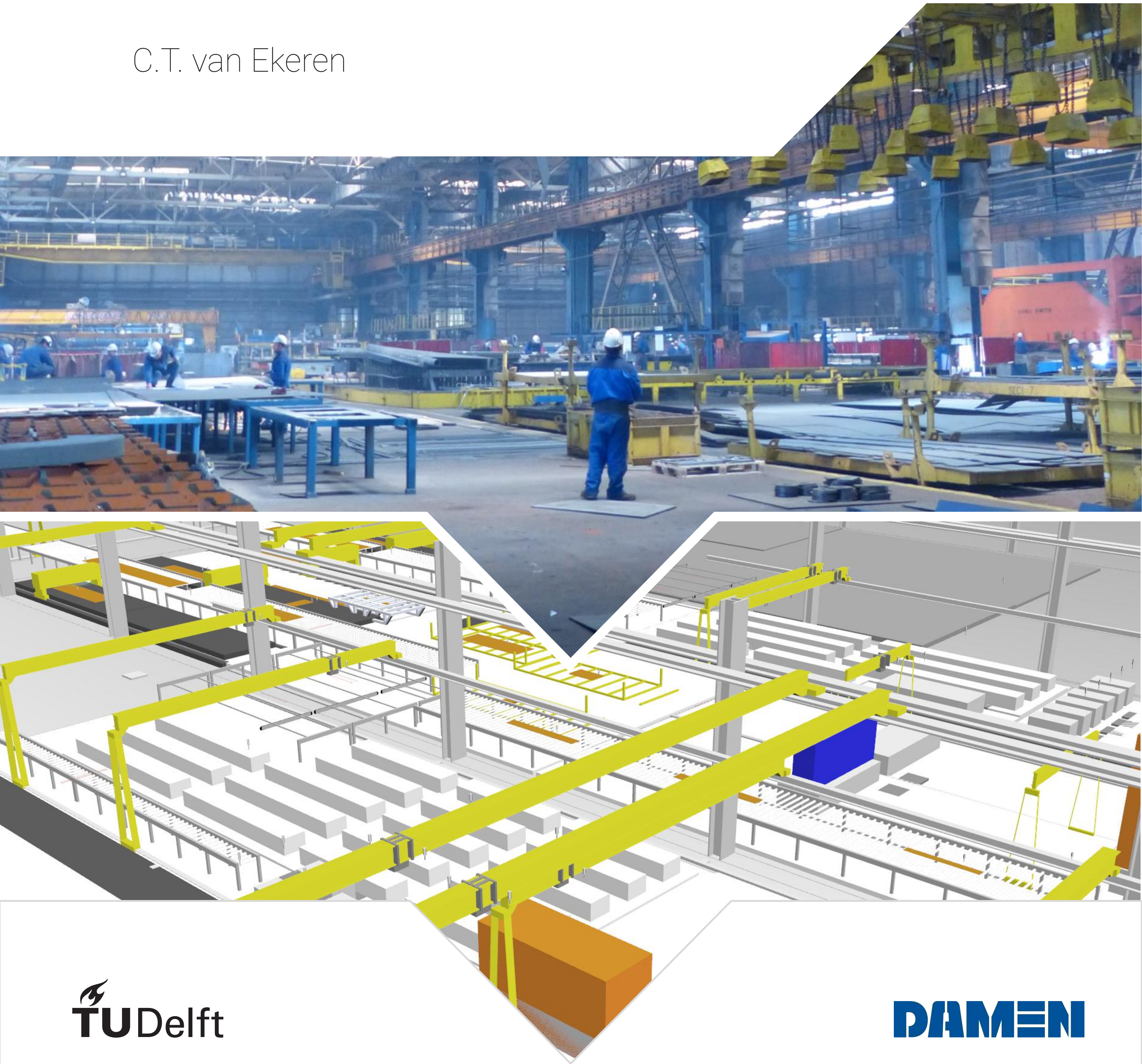
Process improvement of Damen Shipyard Galati pre-processing

Merging two pre-processing facilities by implementing Lean Manufacturing

C.T. van Ekeren



Thesis for the degree of Master of Science in Marine Technology in the specialisation of Ship Production

Process improvement of Damen Shipyard Galati pre-processing

Merging two pre-processing facilities by implementing Lean Manufacturing

By

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Performed at

Damen Shipyards Gorinchem

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Abstract

An improvement study to the pre-processing process of Damen Shipyards Galati (DSGa) is performed. Benchmark analysis shows that the current pre-processing process underperforms, compared to industry peers. The objective is to increase DSGa's throughput and decrease space utilisation, such that pre-processing facilities S1 and S1a can be merged into S1a and DSGa meets the industry 'standard'. Lean Manufacturing shows the potential to enable improvement and is adopted to initiate process redesign. The Lean principles drive the approach of this study, which studies the 'current state', defines improvement strategies and implements the strategies in 'future states'.

Lean Manufacturing focuses on the shortening of the production flow by eliminating waste. Hence the value within the DSGa pre-processing process is determined, being a physical transformation of a product according the customer expectation. Since there is no clear main flow and the process is rather complex due to the existence of several routines, limits concerning straightforwardness and completeness are observed concerning the implementation of the 'value stream mapping' approach. Discrete event simulation is proposed to incorporate the dynamic behaviour of the process. Key Performance Indicators (KPI), related to space utilisation (and thus process design), are defined by means of layout description and Material Flow Analysis (MFA). The throughput related KPI's are defined by means of simulation.

Waste analysis is executed to initiate improvements. The effect of the current 'batch processing' is underlined, resulting in inventory, waiting and transport waste. Moreover, inefficient sub-processes are found. Only about 22% of the space is used for value adding processes. On average all parts travel about twice the facility length and are transported about 20 times. Besides, the parts are on average 140 hours 'in the process' from which only 1.25 hours is value adding. Station occupancy and resource utilisation show an unlevelled process and significant inventory building up.

Literature poses several improvement options which are either further outlined or abandoned, based on their feasibility and applicability for the DSGa case. Product lines need to be defined to benefit from repeated manufacturing and facilitate continuous, uniform flows. Product lines based on routines, customer demands, and part attributes exist. The implementation of the Lean Manufacturing flow and timing principles is directly related to the parts generation, which make that key for improvements. Additional constraints on the nestings result. Quantitative argumentation is provided about the effect of the batch size reduction by implementing 'improved' nestings, initiating layout redesigns.

Multiple scenarios are defined to study the effect of nesting constraints, namely: 'cutting less sections from a plate' and 'cutting less product lines from a plate', which reduce the required sorting space and allow design freedom respectively. The cascading layout design process is described and scenario model construction is discussed.

When implementing the constraint 'cutting less sections from a plate' and designing the layout conform, the ratio between throughput and space utilisation is improved 2.6 times. Moreover the part throughput is increased by a factor 5.4, approaching a much more continuous flow. The implementation of the second constraint localises apparent bottlenecks. Hence a factor 2.7 and 7 are found respectively. The initiated design freedom of the second constraint enables further logistic improvement, reducing the number of transports and improving part throughput by a factor 8.3. Hence at expense of 2.2% of the yard's annual turnover the process can be improved by a factor 3.1, meeting the industry standard. Hence the objective of this study is met. For all scenarios the sorting transport remains critical. Supplement model analysis shows that the implementation of a conveyor system, including a Celluveyor sorting technique, shows much improvements on annual throughput, resulting in an improvement ratio of 3.3 to 4.6.

Preface

A saying says: Knowledge begins and ends in experience, but it does not end in the same experience in which it begins (C.I. Lewis). Definitely that is true for my graduation project, being a process improvement study focused on Damen Shipyards Galati pre-processing process. That is also the reason why I would like to acknowledge some persons which helped me developing understanding, experience and positive criticism.

This report is made in partial fulfilment of the requirements for the Master of Marine Technology. The Graduation Project entailed a nine months internship, which is full filled at Damen Shipyards, in Gorinchem.

First of all, I would like to thank Jeroen Pruyn, being my TU Delft supervisor, for his guidance. The meetings we have had were open, constructive and motivating.
Furthermore I would like to express my gratitude to Don Hoogendoorn, being my daily supervisor at Damen Shipyards. His motivation and commitment are inspiring, and gave me an additional drive to continue and finalise this study.
The other members of the Damen Simulation team, namely Jack Teuben, Bas Damman, and Timo Kreule are thanked for their discussions and value adding work. Also those involved on the Romanian side deserve my thanks for their contribution by means of data provision and technical support. Working as a team is challenging, but also enabled me to enthusiastically progress this report. I would like to thank Dirk Steinhauer on behalf of Simplan for our in-depth, abstract and logic discussions.
Underlying is that: ‘A man’s heart deviseth his way, but the Lord directeth his steps’ (Proverbs 16:9).

Kees van Ekeren, Gorinchem, 2018

Contents

Abstract iii

Preface v

1 Introduction 1
1.1 Background . . . 1
1.2 Project statement . . . 7

2 Value identification and mapping approach 11
2.1 Lean Manufacturing framework description . . . 11
2.2 Step 1. Value identification . . . 13
2.3 Step 2. Preliminary value stream mapping . . . 14
2.4 Summary . . . 20

3 Current State Map construction and analysis 21
3.1 Plate storages . . . 22
3.2 Cutting stations . . . 24
3.3 Tapering stations . . . 31
3.4 Forming stations . . . 32
3.5 Grinding stations and part processing spaces . . . 35
3.6 Flanging stations . . . 38
3.7 End buffers . . . 39
3.8 Transport facilities . . . 39
3.9 Key Performance Indicator definition . . . 39
3.10 Scoping . . . 43
3.11 Summary . . . 44

4 Simulation model definition 45
4.1 Model objective . . . 45
4.2 Model construction . . . 46
4.3 Model verification . . . 48
4.4 Model validation . . . 49
4.5 Summary . . . 54

5 Current State performance analysis 55
5.1 Part throughput analysis . . . 55
5.2 Annual station throughput analysis . . . 57
5.3 Resource utilisation analysis . . . 59
5.4 Summary . . . 62

6 Improvement strategy development 63
6.1 Lean Manufacturing framework description . . . 63
6.2 Step 3. Create flow . . . 65
6.3 Step 4. Establish pull . . . 72
6.4 Improvement strategies delineation . . . 79
6.5 Summary . . . 84

7 Scenario definition approach 85
7.1 Cutting group batch size experiment . . . 85
7.2 Nesting implications . . . 87
7.3 Summary . . . 88

8 Improvement scenario 1 analysis 89
  8.1 Scenario description 89
  8.2 Model construction 93
  8.3 Throughput analysis 95
  8.4 Summary 97

9 Improvement scenario 2 analysis 99
  9.1 Scenario description 99
  9.2 Model construction 101
  9.3 Throughput analysis 102
  9.4 Summary 104

10 Improvement scenario 3 analysis 105
  10.1 Scenario description 105
  10.2 Model construction 109
  10.3 Throughput analysis 110
  10.4 Summary 113

11 Valuation metric comparison 115
  11.1 Comparison layout related metrics 115
  11.2 Comparison throughput related metrics 116
  11.3 Comparison objective related scenarios 118
  11.4 Summary 118

12 Improvement scenario 4 outlook 119
  12.1 Crane deployment analysis 119
  12.2 Parcel Delivery industry application 119
  12.3 Scenario description 120
  12.4 Model construction 123
  12.5 Throughput analysis 124
  12.6 Comparison and bottleneck improvement iteration 125
  12.7 Summary 126

13 Conclusion and discussion 127
  13.1 Conclusion 127
  13.2 Recommendations 129
  13.3 Future research. 130

Bibliography 131

Appendices 134

A Data collection and description 135

B Process model description S1 141

C Process model description S1a 155

D Current State flow and waste definition 167

E Simulation model verification and validation 185

F Current state performance analysis detailed results 191

G Improvement strategy development detailed analysis 199

H Scenario analysis results 205

1

Introduction

The history of the family owned company Damen Shipyards dates back to 1927. Expansion has continued ever since. Today, Damen Shipyards operates in many shipbuilding sectors and has gained a prominent and trusted reputation throughout the world. Damen Shipyards operates multiple new build yards. Damen Shipyards Galati (DSGa), located at the Romanian Danube banks, is one of the largest yards.

Competitiveness forces Damen to reduce product prices and lead times. In order to reduce the delivery times, standard products are currently build and held in stock, which is costly. Therefore the current focus is on lead time reduction, initiating the need for process improvement projects.

This report addresses those developments by focusing on the improvement of the DSGa yard. More specifically it studies its pre-processing process. Section 1.1 outlines the project background. Subsequent the research problem, research questions, scope and approach are outlined in Section 1.2.

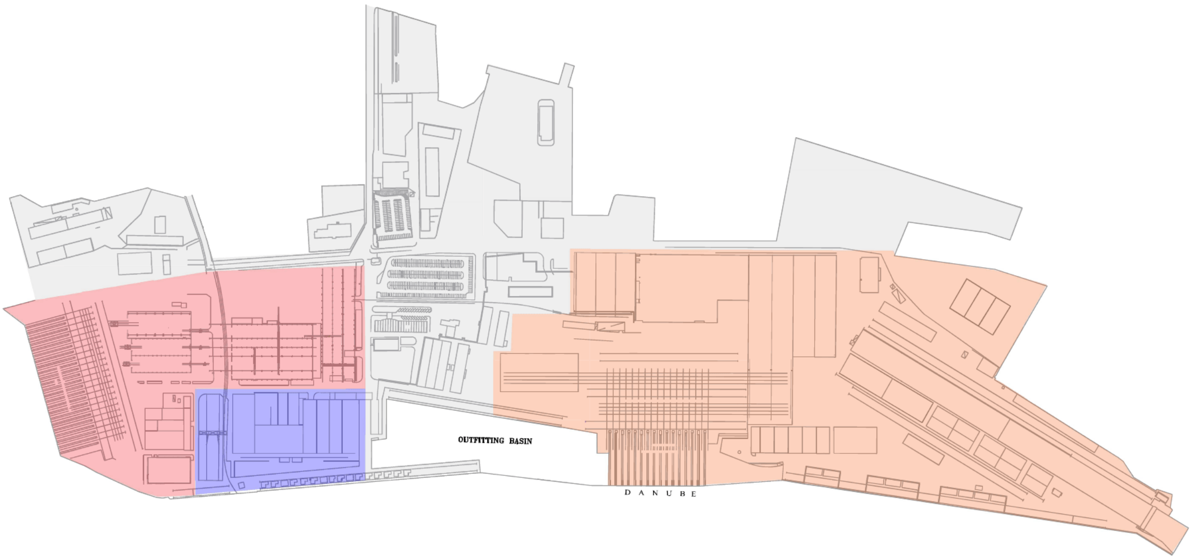
1.1. Background

The Damen Shipyards Galati layout and process is briefly described and benchmarked with comparable companies in Section 1.1.1 and Section 1.1.2 respectively. Room for improvement is found. Hence the third Section discusses which improvement frameworks could be applied to DSGa's pre-processing. Section 1.1.4 introduces how the study's objective is combined with the Damen Corporate Research (DCR) Production Optimisation project.

1.1.1. Damen Shipyards Galati

Historically (1927-90) the strategy of Damen Shipyards was to subcontract hull manufacturing at third party yards, followed by system integration at Damen Shipyards' sites. Recently, Damen Shipyards has changed its strategy, driven by the subcontractors capacity lack, and is now producing entire ships at Damen yards [15]. This strategy change manifested itself in the acquisition of the Galati yard [12].

Over the years Damen Shipyards Galati has expanded significantly. Currently the yard consists of three main areas, as indicated in Figure 1.1 [11]. Section 1 (S1) and section 1a (S1a) are, due to this expansion, dedicated to approximately the same activities, namely: pre-processing, sub panel-, main panel-, section-, block- and hull assembly. Section 1b is dedicated to mechanical component-, module skid- and small component fabrication workshops.
The DSGa portfolio is very diversified in terms of ship types and sizes as it includes tugs, anchor handlers, coast guard vessels, navy vessels, yachts, platform supply vessels and logistic support vessels, ferries, dredgers and barges [14]. Moreover, the portfolio contains steel and aluminium structures, which implies both steel and aluminium processing takes place at the yard. The aluminium processing is relatively new for the yard and is mainly done in S1 with dedicated equipment [17].



Red area: section 1 (S1), orange area: section 1a (S1a), blue area: section 1b (S1b)
Figure 1.1: DSGa Layout - overview different sections, [23]

In Figure 1.2 the assembly processes and logistics are presented. Damen Yard Support department has developed this scheme. The indicated colours follow the light spectrum, indicating the sequence.

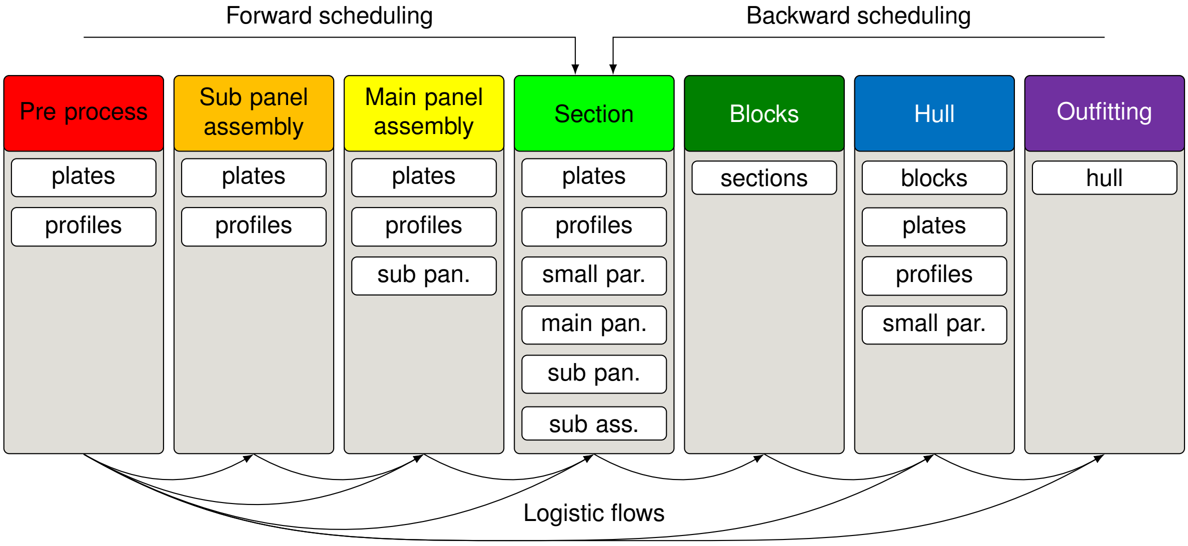


Figure 1.2: Hull breakdown - 'As Is' assembly processes and logistics [19]

For each breakdown the product input entities are presented, providing insight in the different interim products. In the pre-processing process raw plates and profiles are processed to cut plate parts, profile parts and small parts. Cut plates and profiles are required for the assembly of sub and main panels. The plates, profiles, small parts, main panels, sub panels and sub assemblies are assembled to ship sections. Subsequently, the sections are assembled into blocks, while these blocks together with some other plates, profiles and small parts are assembled into the (entire) hull. Finally, the hull is being outfitted. The logistic flow illustrates the part requirements of the different steps.

In Figure 1.3 the processing steps are shown on the map of the yard. The colour coding is conform the definition in Figure 1.2. It is clearly visible that the yard contains two more or less identical areas (i.e. S1 and S1a). To indicate whether all available area is required for executing the pre-processing processes the ratio between throughput (measured process output) and required space is compared with industry peers.

