	22	8	0
12201	6A	341	0	0	262	22	8	0
12300	6B	341	0	0	262	22	8	0
12301	6B	341	0	0	262	22	8	0
12400	6B	341	0	0	262	22	8	0
12401	6B	341	0	0	262	22	8	0
12500	6B	588	0	0	395	21	12	0

Table G.3: Reference sections for product data of PSV3300

Section	Provided by DSGa?	Cutting Group	Reference Section	Mass [Ton]
11100	No	1	11400+11401	93
11102	No	5a	11902	8
11200	No	1	11400+ 11401	93
11300	No	3	11400	53
11301	No	3	11401	39
11302	No	3	11401	39
11400	Yes	3	11400	53
11401	Yes	3	11401	39
11402	No	3	11401	39
11500	No	3	11400	53
11501	No	3	11401	39
11502	No	3	11401	39
11600	No	4	11400	53
11601	No	4	11400	53
11602	No	4	11401	39
11604	No	4	11401	39
11606	No	4	11401	39
11608	No	4	11401	39
11700	Yes	2	11700	40
11701	No	2	11401	39
11800	Yes	2	11800	26
11801	No	6a	12301	17
11802	No	6b	12301	17
11900	No	5a	11902	8
11901	No	5a	11902	8
11902	Yes	5a	11902	8
11903	No	5a	11902	8
11904	No	5b	11902	8
11905	No	5b	11902	8
11906	No	5b	11902	8
11907	No	5b	11902	8
11908	No	5b	11902	8
11909	No	5b	11902	8
12100	No	6a	12301	17
12101	No	6a	12301	17
12200	No	6a	12301	17
12201	No	6a	12301	17
12300	No	6b	12301	17
12301	Yes	6b	12301	17
12400	No	6b	12301	17
12401	No	6b	12301	17
12500	Yes	6b	12500	33
12501	No	6b	Not included	N/A
15800	No	6b	Not included	N/A

Table G.4: The number of parts per section of an ASD2913 tug, for the various end buffers

	End Buffers									
Section	**910**	**920**	**930**	**940**	**950**	**960**	**970**	**980**	**990**	**Total**
101	0	32	0	8	0	0	0	0	0	40
102	0	18	0	4	0	1	0	0	0	23
201	216	0	20	150	28	14	0	0	0	428
301	196	115	28	582	4	28	14	26	0	993
303	102	76	35	433	0	88	0	0	0	734
304	123	18	15	321	13	0	0	14	0	504
401	26	20	11	202	0	20	0	0	0	279
402	16	81	19	221	34	11	12	0	0	394
501	46	0	0	48	0	0	0	0	0	94
502	12	89	0	69	0	0	0	0	0	170
601	9	0	0	21	0	0	0	0	0	30
602	4	0	0	16	0	0	5	2	0	27
603	75	10	0	77	0	0	0	2	0	164
701	12	0	0	110	0	0	0	0	0	122
Total	837	459	128	2262	79	162	31	44	0	**4002**

Table G.5: The number of parts per section of a PSV3300, for the various end buffers.

	End Buffers									
Section	**910**	**920**	**930**	**940**	**950**	**960**	**970**	**980**	**990**	**Total**
11100	407	25	71	594	0	131	0	7	0	1235
11200	407	25	71	594	0	131	0	7	0	1235
11700	203	14	4	384	15	31	0	0	0	651
11701	148	10	39	230	0	81	0	7	0	515
11800	136	4	30	244	0	24	0	8	0	446
11300	259	15	32	364	0	50	0	0	0	720
11301	148	10	39	230	0	81	0	7	0	515
11302	148	10	39	230	0	81	0	7	0	515
11400	259	15	32	364	0	50	0	0	0	720
11401	148	10	39	230	0	81	0	7	0	515
11402	148	10	39	230	0	81	0	7	0	515
11500	259	15	32	364	0	50	0	0	0	720
11501	148	10	39	230	0	81	0	7	0	515
11502	148	10	39	230	0	81	0	7	0	515
11600	259	15	32	364	0	50	0	0	0	720
11601	259	15	32	364	0	50	0	0	0	720
11602	148	10	39	230	0	81	0	7	0	515
11604	148	10	39	230	0	81	0	7	0	515
11606	148	10	39	230	0	81	0	7	0	515
11608	148	10	39	230	0	81	0	7	0	515
11102	7	14	2	68	0	24	0	2	0	117
11900	7	14	2	68	0	24	0	2	0	117
11901	7	14	2	68	0	24	0	2	0	117
11902	7	14	2	68	0	24	0	2	0	117
11903	7	14	2	68	0	24	0	2	0	117
11904	7	14	2	68	0	24	0	2	0	117
11905	7	14	2	68	0	24	0	2	0	117
11906	7	14	2	68	0	24	0	2	0	117
11907	7	14	2	68	0	24	0	2	0	117
11908	7	14	2	68	0	24	0	2	0	117
11909	7	14	2	68	0	24	0	2	0	117
11801	63	28	8	149	3	90	0	0	0	341
12100	63	28	8	149	3	90	0	0	0	341
12101	63	28	8	149	3	90	0	0	0	341
12200	63	28	8	149	3	90	0	0	0	341
12201	63	28	8	149	3	90	0	0	0	341
11802	63	28	8	149	3	90	0	0	0	341
12300	63	28	8	149	3	90	0	0	0	341
12301	63	28	8	149	3	90	0	0	0	341
12400	63	28	8	149	3	90	0	0	0	341
12401	63	28	8	149	3	90	0	0	0	341
12500	247	79	17	217	0	28	0	0	0	588
Total	5030	766	884	8621	45	2650	0	121	0	**18117**

H

Average Steel Processing Times

This appendix shows average processing times for steel parts, as provided by the Damen Yard Support department.

Table H.1: Average steel preprocessing times

Plate process	Time (Minutes)	Remark
Cutting plasma	60	
Cutting oxy-gas t>20 mm	180	
Sort big	5	Current DSGa time
Sort small	2	Current DSGa time (hand)
Tapering	45	Only straight plates
Forming 2D plate roller	30	Av. Plate is 0.5 tons (small)
Forming 3D plate press	80	Av. Plate is 0.5 tons (small)
Forming 3D roller press	40	Av. Plate is 0.5 tons (small)
Forming 3D line heating	80	Av. Plate is 0.5 tons (small)
Grinding big	15	
Grinding small	5	
Flanging/knuckle big	15	
Flanging/knuckle small	5	

Plate process	Time (Minutes)	Remark
Cutting robot	11	
Cutting flat bars	11	On cutting robot
Cutting manual	20	
Sort big	3	
Sort small	1	
Tapering (after manual cut)	15	Tapering of flat bar
Grinding long	12	
Grinding small	2	
Knuckle	10	
Forming	30	
Straightening	15	

Table H.2 shows the setup times for the various machines. The changeover time is the time that is required when the thickness of the part does not fall within the range of the thickness of the previous plate. These ranges are also stated in H.2.

Table H.2: Setup, changeover and outfeed times of various machines and equipment

Machine	**Setup Time (Minutes)**	**Changeover Time (Minutes)**	**Remark**
Plate Roller	15		
Line heating platform	5		
Press brake	1	30	Thickness ranges: t $< 10mm$, $10 \leq t < 14mm$, $14 \leq t < 18mm$, t $\geq 18mm$
Cutting Machine	5	10	Thickness ranges: t $< 14mm$, $14 \leq t \leq 20mm$,
Grinder	1		
Tapering	15		

I

Estimation of Utilization

In this document a static estimation is made for the utilization of the various pieces of equipment in pre-processing section 1A. Tables I.1 to I.6 show these figures for the cutting department, forming department, flanging department, grinders and tapering station, respectively. Table I.7shows an overview for all equipment for both the current throughput and the desired throughput.

Table I.1: Estimation of working hours of the cutting department

Ship type	# Parts	# Plates	# Thin Plates (t $\leq 20mm$)	Cutting time (Hours)	Setup Time (Hours)	Changeover time (Hours)	Subtotal (Hours)	Total (Hours)
ASD2913	4002	128	116	116	10	2	128	140
PSV3300	18117	661	642	642.00	54	11	706	777

Table I.2: Estimation of working hours of the 2D forming plate roller

Ship type	# Formed Parts	Forming time (Hours)	Setup Time (Hours)	Subtotal (Hours)	Total (Hours)
ASD2913	177	89	44	133	146
PSV3300	180	90	45	135	149

Table I.3: Estimation of working hours of the line heating platform

Ship type	# Formed Parts	Forming time (Hours)	Setup Time (Hours)	Subtotal (Hours)	Total (Hours)
ASD2913	99	132	8	141	155
PSV3300	34	46	3	49	54

Table I.4: Estimation of working hours of the press brake

Ship type	Number of flanged parts	Flanging time (Hours)	Setup Time (Hours)	Changeover Time (Hours)	Subtotal (Hours)	Total (Hours)
ASD2913	239	34	4	24	62	68
PSV3300	587	82	10	59	150	166

Table I.5: Estimation of working hours of the grinders

Ship type	Number of ground parts	Grinding time (Hours)	Setup Time (Hours)	Subtotal (Hours)	Total (Hours)	Total per grinder (Hours)
ASD2913	3105	355	52	407	447	30
PSV3300	16818	1944	280	2224	2447	163

Table I.6: Estimation of working hours of the tapering station

Ship type	Number of tapered parts	Tapering time (Hours)	Setup Time (Hours)	Changeover Time (Hours)	Subtotal (Hours)	Total (Hours)
ASD2913	27	20	7	7	34	37
PSV3300	0	0	0	0	0	0

Table I.7: Overview of utilization of the various pieces of equipment

Equipment	1 Tug	1 PSV	3.6 PSV's + 6.6 Tugs		6 PSV's + 11 Tugs	
	Hours	Hours	Hours	Utillization	Hours	Utilization
Cutting machine lane 2 - 1	42	233	1117	28%	1861	47%
Cutting machine lane 2 - 2	42	233	1117	28%	1861	47%
Cutting machine lane 3	56	311	1489	37%	2482	62%
2D Plate Roller	146	149	1498	37%	2497	62%
Line Heating Platform	155	54	1213	30%	2022	51%
Press brake	68	166	1045	26%	1742	44%
Grinder	30	163	784	20%	1307	33%
Tapering	37	0	243	6%	405	10%

J

Verification of the model

To verify the constructed simulation model, a verification checklist is composed. With this checklist, it is investigated whether the model behaves the way it should according to the process data in appendices C and D. This list can be found in table J.1.

For the verification, five testing methods are used. These are explained in section 5.1.3.

Table J.1: Verification Checklist

No.	Verification test	Verification method	Check
	Raw plate storage		
1	Storage on thickness per cutting group	sample test and cumulative plate number test	V
2	Lifo stack unloading	track and trace	V
3	Lifo stack loading	track and trace	V
4	Conveyor stack maximum	track and trace	V
5	FIFO crane request sequence per stack	settings	V
6	Thick plates to other conveyor	track and trace	V
7	Rack filling before truck request	new call chain analysis	V
8	Section transporter carries maximum 100ton	new call chain analysis	V
9	Only two stacks at once on conveyor	visual inspection	V
	Cutting stations		
10	Lifo stack unloading	track and trace	V
11	cutting machine change over time	track and trace of several plates with different thicknesses	V
12	cutting programe duration	timing process by means of break points.	V
13	Hand signing and scrap cutting execution	timing process by means of break points.	V
14	FIFO crane requests for sorting	track and trace / settings	V
15	Forming plate destination	track and trace / visual inspection	V
16	Main panel destination	track and trace / visual inspection	V
17	Main panels are moved to S1A	track and trace / visual inspection	V
18	Tapering destination	track and trace / visual inspection	V
19	Big parts by crane	track and trace / visual inspection	V
20	Small parts by hand	track and trace	V
21	Container full criterion	new call chain analysis	V
22	Container stacking when full	visual inspection	V
23	Loading small on large container when large container is full	new call chain analysis	V
24	Container transport to PPS or buffer	new call chain analysis	V
	Tapering stations		
25	Part enters infeed buffer and wait until section number is processed (S1A)	new call chain analysis	V
26	Part enters infeed buffer and is LIFO unstacked on space (S1)	visual inspection	V
27	FIFO processing and loading on container	track and trace	V
28	Transport container when all parts are processed	new call chain analysis	V
29	Different processes for thick and thin parts	new call chain analysis	V
	Forming stations		
30	Part enters infeed buffer starts directly (S1A)	track and trace	V
31	Containers (FIFO) are unstacked on space (LIFO) (S1)	track and trace	V
32	All parts are processed on S1A Plate roller or S1 Pressure Press	track and trace	V
33	Parts are rotated to correctly enter the presses	visual inspection	V
34	3D plates are also processed on Line Heating (S1A) or Roller Pressure Press (S1)	track and trace	V
35	Sorting and packing per section	sample test and cumulative plate number test	V
36	Crane requests are executed FIFO apart from parts which have priority	new call chain analysis	V
37	Maximum loading capacity	new call chain analysis	V
38	End buffer transport	visual inspection	V
	Part processing spaces		
39	Parts are sorted for processing or end buffers (LIFO)	track and trace	V
40	Priority for unpacking above processing	new call chain analysis	V
41	Different transport equipment are used	track and trace	V
42	Small parts to belt grinder	track and trace	V
43	Big parts are processed on work bench	track and trace	V
44	Big parts are rotated before other side is grinded	track and trace	V
45	Parts are also bevelled, before grinding	track and trace	V
46	Small parts for flanging on pallet	track and trace	V
47	Pallet is moved by fork lift (S1A)	visual inspection	V
48	Large parts move to flanging one by one (S1A)	track and trace	V
49	Large parts for flanging on container (S1)	track and trace	V
50	Pallet is loaded on container and sent to flanging jointly (S1)	new call chain analysis	V
51	Sorting and packing for end buffers	track and trace	V
52	Maximum loading capacity	new call chain analysis	V
	Flanging process		
53	Pallets and containers are unpacked (LIFO)	track and trace	V
54	Smaller parts do not require cranes	track and trace	V
55	Big parts require cranes to be processed	track and trace	V
56	Crane requests are executed FIFO	new call chain analysis	V
57	Parts are rotated to correctly enter the presses	visual inspection	V
58	Parts are moved back to PPS same way as the entered	track and trace	V

K

Order Times and Inter-arrival Times of the Preprocessing Model

K.1. Preprocessing of Sections

This document shows timings of the model of the preprocessing department of section 1A of DSGa. Based on these values, the Flow time of a batch is computed using a few figures:

- T_A: The average of inter-arrival times. This is equal to 45 hours and 20 minutes.
- S_A: The standard deviation of inter-arrival times. This is equal to 39 hours.
- T_O: The average of order times. This is equal to 38 hours.
- S_O: The standard deviation of order times. This is equal to 34 and a half hour.
- u: the utilization of parts processing areas is computed as the ratio of the sum of all job times to the total passed time. This is equal to 80%.

Table K.1: Order times and inter-arrival times of the preprocessing department of DSGa.

Section	Processing Area	Number of parts	Start time [Hrs]	Finish time [Hrs]	Order time [Hrs]	Inter arrival time [Hrs]
522023-11801	1	333	34.15	56.78	22.62	
522023-12200	1	333	58.52	81.27	22.75	24.37
522023-11900	1	115	83.99	98.86	14.87	25.47
522023-11903	1	115	100.51	103.23	2.72	16.52
522023-11906	1	115	105.9	120.61	14.71	5.39
522023-11909	1	115	123.14	126.13	2.99	17.24
511010-201	1	399	128.61	176.54	47.93	5.47
511010-301	1	925	178.8	251.25	72.45	50.19
511010-304	1	465	267.05	292.11	25.07	88.25
522021-11900	1	115	294.08	296.95	2.87	27.03
522021-11903	1	115	298.55	313.17	14.63	4.47
522021-11906	1	115	315.28	318.12	2.85	16.73
522021-11909	1	115	320	322.87	2.87	4.72
511010-502	1	140	336.45	367.5	31.06	16.45
511010-603	1	164	368.83	387.1	18.27	32.39
522021-12300	1	333	388.48	483.24	94.76	19.65
522021-12401	1	333	484.92	507.63	22.71	96.43
511011-102	1	22	510.43	511.13	0.7	25.52
511011-303	1	700	513.11	563	49.89	2.68
522021-11600	1	695	577.88	707.85	129.97	64.77
522021-11601	1	695	721.86	770.17	48.31	143.98

Table K.1: Order times and inter-arrival times of the preprocessing department of DSGa.