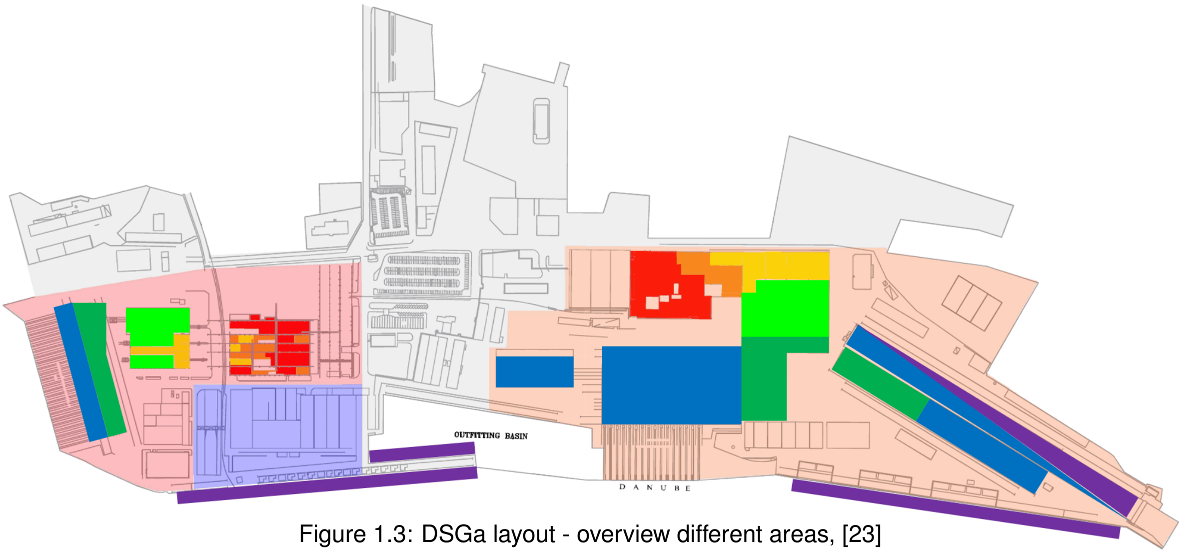


Figure 1.3: DSGa layout - overview different areas, [23]

1.1.2. Benchmarking

The performance of DSGa pre-processing is benchmarked with other successful companies involved with pre-processing such as IHC Metalix and 247TailorSteel. While IHC Metalix is also involved in shipbuilding, 247TailorSteel is not.

The benchmark indicators are presented in Table 1.1. Damen Yard Support provided the figures of DSGa and IHC Metalix, while figures for 247TailorSteel are based on recent annual throughput and conservative (relative to ratio objective) gross area estimations. The gross area, throughput and the respective ratios are presented in Table 1.1. Noteworthy is that 247TailorSteel operates 24-7, while DSGa and IHC Metalix operate two shifts per day for five days a week. Therefore the throughput ratio is normalised to one shift and five days per week. Based on the ratio between annual throughput in tons of steel and required gross area, DSGa has a significantly lower performance compared to IHC Metalix and 247TailorSteel.

Table 1.1: Benchmark pre-processing companies

Company	Gross area [m^2]	Throughput [t/year]	R.*	Remark	R.**	R.***
DSGa	13,000	21,000	1.6	≈16-5 operation	0.8	1
IHC Metalix	6,000	30,000	5	16-5 operation	2.5	3.1
247TailorSteel	3,500	45,000	12.9	24-7 operation	2.8	3.4

* Ratio between throughput and gross area. ** Ratio normalised for time. *** Ratio normalised to 1.

Explanation is found in the different process organisations. In contrast to DSGa, IHC Metalix has implemented Lean Manufacturing principles like Just In Time and a clear trace-ability of parts [38]. Clear trace-ability of parts links to the Lean Manufacturing principle Poke Yoke, which is a method to translate the production process such that it is nearly impossible to make mistakes [50]. At IHC Metalix this manifests itself in a specific sorting and delivering of parts on building sequence, by numbering and coding the parts with the relevant (assembly) information [38].

Besides, 247TailorSteel is particularly strong in automatic data processing, by implementing an extensive MOM system. Furthermore special attention is drawn to a transparent and lean flow, which is realised by reducing unnecessary movements and transport. Moreover, the company is able to level the flow by assigning specific work stations to specific tasks as there is focus on on-time and on-demand delivery of parts [1].

Contrary, in the current pre-processing process of DSGa the process is arranged on section level, which implies that material batches (with all parts a section) move through the process. This induces a lot of inventory in the neighbourhood of processing steps, which results in extensive space occupation. Hence no clear trace-ability of parts, transparent flow or lean flow can be recognised. Furthermore no Lean Manufacturing principles, like Just in Time, are implemented.

As a consequence, there is significant room for improvement at DSGa to increase throughput or decrease space utilisation. In order to prepare DSGa for the future, it is important to reduce the currently used gross area and improve the throughput ratio to industry peer levels, being a factor 3.
If space utilisation is significantly reduced the S1 and S1a facilities could be merged in S1a. This is preferred by the Galati management board [18, 20]. Such the transport between both facilities is mitigated. Moreover the freed space in the S1 facility can be very well used for other activities [20, 21].

1.1.3. Production improvement concepts

When it comes to improving production the fundamental question is 'what are the available improvement theories and what are the differences between them' [58, 72]. The underlying question relates to the development of a rationale for navigating through the solution space.

Hayes and Wheelwright [34] developed the process-product matrix (Figure 1.4). On the left are four different manufacturing process stereotypes; from job shop to continuous flow. Horizontally different product mix types are plot. Netland [58] used this matrix to plot the epicentres of difference well known manufacturing improvement theories. The epicentre is there where the implementation has the largest effect. It is assumed that the epicentres of each of the production improvement concepts can be found in the industry they were developed in.

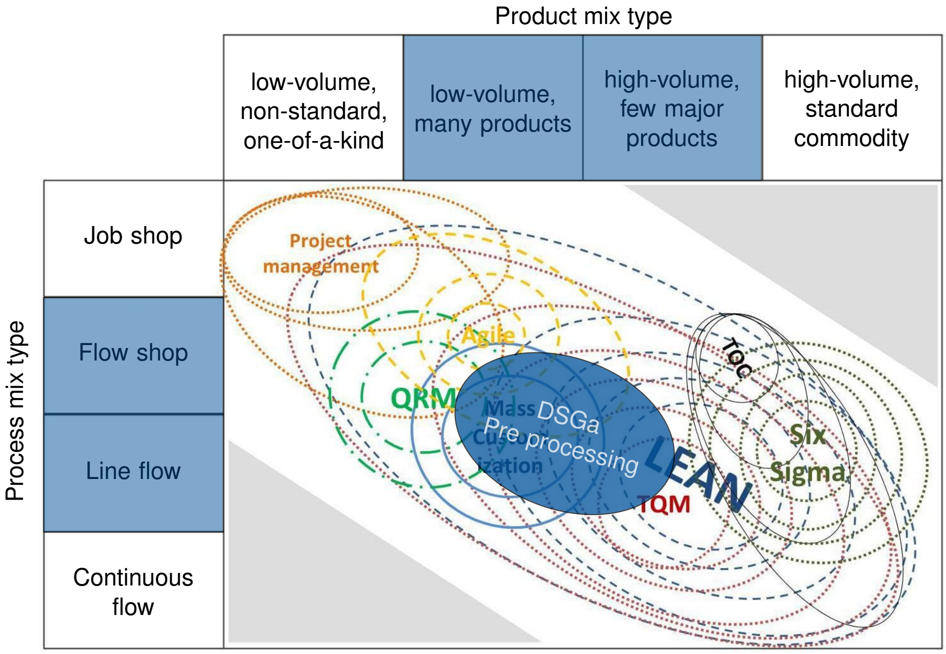


Figure 1.4: Concept epicentres of manufacturing strategies [58], based on Hayes and Wheelwright [34].

The process of Damen Shipyards Galati pre-processing is mapped in Figure 1.4 as 'low-volume, many products'/ 'high-volume, few major products'. Although ships are produced as a 'low-volume, non-standard, one-of-a-kind products', its building blocks not necessarily are. Especially the pre-processing products as introduced in Figure 1.2. Besides, sub panels and main panels are non standard commodities that are more or less unique.

The DSGa pre-processing 'product mix type' and 'process mix type' combination reflect the epicentres of Mass Customisation and Lean Manufacturing. Mass customisation is a strategy that makes it possible for a company to customise products to individual customer requirements, while producing those with mass production standards [58, 62]. In contrast, Lean Manufacturing focuses on shortening the production flow by reducing waste [50]. As shown the implementation of Lean Manufacturing has been successful for IHC Metalix by improving its pre-processing processes. Since Lean Manufacturing extends on Mass Customisation and it proved to be successful for other pre-processing processes, this framework is adopted in this study.

What is Lean Manufacturing?

Although Lean Manufacturing is often referred to as a set of tools that will speed up the (manufacturing) process, it is more than a set of tools as Liker [50] expresses in his book 'The Toyota Way'. Lean Manufacturing requires a way of thinking that focuses on creating a work flow through value-adding processes without interruption that cascades back from customer demand by only replenishing at short intervals what the next operation needs (e.g. one-piece flow and pull system). In this system a culture of 'continuous improvement' is being created. Liker [50] distinguishes several layers in this Lean Manufacturing thinking (Figure 1.5).

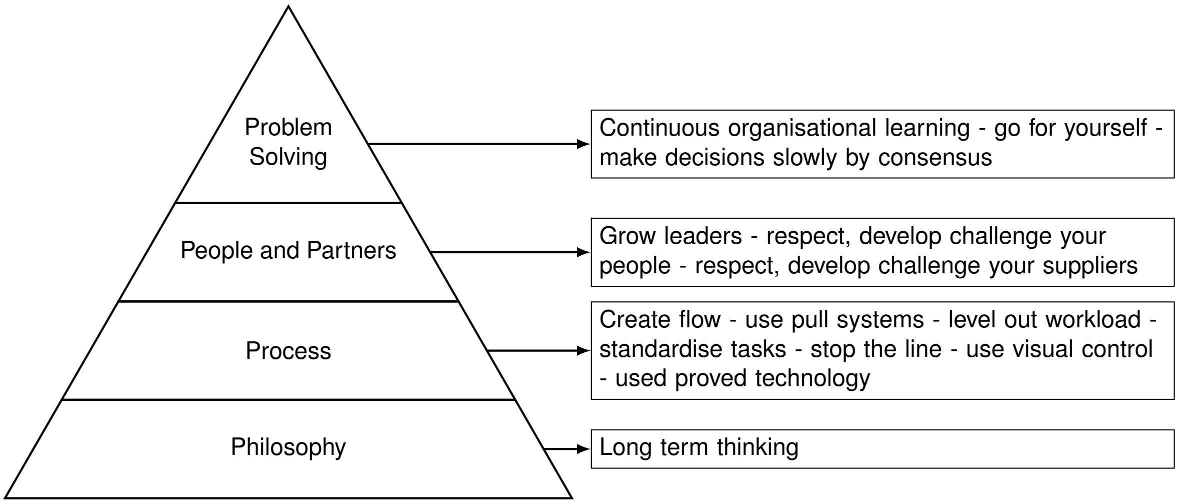


Figure 1.5: 4 P's model of the Toyota Way

The four levels of Lean Manufacturing are described by fourteen principles, which are abbreviated and presented in Figure 1.5. The long-term 'philosophy' is the basis of the other layers. 'Process' forms the second layer and includes the overall company behaviour such that its principles can be applied to all segments within companies, offices, workshops, services and warehousing. The third layer 'People and Partners' relates to people within the company and its suppliers. Finally, the fourth layer 'Problem Solving' captures the long term thinking within Lean Manufacturing of continuous improvement. An approach for implementing the Lean Manufacturing framework is presented below.

Lean Manufacturing framework implementation approach

In their book 'Lean Thinking', Womack and Jones [87] outline five steps for implementing Lean Manufacturing. These are summarised in Figure 1.6 showing the cyclic behaviour of implementing the Lean Manufacturing principles [44, 61]:

1. Specify the value desired by the customer: Investigate the processes from customers perspective and define the needs of the customers.
2. Identify the value stream for each product and challenge all waste: Mapping of the processes will help understanding how the value for the customers is build.
3. Make the product flow through the value creating steps: The aim is to create a value stream and one-piece flow, as well as to avoid or reduce the batch size and queuing, if possible.
4. Introduce pull between all steps where continuous flow is possible: Adjustment of the production to the customers needs and requirements and produce when and what the customers want. The production processes should be supported by Just In Time and standardisation.
5. Manage towards perfection by continuously improving the process: Once the above-listed actions are performed, they should be supported by continuous improvement.

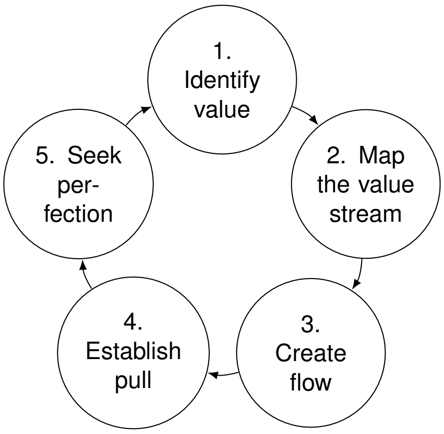


Figure 1.6: Principles of Lean

The first two steps mainly focus on the definition of value in the process, while the third and fourth step focus on the introduction of flow. The fifth step underlines the continuous improvement character.

1.1.4. DCR - Production Optimisation

Next to improving the pre-processing process at DSGa, Damen Shipyards wants to analyse whether Manufacturing Simulation and Robotic Production are appropriate tools to for improving processes like the DSGa process.

The current trend of automation and data exchange, known as Industry 4.0, is rapidly changing the way products are being manufactured. In order to anticipate on this development Damen Research & Development wants to expand its expertise of production optimisation [16]. For this reason the Damen Corporate Research (DCR) Production Optimisation project has been established. The DCR Production Optimisation program investigates the promising concepts of Manufacturing Simulations and Robotic Production, and studies its applicability and feasibility [15]. The program will ultimately recommend to either implement or reject these concepts. This report focuses on the concept of Manufacturing Simulation.

A numerical simulation of the production process provides the opportunity to maximise yard utilisation, optimise production strategies and predict the impact of improvement measures [15]. Manufacturing Simulation is a suitable tool as it allows detailed analysis of production or logistic systems concerning dynamic relationships and interactions [76]. Moreover, it enables cost efficient and transparent trials to be executed without any financial risks other than the time invested in the simulation. Finally, based on a proper validation it can function as an objective basis for communication [15, 77].

The implementation of Manufacturing Simulations depends on the user goal as it can be used in production planning and control as well as to support decisions in strategic production facility planning [75]. Firstly, if Manufacturing Simulations are used to support production planning and control, data has to be updated regularly. This is the case for product data determining the system load, but could also be required for organisational and process data. Technical data are usually not changed on a regular basis unless substantial changes have to be made in the production system to cover requirements of new products [76]. Secondly, in case Manufacturing Simulations are used to answer a strategic question, the role of input data is slightly different as process and technical data fulfil the same role. Moreover, the role of organisational data is less stringent when a strategic goal defined. Concerning product data, regular updating is not required as no actual planning is involved [76].

The DSGa yard is used as a case study for the DCR production optimisation program. The size of the yard, existence of S1 and S1a sections and the diversified vessel portfolio at DSGa make it the appropriate case to test the applicability and feasibility of Manufacturing Simulation as part of the DCR production optimisation program.

1.2. Project statement

As described in Section 1.1.2 the pre-processing of DSGa underperforms compared to peer companies. In order to improve the ratio between required gross area and throughput, the throughput has to be increased or space utilisation decreased. Lean Manufacturing has the potential to realise this. Therefore, the objective of this report is to increase DSGa's throughput and decrease space utilisation, by implementing the Lean Manufacturing framework such that facility S1 and S1a can be merged in S1a. Secondly an improvement ratio of 3 on throughput versus utilised space is strived for in order to meet peers performance, by further reducing space. To obtain this objective the following main research question is defined:

To what extent can the two pre-processing areas of DSGa (i.e S1 and S1a) be merged into S1a, in order to optimise space utilisation and throughput, by redesigning the process, based on the Lean Manufacturing framework?

In order to answer this main research question, sub-questions are defined in Section 1.2.1. Furthermore the scope and approach are described in Section 1.2.2 and Section 1.2.3 respectively.

1.2.1. Research questions

The main research question is decomposed into several research sub-questions. The first question focuses on description of the current performance of DSGa using the static Lean approach of value stream mapping. Because of the process complexity dynamic simulation modelling is used to quantify the time related aspects. The construction and analysis thereof are addressed in the second question. This is essential for outlining waste and studying the impact of redesigning and improvements.

The third question investigates what process improvement strategies can be applied. The effect of these improvement strategies is studied in the fourth question. The questions will answer to what extent the two pre-processing areas (i.e. S1 and S1a) can be merged.

1. How can the performance of the current pre-processing process be described by means of the static Value Stream Mapping approach?
2. What is the quantitative performance of the current pre-processing process obtained by means of dynamic simulation analysis?
3. What process improvement strategies can be proposed, for redesigning the process, based on the Lean Manufacturing framework?
4. What is the quantitative effect of the proposed improvement strategies in terms of space utilisation and throughput?

1.2.2. Scope

The scope of this report contains several elements. First, only the pre-processing process of DSGa is considered. Secondly, the strategic character of the modelling is described. Thirdly the portfolio of DSGa is mimicked by only limited amount of product data. Fourthly, although several improvement strategies exist, this report focuses on Lean Manufacturing. Fifth, only the freed space in facility S1a will be considered. Process redesign changes with mayor financial consequences are considered to be within scope. Finally, the selection of Manufacturing Simulation software is out of scope. A more detailed rationale is given below:

1) The focus of this report is on the pre-processing process of DSGa only. This process entails the following processing steps: cutting, bevelling / tapering, forming, grinding and flanging / buckling. The entire process cannot be fully described as only a limited amount of resources, data and time are available. The pre-processing process has been chosen because of the material explosion after cutting. At that stage the relative amount of parts is largest as they are cut but not yet assembled. This existence of a large number of parts has a logistic effect on process flows.

Although the pre-processing phase is not the first step in the shipbuilding process it has a clear start. This first step in the shipbuilding process is the shot blasting of raw material. Since this process is a direct input-output process and an output buffer is established, the performance of this process has minor influence on the pre-processing process.

Within a process all steps contribute to total performance. Therefore it needs to be noted that excluding part of the process out of scope will result in a local optimum. A disadvantage of this is that the local optimum is not necessarily a global optimum.

2) For the purpose of this study a strategic model is concerned. The effect it has on the data collection is described in Section 1.1.4. This mainly implies that less organisational and product data variations need to be introduced.

3) In order to study the performance of the process the portfolio of DSGa needs to be mimicked. Mimicking the entire portfolio and all sections of each vessel would require very extensive data collection. Moreover, since a strategic goal is defined the role of data is slightly different.

For that reason only two vessel types will be considered, namely a tug and a platform supply vessel (PSV). From these vessels several characteristic sections are taken into consideration. The number of sections depends on the vessel type and the portfolio considered in this report is build up out of these two vessels. The definition of the portfolio is described in more detail in Section 2.3.1.

As the behaviour of the system needs to be assessed to study the effect of the portfolio, further description about the data set is included in Appendix A.

4) Several operational theories exist. This report focuses on Lean Manufacturing, although this theory is not isolated from others. One theory is chosen to limit the process improvement proposal solution space. Lean Manufacturing is suitable for the pre-processing process as it concerns a physical production process. In Figure 1.5 several Lean Manufacturing principles are summarised. Mainly the second layer (i.e. Process) is being used, because the first (i.e. Philosophy) and fourth layer (i.e. Problem Solving) relate to cultural mindset and implementing the improvements. The third layer (People and Partners) is not directly related to internal logistic flow improvements.

5) Reducing space utilisation opens opportunities for customer process redesign. When meeting the objective of this study the S1 facility is freed up, which is appreciated by the Galati board since is enables the set up of a separate aluminium processing line [18]. It enables yard throughput increase concerning aluminium production, which is preferred given future prospects [14, 20]. In the process of this developments this study will focus on the freeing up the required space. Within this study the customer process redesign of the S1a facility is globally considered. The related S1 facility redesign is not considered in this study.

6) Redesigning the process, based on the Lean Manufacturing framework, can result in mayor financial consequences. This is report assumes that investments could be made if payback supports this.

7) This report considers the selection of appropriate Manufacturing Simulation software to be out of scope. Consequently, a simulation package called Technomatix Plant Simulation by Siemens is used. It is a discrete event, object oriented software package. Moreover, the Simulation Toolkit Shipbuilding (STS) is used to incorporate shipbuilding specific objects. Discrete event simulation is particularly good at handling discontinuities that take place in the pre-processing process. Furthermore, the computational performance of discrete event simulations is much better versus other simulation methodologies. However, the disadvantage of using discrete event simulation is that is not particularly strong in handling pull systems, which are common in the Lean Manufacturing framework.