Section	Processing Area	Number of parts	Start time [Hrs]	Finish time [Hrs]	Order time [Hrs]	Inter arrival time [Hrs]
522021-11604	1	478	772	800.75	28.75	50.14
522021-11606	1	478	803.56	844.86	41.3	31.56
511015-401	1	262	847.84	865.4	17.56	44.28
511015-601	1	30	867.08	870.57	3.5	19.24
511015-701	1	122	871.69	898.81	27.11	4.62
522023-12301	1	333	899.84	964.18	64.34	28.15
522023-12500	1	576	965.94	1034.18	68.24	66.09
522021-11200	1	1173	1037.57	1128.67	91.1	71.63
522021-11700	1	624	1133.03	1186.21	53.19	95.46
511012-101	1	38	1187.98	1200.87	12.9	54.95
511012-301	1	925	1201.88	1282.55	80.67	13.9
511012-401	1	262	1298.82	1305.28	6.46	96.94
511012-601	1	30	1307.52	1324.03	16.52	8.7
511012-701	1	122	1327.83	1371.32	43.48	20.31
522021-11801	1	333	1373.3	1398.88	25.58	45.47
522021-12200	1	333	1401.07	1423.45	22.38	27.77
511013-201	1	399	1538.53	1584.5	45.98	137.46
511013-304	1	465	1588.38	1613.96	25.58	49.85
522023-11601	1	695	1616.46	1690.22	73.76	28.08
522023-11606	1	478	1704.64	1734.18	29.54	88.18
511014-402	1	365	1737.29	1787.89	50.59	32.65
511014-601	1	30	1801.96	1807.18	5.23	64.66
511014-602	1	25	1808.45	1826.99	18.54	6.49
511011-402	1	365	1828.16	1876.1	47.94	19.71
511011-602	1	25	1878.03	1881.66	3.64	49.87
522021-11301	1	478	1883.12	2024.15	141.03	5.09
522021-11401	1	478	2028.01	2072.4	44.4	144.89
522021-11501	1	478	2075.87	2118.03	42.16	47.86
523023-11901	1	115	2120.73	2123.74	3.01	44.86
523023-11904	1	115	2137.96	2140.88	2.92	17.23
523023-11907	1	115	2143.53	2146.38	2.86	5.57
522023-11701	1	478	2160.89	2190.49	29.6	17.37
523021-11901	1	115	2194.12	2280.45	86.32	33.23
523021-11904	1	115	2283.92	2287.06	3.13	89.8
523021-11907	1	115	2289.62	2304.37	14.75	5.7
511013-401	1	262	2306.64	2312.14	5.5	17.02
511013-601	1	30	2315.53	2332.55	17.02	8.89
511013-701	1	122	2333.93	2382.73	48.8	18.4
523021-12301	1	333	2384.47	2459.44	74.97	50.54
523021-12500	1	576	2472.91	2530.46	57.55	88.44
511014-201	1	399	2546.66	2592.47	45.81	73.75
511014-304	1	465	2594.51	2620.46	25.95	47.85
523021-11601	1	695	2622.48	2695.24	72.77	27.97
523021-11606	1	478	2698.08	2743.43	45.34	75.61
511015-102	1	22	2748.09	2760.75	12.66	50
511015-301	1	925	2762	2833.8	71.81	13.91
511015-303	1	700	2839.28	2889.95	50.67	77.28
523023-11802	1	333	2904.35	2916	11.65	65.07
523023-12400	1	333	2929.81	2952.08	22.26	25.47
522023-11300	1	695	2953.72	3054.88	101.16	23.91
522023-11400	1	695	3057.15	3105.38	48.23	103.43
522023-11500	1	695	3107.22	3155.62	48.41	50.07

Table K.1: Order times and inter-arrival times of the preprocessing department of DSGa.

Section	Processing Area	Number of parts	Start time [Hrs]	Finish time [Hrs]	Order time [Hrs]	Inter arrival time [Hrs]
523021-11701	1	478	3169.2	3200.01	30.81	61.99
523023-12100	1	333	3203.58	3240.19	36.6	34.38
523023-12201	1	333	3243.21	3266.16	22.96	39.62
523023-11100	1	1173	3268.17	3365.39	97.23	24.96
512010-101	1	38	3370.86	3372.04	1.18	102.7
512010-301	1	925	3385.29	3460.07	74.78	14.43
512010-501	1	85	3465.3	3481.31	16.01	80.01
523021-12101	1	333	3482.61	3504.87	22.26	17.31
512010-401	1	262	3507.31	3528.93	21.62	24.7
512010-601	1	30	3531.1	3539.84	8.74	23.79
512010-701	1	122	3553.7	3583.77	30.07	22.6
523023-11600	1	695	3584.78	3697.37	112.59	31.08
523023-11604	1	478	3700.29	3729.62	29.34	115.51
512011-201	1	399	3744.71	3792.53	47.82	44.42
512011-304	1	465	3796.33	3821.53	25.21	51.61
512013-402	1	365	3823.23	3894.73	71.49	26.9
512013-602	1	25	3896.75	3914.86	18.1	73.52
523021-11100	1	1173	3917.68	4040.26	122.58	20.93
512012-402	1	365	4057.69	4090.16	32.47	140.01
512012-602	1	25	4105.29	4109.33	4.04	47.59
512012-102	1	22	4111.14	4111.87	0.73	5.85
512012-303	1	700	4113.12	4307.87	49.07	1.98
522023-12100	2	333	34.41	74.79	40.38	
522023-12201	2	333	75.97	101.11	25.15	41.55
522023-11901	2	115	103.09	107.59	4.49	27.13
522023-11904	2	115	120.9	125.45	4.56	17.8
522023-11907	2	115	127.26	144.03	16.77	6.36
511010-101	2	38	145.24	169.36	24.12	17.98
511010-501	2	85	169.89	173.12	3.23	24.66
522021-11901	2	115	174.87	225.09	50.22	4.98
522021-11904	2	115	226.62	243.15	16.53	51.75
522021-11907	2	115	244.51	248.68	4.17	17.89
511010-401	2	262	299.75	320.64	20.89	55.24
511010-601	2	30	322.28	341.93	19.65	22.53
511010-701	2	122	342.5	371.56	29.06	20.22
522021-12301	2	333	384.12	486.29	102.17	41.62
522021-12500	2	576	487.74	556.66	68.92	103.62
511011-201	2	399	557.85	601.8	43.95	70.11
511011-301	2	925	602.8	679.19	76.38	44.96
511011-304	2	465	682	720.73	38.73	79.2
511015-402	2	365	722	750.12	28.12	39.99
511015-602	2	25	751.33	769.66	18.33	29.33
522023-11802	2	333	947.2	970.89	23.68	195.87
522023-12400	2	333	984.11	1011.99	27.87	36.91
522021-11100	2	1173	1012.99	1091.41	78.42	28.87
522021-11701	2	478	1105.92	1136.62	30.7	92.93
511012-102	2	22	1138.39	1139.97	1.58	32.47
511012-303	2	700	1153.06	1209.86	56.81	14.67
522023-11100	2	1173	1224.11	1305.16	81.05	71.06
522023-11200	2	1173	1320.11	1398.22	78.12	95.99
511012-402	2	365	1400.91	1443.39	42.49	80.8
511012-602	2	25	1444.6	1447.35	2.75	43.7

Table K.1: Order times and inter-arrival times of the preprocessing department of DSGa.