STS cannot solely be used for operational control but is also applicable on strategic level [77]. For the first it allows detailed definition of settings. For the latter it allows high level definition of processes by disabling all lower level derivations. Using this property is inline with the strategic goal as underlined in item 2.

1.2.3. Approach

This report uses the Lean Manufacturing framework approach throughout the different Chapters, as shown Figure 1.7. In order to facilitate a clear understanding of this report an overview of the different Chapters is given. An overview of the relations between them is presented. The different colours in the Figure outline the research questions.

Chapter 2 defines what actually the value in the pre-processing process is. Furthermore it outlines whether the Lean Manufacturing value stream mapping approach can be used. This specifically deals with the construction of valuation metrics (KPI's) to determine the ratio between value- and non-value-adding activities and facilitate comparison 'current state' and 'future states'.

Chapter 3 describes and analyses the 'current state', based on the Lean Manufacturing framework. The layout and flow are described and the different waste types are assessed. Moreover the design related key performance indicators (KPI) are defined. Hence it provides a process overview and answers the first research question.

Chapter 4 deals with the process of constructing a discrete event simulation model, in order to provide quantitative argumentation for the waste analysis results and obtain the time related valuation metrics. The model construction, behaviour, verification and validation are discussed.

Chapter 5 presents the simulation model results and provides feedback on the waste analysis in Chapter 3. Furthermore the time related indicators are derived to enable comparison with future states. Doing so the second research question is addressed.

Chapter 6 provides improvement strategies, based on literature and applicability analysis. As a result different improvement options are listed and a starting point is delineated. It answers the third research question.

Chapter 7 delineates several improvement scenarios based on current situation experiments and nesting constraints, which resulted from the starting point in Chapter 6.

Chapters 8 to 10 discuss the scenario design, model construction and valuation metric analysis of the three scenarios, to underlined the effect of the improvement strategies.

Chapter 11 compares and summarises the valuation metric results of the scenarios compared to the current state and each other. Doing so it answers the fourth research question.

Chapter 12 provides a future outlook scenario which assesses the main resulting issues for the previous scenarios, by introducing conveying systems.

Chapter 13 gathers all the conclusions from the individual chapters and presents the main findings of this study. Furthermore some recommendations and future research topics are given.

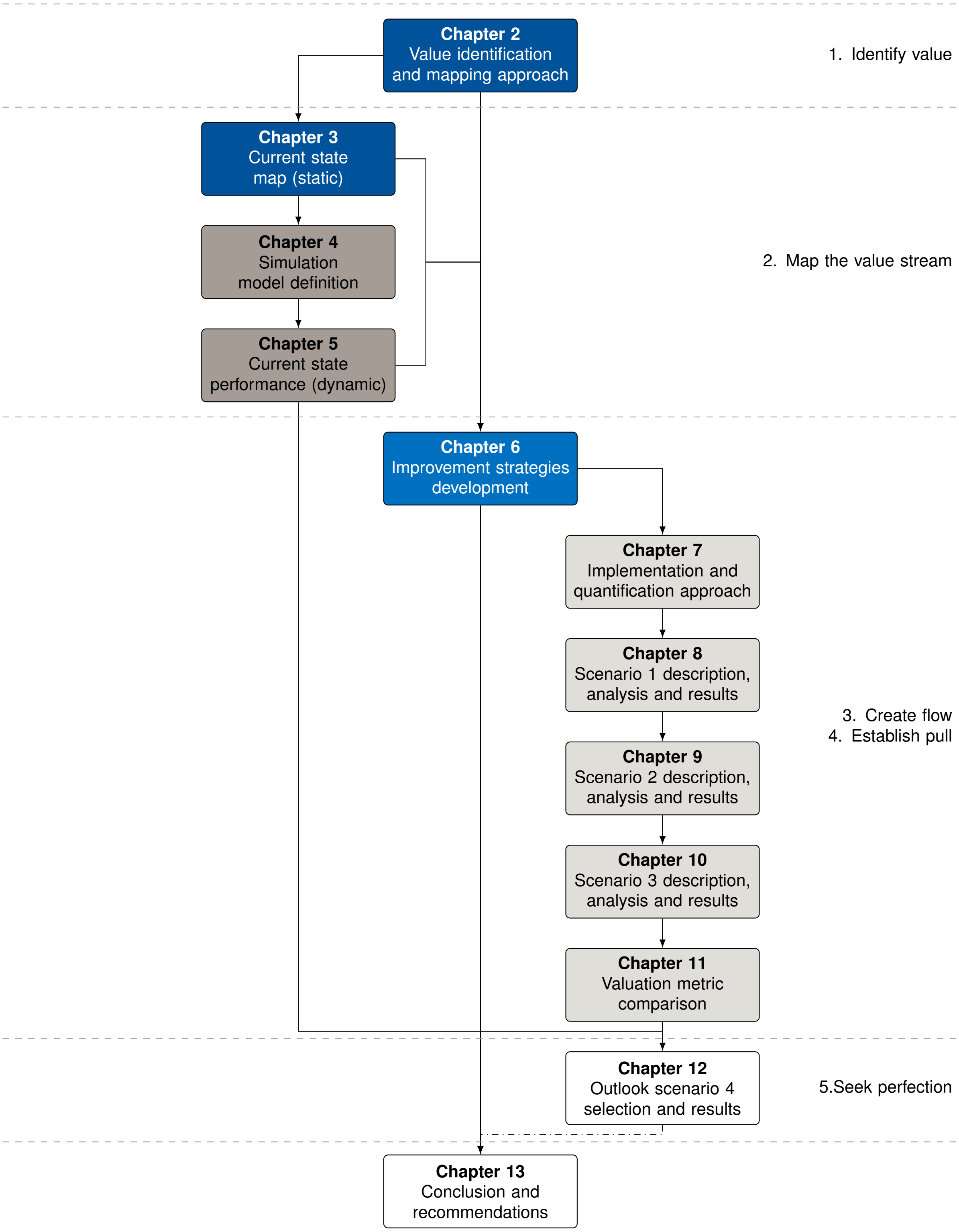


Figure 1.7: Flowchart of report topics and Chapter relations

2

Value identification and mapping approach

As described in Section 1.2.3 the Lean Manufacturing framework makes use of five principles (Figure 2.1). By applying the first two principles: 1) identify value and 2) map the value stream, the current process is analysed and the following research question answered:
How can the performance of the current pre-processing process be described by means of the static Value Stream Mapping approach?

Section 2.1 describes principle one and two of the Lean Manufacturing framework. Section 2.2 deals with the Lean Manufacturing principle 'identify value'. Section 2.3 attempts to apply the value stream mapping approach. However, as this is rather complex an adjusted approach is being used. To describe the performance valuation metrics are defined. The adjusted approach is continued in Chapter 3 and Chapter 5.

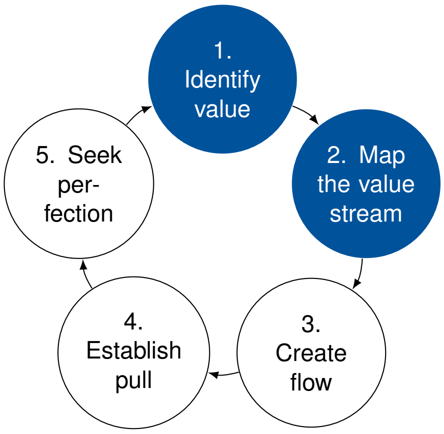


Figure 2.1: Principles of Lean Manufacturing, focused on current process analysis

2.1. Lean Manufacturing framework description

Some historic background is provided on the Lean Manufacturing framework. Moreover, the first two Lean Manufacturing principles (Figure 2.1) are discussed and an implementation methodology is proposed.

2.1.1. Distinctive character of Lean Manufacturing

Back in 1950-1960 the Toyota Production System (TPS) was developed, in order to enable Toyota to become competitive on global markets. Toyota discovered that it could simultaneously achieve high quality, low cost, and Just In Time delivery by 'shortening the production flow by eliminating waste'. This plain concept forms the basis of TPS. It exposes the differentiation from the older mass production paradigm it replaces. Ideally TPS requires a continuous one-by-one flow. Realistically, the practitioners of TPS understand that performance of the system will improve if the system is moving towards continuous flow by eliminating waste. This new paradigm of manufacturing is called Lean Manufacturing [49, 50].

In their book 'Lean Thinking', Womack and Jones [87] outline five steps for implementing Lean Manufacturing. The first step is the identification of value in the process. Such value-added activities transform the product into something the customer wants. In manufacturing processes, this is generally a physical transformation of a product according the customer expectation. In order to enable this, the mass production paradigm focuses on the efficiency of value-added activities. However, Lean Manufacturing focuses on value-added flow and the efficiency of the overall system [49, 87].

Within Lean Manufacturing waste is 'everything that adds to the time and cost of making a product, but does not add value to the product from the customers point of view' [49]. This distinctive property of Lean Manufacturing has been adopted by other operational strategies ever since and has been proven to be successful in many organisations [45, 50].

2.1.2. Value definition and mapping approach

To identify the value it is important to know what the customer wants from the process [49]. This question should be asked prior to the determination of 'what transformation steps are needed to turn materials in the process into what the customer wants', as such the non-value-added steps are identified and separated. Sometimes, however, some non-value-added steps are necessary to enable the value-added processes. As such there are three types of operations:

- Value adding (VA)
- Non value adding (NVA)
- Necessary but non value adding (NNVA)

Hines and Rich [35] explain that 'non-value adding' activities concern pure waste and involve unnecessary actions which should be eliminated completely. 'Necessary but non-value adding' operations may be wasteful but are necessary under the current operating procedures. In order to eliminate these types of operation it would be necessary to make major changes to the current operating system such as creating a new layout.

According to TPS the 'non-value adding' activities can be separated in several categories: Transport, Inventory, Motion, Waiting, Overproduction, Over-processing and Defects. Liker [50] introduces another type of waste being skill. Nowadays these waste types are being referred to as TIMWOOD'S based on the first letters of the waste types, which are described below [47, 50, 56]:

- Transportation: Unnecessary moving equipment, tools and materials from one location to another.
- Inventories: Manufacturing more than customer demand and building up unnecessary stocks.
- Motion: Unnecessary movement by people walking to get things which should be located closer to the point of use.
- Waiting: Delays between operations because parts are missing, stopped work, or waiting for parts, machines or people.
- Overproduction: Making too much by completing a task before it is needed or making products that the customer does not need.
- Over-processing: Duplicate or redundant operations and performing not needed wasteful steps.
- Producing defective products: Failing to produce a quality part, generating rework or scrap, not delivering the product or service 'right the first time'.
- Skill - Failing to use skills and capabilities of the workforce by not listening to people, or not using their knowledge or learning from past mistakes/issues.

The value stream is the collection of all of the activities, both value-added and non-value-added, that generate a product or service that meets customer needs. The Value Stream Mapping (VSM) technique shows how both materials and information flow as a product or service moves through the process value stream [51]. Lean Manufacturing makes extensive use this technique [87].

In order to define a VSM the following procedure is to be adopted [51, 69, 82]:

1. Establish customer requirements: This involves the type of product and rate at which it is demanded. This is similar to the the 'Identify Value' principle of Lean Manufacturing.
2. Delineate major processes: Here the major process steps are determined to create the demanded product type. Major processes follow for 80% the same process steps. The remaining 20% is captured by a shared resource principle. Hence the VSM has a static view on the process.
3. Measure process data: Typical data has to be measured varying with the product type. Examples are: cycle time, changeover time, up-time, space utilisation.
4. Determine system triggers for information flow: Introduction of certain symbols to present the information flow more easily.
5. Draw the Current State map (CSM): Drawing of current state, which needs to be only for 70% correct, in order to not get confused in the details.
6. Review map for process inefficiencies: This concerns the analysis of waste types, determination of ratio between value-added and non-value added processes, line balance, takt times, or flow systems.
7. Determine action plan: Based on the review of inefficiencies and determination of possible solution propositions an action plan can be constructed, which will result in a list of opportunities to improve.
8. Draw Future State Map (FSM): Based on the action plan a future state map can be constructed.
9. Develop project plan: Execute the proposed improvements.

The establishment of CSM and FSM underline the instantaneous character and cyclic methodology of implementation of improvement project results. When the future state is established the methodology can be applied again in order to realise the 'ideal state', which is also captured within the 'seek for perfection' principle, as illustrated in Figure 1.6.

2.2. Step 1. Value identification

Within Lean Manufacturing the value is determined by 'customers'. Therefore, Section 2.2.1 identifies the customers. Secondly, Section 2.2.2 defines the process steps at which value is created.

2.2.1. Customer definition

A customer is 'a party that receives or consumes products (goods or services) and has the ability to choose between different products and suppliers' [6]. For the pre-processing process, customers are the parties which receive the pre-processing products, such as DSGa's sub panel-, main panel-, section-, and hull assembly and outfitting (see Figure 1.2).

In Figure 2.2 the 'customer' demands are mapped in time indicating the moment in time on which the parts are demanded. The phase durations are not depicted on a time scale but on time sequence since the section assembly process takes much longer than the pre-processing process.

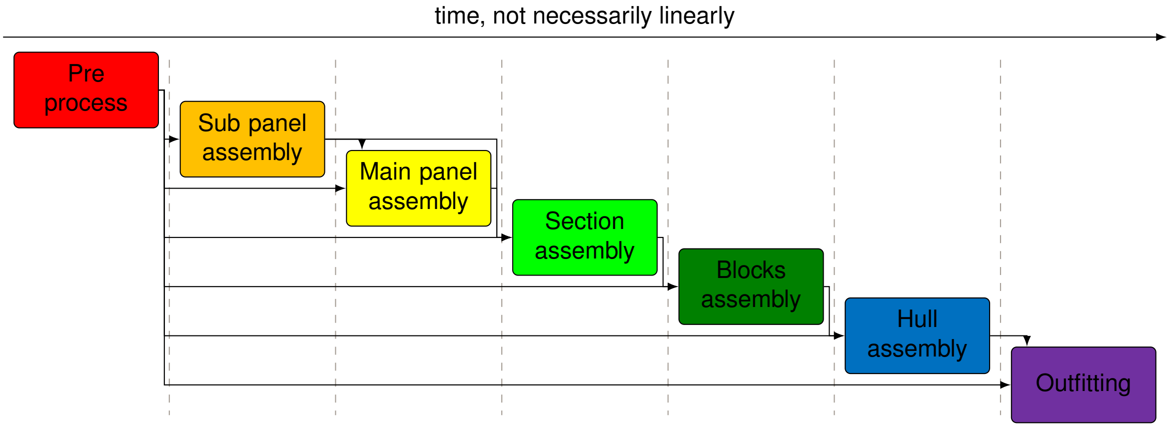


Figure 2.2: Pre-processing customers' demand mapped in time

The demand cascades in time. Not all process steps have a direct start-finish relationship. The main panel assembly is dependent on the output of the pre-processing process and the sub panel assembly.

However, main panel assembly, as a separate process step, can already start when the sub panel assembly is not yet finished, as long as the parts from the pre-processing process are delivered. This time difference is often a matter of days.
This relation is not applicable for the main panel- and section assembly (Figure 2.2). In section assembly different main panels are assembled together with smaller parts from pre-processing. It can only start when all those parts are received.
Although DSGa is involved in block building, this step is not specifically distinguished. The block building process makes use of both the logistic flows of section- and hull assembly.

2.2.2. Customer demand definition

The 'customers' want to have two types of product, namely plates and profiles, which require a specific physical appearance created by specific processing steps. Figure 2.3 provides an overview of the possible pre-processing steps.

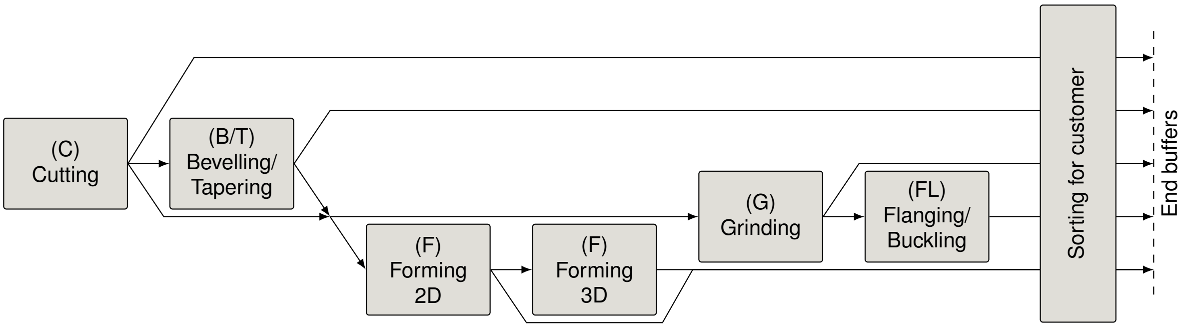


Figure 2.3: Part routing in pre-processing

All plates are cut first at a cutting machine. The parts can be bevelled or tapered. Several bevel types exist, such as V/Y or K/X seams. There are several ways to bevel the parts. Firstly, some cutting machines have the functionality to bevel directly when cutting. Secondly, bevelling can be done by means of a semi automatic tractor and thirdly, bevelling can be done by means of grinding. Tapering is often done by semi automatic tractor.
Moreover parts can be formed. Profile parts require frame bending, which can be either be a single or a double curvature. Forming plate parts involves the creation of a 2D or 3D shape, which imply a bend in the 2D or 3D plane respectively. In order to fulfil the 3D requirement the part needs to undergo an additional forming step (see two steps in Figure 2.3).
Furthermore, the part can require grinding. While for small parts the contour is grinded, for larger parts mainly the holes are grinded. For profiles, which originate from the profile cutting line, only the edges and holes require grinding. In case the profile is cut from plate, the contour needs to be grinded except for the side where the part will be welded.
Finally, parts can be flanged or buckled. Flanging is most often performed for smaller parts, while buckling is often required for bigger parts, like bulkheads. These processes can be executed for both plates and profiles.

At the work steps, shown in Figure 2.3, value-adding activities are performed as a transformation of product according to customer demand. Since the customer does not want general processed parts, but exactly those which it needs, sorting is also considered to be a value-adding activity.

2.3. Step 2. Preliminary value stream mapping

Subsequent to value definition value stream mapping takes place. Prior to the delineation of the major processes the product data is described in Section 2.3.1. Apparently it is complex to apply the regular VSM approach and therefore an alternative approach is proposed in Section 2.3.3. The VSM deals with reviewing process inefficiencies and the determination between value and non value add. Hence value indicators are defined in Section 2.3.4. Finally an approach for executing the value stream mapping is given in Section 2.3.5.

2.3.1. Product data definition

First the portfolio definition, as discussed in Section 1.2.2, is justified. Secondly related drawbacks are discussed. Finally the product data set is explained.

Product data set composition justification

The annual DSGa yard capacity is evaluated, which results in annual capacity measures [19, 24]. DSGa itself makes a clear distinction between tugs and work boats (ASD tug, Stan tug, MultiCat, barges) and offshore and cargo vessels [11]. It manifests itself by a separate production line for tugs and work boats. Moreover a production line equipped with a dry dock is dedicated to building larger vessels, like Platform Supply Vessels, Offshore Carriers, Survey vessels and Ferries [14].

An overview of the ship deliveries between January 2005 and January 2018 is presented in Figure 2.4 [9, 12]. Plotting all specific ship types results in many distinctions. Therefore Research vessels, Accommodation vessels and Survey vessels are jointly plot as Survey vessels. This also concerns the defence related vessels.