Section	Processing Area	Number of parts	Start time [Hrs]	Finish time [Hrs]	Order time [Hrs]	Inter arrival time [Hrs]
522021-12100	2	333	1448.22	1473.98	25.76	3.61
522021-12201	2	333	1475.05	1513.09	38.03	26.84
511013-101	2	38	1514.1	1538.1	24	39.04
511013-301	2	925	1538.85	1618.38	79.53	24.75
511013-501	2	85	1633.05	1639.36	6.31	94.2
522023-11602	2	478	1640.32	1690.32	50	7.26
522023-11608	2	478	1705.44	1738.86	33.42	65.12
511014-502	2	140	1752.63	1784.25	31.62	47.19
511014-603	2	164	1785.02	1803.16	18.14	32.39
511011-502	2	140	1804.19	1829.28	25.09	19.17
511011-603	2	164	1830.73	1848.35	17.62	26.54
522021-11302	2	478	1849.6	2026.42	176.82	18.87
522021-11402	2	478	2042.41	2088.63	46.22	192.82
522021-11502	2	478	2090.48	2122.39	31.91	48.07
523023-11102	2	115	2137	2141.91	4.91	46.52
523023-11902	2	115	2143.99	2160.31	16.32	7
523023-11905	2	115	2163.07	2167.7	4.63	19.08
523023-11908	2	115	2170.41	2186.77	16.37	7.34
522023-11800	2	403	2188.32	2214.15	25.83	17.91
523021-11102	2	115	2215.38	2267.28	51.9	27.06
523021-11902	2	115	2280.99	2285.67	4.68	65.61
523021-11905	2	115	2287.04	2291.24	4.2	6.05
523021-11908	2	115	2305.22	2309.83	4.61	18.18
511013-402	2	365	2311.11	2377.22	66.11	5.89
511013-602	2	25	2378.58	2382.3	3.72	67.47
523021-11802	2	333	2383.42	2475.7	92.28	4.84
523021-12400	2	333	2476.98	2506.31	29.33	93.56
511014-101	2	38	2507.27	2520.78	13.51	30.29
511014-301	2	925	2521.57	2598.94	77.37	14.3
511014-501	2	85	2601.34	2617.27	15.93	79.77
523021-11602	2	478	2618.52	2691.05	72.53	17.18
523021-11608	2	478	2694.09	2743.98	49.9	75.56
511015-201	2	399	2747.43	2792.02	44.59	53.34
511015-304	2	465	2793.15	2819.81	26.66	45.72
523023-12300	2	333	2833.29	2859.84	26.55	40.14
523023-12401	2	333	2861.34	2890.19	28.85	28.05
522023-11301	2	478	2891.85	3059.19	167.34	30.51
522023-11401	2	478	3073.88	3122.24	48.36	182.03
522023-11501	2	478	3125.14	3170.97	45.83	51.26
523021-11800	2	403	3172.93	3198.72	25.79	47.79
523023-12101	2	333	3199.83	3227.1	27.27	26.9
523023-11200	2	1173	3240.52	3342.4	101.89	40.68
512010-102	2	22	3345.22	3346.87	1.66	104.7
512010-303	2	700	3360.17	3418.91	58.74	14.95
523021-11801	2	333	3432.51	3460.83	28.32	72.34
523021-12200	2	333	3462.53	3488.28	25.75	30.03
512010-402	2	365	3489.32	3532.26	42.94	26.78
512010-602	2	25	3533.47	3539.78	6.32	44.15
523023-11601	2	695	3553.09	3696.77	143.67	19.63
523023-11606	2	478	3698.4	3745.14	46.74	145.3
512011-101	2	38	3746.99	3748.91	1.92	48.6
512011-301	2	925	3749.86	3842.32	92.46	2.87

Table K.1: Order times and inter-arrival times of the preprocessing department of DSGa.

Section	Processing Area	Number of parts	Start time [Hrs]	Finish time [Hrs]	Order time [Hrs]	Inter arrival time [Hrs]
512011-501	2	85	3844.65	3847.98	3.33	94.79
512013-502	2	140	3849.26	3896.04	46.78	4.61
512013-603	2	164	3897.07	3914.94	17.86	47.81
523021-11200	2	1173	3916.53	4036.74	120.21	19.46
512012-502	2	140	4041.05	4065.36	24.32	124.52
512012-603	2	164	4066.39	4083.27	16.88	25.34
512012-201	2	399	4084.14	4128.52	44.38	17.75
522023-12101	3	333	34.75	74.45	39.7	
522023-11102	3	115	76.47	82.9	6.43	41.72
522023-11902	3	115	96.9	101.46	4.56	20.43
522023-11905	3	115	103.79	120.62	16.83	6.89
522023-11908	3	115	123.47	127.73	4.26	19.68
511010-102	3	22	129.87	171.66	41.79	6.4
511010-303	3	700	172.54	241.22	68.67	42.67
522021-11102	3	115	243.1	247.39	4.29	70.56
522021-11902	3	115	249.15	265.38	16.24	6.04
522021-11905	3	115	268.04	272.76	4.72	18.89
522021-11908	3	115	274.83	291.2	16.37	6.78
511010-402	3	365	293.1	323.76	30.66	18.27
511010-602	3	25	338.07	342.92	4.85	44.98
522021-11802	3	333	344.24	488.18	143.93	6.17
522021-12400	3	333	491.1	531.93	40.83	146.86
511011-101	3	38	533.45	534.83	1.38	42.35
511011-501	3	85	536.11	539.68	3.57	2.66
522021-11602	3	478	553.13	702.61	149.48	17.02
522021-11608	3	478	705.54	752.57	47.03	152.41
511015-502	3	140	754.76	773.33	18.57	49.22
511015-603	3	164	774.27	778.94	4.67	19.51
522023-12300	3	333	960.21	985.97	25.76	185.95
522023-12401	3	333	988.41	1016.6	28.19	28.2
522021-11800	3	403	1019.49	1105.43	85.94	31.08
511012-201	3	399	1107.75	1155.57	47.82	88.27
511012-304	3	465	1157.3	1183.22	25.92	49.55
511012-501	3	85	1184.78	1187.66	2.88	27.48
511012-502	3	140	1230.25	1253.49	23.24	45.47
511012-603	3	164	1255.32	1275.36	20.05	25.07
522021-12101	3	333	1378.09	1403.99	25.9	122.78
511013-102	3	22	1540.57	1541.64	1.07	162.47
511013-303	3	700	1544.07	1613.16	69.09	3.5
522023-11600	3	695	1615.22	1681.89	66.67	71.16
522023-11604	3	478	1684.28	1728.52	44.24	69.06
511014-401	3	262	1731.52	1752.57	21.05	47.24
511014-701	3	122	1754.25	1805.21	50.96	22.73
511011-401	3	262	1806.5	1827.95	21.45	52.24
511011-601	3	30	1829.74	1835.69	5.94	23.24
511011-701	3	122	1848.64	1879.55	30.91	18.9
522021-11300	3	695	1880.34	2024.54	144.2	31.7
522021-11400	3	695	2026.39	2074.2	47.81	146.05
522021-11500	3	695	2088.81	2121.79	32.98	62.42
523023-11900	3	115	2123.6	2139.88	16.28	34.79
523023-11903	3	115	2142.18	2147.18	4.99	18.58
523023-11906	3	115	2161.9	2166.52	4.62	19.71

Table K.1: Order times and inter-arrival times of the preprocessing department of DSGa.

Section	Processing Area	Number of parts	Start time [Hrs]	Finish time [Hrs]	Order time [Hrs]	Inter arrival time [Hrs]
523023-11909	3	115	2169.14	2185.98	16.85	7.24
522023-11700	3	624	2187.5	2232.59	45.08	18.36
523021-11900	3	115	2234.49	2267.76	33.27	46.98
523021-11903	3	115	2282.63	2287.23	4.6	48.15
523021-11906	3	115	2290.25	2306.6	16.35	7.62
523021-11909	3	115	2309.27	2313.66	4.39	19.01
511013-502	3	140	2315.93	2336.04	20.11	6.66
511013-603	3	164	2337.31	2362.69	25.38	21.38
523021-12300	3	333	2376.12	2476.75	100.62	38.82
523021-12401	3	333	2478.93	2520.69	41.76	102.81
511014-102	3	22	2523.36	2524.14	0.78	44.42
511014-303	3	700	2526.49	2594.94	68.45	3.14
523021-11600	3	695	2597.05	2688.5	91.45	70.56
523021-11604	3	478	2690.77	2737.3	46.54	93.71
511015-101	3	38	2739.81	2741.31	1.49	49.05
511015-501	3	85	2742	2744.88	2.88	2.19
523023-12301	3	333	2746.63	2864.77	118.14	4.63
523023-12500	3	576	2866.47	2915.32	48.85	119.84
522023-11302	3	478	2928.83	3057.97	129.14	62.37
522023-11402	3	478	3073.48	3121.85	48.37	144.65
522023-11502	3	478	3125.09	3172.14	47.04	51.61
523021-11700	3	624	3175.51	3220.19	44.68	50.42
523023-11801	3	333	3221.48	3246.63	25.15	45.98
523023-12200	3	333	3248.4	3274.03	25.63	26.92
512010-201	3	399	3275.3	3385.86	110.56	26.9
512010-304	3	465	3388.23	3414.9	26.67	112.93
523021-12100	3	333	3416.58	3457.85	41.27	28.35
523021-12201	3	333	3459.45	3485.33	25.87	42.87
512010-502	3	140	3486.65	3534.54	47.89	27.2
512010-603	3	164	3535.48	3553.04	17.56	48.83
523023-11602	3	478	3558.68	3699.39	140.71	23.2
523023-11608	3	478	3703.46	3748.06	44.6	144.78
512011-102	3	22	3751.61	3753.91	2.3	48.15
512011-303	3	700	3755.58	3824.28	68.7	3.98
512013-401	3	262	3826.57	3848.27	21.7	70.98
512013-601	3	30	3850.48	3868.61	18.13	23.91
512013-701	3	122	3869.47	3915.56	46.09	19
512012-401	3	262	3920.12	3968.99	48.87	50.64
512012-601	3	30	3984.82	3991.33	6.51	64.7
512012-701	3	122	3992.7	4040.53	47.82	7.89
512012-101	3	38	4041.57	4043.28	1.71	48.86
512012-501	3	85	4056.42	4062.6	6.18	14.85

K.2. Flanging

Table K.2 shows the order times and inter-arrival times of batches of flanged parts at the flanging area. Based on these values, the following key figures are computed:

- T_A: This is equal to 22 hours and 48 minutes.
- S_A: This is equal to 24 hours and 20 minutes.
- T_O: This is equal to 11 hours and 9 minutes.
- S_O: This is equal to 10 hours.
- u: the utilization of the flanging area is computed as the ratio of all the time one or more batches is present at the flanging area in a year, to the total time passed in this year. This is equal to 36%.