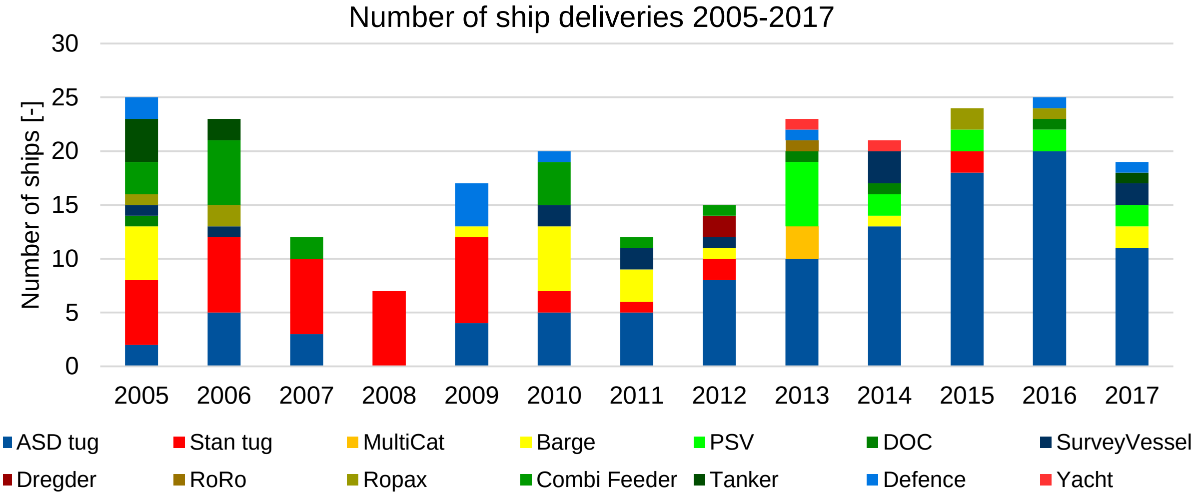


Figure 2.4: Cumulative number of parts per entire process duration

The data collection would be very extensive when the entire portfolio and all sections per ship are considered. Figure 2.4 shows that over the last five years particularly many ASD tugs and PSV's are delivered. The average building period of a vessel is in the order of a year [17], which should be accounted when reviewing the ship delivery data. In 2017 12 'tugs and work boat' class and 6 'offshore vessel' class vessels are build [12]. These figures are inline with the previous years.

Including an ASD tug and PSV in the portfolio incorporates the difference in part groups. Smaller vessels contain relatively more to be formed parts. Larger vessels contain relatively more large main panel parts. Hence a sustained ratio between small and large ships makes sense.

Several ASD types are being build. Detailed analysis shows that the ASD2913 is a common type. The PSV's mainly are PSV3300 vessels. Furthermore, contrary to the PSV5500, this type is not designed by implementing Design For Production strategies [19]. Since that is more common for larger vessels the PSV3300 is more appropriate. Hence incorporating both vessel types in the data set makes sense.

Including a third vessel type has an extensive implication on the data collection. Moreover no clear third vessel type can be delineated [12, 19]. Furthermore the differences between different sizes of the same vessel type could be as large as the difference between different vessel types [19].

Therefore out of the entire Damen portfolio a selection of two indicative ship types has been made, namely a ASD2913 Tug and a PSV3300, to construct the annual portfolio. The ASD replaces all 'tugs and work boats' vessels. The PSV replaces all offshore and cargo vessels. Furthermore look-a-like (starboard/portside) section approximations are made. Making such approximations is conform the strategic objective as outlined in Section 1.2.2 and is done in close cooperation with DSGa and the Damen Yard Support department. Hence the following measures are obtained.

- 18 ships (12 tugs, 6 offshore/cargo vessels)
- ≈ 14,000-20,000 [ton]

There is some data inconsistency due to these approximations since the weight accumulation of the two ship types does not correspond with the throughput in tons. The difference is explained. The 20,000 tons measure is not found in formal annual documentation but is based on Yard Support Department internal calculations. For their calculations they use the same data to obtain the number of ship deliveries. However they approximate the offshore/cargo vessels by PSV5000 vessels solely. Detailed analysis of the ship delivery data for 2015-2017 shows that this overestimates the ship sizes. Therefore the PSV3300 vessels are considered within this study. This results in an approximate throughput of 14,000ton. Within this study the first statement is used mostly since certainty about the number of ship types exists.

Drawback discussion

This approach has several drawbacks. Most important, some deviation with the reality is introduced as the variety of product data is decreased. It is complicating studying the extent to with the process is able to react on changes in the portfolio. This effect can reasonably be mitigated by varying the processing sequences of ships, ship sections and cutting groups. Damen Yard Support is familiar with this approach for strategic simulation purposes.

Based on the analysis of the product data improvement scenarios are developed. Hence there is a chance that the defined scenarios are not able to anticipate on other ship types. Although only a limited amount of ships/ship sections are available, a lot of interim products are available, like sub panels or main panels. This makes the developed improvement scenarios more robust. Obviously building tugs requires a different process than building container vessels. However, when using the current portfolio build up the deviation is already significantly narrowed.

Extending the data set is theoretically possible by using tools as pattern recognition, machine learning or parametric scaling. Those tools are not straightforward as the part data, routine data and end buffer data are currently not digitally available. This mainly affects using the pattern recognition and machine learning tools. The difficulty with parametric scaling is the data is it depends on the population parameters (mean and variance) which cannot be clearly extracted as boolean routine data is available. Furthermore the scaled data also has to make physically sense.

Last the relation between the raw plates and the plate parts needs to be artificially established. The product data is not comprehensive enough to use commercial nesting tools for that. Moreover area definition is critical since the part area is approximated by rectangles, which does not allow the construction of rule-of-thumb nesting algorithms.

Data set explanation

The data set has the following data packages included (Table 2.1). The first package is the project data, which is user specific and can therefore be changed for building up different portfolios. The next data package concerns the part data. These data is specifically related to each ship type and cannot be changed. The nesting data links the raw material to the to be cut parts. The routing data contains the routing type and the actual (value added) processing times. Detailed explanation is provided in Appendix A

Table 2.1: Product data format

Project data	Part data	Nesting data	End buffer data	Routing data	
Project, section	Part ID, description, geometry, weight	Nesting numbers	End sorting code, panel names, assembly orders	Type	Time

Based on the number of ships per year and the product data per ship the annual product data set is defined. For the continuation of the study this product data set is referred to.

2.3.2. Delineation of major processes

Major processes should follow for 80% the same process steps in order to make an appropriate VSM as mapping all flows is too extensive [82]. These processes can involve shared and dedicated resources.

Where dedicated resources concern one specific process, shared resources are used by different processes. Consequently, shared resources should be carefully considered [51, 82]. By means of incorporating margins on the shared resources the uncovered 20% can be assessed.

Table 2.2 presents the different routines. The codes correspond to the first letter(s) of the processing steps as defined in Figure 2.3. Subsequently, the number of parts for each possible process is listed together with the cumulative weight in order to determine the size of the parts. As in shipbuilding the size of the parts can differ significantly, a closer look is taken at small (≤ 20kg) and large (> 20kg)parts. This distinction is based on crane requirement.

Table 2.2: Normalised part routing appearance

	All parts			Parts weight <= 20kg			Parts weight >20kg		
Routing	Number*	Weight**	Area***	Number	Weight	Area	Number	Weight	Area
C	0.24	0.48	0.47	0.16	0.02	0.02	0.08	0.46	0.45
C-B/T	0	0.01	0	0	0	0	0	0.01	0
C-B/T-F	0	0	0	0	0	0	0	0	0
C-B/T-G	0	0.01	0	0	0	0	0	0.01	0
C-B/T-G-Fl	0	0	0	0	0	0	0	0	0
C-F	0.02	0.14	0.11	0	0	0	0.01	0.14	0.11
C-F-G	0.02	0.02	0.02	0.01	0	0	0.02	0.02	0.01
C-G	0.69	0.32	0.36	0.53	0.05	0.06	0.17	0.27	0.31
C-G-Fl	0.02	0.01	0.02	0.01	0	0	0.01	0.01	0.01
C-Fl	0.01	0.01	0.02	0.01	0	0	0	0.01	0.02
Total	1	1	1	0.72	0.07	0.08	0.28	0.93	0.92

* Normalised number of parts per specific routine, ** normalised cumulative weight of all parts, *** normalised cumulative area of all parts – (Nonstandard variant is included in Table D.1)

Several notions concerning Table 2.2 exists. Firstly, bevelling can also be performed on the cutting machine, which implies that some routing possibilities can be merged (e.g. C-B/T-G can be merged with C-G). Secondly, no standard flow which at least 80% of the parts follow is observed. The observation applies to all three measured units. The C-G route is numerically reasonably large, but this concerns small parts mainly. Considering this to be the standard flow results in a flawed approach as small parts are much easier to handle than large parts and grinding requires much less resources than (e.g.) forming. Furthermore for grinding much less resources are required than e.g. forming.

Consequently, there are several severe limitations to using VSM for DSGa's pre-processing process. The main limitations relate to complex routing (shared resources), absence of a clean standard flow and part variability.

2.3.3. Mapping complex routines

The regular VSM approach has limits when implementing complex routines, which has been acknowledged in literature as well by Schmidtke et al. [70] and McDonald et al. [52]. Both studies propose the utilisation of discrete event simulation for obtaining the VSM. Discrete event simulation is suitable as it includes dynamic relations between different processes, which could not be addressed using the static view provided by VSM [33, 52]. The dynamic relations within the simulation model will cover the buffer and waiting times. Subsequently the process time, cycle time and up time can be determined. Moreover, simulation incorporates feasibility and trade-off analysis, which enables the shared resource principle to be addressed more easily [70].

Despite the limitations of the VSM technique the construction of a 'current state map' (CSM) is useful as its elements can still be constructed. [51, 71]. The layout and flow analysis, as part of the CSM, support the construction of a simulation model [52].

Material Flow Analysis (MFA) can be used to analyse the significance of each flow. MFA refers to the analysis of throughput of process chains comprising manufacturing, consumption, recycling and disposal of materials [4, 5]. It is based on accounts in physical units (usually in terms of tons), quantifying the inputs and outputs of those processes.

2.3.4. Valuation metrics

The sixth step of the VSM approach discussed in Section 2.1.2 concerns the review of process inefficiencies, by a Lean Manufacturing waste analysis. Furthermore it entails the determination of the ratio between value-added and non-value-added processes. For this reason and for enabling comparison between current state models and future state models, key performance indicators (KPI) are defined.
These KPI's need to incorporate the objective of the main research question, namely performance on space utilisation and throughput. Moreover KPI's are derived from the Lean Manufacturing framework. [3, 60]. Valuation metrics should support quantifying decisions [37]. Additional metrics, although be being correct, do not provide additional information to do so [3]. Furthermore by defining a high number of metrics the risk of contradiction is enhanced. Hence the following metrics are defined:

KPI_1 to KPI_4 concern space utilisation and are layout design measures. KPI_1 is defined as the total available area for executing pre-processing activities. The total area metric is appropriate since space utilisation cannot straightforwardly be checked mathematically [76]. Moreover it clearly addresses the main research question. The total area can be divided in process area, infeed and outfeed, indicating what area is used for value adding processes and what not [35]. This measures is incorporated in KPI_2. Strictly speaking buffers enable certainty about part arrival, which is valuable. Nevertheless it does not enable physical product transformation. Furthermore sorting spaces are not including in process space, because no clear rules exist to define what valuable sorting space is.

$$\mathrm{KPI}_1 = \mathrm{Area}_{\mathrm{total}}$$

$$\mathrm{KPI}_2 = \frac{\text{Process space}}{\text{Total space}}$$

To study the available space arrangement and transport waste, the transport distances are studied [49]. Those are important layout redesign measures [46, 49]. By accumulating the multiplication of the MFA results and the related transport distances it is determined what percentage of the entire flow 'travels' which distance. The KPI is defined as the mean transport distance per part, in the units of 'number of parts' and 'cumulative weight' to incorporate the difference between small and large parts. This KPI incorporates both the non-value-adding- and necessary-non-value adding activities [35].

$$\mathrm{KPI}_3 = \text{Mean transport distance} = \bar{s} \text{ for } \begin{cases} \text{Number} \\ \text{Weight} \end{cases}$$

The implication of a specific distance travelled is enhanced by the time it takes [49]. For the longer distances more 'transfer points' are occurring, which are more susceptible for waiting times, due to resource availability [46]. Hence the number of transport moves is incorporated in the next KPI, indicating the number of crane, carriage, conveyor or manual actions used:

$$\mathrm{KPI}_4 = \text{Mean number of transport moves} = \bar{n} \text{ for } \begin{cases} \text{Number} \\ \text{Weight} \end{cases}$$

Within Lean Manufacturing the 'time to market' is vital [60]. This KPI is particularly important from Lean Manufacturing perspective since it captures the extend to which the flow is continuous and value adding [50, 87]. To study this time aspect the part throughput analysis is assessed next, which mainly concerns the definition of the duration of each work step per part [60]. It captures the time effect of inventory building up [49]. The entire process is defined as the time between a raw plate entering the facility on the infeed conveyor and the processed part entering the end buffer. A distribution of parts versus 'entire process time' is constructed. The average is included in KPI_5.

$$\mathrm{KPI}_5 = \text{time average of 'entire process time' per individual part distribution} = \bar{x}_{\mathrm{time}}$$

This KPI can also be defined for the strictly value adding activities to enable comparison [3, 35]. For cutting this time is defined as the cutting program duration, which really transforms the plate in parts that the customer wants. The processing work steps also enable a physical transformation of the part, being value added steps. The cumulative durations are used.

Besides the yard throughput is dealt with, which deals with the station/yard occupancy. For the development of KPI's three measures are of interest. The first one (KPI_6) has to capture the ability of the system to meet annual capacities, for which the cumulative annual throughput is appropriate [3]. The definition of this KPI is driven by the objective of the main research question. The scrap weight is excluded from the determination of the throughput as a matter of definition.

$$KPI_6 = \text{maximum throughput per year (weight)}$$

Moreover KPI's have to capture whether the work stations have a levelled throughput [60]. This property is of importance as it is strongly related to the establishment of a smooth, uniform flow [50, 79, 87]. This is captured by the 'station occupancy rate' (KPI_7), distinguishing the difference between idle and occupied time of each work station. The unit weight is used in order to incorporate the difference between parts. Since the entire station is considered, insight in the in/outfeed buffer loading is obtained. Such it links to daily 'work in progress' measures per station [78]. For a Lean, levelled flow KPI_7 need to be close to 1, since this means that the station load is spread per time unit.

$$KPI_7 = \text{station occupancy rate} = \frac{x_{all}\text{-}x_{idle}}{x_{all}} \text{ for } \begin{cases} \text{Cutting} \\ \text{Forming} \\ \text{PPS} \\ \text{Flanging} \end{cases}$$

Moreover it is of interest to what extend the work station is active when being occupied, which is assessed by KPI_8, distinguishing the degree of occupancy when being occupied [49]. Conform the Lean Manufacturing framework objective this KPI need to be close to zero, since this means that the station load is always equal.

$$KPI_8 = \text{active station occupancy variability} = \frac{\sigma_{\text{occupancy}}}{\mu_{\text{occupancy}}} \text{ for } \begin{cases} \text{Cutting} \\ \text{Forming} \\ \text{PPS} \\ \text{Flanging} \end{cases}$$

Closely related are the resource utilisation measures, which are machine related contrary to the station related KPI_7 and KPI_8. It distinguishes the ratio between utilised time and total time. It provides measures of the waiting waste, which is further addressed in Chapter 3 [75]. Whether the utilised time is also value adding is resource specific.

$$KPI_9 = \text{resource utilisation} = \frac{\text{utilised time}}{\text{total time}} \text{ for } \begin{cases} \text{Cutting machines} \\ \text{Presses} \\ \text{Cranes} \\ \text{Carriages} \end{cases}$$

In this study the extent to what the two pre-processing areas of DSGa (i.e S1 and S1a) can be merged into S1a is investigated. Investments in new equipment can be made for redesigning the process. Furthermore the current deployed equipment can be replaced. Hence the investments need to be monitored as well. The following KPI is constructed:

$$KPI_{10} = \text{Required investments}$$

Finally the ratio between throughput and space utilisation is defined, since this measure is included in the objective of this study. Combined with KPI_{10} marginal effects are captured.

$$KPI_{11} = \frac{\text{Throughput}}{\text{Required space}}$$

2.3.5. Approach

Some of the KPI's can be determined by means of the static regular VSM approach, namely KPI_1 to KPI_4, because they are not directly time related. Hence those KPI's are defined by means of layout and flow description. MFA is used to define KPI_3 and KPI_4. This approach is followed in Chapter 3.
Contrary the throughput related measures cannot be determined with the static approach. Therefore a simulation model is constructed. Discrete event simulation is suitable to cover the buffer and waiting times. Hence the objective of the simulation model is to enable the determination of the throughput related KPI's (KPI_5 to KPI_9).
As explained above, the KPI's provide feedback on the waste analysis executed as part of the review of process inefficiencies and enable comparison with future state scenarios. Definition of future state scenarios result from the seventh VSM step, namely the determination of an action plan, which entails a list of opportunities to improve.

Conclusively the following steps are adopted.
1. Description of layout analysis of flow by means of Material Flow Analysis (MFA) to obtain KPI_1 to KPI_4 and perform the waste analysis.
2. Description, construction and analysis of simulation model to obtain KPI_5 to KPI_9 and provide feedback on the waste analysis.

2.4. Summary

In this Chapter the first two Lean Manufacturing principles ‘identify the value’ and ‘map the value stream’ are reviewed in order to address the first research question.
How can the performance of the current pre-processing process be described by means of the static Value Stream Mapping approach?

An approach to identify and map the value in a process is outlined. First the distinctive character of Lean Manufacturing is appointed, which shows a focus on efficiency improvement of both the value and non value adding activities.
First it needs to be determined what the customer wants from the process, because that defines the value. Subsequently the operations can be categorised into value-, non-value- and necessary-non-value-adding operations. For this seven types of waste are introduced within this framework. A methodology to map the process by means of a Value Stream Mapping (VSM) technique is proposed, which outlines the construction of a current and future state map (CSM/FSM).

Hence first the DSGa pre-processing ‘customers’ and their ‘demands’ are defined. The customers are the subsequent processes (sub panel-, main panel-, section-, block- and hull assembly) and demand specific plates and profiles with a specific physical appearance, created by specific processing steps.

It is investigated whether the VSM approach can be adopted. Prior to the quantification of routines the annual yard portfolio is constructed and the product data is described. The portfolio is mimicked by 12 ASD tugs and 6 PSV vessels.
Since there is no clear main flow and the process is rather complex due to the existence of several routines, limits concerning straightforwardness as well as completeness are observed. Discrete event simulation is proposed to incorporate the dynamic behaviour of the process. Elements of the VSM approach for constructing a CSM are still of use. Finally layout description, flow analysis by Material Flow Analysis and simulation model construction is proposed.

For the determining the ratio between value-adding and non-value-adding processes and enabling comparison between current state models and future state models, key performance indicators (KPI) are defined. These KPI's incorporate the objective of the main research question and link to the Lean Manufacturing framework performance concepts. In Chapter 3 the design related KPI's are outlined, by describing the performance of the current state by means of the static VSM approach. In Chapter 5 the time related KPI's are obtained by means of simulation.

3

Current State Map construction and analysis

The previous Chapter shows that the construction of a current state map is a proven technique to surface the value in a process. In this Chapter a current state map of the pre-processing process of DSGa is constructed. The current pre-processing facilities are described and the related flows are outlined, by means of Material Flow Analysis. Second waste existence is investigated, conform the VSM approach. Subsequently the space related KPI's are defined, namely KPI_1 to KPI_4. Furthermore the flow and waste analysis supports the construction of a simulation model by investigating what the model should in- or exclude. These steps are visualised in Figure 3.1.

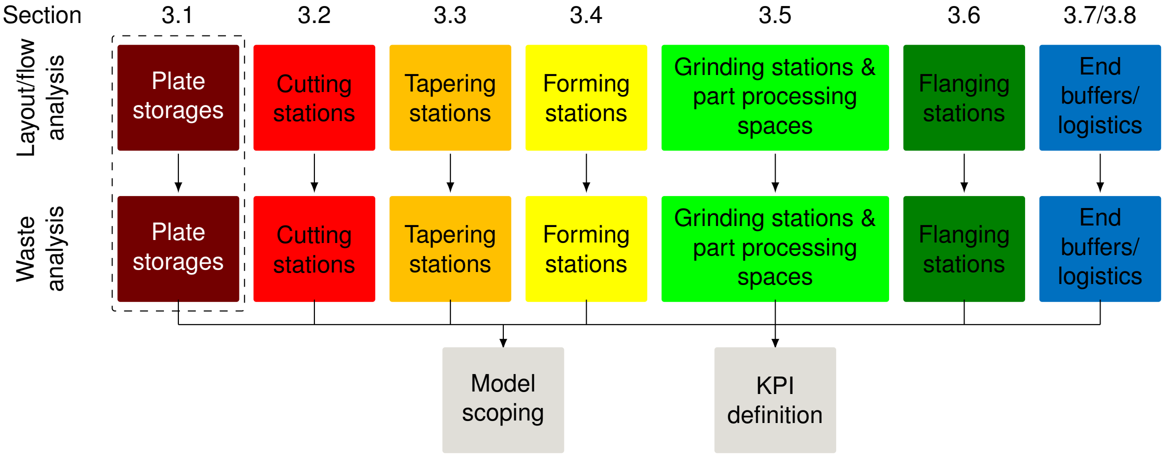


Figure 3.1: Structure overview Chapter 3.