Based on the values in table K.2, it appears that of all the flanging area is utilized, 70% of time one batch is present at the flanging area, 20% of time two different batches are present and 10%, three different batches are present at the flanging area simultaneously.

Table K.2: Order times and inter-arrival times at the flanging area

Section	Started [Hrs]	Finished [Hrs]	Order Time [Hrs]	Inter-arrival Time [Hrs]
522023-11801	53.85	56.66	2.81	
522023-12101	57.05	74.35	17.29	3.2
522023-12100	57.14	74.68	17.54	0.09
522023-12200	78.37	81.16	2.79	21.23
522023-12201	98.21	101	2.79	19.84
511010-201	148.62	151.41	2.79	50.41
511010-501	171.59	173.03	1.44	22.98
511010-303	221.34	240.42	19.08	49.74
511010-301	246.48	250.78	4.3	25.15
511010-304	290.84	291.58	0.74	44.36
511010-402	298.55	318.1	19.55	7.71
511010-401	315.2	318.85	3.65	16.65
511010-601	323.41	341.72	18.31	8.21
511010-602	338.74	342.36	3.62	15.34
511010-502	339.42	367.12	27.7	0.68
511010-701	346.54	370.01	23.47	7.12
511010-603	384.93	386.42	1.49	38.39
522021-12300	467.6	483.13	15.53	82.67
522021-12301	481.51	486.18	4.67	13.91
522021-11802	484.14	488.07	3.93	2.63
522021-12401	504.73	507.52	2.78	20.6
522021-12400	514.35	531.83	17.47	9.62
511011-501	537.87	539.6	1.73	23.51
522021-12500	539.81	553.98	14.17	1.95
511011-303	553.85	560.88	7.03	14.04
511011-201	580.44	584.27	3.83	26.59
511011-301	674.55	678.5	3.95	94.11
522021-11602	683.52	702.46	18.94	8.97
511011-304	720.34	720.62	0.28	36.82
511015-402	727.6	747.44	19.84	7.26
522021-11608	746.09	752.39	6.31	18.49
511015-602	752.1	769.37	17.26	6.02
511015-502	769.14	773.01	3.87	17.03
511015-603	777.06	778.59	1.53	7.92
522021-11604	796.27	799.82	3.55	19.22
522021-11606	840.47	843.97	3.5	44.19
511015-401	849.71	851.23	1.52	9.24
511015-601	867.92	870.13	2.22	18.21

Table K.2: Order times and inter-arrival times at the flanging area

Section	Started [Hrs]	Finished [Hrs]	Order Time [Hrs]	Inter-arrival Time [Hrs]
511015-701	873.76	895.96	22.2	5.84
522023-12301	961.29	964.07	2.78	87.53
522023-11802	967.99	970.78	2.78	6.71
522023-12300	971.04	985.87	14.83	3.05
522023-12400	995.82	1011.88	16.06	24.78
522023-12401	1012.42	1016.49	4.07	16.6
522023-12500	1018.61	1032.92	14.31	6.19
522021-11100	1085.07	1090.02	4.95	66.46
522021-11200	1110.38	1114.49	4.1	25.32
511012-201	1128.07	1130.86	2.79	17.68
522021-11701	1132.35	1136.45	4.1	4.29
511012-304	1182.76	1183.07	0.31	50.41
511012-501	1186.39	1187.59	1.19	3.63
511012-303	1202.16	1209.19	7.03	15.77
511012-502	1233.39	1252.25	18.87	31.23
511012-301	1256.28	1281.99	25.71	22.89
511012-603	1258.18	1275.07	16.89	1.91
522023-11100	1297.35	1303.62	6.26	39.17
511012-401	1300.79	1303.89	3.1	3.43
511012-601	1320.22	1323.59	3.37	19.43
511012-701	1329.85	1355.55	25.7	9.63
522023-11200	1392.08	1397.26	5.18	62.23
522021-11801	1393.48	1398.77	5.29	1.39
522021-12101	1401.1	1403.88	2.78	7.62
522021-12200	1420.55	1423.34	2.79	19.45
511012-402	1427.92	1443.07	15.16	7.37
511012-602	1445.36	1447.15	1.79	17.45
522021-12100	1471.08	1473.87	2.79	25.71
522021-12201	1498.18	1512.98	14.79	27.1
511013-201	1547.16	1565.48	18.32	48.98
511013-303	1593.49	1612.32	18.84	46.33
511013-301	1612.29	1617.9	5.61	18.8
511013-304	1612.48	1613.54	1.05	0.2
511013-501	1635.02	1639.26	4.24	22.54
522023-11602	1666.89	1690.06	23.17	31.87
522023-11604	1712.27	1728.29	16.02	45.38
522023-11606	1728.02	1732.76	4.75	15.74
511014-401	1733.15	1735.82	2.67	5.14
522023-11608	1734.12	1738.64	4.52	0.97
511014-502	1755.92	1783.85	27.93	21.8
511014-701	1757.1	1803.46	46.36	1.18
511014-402	1780.78	1787.48	6.7	23.68
511014-603	1800.18	1802.65	2.47	19.4
511014-601	1802.71	1805.83	3.12	2.52
511011-401	1808.11	1826	17.89	5.41
511011-502	1809.05	1828.43	19.39	0.93
511014-602	1809.09	1826.49	17.4	0.05
511011-601	1830.87	1835.41	4.54	21.78
511011-603	1833.66	1835.7	2.03	2.79
511011-701	1852.19	1877.79	25.6	18.53
511011-402	1855.59	1875.7	20.11	3.4
511011-602	1878.53	1881.24	2.71	22.93

Table K.2: Order times and inter-arrival times at the flanging area

Section	Started [Hrs]	Finished [Hrs]	Order Time [Hrs]	Inter-arrival Time [Hrs]
522021-11301	2001.73	2023.95	22.22	123.2
522021-11302	2019.79	2026.24	6.44	18.06
522021-11401	2064.34	2072.19	7.85	44.55
522021-11402	2071.14	2088.23	17.09	6.8
522021-11501	2098.83	2117.77	18.94	27.69
522021-11502	2118.6	2122.22	3.61	19.77
522023-11701	2170.62	2186.63	16.01	52.02
511013-401	2308.67	2310.44	1.78	138.05
511013-601	2328.56	2332.08	3.52	19.89
511013-502	2330.32	2335.67	5.35	1.77
511013-701	2335.99	2379.02	43.03	5.67
511013-402	2338.38	2376.85	38.48	2.39
511013-603	2352.2	2362.41	10.21	13.82
511013-602	2379.61	2381.8	2.19	27.41
523021-12301	2456.29	2459.33	3.04	76.67
523021-11802	2458.62	2475.59	16.97	2.33
523021-12300	2459.83	2476.64	16.81	1.21
523021-12400	2501.27	2506.2	4.93	41.44
523021-12401	2503.1	2520.59	17.48	1.83
523021-12500	2525.91	2528.17	2.26	22.81
511014-201	2570.49	2573.28	2.78	44.58
511014-303	2574.83	2593.54	18.71	4.34
511014-301	2593.33	2598.13	4.79	18.5
511014-501	2603.65	2617.17	13.53	10.31
511014-304	2619.42	2620.2	0.77	15.78
523021-11602	2670.07	2690.88	20.81	50.64
523021-11604	2719.38	2737.03	17.65	49.32
523021-11606	2722.19	2743.16	20.97	2.81
523021-11608	2722.5	2743.55	21.04	0.31
511015-501	2743.64	2744.8	1.17	21.13
511015-201	2771.63	2787.1	15.46	28
511015-301	2816.06	2832.5	16.44	44.42
511015-304	2818.6	2819.66	1.06	2.54
523023-12300	2856	2859.73	3.73	37.4
523023-12301	2860.1	2864.67	4.57	4.1
511015-303	2880.49	2888.45	7.96	20.39
523023-12401	2885.35	2890.08	4.73	4.86
523023-11802	2911.02	2915.88	4.86	25.67
523023-12500	2911.25	2914.77	3.52	0.23
523023-12400	2937.17	2939.97	2.79	25.92
522023-11302	3048.07	3057.04	8.97	110.9
522023-11301	3051.38	3058.81	7.43	3.31
522023-11402	3101.24	3121.62	20.39	49.86
522023-11401	3101.51	3121.88	20.38	0.27
522023-11501	3151.26	3170.8	19.54	49.75
522023-11502	3152.12	3171.77	19.65	0.86
523021-11701	3192.02	3195.56	3.54	39.89
523023-12101	3222.45	3226.99	4.54	30.43
523023-12100	3223.31	3240.07	16.77	0.86
523023-11801	3243.74	3246.53	2.78	20.43
523023-12201	3250.61	3266.05	15.44	6.87
523023-12200	3270.81	3273.92	3.11	20.2