The description of the flow and waste is structured by work station (dashed frame in Figure 3.1). First the plate storages are discussed, in Section 3.1. Subsequently the other stations are described in Section 3.2 to Section 3.6. In Sections 3.7 and 3.8 some coherent notions about end buffers and transport facilities are made. Subsequently the KPI's are determined and the model scoping is discussed, in Section 3.9 and Section 3.10. Doing so the first research question is addressed:
How can the performance of the current pre-processing process be described by means of the static Value Stream Mapping approach?

The flow description is based on the 'process model descriptions', which are a detailed description of the yard processes and are validated with DSGa. They are included in Appendices B and C. In order not to loose the overview first the layouts of facility S1 and S1a are presented in the upper and lower part of Figure 3.2 respectively. In both facilities approximately the same activities are executed. Flow charts are drawn. Based on the product data conditional statements are developed for obtaining

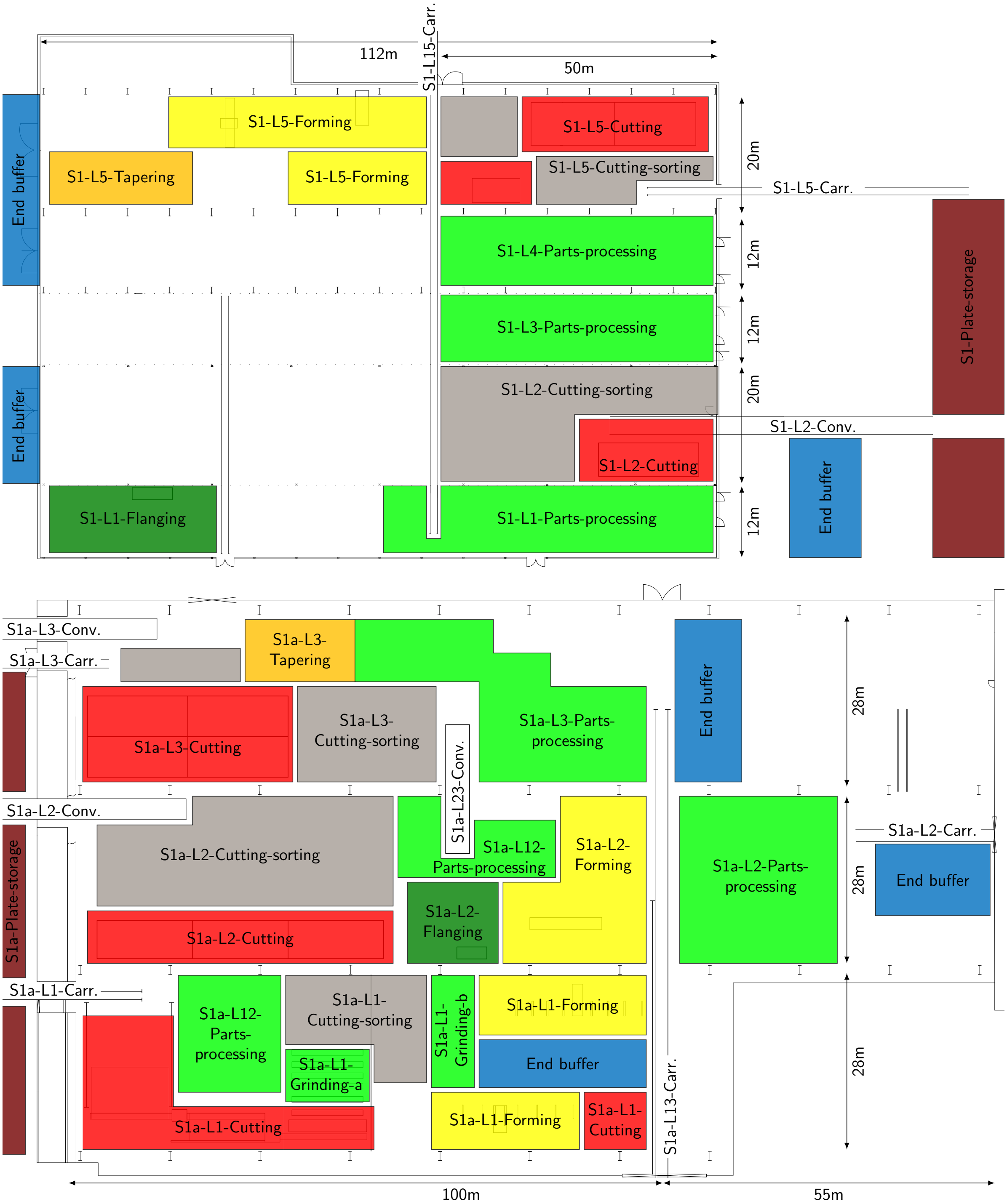


Figure 3.2: Current layout of pre-processing areas. Upper part - S1, lower part - S1a

the MFA indicators. Those conditional statements are specifically described in Appendix D.2. In the flow diagrams two physical units are presented, namely the ‘part number’ and ‘cumulative part weight’ respectively. They are normalised by their flow origination. More detailed diagrams are enclosed in Appendix D, in which also the transport distances/means are presented for each movement. Their exactness is conform the objective of the value stream current state map approach [51].

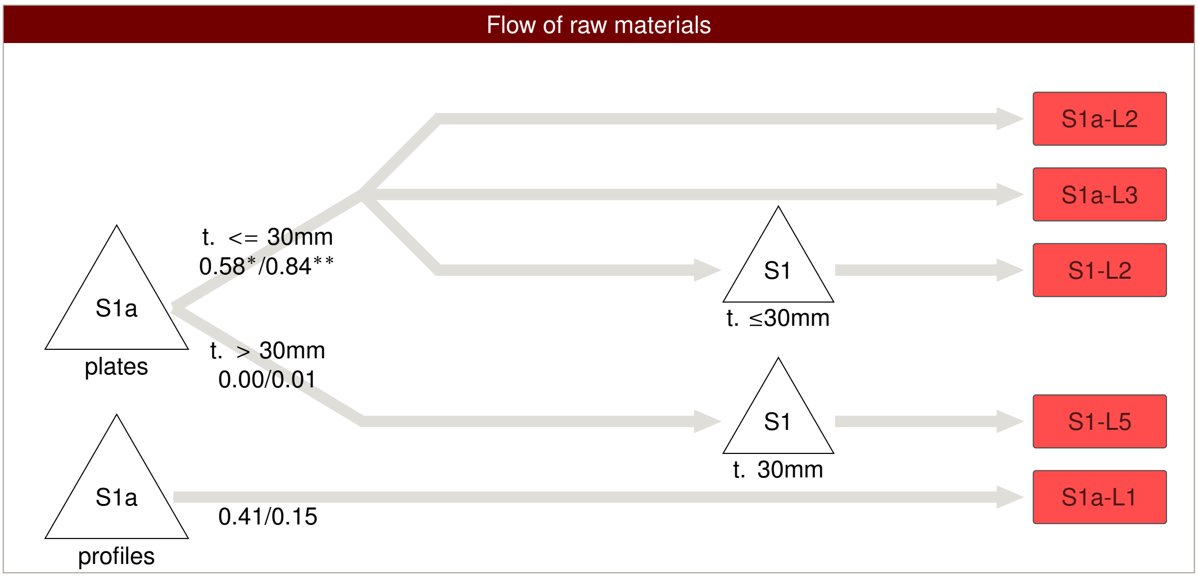
3.1. Plate storages

The raw material plate storages are discussed first since it is the start of the process (Section 1.2.2). The layout and flow are described in Section 3.1.1. Then the waste analysis is presented.

3.1.1. Plate storage layout and flow description

DSGa has one main shot primer facility to blast and primer the raw plates, positioned in S1a. After blasting the plates are stored. For the continuation of this study those plates are indicated as raw plates/profiles, distinguishing them from cut parts.

Because cutting takes place in both S1 and S1a the raw plates are moved from S1a to the plate storage in S1, which is visualised in Figure 3.3. From the storages (brown/red colour in Figure 3.2) several cutting departments are fed. In Figure 3.3 those are indicated by the names provided in Figure 3.2.



* normalised number of parts, ** normalised cumulative part weight.

Figure 3.3: Flow of raw material entrance, in Figure 3.2

For the transportation it is of importance that the plates are cut in batches (cutting groups), which contain all plates required to cut all parts of a number of ship sections. The reason why currently several sections are bundled is because of material usage minimisation when nesting all parts. The number is in the order of four to six sections, depending on the section size.

Thick plates are subtracted from the plasma cutting groups and sent separately to the oxy acetylene cutting station. For the plasma cutting stations the rule applies; the parts are cut and processed in the same facility. The thick parts form an exception and are processed in the facility where the thin parts are cut and processed.

MFA is used to quantify the contribution of the each flow. The result is displayed in Figure 3.3. A detailed overview of the related transport distances is provided in Figure D.2 because for each cutting station the logistic flows are different. The decision where to cut a plate cutting group depends on the attributes of the cutting stations (machine functionalities). This is further discussed in Section 3.2.1.

Concerning profiles, there are mainly two types, namely Holland profiles and flat bars. Currently the flat bar profiles are cut from plates and added to the plate cutting group nestings. Holland profiles are also nested in cutting groups containing several sections. However a nested profile contains only parts of one section. The other profiles (square bar, round bar, etc.) are moved inside similarly. This flow is also indicated in Figure 3.3. A detailed overview, including the transport distances, is included in Figure D.2.

3.1.2. Plate storages waste analysis

Generally plate storages do not contribute to the value the customer receives. From this perspective plate storages should be fully eliminated. In the current situation all plates of one cutting group are moved at once to S1, building up inventory piles. Also at the S1a plate storage all plates for one cutting group are stored prior to cutting.

Due to current spread of facility S1 and S1A much transportation takes place. This becomes apparent when assessing the MFA results. This is a large amount of waste.
In the current situation to be transported goods are bundled/clustered to minimise transport movements. Bundling goods implies that goods are stored for at least the time it takes to prepare one bundle, which actually is a inventory waste. This observation is strengthened by the fact that transportation takes by preference place during the night shift to interfere less with other yard operations. Some trade-off between the transportation waste and inventory waste exists.
Cut thick parts are moved back to S1a when the section is processed/assembled there, resulting in additional transportation. The MFA shows that it only affects a few parts. From that perspective the thick parts are not the first concern for the CSM analysis.

However plate storages enable certainty about delivery dates and planning. On time delivery is something which has value. Consequently the balanced conclusion is that no unnecessary stocks should be build up. In order to enhance this the Lean Manufacturing framework proposes to include the raw material supplier in the chain. Doing so part of the inventory can be levelled to the suppliers. This is captured in the third layer of the 4P model.

3.2. Cutting stations

The raw material plates are moved to several cutting stations, which are further explained in Section 3.2.1. Related waste analysis is presented in Section 3.2.2.

3.2.1. Cutting stations layout and flow description

DSGa has five cutting stations, marked in red (Figure 3.2). Their names are based on their location on the map. First a general description and the machine functionalities are presented. The machine functionalities are discussed in the waste analysis in Section 3.2.2. Secondly the main flows are described. First the profile cutting station (S1a-L1) is described. Then the plasma cutting stations are described (S1a-L2, S1a-L3 and S1-L2). Last the oxy acetylene cutting station is described (S1-L5).

Station and machine functionalities

Cutting station S1a-L1 consists of a profile cutting robot (left in Figure 3.2) and a profile sawing station (right in Figure 3.2). Photos are included in Figures 3.4a and 3.4b respectively. Cutting station S1-L5 consist of an oxy acetylene cutting machine dedicated to cutting thick plates (t.>30mm). The other cutting stations have plasma cutting machines dedicated to cutting the other plates. The S1a plate and oxy acetylene cutting machines approximately reached their economic lifetime. In Figure 3.4 the cutting stations are shown. In Table 3.1 an overview of the specifics of the cutting machines is presented.

Table 3.1: Cutting machine functionalities

Cutting machine	S1a-L1*	S1a-L2	S1a-L3	S1-L2	S1-L5
No. portals	1	2	1	1	1
No. cutting beds	-	3	2x2 synchronous beds	1	4
Marking	yes	yes	yes	yes	yes
Signing	yes	yes	no	yes	no
Cutting	plasma	wet plas	wet plasma	dry plas	oxy fuel
Bevelling v/y-seams	yes	yes	no	yes	no
Grid cutting	no	no	no	no	no
Grinding	edges	-	-	-	-
Max thickness	profiles	≤ 30mm	≤ 30mm	≤ 30mm	all
Speed	fast	fast	fast	fast	slow
Aluminium	no	no	no	yes	no

* This cutting station also contains a sawing machine, only the plasma robot is listed.

Concerning Table 3.1: Per cutting station the number of portals and cutting beds is given. Cutting machine S1a-L2 has two portals, with the same characteristics. Cutting machine S1a-L3 has two cutting beds. However it is able to do synchronous cutting, by deploying four beds.

(a) Cutting machine S1a-L1-cutting-robot (b) Cutting machine S1a-L1- sawing-machine

(c) Cutting machine S1a-L2 (d) Cutting machine S1a-L3

(e) Cutting machine S1-L2 (f) Cutting machine S1-L5

Figure 3.4: Cutting machine photos

Furthermore cutting machine functionalities are listed, namely marking, signing, cutting, bevelling v/y seams, and grid cutting. For the profile cutting line also the grinding functionality is added. Related setup, process and changeover times are included in Appendix D.3.1.

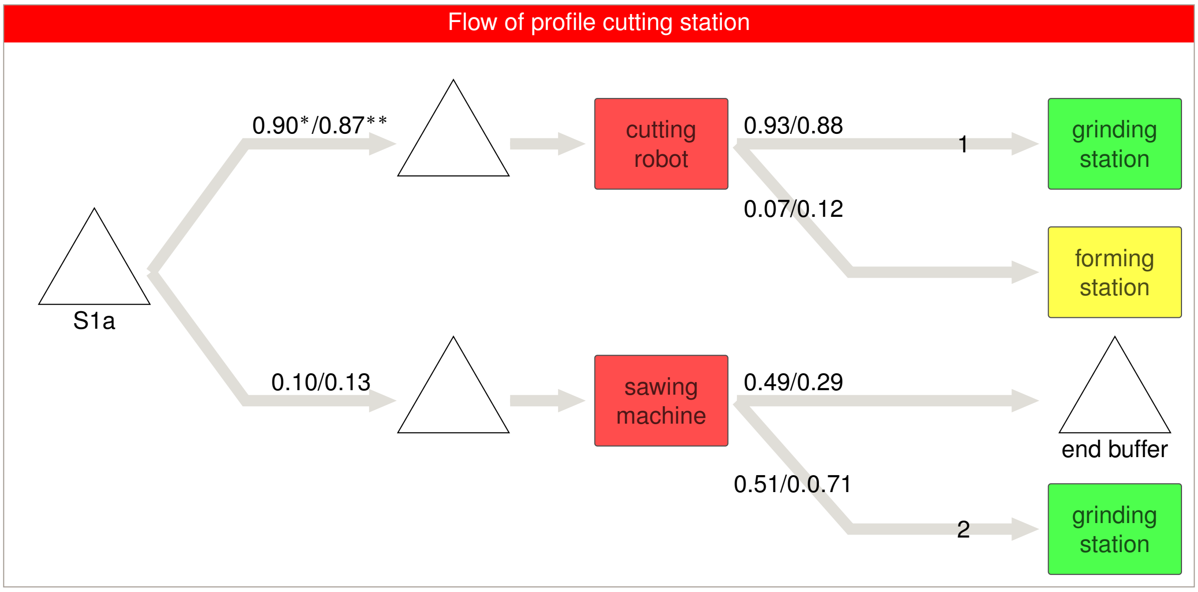
The oxy fuel / acetylene cutting machine is able to cut plates with all thicknesses. However since plasma cutting technique results in faster cutting compared to oxy acetylene cutting plasma cutting is preferred for thicknesses under 30mm. The wet plasma functionality requires additional cleaning.

Profile cutting station S1a-L1

By means of the profile cutting robot Holland profiles and flat bars can be cut. Currently only Holland profiles are cut. The sawing machine is used to cut massive round-, squared-, angle bars and pipe for construction purposes. Both the robot and the sawing machine are presented in Figure 3.5.

After cutting on the profile cutting robot the parts are either sent to the grinding station (S1a-L1-grinding-a) or the forming station (S1a-L1-forming). The to be formed parts are transported in bundles. Those parts are grinded afterwards because some overlength is applied for the forming process. This is done in S1a-L1b-grinding.

From the input buffer at the sawing machine, the parts are loaded onto the sawing machine. After sawing two flows originate, namely to the end buffer and to grinding. The first flow concerns parts for external subcontractors.

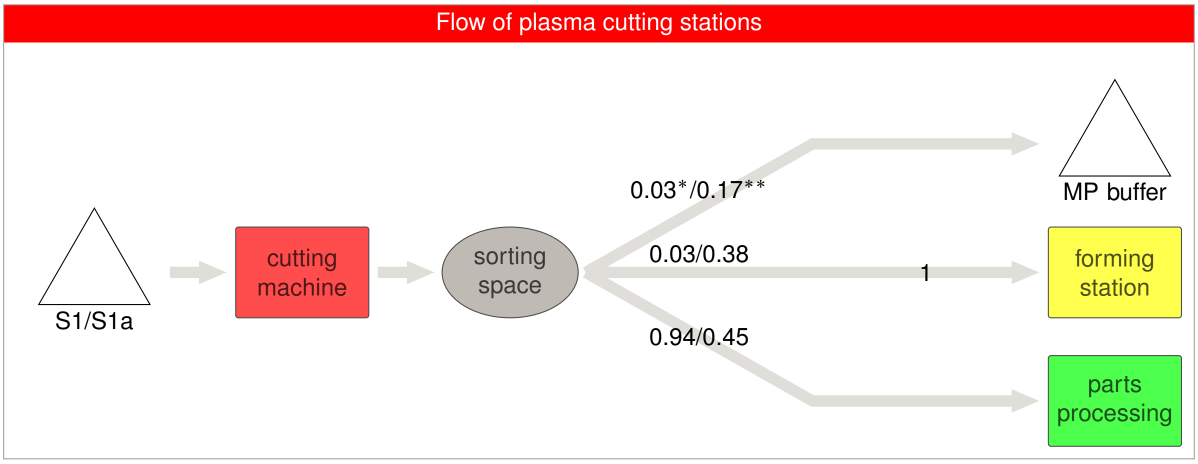


* normalised number of parts, ** normalised cumulative part weight.

Figure 3.5: Flow of profile cutting station, in Figure 3.2

Plasma cutting stations, S1a-L2, S1a-L3 and S1-L2

The generic flow of the plasma cutting station is visualised in Figure 3.6. A batch of plates arrives from the plate storages on a conveyor or carriage. After the cutting process the parts are sorted on section level and loaded on different containers or stacks on the sorting space. The containers or stacks are moved to either the main panel (MP) end buffer, forming station, or parts processing spaces.



* normalised number of parts, ** normalised cumulative part weight.