Table K.2: Order times and inter-arrival times at the flanging area

Section	Started [Hrs]	Finished [Hrs]	Order Time [Hrs]	Inter-arrival Time [Hrs]
523023-11200	3337.42	3341.24	3.83	66.6
523023-11100	3342.28	3360.29	18.01	4.86
512010-201	3360.99	3364.54	3.55	18.71
512010-303	3409.98	3418	8.02	49
512010-304	3413.97	3414.81	0.84	3.99
523021-12100	3439.13	3457.74	18.61	25.16
512010-301	3439.39	3458.71	19.32	0.26
523021-11801	3443.51	3460.72	17.21	4.12
512010-501	3480.02	3481.22	1.2	36.51
523021-12201	3482.43	3485.22	2.79	2.41
523021-12200	3485.39	3488.17	2.79	2.96
523021-12101	3489.82	3504.76	14.94	4.44
512010-402	3507.05	3529.65	22.6	17.23
512010-502	3509.62	3534.21	24.59	2.57
512010-401	3510.98	3515.99	5.01	1.36
512010-601	3531.94	3539.17	7.23	20.97
512010-602	3534.26	3539.3	5.04	2.32
512010-603	3538.24	3552.75	14.51	3.98
512010-701	3555.74	3580.8	25.06	17.5
523023-11602	3676.6	3699.21	22.61	120.87
523023-11604	3724.81	3729.36	4.55	48.21
523023-11606	3726.95	3744.8	17.85	2.14
523023-11608	3730.83	3747.9	17.07	3.88
512011-201	3753.12	3768.89	15.77	22.29
512011-303	3803.93	3823.54	19.61	50.81
512011-304	3820.19	3821.28	1.09	16.26
512011-301	3823.02	3841.89	18.87	2.83
512013-401	3840.12	3842.42	2.3	17.1
512011-501	3846.79	3847.88	1.09	6.67
512013-601	3851.28	3868.29	17.01	4.49
512013-402	3865.04	3894.31	29.27	13.75
512013-502	3865.63	3895.5	29.87	0.59
512013-701	3872.78	3913.66	40.87	7.16
512013-602	3897.39	3914.33	16.93	24.61
512013-603	3899.73	3914.57	14.84	2.33
512012-401	3961.84	3967.58	5.74	62.11
512012-601	3987.26	3991.04	3.79	25.41
523021-11200	3992.19	4034.87	42.67	4.93
523021-11100	3992.76	4035.65	42.89	0.57
512012-701	3995.7	4037.09	41.4	2.94
512012-501	4058.89	4062.48	3.59	63.19
512012-502	4059.01	4064.88	5.87	0.12
512012-603	4080.99	4081.9	0.91	21.98
512012-402	4086.11	4089.73	3.63	5.12
512012-602	4105.92	4108.88	2.96	19.81
512012-201	4107	4111.28	4.29	1.08
512012-303	4153.84	4160.5	6.66	46.84

K.3. Forming

K.3.1. Current Situation

Table K.3 shows the order times and inter-arrival times of batches of formed parts at the forming area in the current. Based on these values, the following key figures are computed:

- T_A: This is equal to 123 hours and 7 minutes.
- S_A: This is equal to 82 hours and 48 minutes.
- T_O: This is equal to 158 hours and 48 minutes.
- S_O: This is equal to 65 hours and 22 minutes.
- u: the utilization of the forming area is computed as the ratio of all the time one or more batches is present at the forming area in a year, to the total time passed in this year. This is equal to 73%.

Table K.3: Order time and inter-arrival time at the forming area

Cutting Group	Started [Hrs]	Finished [Hrs]	Order Time [Hrs]	Inter-arrival time [Hrs]
511010-1	154	360.9	206.89	-
511010-2	289.99	466.07	176.08	135.99
511011-1	418.99	651.59	232.6	128.99
522021-4	651.74	701.8	50.07	232.75
511015-2	700.84	821.68	120.84	49.1
522021-1	920.88	962.09	41.21	220.04
522021-2	1044.51	1157.39	112.88	123.63
511012-1	1112.87	1347.12	234.25	68.36
522023-1	1211.81	1350.88	139.07	98.93
511012-2	1211.91	1451.65	239.74	0.1
511013-1	1470.74	1683.74	213	258.83
522023-4	1588.75	1728.46	139.71	118.01
511014-2	1589.92	1801.12	211.2	1.17
511011-2	1663.51	1906.02	242.52	73.58
522021-3	1902.69	1994.46	91.77	239.18
522023-2	2094.21	2209.44	115.23	191.52
511013-2	2160.48	2314.63	154.15	66.27
511014-1	2376.64	2571.39	194.75	216.16
523021-4	2572	2622.11	50.12	195.35
511015-1	2602.26	2817.33	215.08	30.26
523021-2	2863.9	2979.29	115.39	261.64
522023-3	2905.87	3008.48	102.6	41.98
523023-1	3152.58	3195.58	43.01	246.7
512010-1	3197.77	3410.5	212.74	45.19
512010-2	3341.19	3515.48	174.29	143.42
512011-1	3480.02	3707.43	227.41	138.83
523023-4	3490.65	3698	207.35	10.63
512013-2	3581.89	3826.06	244.17	91.25
523021-1	3731.95	3799.68	67.72	150.06
512012-2	3753.11	3947.09	193.98	21.16
512012-1	3847.4	3969.26	121.86	94.29

K.3.2. Swifter 3D-forming process

Table K.4 shows the order times and inter-arrival times of batches of formed parts at the forming area in the situation with swifter forming. Based on these values, the following key figures are computed:

- T_A: This is equal to 127 hours and 27 minutes.
- S_A: This is equal to 87 hours and 8 minutes.
- T_O: This is equal to 124 hours and 55 minutes.
- S_O: This is equal to 51 hours and 47 minutes.
- u: the utilization of the forming area is computed as the ratio of all the time one or more batches is present at the forming area in a year, to the total time passed in this year. This is equal to 68%.

Table K.4: Order time and inter-arrival time at the forming area with swifter 3D-forming process

Cutting Group	Started [Hrs]	Finished [Hrs]	Order Time [Hrs]	Inter-arrival time [Hrs]
511010-1	171.97	321.83	149.86	
511010-2	299.89	394.68	94.79	127.92
511011-1	466.35	631.87	165.52	166.46
522021-4	678.12	730.11	51.99	211.76
511015-2	723.86	802.86	79	45.74
522021-1	946.97	989.16	42.2	223.11
522021-2	1082.61	1153.52	70.91	135.65
511012-1	1139.11	1306.13	167.01	56.5
511012-2	1234.95	1400	165.05	95.84
522023-1	1253.55	1424.57	171.02	18.6
511013-1	1543.06	1710.31	167.25	289.51
522023-4	1661.86	1802.82	140.95	118.81
511014-2	1664.92	1832.67	167.76	3.05
511011-2	1753.89	1905.28	151.39	88.98
522021-3	1999.77	2089.45	89.68	245.88
522023-2	2169.91	2239.83	69.92	170.14
511013-2	2241.1	2314.82	73.73	71.19
511014-1	2481.07	2645.44	164.37	239.97
523021-4	2671.77	2720.53	48.76	190.7
511015-1	2721.12	2867.71	146.59	49.35
523021-2	3005.51	3082.23	76.71	284.39
522023-3	3010.6	3152.57	141.97	5.08
523023-1	3274.1	3315.66	41.57	263.5
512010-1	3323.45	3489.87	166.42	49.35
512010-2	3481.21	3563.06	81.85	157.76
523023-4	3629.7	3754.7	125.01	148.49
512011-1	3630.43	3849.08	218.65	0.73
512013-2	3725.21	3941.3	216.1	94.78
523021-1	3873.95	3970.46	96.51	148.75
512012-2	3916.64	4058.75	142.11	42.69
512012-1	3995.66	4183.42	187.76	79.02

L

Explanation of Process Image

This document gives an explanation on the diagram where the MCT* of the preprocessing department is determined, such as figure 5.12.

Per scenario, the total time is indicated by white, red and green parts:
The green parts show value adding times and major transports, such as actual operations being performed on a part such as forming or bringing a batch of parts from a sorting space to a parts processing area.

The red parts show packing and unpacking times and small transports, such as unpacking a part from a container on a parts processing area or placing a part onto the press brake.

The white parts show the waiting times, where a part is actually stationary.

Figure L.1 shows the same process as seen in figure 5.12. The numbers in the figure correspond to the numbers in the list below so it gives an indication of the steps that are taking place.

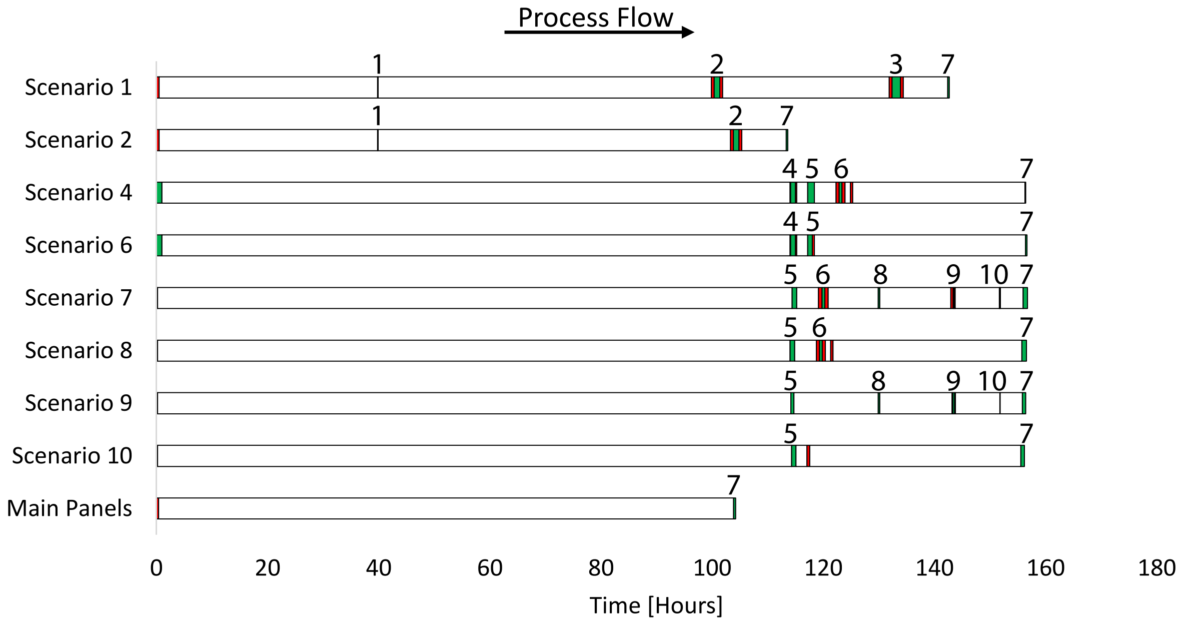


Figure L.1: Explanation of the information in the process image

1. Transport to Forming Area
2. 2D Forming
3. 3D Forming
4. Tapering
5. Transport to Parts Processing Area
6. Grinding/Beveling
7. Transport to End Buffer
8. Transport to Flanging Area
9. Flanging
10. Transport back from Flanging Area to Parts Processing Area

It is chosen not to state this information for every MCT-determining figure of every improvement suggestion, as this exceeds the aim of these figures: showing the process can be shortened substantially with simple improvement measures.

M

Pain Points

This document shows and gives an explanation on some of the stated pain points of the preprocessing department.

M.1. Press Brake

There is a number of issues experienced with the press brake, based on the fact that from every section with flanged parts, these parts are transported to one flanging station where in some cases the operator of the press brake gets to handle three batches of different sections at once. As stated in appendix K, the utilization of the flanging area is found to be equal to 36%, where conform the QRM-definitions, the utilization includes all the time a resource is occupied for any task, so it is defined as the ratio of all the time one or more batches is present at the flanging area in a year, to the total time that has passed in this year. Of course 36% is not a terrible utilization so in conventional management philosophy this would not be a point of interest. It appears that 70% of utilized time, one batch is present at the flanging area, 20% of utilized time, two batches area present and 10% of utilized time, three batches are present simultaneously. It appears that the pain experienced by the foremen is involved with this situation. When two batches are present simultaneously, this automatically means that one of these batches has to wait until the other batch is finished, causing a lot of waiting time. While this is happening, the parts processing area also has to wait for the flanged parts to return, before the parts processing area can finish its tasks for the entire section.

As these waiting times are included in the flow times, it is interesting to have a look at the flow time of the flanging area. Appendix K shows the order times and inter-arrival times of the flanging area. As seen in the same appendix, the following key figures are found for the flanging area:

T_A: 22 hours and 48 minutes
S_A: 24 hours and 20 minutes
T_O: 11 hours and 9 minutes
S_O: 10 hours
u: 36%.

T_A and S_A lead to a variability of arrival times V_A of 1.11. With the stated values of T_O and S_O a variability of throughput times V_T is found of 0.90. These two together give the average variability AV of 1.03.

The utilization of 36% yields a value of M of $\frac{0.36}{1-0.36}$=0.57.

With AV, M and T_O known, a flow time is found of (1.03 * 0.57 * 11.15) + 11.15 = 17 hours and 38 minutes, while the total touch time for the average batch of flanged parts is around one and a half hour. This means that a parts processing area, after grinding a batch has to wait for almost 18 hours while these parts are flanged.

M.2. Line Heating

As seen in section 6.2.2, line heating is perceived to be a slow process. From section 5.1.1 it is known that a 3D-formed part first is brought into a 2D curve and then placed at the floor, until the line heating platform is available.

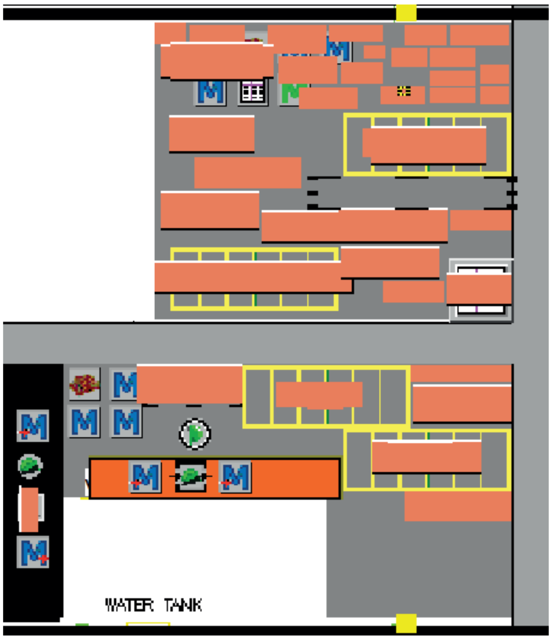


Figure M.1: Occupation of the forming area

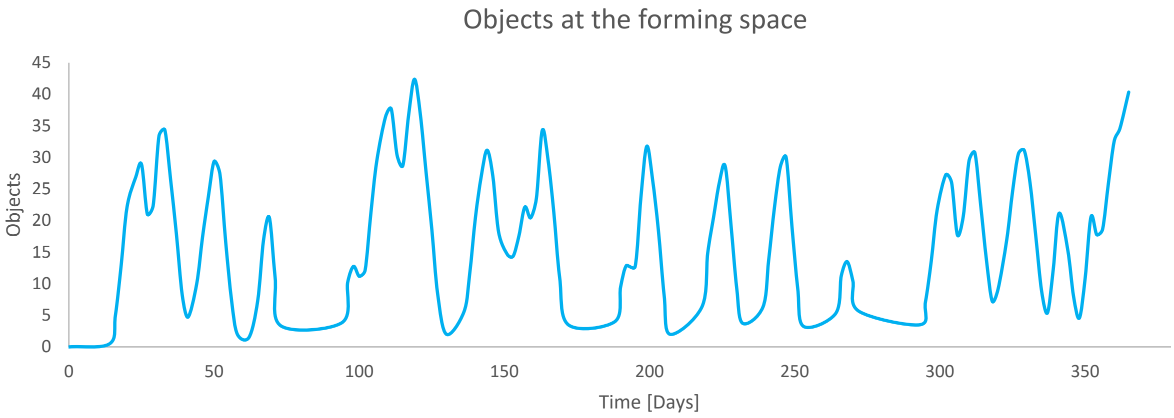
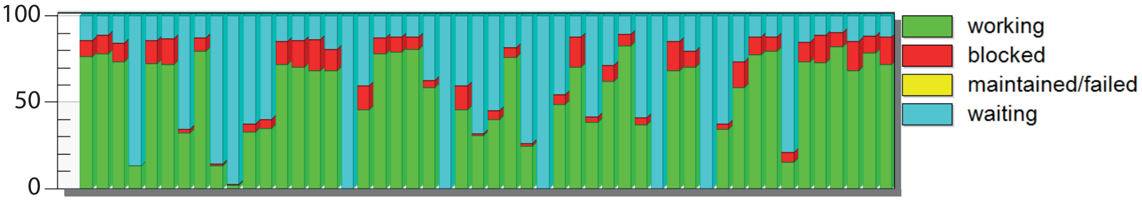
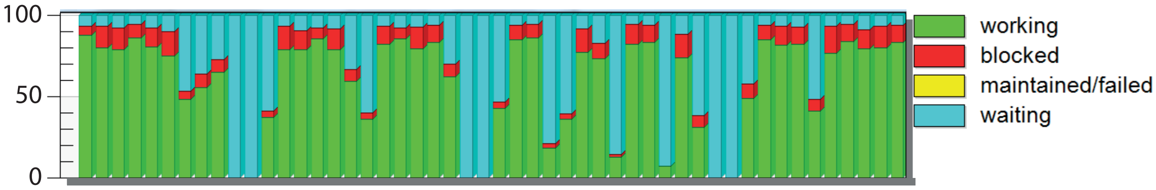