Figure 3.6: Flow of plasma cutting stations, in Figure 3.2

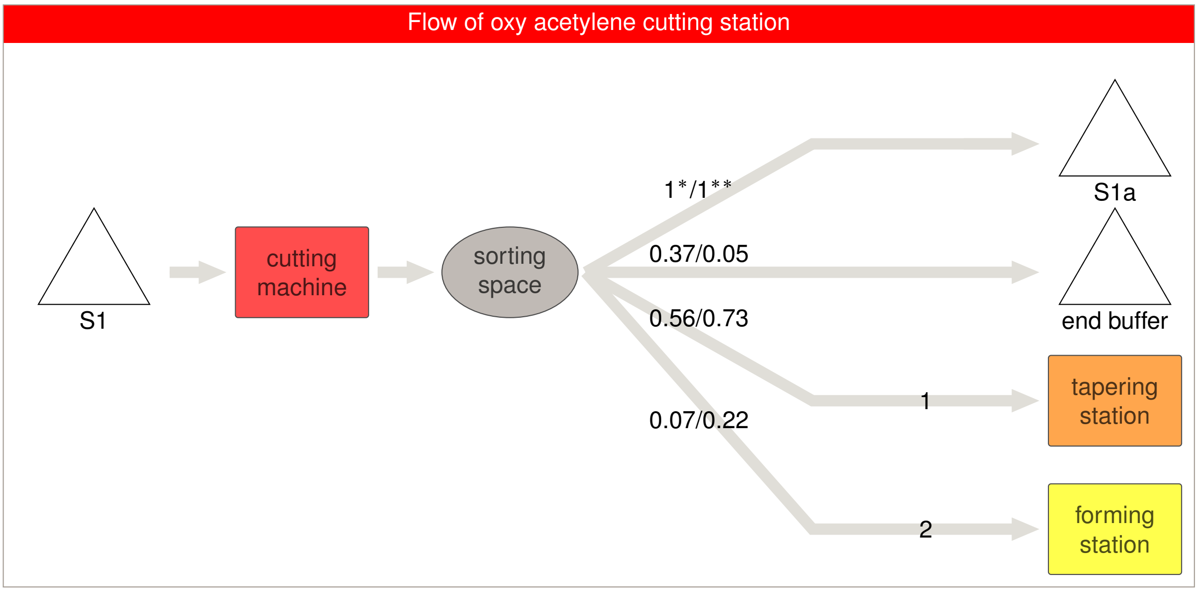
Based on the routine description in Section 2.2.2 it is expected that the parts would leave to the outfeed buffer, bevelling/tapering station, forming station and grinding station. However in Galati the process is organised differently. Parts enter the bevelling/tapering station via the parts processing spaces.

1. The to be formed parts are moved to the forming stations. In S1 they are first batched on a container. In S1a they are moved one by one.
2. S1 and S1a both have several part processing spaces (PPS). Subsequently different logistic flows are present from which a detailed overview is provided in Figure D.4.
3. In S1 the main panels are moved outside again by the conveyor. Then they are loaded onto a section rack and moved to the end buffer location at the right side of the facility or at the main panel line in S1a. In S1a they are moved one by one to the entrance of the main panel line.

Throughput analysis is performed. Figure 3.3 shows that the plasma cutting stations are able to process the same part scope. It depends on the performance of each individual cutting station how the throughput is divided over the three stations. This is not assessed because it depends on the detailed station performance, which cannot be easily defined by MFA.
In Appendix D.2 the MFA conditions are further explained. In Figure 3.6 the results are presented. In Figure D.4 a diagram per individual cutting station is drawn and the logistic flows are delineated and quantified.

Oxy acetylene cutting station S1-L5

The thick plates of a cutting group are cut on the oxy acetylene cutting machine, independently where the rest of the cutting group is cut. The raw thick plates are separated form the others at the S1a plate storage. They are moved to S1 per individual cutting group.
After cutting, the thick parts are moved to the subsequent stations. Based on the routine description in Section 2.2.2 four destinations can be distinguished. However because thick plates are mostly main panels which do not require contour grinding this step is not specifically distinguished.



* normalised number of parts, ** normalised cumulative part weight.
Figure 3.7: Flow of oxy fuel cutting station, in Figure 3.2

Two types of outside stores are distinguished, namely end buffer and S1a. When the rest of the plates (t.≤30mm) is cut in S1a, the thick plates need to be transported back. The further pre-processing (tapering/forming) is then also performed in S1a. Hence the material flow analysis result of the S1a buffer is 1/1, indicating a 100% flow. Without incorporating the performance of the plasma cutting stations and the number of cutting groups processed in each facility (S1/S1a), no proper flow separation between the S1a buffer and the other three exits can be made. The flows and throughput measures are included in Figure 3.7. In Figure D.5 a detailed overview of the transport means is provided.

3.2.2. Cutting stations waste analysis

The objective of this Paragraph is to identify the waste within the individual cutting organisations and processes. Several topics are discussed, namely: batch size, transportation of cut parts, machine functionalities and profile cutting line position. An overview is provided in Figure 3.8.

Nesting of all parts of an entire section

In Section 2.2.1 the demand of the 'customers' was mapped in time. It is observed that the demand cascades in time. Consequently, from the demand side, a time phase difference is present between the different customers. Because all parts of a section are cut in one batch, all parts for the subsequent process steps are cut in the same interval. This is illustrated in Figure 3.9. It implies that the parts

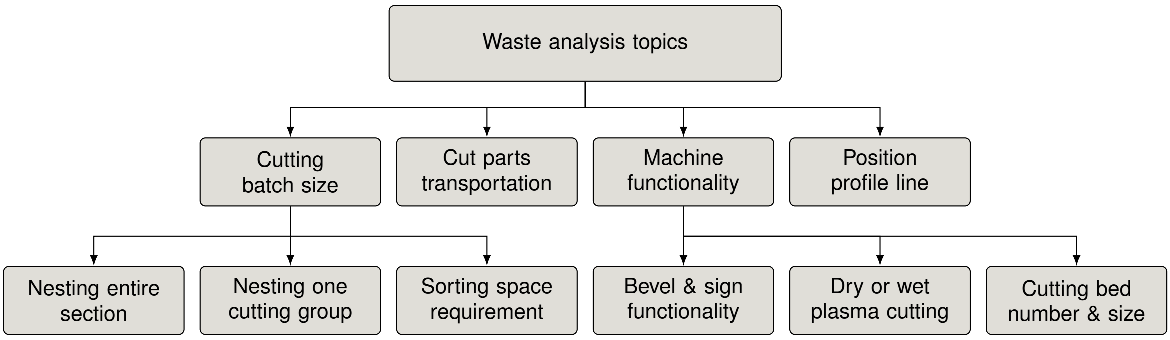


Figure 3.8: Waste analysis in cutting station, topic overview

which are cut for main panel-, section-, block- and hull assembly build up inventory, as only the parts for sub panel assembly are used directly. To mitigate this the parts should not be cut by section, but by subsequent process steps demand.

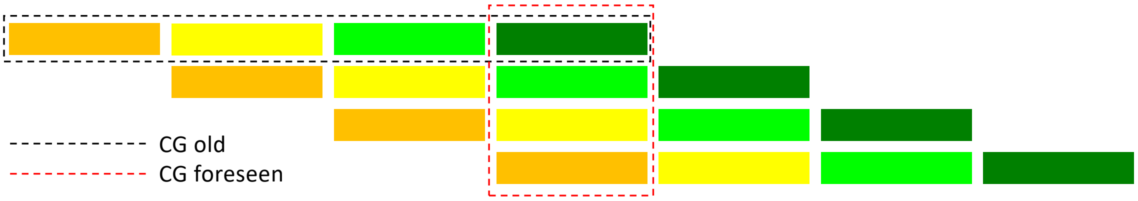


Figure 3.9: Cutting group definition, old: cut all parts of a section, foreseen: cut for subsequent demand.

Nesting of several sections in one cutting group

Not only a time phase difference is present for the different subsequent process steps, but also within a single process step. This is explained by a thought experiment. Imagine that all three plasma cutting stations process one cutting group and a cutting group contains the parts for four sections. When the cutting stations have finished their cutting groups, parts are processed at the part processing spaces. Only when (1) cutting groups are processed twice as fast as supplied, (2) supply cascades equally in time and (3) processing always has the same duration, no waiting or building up inventory occurs. Else the part processing space will be waiting or the cut parts will be building up inventory. The thought experiment is included in Appendix D.4. The idea is visualised in Figure 3.10.

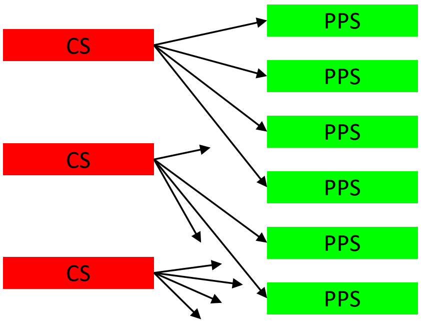


Figure 3.10: Assignments of sections to part processing areas

Currently there is no standard relation between the cutting and parts processing time, because both durations highly depend on section/part attributes. Besides the possible variation of the number of sections in one cutting group distort this relation. Secondly the supply does currently not necessarily equally cascade in time, because of different plate nesting attributes and station characteristics resulting in different cycle durations. The third statement can be explained likewise the first.

Conclusively cutting several sections in one cutting group requires more extensive organisation in order not have waiting or inventory waste. As that lacks in the current situation both types of waste are present. There is a preference for building up inventory over letting the part processing spaces waiting. The difficulty of the extensive organisation is increased by the fact that three part processing spaces are located in S1 and three in S1a. Apparently still a lot of transporting is created.
Within the Lean Manufacturing framework this problem is acknowledged by the levelling principles. When enabling a direct input output relation between two different work stations this problem is mitigated.

Sorting space requirements
An important side note of cutting, sorting, transporting and processing in large batches is the necessity for sorting and the risk of loosing parts. In Figure 3.11 some photos are presented to underline the inventory presence caused by cutting on section and cutting group level.
As a result of cutting on section level and cutting in cutting groups much space is required for sorting all parts. Because after cutting the parts are sorted for outside buffer, part processing and forming about 2-3 stacks/containers per section are present on the sorting space. This is visualised in Appendix D.5, in Figures D.13 and D.14.

(b) Cutting all parts for a section

(a) Cutting all parts for a section

(c) Cutting all parts for a cutting group

Figure 3.11: Illustration inventory waste effect

Transportation of cut parts
In the previous Section the transport distances became apparent. Transportation on itself is not a wasteful activity. However the back and forth transport of parts is considered to be wasteful. This kind of transport occurs. For example, in S1 the main panel parts are first moved out by a conveyor than moved by crane and truck. They also could have been transported by crane only. However this would have caused more crane clashes.

Hence a second notion surfaces. The customer demands locations are far away from the source locations. As customer demand locations can be closer part of the required transport activities are considered to be wasteful.

Dry or wet plasma cutting

As plasma cutting machines can cut thinner plate faster it is logic to cut thinner plate at those machines, instead of using oxy acetylene cutting machines. The Lean Manufacturing framework does no provide argumentation to use the oxy acetylene cutting machine also for cutting thin plates, contrary to the Theory of Constraints (TOC) framework [31].

The question whether to use dry or wet plasma cutting machines is addressed here. According to the Lean Manufacturing framework waste is everything which makes the production flow longer. An important argument for dry plasma cutting beds, contrary to wed plasma cutting beds, is the reduction of the cleaning activities. Within this light cleaning actually is a redundant process, not creating any value, being an over processing type of waste.

Bevel and sign functionality

Some cutting machines do not have a bevelling or signing functionality (Table 3.1). Within the Lean Manufacturing framework the focus is on using proven technologies, which add value. Bevelling transforms the product in something the customer wants. Signing enhances sorting and therefore generates value as well. Besides, signing by plasma is faster than by hand writing. Hence those functionalities are to be used. Not using them is a form of waste.

Secondly, the over processing and defect waste types can be mitigated by implementing automatic bevelling and signing. The use of the cutting machine program enhances a standard quality end product. Besides possible mistakes by the human factor in the repetitive signing work steps, can be easily reduced by incorporating it.

Not only cutting machines need to have the functionalities also the information management should be conform. The ability to sign automatically makes manual signing a superfluous step. However within the Lean Manufacturing framework a strong focus is on the integration between man and machine, instead of on full automation. Automatic signing should therefore also be valued from that perspective.

Cutting bed size

The interaction between the cutting portal(s) and the cutting bed(s) is investigated. When the plate is being cut both the portal and the cutting bed are deployed. When manual singing, scrap cutting and removing, and sorting the cutting bed is still deployed and the portal is not deployed anymore. Being not deployed is a form of waiting waste, according to the Lean Manufacturing framework. Increasing the number of cutting beds reduces the waiting time of the cutting portals.

Cutting machine S1a-L3 has two synchronous cutting beds, which means that this cutting machine has just two deployable beds, because the synchronous cutting functionality is hardly used. From a Lean Manufacturing perspective the use of synchronous cutting is not preferred, due to increased material explosion and additional sorting. The value added cutting time per plate is also not reduced.

Cutting station S1a-L2 has two portals and three beds. This enables the reduction of waiting time for the cutting portals. However proper matching of process times is required. Quantitative analysis is required to reveal whether this is case in the DSGa process.

Cutting station S1-L2 has one portal and one bed. Hence the waiting waste is clearly distinguished.

The waiting of the cutting beds/portals can also be reduced by decreasing the contributions of signing, scrap cutting and sorting. Signing was already addressed earlier.

Handling scrap is an entire non value adding activity. However scrap cannot entirely be eliminated and therefore needs to be handled as efficient as possible. In the current way of working scrap is still cut manually. There is room for improvement since the scrap cutting lines could also be integrated in the nestings. Consequently the scrap is already cut in manageable pieces so no manual cutting is required and the scrap can be deposited directly. Besides the scrap can be handled as one entire piece, reducing the movements.

When analysing the current sorting process much movement is observed. As normally large (3m x 12m) plates are cut a lot of parts are exploded when cutting is finished. A higher number of parts results in more sorting. The fact that the parts are less accessible makes that sorting also takes longer. Hence the height and size of the cutting bed contribute.

Profile cutting line

The entire profile cutting system requires much space. Since the infeed conveyor can be positioned outside the facility shed as well, all additional transportation and movement to fill the infeed conveyor is a waste.

Contrary to the relation between plate cutting stations and parts processing spaces the relation between the profile cutting station and grinding station is direct. Subsequently no additional transport of profile parts takes places and less inventory waste occurs. Because of the distance to the forming station the parts are bundled, which is a non value adding activity.

The profile cutting robot has a bevelling and signing functionality. The first one is exploited. However signing is done by hand, because the nest file does not contain all information. As said this is wasteful.

3.3. Tapering stations

Following the process flow of Figure 2.3 the next work stations to be described are the tapering stations. The layout and flow are described in Section 3.3.1. Section 3.3.2 provides the waste analysis.

3.3.1. Tapering stations layout and flow description

Both S1 and S1a have one tapering department (Figures 3.12a and 3.12b respectively). The tapering stations mainly consist out of an in- and out-feed buffer and dedicated work bench with a semi automatic tractor. The semi automatic tractor has one flame torch.

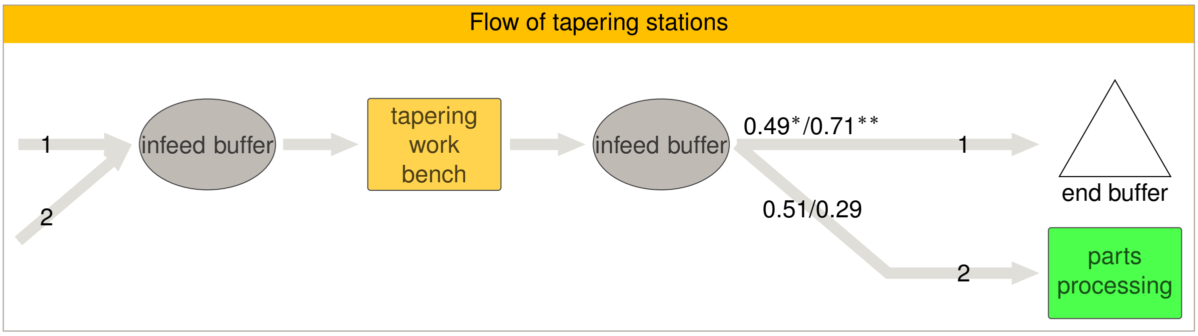
(a) Tapering station S1-L5

(b) Tapering station S1a-L3

Figure 3.12: Tapering station photos

The S1 and S1a flows are identical. Two flows enter the tapering stations. The numbers of the flows refer to Figure 3.7 and Figure 3.20 and are drawn in Figure 3.13.

1. Contrary to thin plates the thick plates are both bevelled and tapered at the tapering station. Thick plates (contrary to thin) are bevelled on the tapering station is because more material needs to be removed. This would take much more time when doing it by grinding only. A more important cause is the absence of a clear routing per part for the smaller parts.
2. In the current situation the smaller parts are bevelled on the cutting machines or by a lot of grinding at the parts processing spaces. Bevelling on a cutting machine is only possible at cutting machines S1a-L2 and S1-L2. Anyway the K/X seams are bevelled by means of grinding. For tapering the thin parts are collected at the parts processing spaces and sent jointly to the tapering station.



* normalised number of parts, ** normalised cumulative part weight.

Figure 3.13: Flow of tapering stations, in Figure 3.2

Once arrived the plates are loaded onto the dedicated workbench with a semi automatic tractor connected to it. This is done by hand or by crane depending on the weight of the part. Once the part is processed it is stored in an outfeed buffer. By means of the cranes and carriages the parts/storage entities are moved to the end buffer or part processing spaces.

The thick plates (flow 2 in Figure 3.13) are moved to the end buffer. The thin plates (flow 1 in Figure 3.13) are moved back to the parts processing spaces. MFA is used to quantify the flows. In the Appendix (Figure 3.13) a detailed overview of the related transport distances is provided.

3.3.2. Tapering station waste analysis

The value adding activity executed at the tapering station is the actual tapering only. The parts are picked up from the infeed buffer and positioned on the table and vice verse. These activities do not create value and are therefore non value adding activities.

As said the semi automatic tractor is equipped with one flame torch, which can easily be extend to three torches. Subsequently only one, instead of multiple, steps is required to obtain a K/X bevel. Doing so the value added activity can be improved.

Currently many parts are not bevelled at cutting machines or at the tapering station due to the absence of part information. Since both processes are more efficient not using them is a type of over-processing waste. It underlines the importance of a proper information flow.

3.4. Forming stations

Like in the previous Sections the layout and flow are described first. Subsequently the waste is discussed in Section 3.4.2.

3.4.1. Forming stations layout and flow description

Three forming departments are distinguished, namely S1a-L1, S1a-L2 and S1-L5. The first is dedicated to forming profiles and described first. Then the plate forming stations are introduced.

Profile forming

Forming profiles main implies frame bending of single or double curvatures. This is done at the frame bender (Hugh Smith 400t), which is located in the lower area of the S1a-L1 forming station. To remove the warping, additional straightening is required on the press located in the upper part of the S1a-L1 forming station. Photos of both machines are included in Figures 3.14a and 3.14b.

(a) Forming station S1a-L1-forming (b) Forming station S1a-L1-straightening

Figure 3.14: Profile forming station photos

The continuation of the flow introduced in Figure 3.5 is described in Figure 3.15. In the infeed and outfeed buffers the bundles are unpacked and packed respectively. The additional straightening step is indicated by the dashed line. Once finished the part is moved to the grinding station S1a-L1-grinding-b. There the overlength, which was applied for easier forming, is cut and the edges are grinded. As a direct input output relation is observed the MFA shows a 1/1 relation.