Figure M.2: Numbers of objects at the forming space over time

Figure M.1 shows this situation, at this particular instance, 28 parts are waiting for the line heating station. To investigate if this happens more often, figure M.2 shows the number of objects present at the forming space in time. This also counts stacks and containers. As this figure is used to find an estimate for the space occupation, a stack of parts and a container of parts are both counted as one object. Of course not every part has the same size, this is also seen in figure M.1 but it does give an idea of the queues that arise for the line heating station. Figure M.3 shows the utilization of both the 2D plate roller and the line heating platform. It is seen that the demand is not very levelled. This is explicable by the fact that the formed parts are first stacked after cutting and transported to the forming area once they are all cut. So these parts do indeed arrive in bursts. Furthermore, from the figure it can be seen that when one of these burst has taken place, the line heating platform is almost fully occupied. Its utilization is bigger than that of the 2D plate roller, even though there are far less parts that go the the line heating platform. The big queue for the line heating station and this utilization show that the line heating station is indeed a bottleneck in the 3D-forming process.



(a) Utilization of the Plate Roller



(b) Utilization of the line heating platform

Figure M.3: Utilization of the forming equipment in section 1A

M.3. Transverse Carriage

An observation of the processes taking place in the preprocessing department shows that almost every inter-lane transport takes place using the transverse carriage. This is quite a labor intensive task as every inter-lane transport actually requires three transports as seen in figure M.4. The requests of the carriage over time are shown in figure M.5. This shows that over the time span of the year, the carriage is requested 2054 times to build 271 sections. This shows that the carriage is used almost eight times per batch and the total movements for inter-lane-transports are on average 23 per batch.

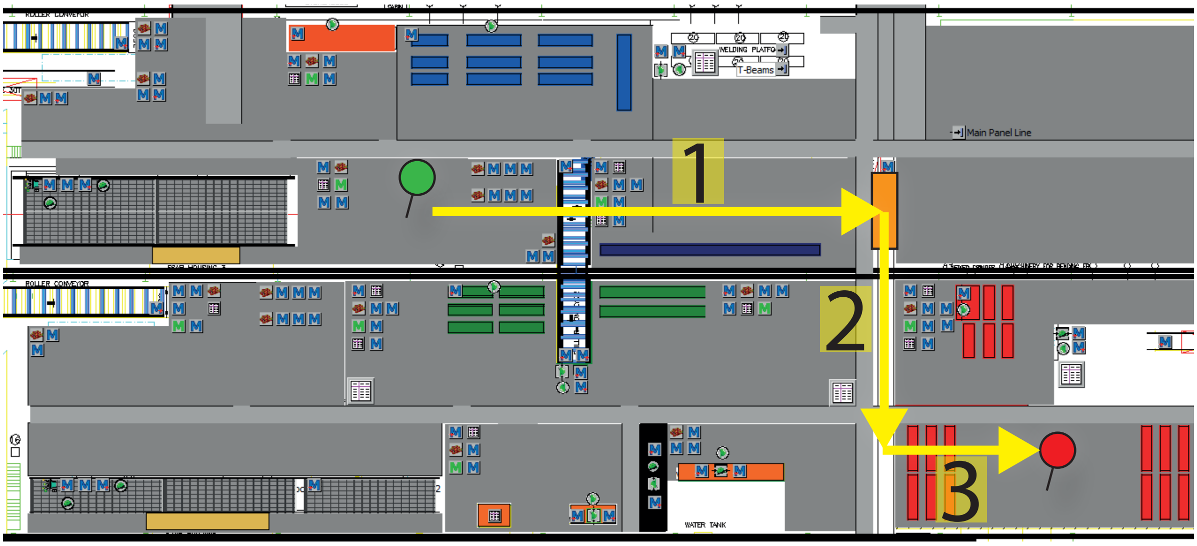


Figure M.4: Every inter-lane transport requires three movements

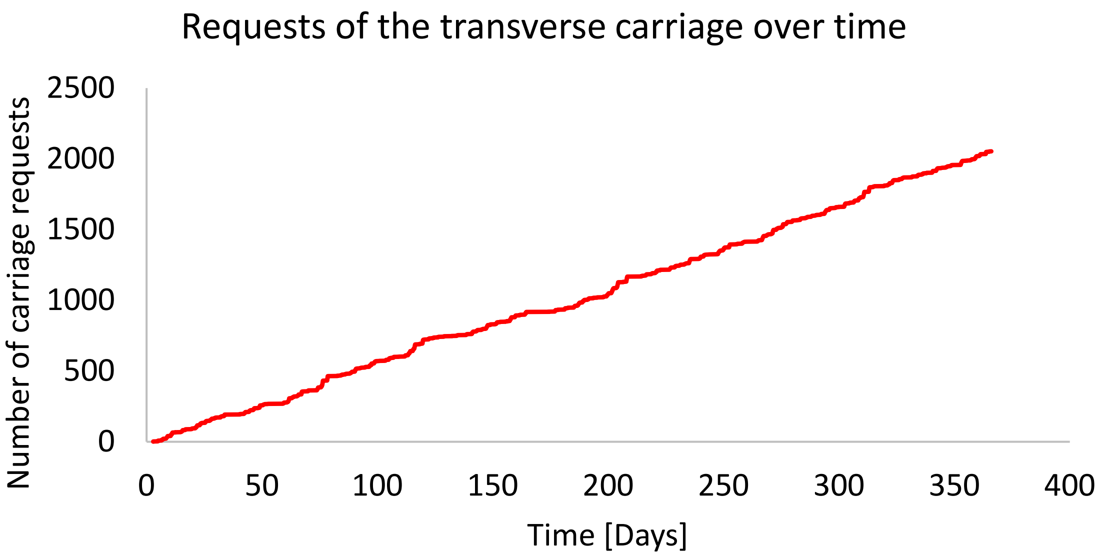


Figure M.5: Number of requests of the transverse carriage over time

Figure M.6 however shows that the carriage itself is no bottleneck in this process, as its utilization is relatively low. It is therefore interesting to see if the number of inter-lane transports can be decreased, however for the carriage itself it does not have a big priority.

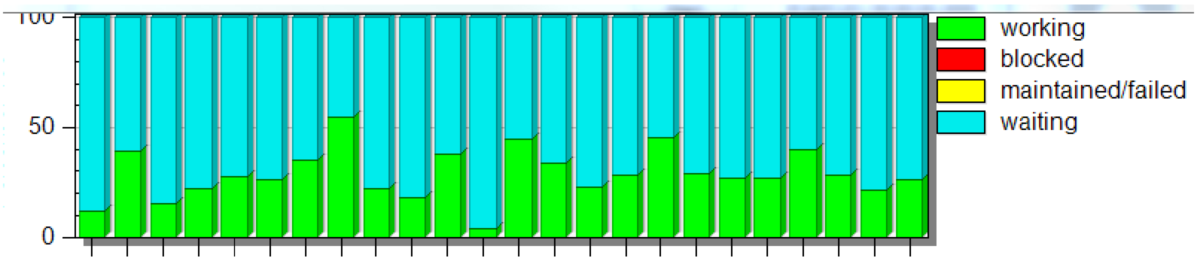


Figure M.6: Utilization of the transverse carriage