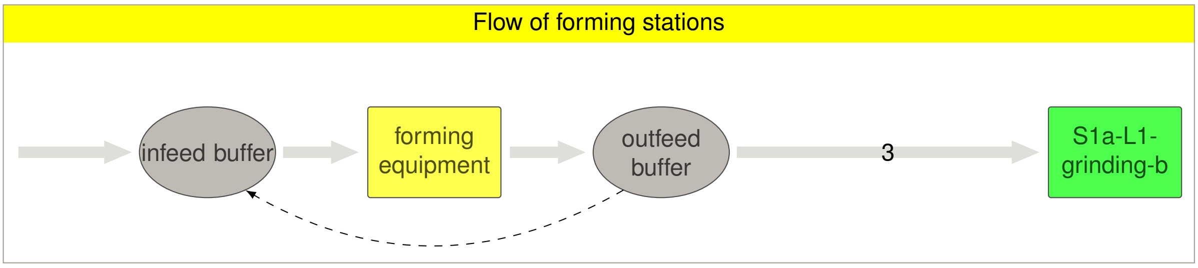
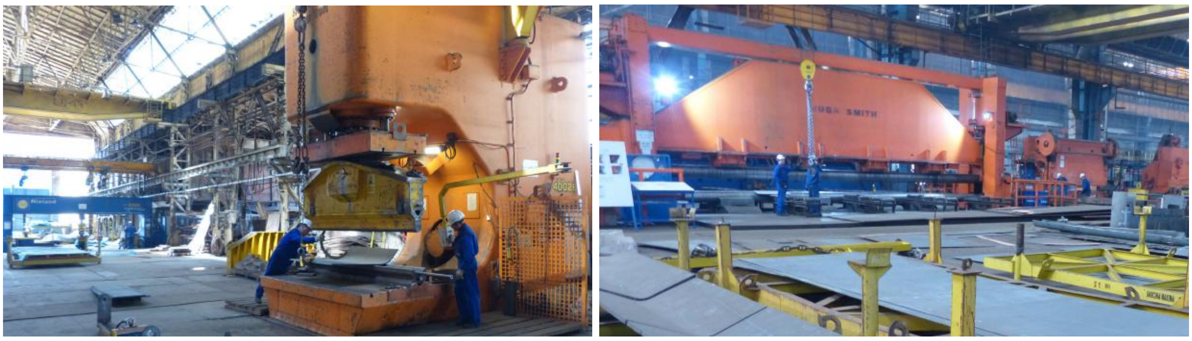


Figure 3.15: Flow of forming stations, in Figure 3.2

Plate forming
Forming departments S1a-L2 and S1-L5 are dedicated to plate parts. Both areas have an in- and outfeed buffer, for storage of arrived parts and some sorting on thickness. The positions of the forming machines are drawn on the layout map in Figure 3.2. Forming plates can be twofold, namely 2D or 3D. The possible available options in DSGa are listed in Appendix D.3.3.
In Figure 3.16 photos of the equipment are presented. In Figure 3.14a on the left the roller pressure press can be observed. The press in front is the pressure press. In Figure 3.16b the roller press and the line heating station are observed left and right respectively.



(a) Forming station S1-L5 (b) Forming station S1a-L2

Figure 3.16: Plate forming station photos

Figures 3.6 and 3.7 show that the parts are sorted for forming after cutting. The continuation of these flows is described here. In S1 and S1a the same flows are recognised. Conform the pre-processing steps clarified in Section 2.2.2 it is expected that after the parts are cut they are first tapered. However in the current situation the parts are first formed because due to size inaccuracy of the forming process overlength is applied. The over length is cut in the section assembly process.

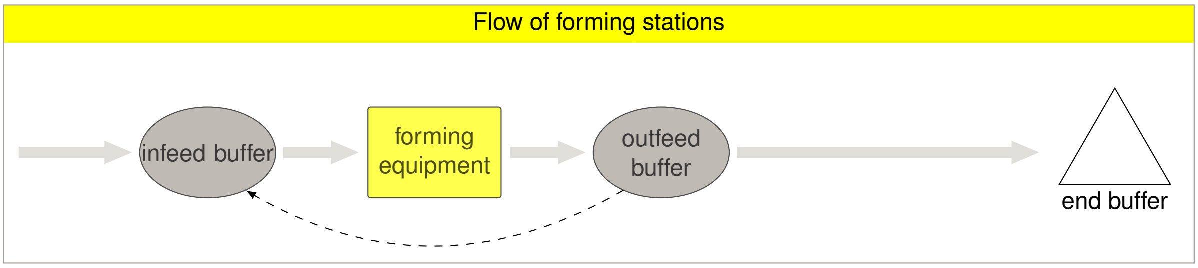


Figure 3.17: Flow of forming stations, in Figure 3.2

Figure 3.17 shows a dashed line between the infeed and outfeed buffer. This illustrates the possibility that two machines/stations are required to generate the required shape. Once finished the parts are moved to the end buffers. Due to the direct input output flows of the forming stations the MFA results is a 1/1 relation. The transport distances are derived and included in Figure D.7. Detailed information about the internal logistics and end buffer locations is available in Appendix B.

3.4.2. Forming station waste analysis

Several aspects are investigated and discussed. The definition of these aspects result from the previous analysis and the product data. First the 3D forming techniques are discussed, followed by the supply and demand variability, the use of transport- or working cranes and the setup time.

3D forming techniques

Forming 3D plates is a combination of stretching and/or shrinking. Stretching is preferred to shrinking, and done preferably at a roller pressure press or at a pressure press with spot stretch tool. Shrinking requires much more time (factor 3-5), very skilled workers and may destroy the material properties when material is heated too much [59]. Over length is applied to mitigate the imprecision of this process. Hence a significant time advantage (factor 3-5) is gained by cold forming (stretching) instead of line heating (shrinking). Furthermore the process can be controlled much better and a standard quality level can be realised. Obviously the investment cost is much higher when investing in cold forming presses instead of flame torches for line heating.

Within the Lean Manufacturing framework the focus is on supplying the customer with quality products. Hence cold forming is preferred over line heating. This is in line with the defect type waste, namely: 'failing to produce a quality part the first time generating rework or scrap'.

Supply and demand variability

A large supply variability of to be formed parts is observed (Appendix D.5), due to the different ships and ship sections. To be formed plates mainly imply shell plates. For a large ship, e.g. platform supply vessel (PSV), the relative number of curved sections is much smaller than for a small ship (e.g. tug). The fact that the parts are either transported in batches (S1) or single (S1a) does not have a large effect on this, because the flow is created at the cutting station.

Consequently either inventory is building up, or the forming machines are waiting idle. Both states are considered to be wasteful according to the Lean Manufacturing framework. Building up inventory of formed parts is unavoidable due to the customer demand batch size.

Transport- or working cranes

The forming station makes extensively use of cranes in order to handle the plates. In the current situation not all forming stations have working cranes assigned. In S1 only the roller pressure press has flexible working cranes. The pressure press has two working cranes, but due to their size they are limited usable for in- and outfeed. The plate forming station S1a has no working cranes. The profile forming stations in S1a have rather flexible working cranes. However for transport in between both stations a transport crane is required. The drawback of having no working cranes is the dependency on transport cranes. Especially in S1a-L2 this is delicate. When assessing the current state layout map (close up presented in Figure 3.18) much crane activity is observed in this area.

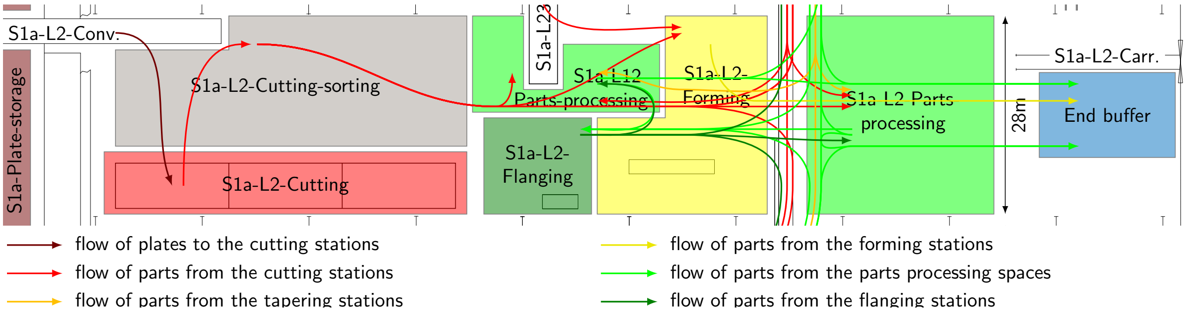


Figure 3.18: Close up - current state layout map DSGa pre-processing

Furthermore the distance between the in- and outfeed buffer and the forming machines/location is noteworthy, which is about 20m. This results in considerable transport of plates and movement of the workers. According to the Lean Manufacturing framework these type of distances are to be removed or drastically shortened. The transport distance is related to the size of the infeed buffer, which depends on the sequence of part cutting and the supply variability.

Setup time
The last notion concerns the setup times. In order to correctly shape the plates their shape is checked with moulds. Those are currently stored in a storage racks. Especially in S1a this storage is not located nearby. This induces significant operator movement to pick up and find the mould before forming can start. This is considered to be a waste type.

3.5. Grinding stations and part processing spaces

This Section is structured likewise the previous Sections. First the layout and flow are shortly dealt with. Then the waste existence is described.

3.5.1. Grinding stations and part processing spaces layout and flow description

The grinding workstations are marked as the green areas in Figure 3.2. S1a-L1-Grinding is dedicated to the grinding activities of the profiles. The part processing spaces are involved with grinding plate parts. Both are described subsequently.

Profile grinding stations
The profile grinding stations are involved with grinding edges, cutting over length and drilling holes in the formed profiles. Here the continuation of the flows described in Figures 3.5 and 3.15 are described. In both Figures the output flows are numbered in order to relate the flows. A general overview is presented in Figure 3.19. Flow 1 is processed in S1a-L1-Grinding-a. Flow 2 and 3 are processed in S1a-L1-Grinding-b.
When the parts arrive in the infeed buffer they are loaded onto the work benches for grinding by either crane or hand. Once processed they are sorted and packed for end buffers. The packaging space is indicated by the grey area in Figure 3.2. Due to the direct input output flow MFA presents a 1/1 relation. In Appendix D.2 the MFA is extended with transport distances.

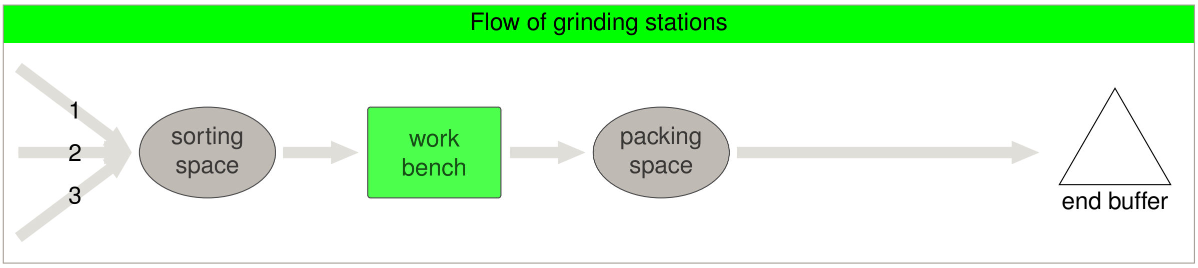
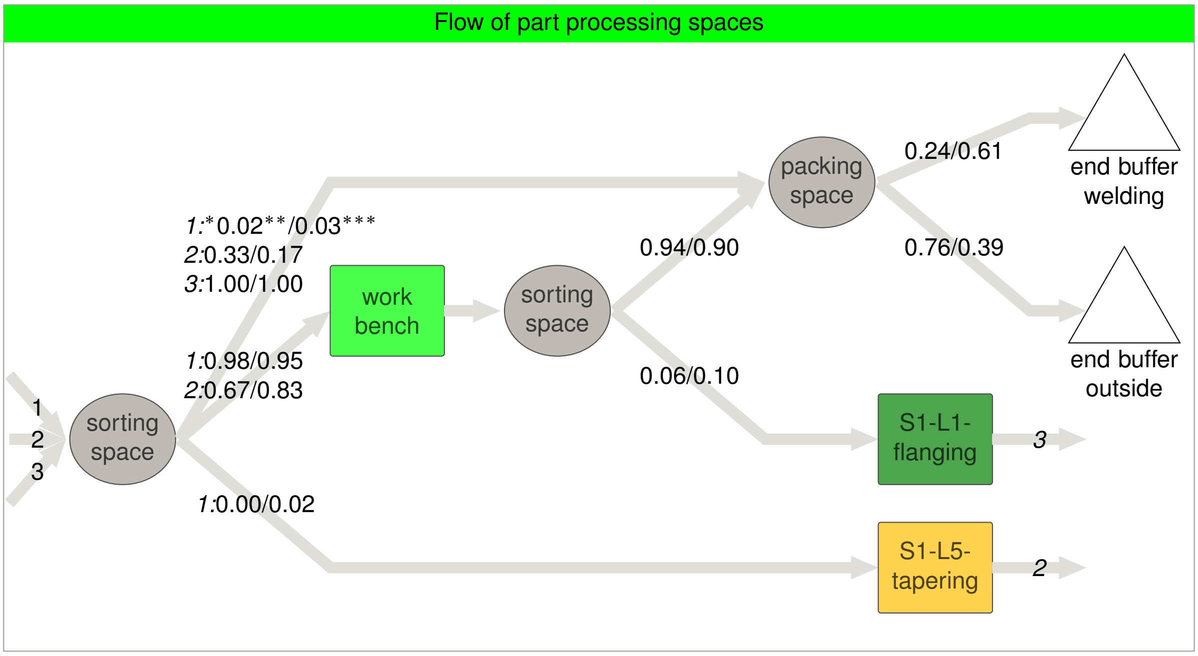


Figure 3.19: Flow of grinding stations, in Figure 3.2

Part processing spaces
All other grinding workstations are called part processing spaces as these areas are used for sub panel building and sorting for end buffers as well. Each part processing space is equipped with one or two small grinding belt machines. Furthermore hand held angle grind tools are present.

The six part processing spaces show a similar internal process. Once a container arrives the parts are sorted for tapering, end buffer and grinding. Three flows are distinguished:
- The to be tapered parts are first sent to the tapering station. This flow was already described in Section 3.3.1. Once processed and returned they follow the same procedure as the other parts.
- The parts for the yard workshops do not require-processing and are directly sorted for end buffers, which is indicated by a direct flow to the packing space (Figure 3.20). This is where the parts are repacked on different containers per end buffer.
- The parts which require grinding are put a work bench and grinded. Larger parts need to be turned so that the other side can be grinded as well. These sub processes are all included in the grinding work step (green box in Figure 3.20). In Appendix B these processes are described in more detail. There it is also explained in detail that the larger (>20kg) follow a slightly different path than the smaller (≤20kg) parts The grinded parts which require flanging are collected and jointly sent to the flanging station.



* entrance flow number, ** normalised number of parts, *** normalised cumulative part weight.

Figure 3.20: Flow of part processing spaces, in Figure 3.2

The sorting and packing spaces are physically the same space. On the packing space the parts are packed for end buffers or sub panels are assembled. Conform the scope of this study the sub panel assembly process is not specifically described. As the assembled sub panels are moved to the welding station the distinction between the welding station end buffer and ordinary end buffer location is made. A more detailed explanation is given in Appendix B.

The application of MFA is not straightforward at first sight. Some additional explanation is required. Three different flows arrive, chronological in time. Hence the MFA shows three results. The external logistics are different so other combinations of cranes and carriages are required. In Figure D.9 those are specifically addressed.

1. This flow originates from the cutting sorting spaces as outlined in Figure 3.7. It contains all parts except for the to be formed parts, main panel plates, and thick parts. In Figure 3.20 it is indicated by the entrance flow number, namely an italic ‘1’.
2. This flow originates from the tapering station and is indicated in Figures 3.13 and 3.20 by entrance number ‘2’. Once this flow is arrived the parts are sorted for end buffer and grinding.
3. The third flow which arrives at the parts processing space is the flow which originates from the flanging station. This flow is indicated by entrance number ‘3’. Those parts are already grinded and are directly ‘moved’ to the packing space.

3.5.2. Parts processing spaces waste analysis

Concerning the waste analysis four notions are made: part entrance process, individual grinding process, sorting for end buffers and profiles cut from plate.

Parts entrance process

When the containers with parts arrive from the cutting stations they are unpacked. The parts are either stored on a stack on the ground (large) (Figure 3.21a) or stored on pallets (small) (Figure 3.21b). The pallets are transported to the small grinding stations.

All this additional transport is a waste. It is supported by the absence of dedicated cranes. Especially in S1a request clashes with other cranes can take place, when trying to move filled containers to or from the parts processing spaces, which will induce waiting. These operations are an over-processing type of waste because it are redundant operations.

(b) Pallets with small parts moved to small grinding station

(a) Unpacking arrived containers

(c) Parts for sub panel assembly stored after grinding

Figure 3.21: Impression inventory waste part processing spaces

Individual grinding process

Over processing or defects waste are likely to occur. Grinding is required to prepare the parts for painting. Hence only the edges which are covered by paint require grinding (radius of 2mm). Within the current process there are no clear standards/measurements to enhance this radius. Consequently over processing waste occurs when the edge is grinded more. Defects waste would involve a grinded radius under 2mm, causing problems later in the process. These types of waste are likely when working with hand held angle grinders.

For a vast number of parts it is clear which edges need to be grinded. However for other parts this might not be clear. Hence defects of over processing can occur as well. This effect results from the absence of part information.

The waiting waste has been defined as follows: Delays between operations because parts are missing, stopped work, waiting for parts, machines or people. Whether this occurs has to be pointed out by quantitative analysis. The opposite of waiting is building up inventory as denoted in Section 3.2.2, which definitely takes place. An example is presented in Figure 3.21.

After grinding the parts are sorted for end buffers. When the parts are for sub panel assembly they are either stored on the work benches (large parts) or on the shop floor (small parts). Clearly unnecessary transport or inventory is recognised. The parts wait at those locations before being assembled. In order to find the correct parts they are put on the shop floor Figure 3.21c, which clearly is a non value adding activity.

Sorting for end buffers

Sorting for end buffers is a value adding activity (Section 2.2.2). However the fact that sorting for end buffers takes place in the parts processing spaces first is not entirely logic. The parts for the yard workshops do not require grinding and could have been separated from the flow directly after the cutting machine. As this is not done these parts are unnecessarily transported, contributing to a transport waste. This notion could be extended for the other end buffers, creating actually only one sorting moment instead of several.

Profiles cut from plate

In the current situation flat bar profiles are cut from plate instead of plate, because it is cheaper material wise. The drawback is that more grinding is required. Another reason to cut profiles for raw profiles is that the profile line logistic flow is more direct since the profiles are directly put on workbenches, grinded and sorted for end buffers. Consequently less waste occurs therein.

3.6. Flanging stations

The last process step which is described in the flanging process. The layout and flow are described in Section 3.6.1. Subsequently the waste analysis is described.

3.6.1. Flanging stations layout description

Both S1 and S1a have a flanging department, indicated by the dark green areas in Figure 3.2. The flanging department mainly consists out of a in- and out-feed buffer and a brake press.

(a) Flanging station S1-L1

(b) Flanging station S1a-L2

Figure 3.22: Flanging station photos

The in- and output flows of the two flanging stations are straightforward as all parts originate from and move to the part processing spaces. In S1 this is done on containers and/or pallets. In S1a the large parts are moved one by one and the small parts are moved on a pallet by a forklift. As a result of this the MFA is simple as there is a direct input output relation. The general flow of both stations is presented in Figure 3.23. Detailed flows, including transport distances, are included in Figure D.10.

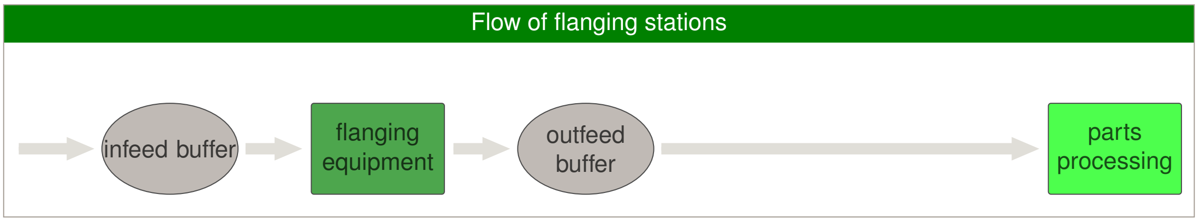


Figure 3.23: Flow of flanging stations, in Figure 3.2

3.6.2. Flanging station waste analysis

First the transport to and from the flanging station is described. Then the role of working cranes is discussed. Last the internal process is valued.

Transport to/from flanging station

Figure D.10 underlines the impact on transport distances, either by crane, carriage or fork truck. Hence a considerable transport waste is recognised here. After flanging the parts are moved back to the part processing areas for sorting for end buffers and sub panel building. Here the transport waste is recognised again as the same route is followed back the part processing spaces.

Transport- or working cranes

Likewise for the forming station also the flanging station makes uses of cranes to load the parts onto the brake press. Although the relative number of part which require crane handling is much smaller the absolute number of parts is not necessarily smaller. Such flanging has about the same crane requirement.

In S1 is the flanging station has a dedicated transport crane as working crane. Since the flanging station is located in the corner of the facility shed interference with other working cranes is not likely. Concerning S1a, less flows interfere with the flanging station. Consequently the notion made for the forming station is less stringent for the flanging station. Moreover flexibility is enabled as the flanging also processes smaller parts, which do not require crane handling. Hence the waiting type of waste due to crane requirement is not very likely.

Internal process

The parts arrive from the parts processing spaces in batches, in S1 and partly also in S1a. The parts below the 20kg are directly picked up from the pallet, put on the brake press and put back on a second pallet. This is an efficient process from movement and transport point of view.

Contrary the larger parts are offloaded from the container onto the space. When the container is offloaded the parts are picked up from the space, flanged and put back onto the container. This process is subjected to transport when putting the parts onto the space. This involves movement of the workers as well. When emptying the container the inventory waste surfaces. Furthermore more area is required to execute the process and the cranes are occupied.

3.7. End buffers

To provide a coherent layout description in this Section the position of the end buffers on the layout map is further described. The blue areas in Figure 3.2 indicate the positions of the end buffers. The end buffers are spaces were the pre-processed parts are stored before being used in the subsequent process steps. The end buffers match with the customers as defined in Figure 1.2. A detailed overview of the different end buffer usages is given in Appendix B and Appendix C.

Because the end buffers are not subjected to a work step no flow or waste are described. The size of the end buffers is depended on ‘to’ and ‘from’ processes. As no value creation is involved the end buffer sizes should be reduced as much as possible.

3.8. Transport facilities

The last described layout related topic is the transport facilities. In the Figure below, Figure 3.24, an overview of the portals per crane lane is provided, by the yellow bars. A detailed overview is provided in the process model descriptions. Besides the carriages (transverse lane) and conveyors (in lane) are indicated, by the grey colours. The orange colours indicate the number of carriages per carriage track.

Crane and carriage usage is particularly susceptible for the waiting waste when they are operate on the same rail. Hence probably much waiting waste will occur. In Figure 3.25 the flows, which are described in Section 3.1 to Section 3.6, are drawn on the layout map. It underlines the transport distance and thus crane requirement and clashes. The construction of Figure 3.25 proved to be a proper means of communication in order to validate and generate feedback on the flow descriptions.

3.9. Key Performance Indicator definition

Subsequent to drawing the current state map process inefficiencies need to be reviewed (VSM approach). The waste analysis is already performed. Here the ratio between value-added and non-value-added is determined by means of the KPI’s, conform the definition in Section 2.3.4. The KPI’s enable comparison of the current state with future states. In this Chapter the approach discussed in Section 2.3.5 is followed. First, in Section 3.9.1, KPI_1 and KPI_2 are defined. Second the transport related KPI’s are defined in Section 3.9.2.

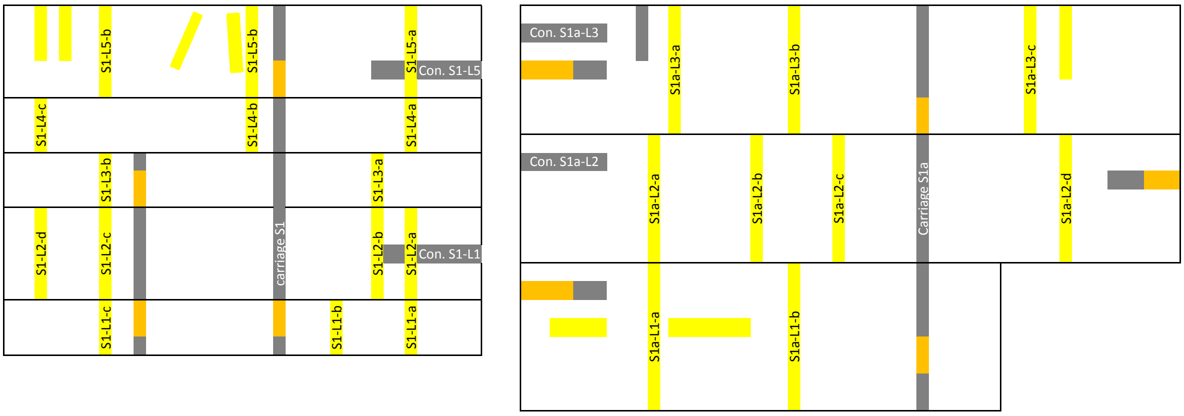


Figure 3.24: Overview number of cranes per lane, conveyor and carriages, left S1, right S1a

3.9.1. Analysis of space requirement

The first KPI's concern space utilisation. KPI_1 is defined as the total available area for executing pre-processing activities, since that is the area which enables a feasible solution, independently from the questions whether the space is actually used or not.

$$KPI_1 = Area_{total} = 12840\ [m^2]$$

A detailed composition of the area is discussed in Appendix D.6 in Table D.3. About 15% is related to the pre-processing profiles. Furthermore, the space utilisation of S1 and S1a (plates) are approximately equal. About 25% of the space (S1 and S1a) is used for sorting after cutting.

The total area is divided in process area, infeed and outfeed, indicating what area is used for value adding processes and what not. This information is captured in KPI defined below. From all DSGa pre-processing area 22% is used for value adding processes.

$$KPI_2 = \frac{\text{Process space}}{\text{In/outfeed space}} = 22\ [\%]$$

The result is obtained by determining the area in which value added processes are executed. For cutting this mainly equals the cutting bed sizes. For tapering and grinding this is equal to the workbench area, including some movement space. For forming and flanging it equals the press work spaces mainly. No specific separation between infeed and outfeed buffers is made. Because only the cutting work stations would have a dictated infeed/outfeed buffer separation.

For the plate cutting and grinding work stations this implies that over 40 plates can be put on the ground next to each other, which is nearly an entire cutting group. This result is obtained by dividing the in/outfeed space by the possible plate area ($36m^2$). This is inline with the inventory waste defined in Section 3.2.2. Working on cutting group or section level requires much space.

Both KPI's capture the total available area. The question remains whether this area is actually used. According to Steinhauer [75] and Nedess et al. [57] mathematically checking the utilisation of a space is not straightforward, because the circumferential size of the (to be) placed objects needs to be considered as well. Whether enough space is available could be checked by means of monitoring the 'still to be placed' requests. However this approach does not provide information about how much space is utilised if enough space is available. Not enough space being available manifests itself in waiting queues. The waiting effect is incorporated in the throughput analysis, in Chapter 5.

3.9.2. Analysis of transport

By accumulating the multiplication of the MFA results and the related transport distances it is determined what percentage of the entire flow 'travels' which distance. The transport distances are included

Figure 3.25: Current state layout map DSGa pre-processing

in the detailed MFA diagrams which are included in Appendix D.2. The KPI is defined as the mean transport distance per part, in the unit of 'number of parts' and 'cumulative weight', as described in Section 2.3.4. Besides the transport distances also the number of transports can be derived, which is included in KPI_4. The transport distance/moves average is considered because some flows can follow several possibilities.

$$\mathrm{KPI}_3 = \text{Mean transport distance} = \bar{s} \text{ for } \begin{cases} \text{Number} \\ \text{Weight} \end{cases}$$

$$\mathrm{KPI}_4 = \text{Mean number of transport moves} = \bar{n} \text{ for } \begin{cases} \text{Number} \\ \text{Weight} \end{cases}$$

First all individual contributions are derived. For the profile related flows this is rather straightforward as they are no parallel processes involved. For cutting thick plate this is more delicate because the cut parts are processed in either S1 or S1a. For thin plates the definition is even more delicate since there are three different cutting stations supplying three different parts processing spaces. The combination determines what the final transport distance is. This applies to a smaller extend to the to be formed and main panel parts. The internal transport distance of the part processing space is taken the same everywhere, which is reasonable because all part processing spaces have a stretched area.

In Figure 3.26 the flow contributions based on part number are plot. The different green, yellow and red data points indicate parallel processes. The purple (thick parts) and light blue (main panels/formed parts) appear three times, related to the three cutting stations. The flow contributions based on cumulative weight are plot in Figure D.25 and show the same behaviour.

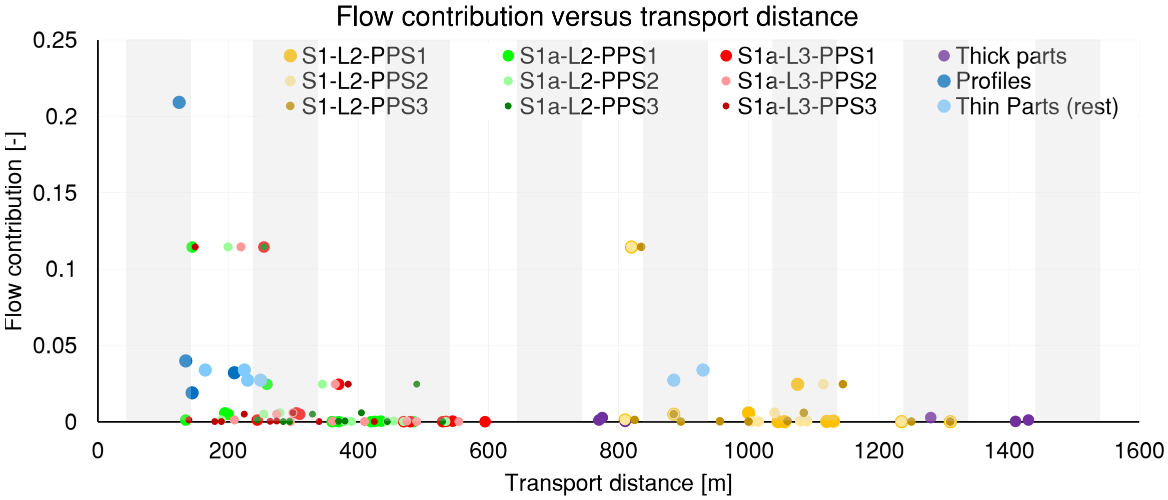


Figure 3.26: Flow contribution per distance transported, based on normalised number of parts

The transport distance between S1 and S1a is clearly observed. The green and red data points, expressing the plate flows origination from cutting stations S1a-L2 and S1a-L3, indicate a much shorter transport distance, compared to the yellow data points.
The left set of purple data points expresses the flows of thick parts which are processed in S1. When the thick parts are processed in S1a the transport distance between S1 and S1a is counted twice, further increasing the transport distance.
Due to flow variations, induced by the different cutting stations and part processing spaces, for a single y-value different x-values are plot. This is recognised in Figure 3.26.

This approach is valuable when investigating the mutual locations of the different stations. For being complete some disclaimers need to be made: First, The transport distances are determined on a 5m precision. For inter workstation transport this is sufficient. However for internal transport a higher precision might be required. This mainly implies for the part processing spaces.
Secondly, when several flow possibilities (part processing spaces) are available the average is considered. Hence the result might be slightly deviated since in reality 'preference selection' can be done. It is expected that the deviation is small since some part processing space are symmetrical. Furthermore variations in- and output flows can balance each other.
Thirdly, the implication of a specific distance travelled is enhanced by the time it takes. Especially for the longer distances more transfer points are occurring, since these are more susceptible for waiting times, due to resource availability. Hence the number transports is considered as well.

The detailed MFA diagrams clearly distinguish all different transport executions. The KPI_4 is derived similarly to KPI_3. The result is plot in Figure 3.27. Again the contribution of the transport between S1 and S1a can be observed. Concerning the part processing space processes mainly the smaller flow contributions (flows including tapering or flanging) are subjected to more transport moves.

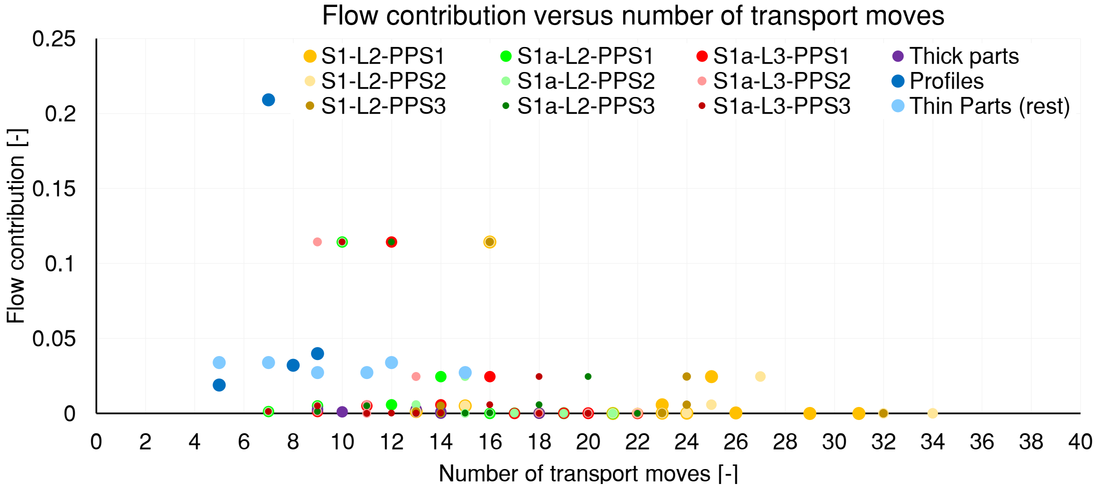


Figure 3.27: Flow contribution per number of transports, based on normalised number of parts

Figure 3.26 clearly shows a non standard distributed data set. Due to this only the average is incorporated in the transport analysis KPI [32]. KPI_3 is defined below. Since influence of the distance between S1a and S1 is significant, they are also determined with exclusion of this transport. Both results are presented below, respectively.

$$KPI_{3,number} = 344 \text{ [m]} / 195 \text{ [m]}$$

$$KPI_{3,weight} = 482 \text{ [m]} / 254 \text{ [m]}$$

In conclusion, most of the parts travel at least three times the facility shed length, which is indicated by the grey bars in Figure 3.26. The transport between S1 and S1a clearly surfaces. Furthermore KPI_4 is defined.

$$KPI_{4,number} = 19.4 \text{ [-]} / 18.5 \text{ [-]}$$

$$KPI_{4,weight} = 20.7 \text{ [-]} / 19.3 \text{ [-]}$$

The parts are significantly tranported. For each transfer loading, positioning and discharge time is required, which contributes to the throughput time. The batch size has an effect on the occurrence. For that reason specific attention is paid to the individual part processes in the next Chapter.
The number of necessary-non-value adding transport moves depends on the routine and is in the order of 5 moves. Conclusively 70% of the transports are non value adding.

3.10. Scoping

The flow and waste analysis supports the construction of a simulation model by investigating what the model should in- or exclude. Modelling is an extensive task, which not only requires the resources for the data collection and process model description but also the modelling itself. Two parts are excluded from the analysis, namely the thick parts and profile flow.

The thick parts flow is excluded of the analysis since its contribution is small, namely less than 1% number wise and less than 0.5% weight wise. Furthermore its process is hardly intertwined with the other processes since cutting takes place in a dedicated cutting station.

The profile parts are excluded from the modelling since this process does not show significant inefficiencies at first. Moreover a direct input-output relation is present between the work steps, which simplifies the shared resource issue. Since the profile cutting station is located in lane 1 of S1a no interaction with the plate pre-processing part in S1a is observed apart form the carriage. Last but not least a capacity lack concerning the construction of the process model description and the modelling is present on the Damen side.

Hence the main focus will be on plate pre-processing part, which account for 90% of the annual throughput and most of the inefficiencies. In the next Chapter the construction of the simulation model is discussed.

3.11. Summary

The following research question has been addressed in Chapter 2 and Chapter 3: *How can the performance of the current pre-processing process be described by means of the static Value Stream Mapping approach?*
To provide insight in the DSGa pre-processing process and the belonging facilities a layout description is given in this Chapter. Several work stations are described, namely: cutting, tapering, forming, grinding and flanging. For each the available equipment is described.

In the previous Chapter it is proposed to use Material Flow Analysis (MFA) to describe the different flows through the different work stations. In this Chapter flow diagrams are constructed to provide insight. MFA indicators where connected to the flow diagrams, namely the normalised number of parts and the normalised cumulative weight. Furthermore the distances over which the parts are transported are presented. All flows are summarised and illustrated in the layout map. This is included in Figure 3.25. This last step proved to be a proper means of communication in order to validate and generate feedback on the flow descriptions.

Besides a qualitative waste analysis is executed. The main point which is observed in this Chapter concerns the effect of cutting in cutting groups and all parts of one section at once. It results in a large material explosion after cutting, creation of large part batches and much handling and sorting. This results in much inventory, waiting and transport waste, in all work stations. Because the batches are repacked and sorted several times these waste types become really apparent.

The large cutting batches and supply variability are a result of improper nesting. Furthermore the nest files lack information for signing and processing. Hence signing has to be done manual and cutting machine functionalities are unused. Besides no direct information is available about grinding edges and flanging geometries. Due to this imprecise processing is observed at the part processing spaces. This enhances the risk of over processing or defects waste.

Furthermore imprecise processing is observed at the forming stations due to using an inefficient combination of forming techniques. This enhances the risk of defects waste. Due to the absence of dedicated cranes the waiting waste is observed.

Last this Chapter obtains the space utilisation related design KPI's which are defined in the previous Chapter. For the determination of the space utilisation the layout description is used. Only about 22% of the space is used for value adding processes. The MFA analysis is used for the determination of the transport distance and number of transports. On average all parts travel about twice the facility length. On average each part is transported about 20 times, either by hand, crane, carriage or conveyor, from which about 5 times is necessary-non-value-adding.
Frankly, this Chapter underlines the effect of the layout, by its size and positioning of workstations. This induces significant transport waste. This is strongly related to building up inventories all over the facility. Furthermore it has an effect on transport crane requirement.

4

Simulation model definition

In Chapter 2 valuation indicators are defined for the determination of the ratio between value-added and non-value-added processes and comparison between current state models and future state models.
By means of static layout description and MFA analysis KPI_1 to KPI_4 are determined in the previous Chapter. The time related KPI's (KPI_5 to KPI_9) cannot be assessed likewise since the regular VSM approach limits when implementing complex routines due to the absence of a clear main flow and shared resources. For this reason Section 2.3.5 proposed the construction and analysis of a discrete event simulation model. Such the second research question is addressed:
What is the quantitative performance of the current pre-processing process obtained by means of dynamic simulation analysis?

The contribution of this Chapter is the description of the discrete event simulation model construction. The model objective is defined in Section 4.1. In Section 4.2 the model definition is described, including model inputs, boundaries and expected behaviour. Section 4.3 and Section 4.4 provide the verification and validation assessment respectively. In Chapter 5 the model is analysed to obtain the KPI's.

4.1. Model objective

Simulation can be used for operational and strategic support (Section 1.1.4). For this study a strategic case is defined, which has implication on the level of detail incorporated in the data collection and model programming. The simulation model has to obtain the time related KPI's. The first objective of the KPI's is to quantify the waste analysis performed in Chapter 3. Based on the KPI's measures of inventory and waiting time are obtained. The second objective is to enable comparison of the current state with future states.
Hence the objective of the simulation model is:
Providing insight in the effect of dynamic, dependent resources on throughput and resource utilisation, to quantify waste in the DSGa pre-processing process and enable comparison between current and future states by obtaining KPI results.

In Section 2.3.4 several KPI's are defined. KPI_5 concerns the part throughput by capturing the average time all parts are 'in the process'. The waste therein is quantified by obtaining the relation for pure value adding activities as well.
KPI_6 captures the ability of the system to meet annual capacities. This KPI is assessed already when discussing the 'rear-end' validation in Section 4.4.
KPI_7 and KPI_8 capture whether the work stations have a levelled throughput. It includes the in/outfeed buffer loading. The first concerns a measure of the number of days being idle. The latter concerns a measure of the variability when being occupied. Both KPI's are related to inventory and waiting wastes since being unlevelled induces either of the wastes.
KPI_9 concerns the resource utilisation measures and distinguishes the ratio between utilised time and the total time. It addresses the waiting waste types.

Hence the routines need to be carefully modelled. For the transportation the use of different transportation means are of importance, namely, cranes/carriages/conveyors and containers/pallets/bundles. A lot of the inventory and waiting result from the batch sizes, which therefore require particular emphasis. For the identification of the waiting of waste interaction between the different equipment, like cutting beds and cranes, is essential.
The objective of the model is not primarily to check the productivity of the organisational performance. Hence there is no specific focus on the utilisation of the workers, as far as they are not the bottleneck. The variations in shifts and work calenders are not considered, because of the strategic goal.

4.2. Model construction

First the input data and model boundaries are described in Section 4.2.1 and Section 4.2.2 respectively. Then an overview of the model is given and the model behaviour is discussed.

4.2.1. Input data definition

Figure 4.1 provides an overview of the input data types required and collected for the construction for a discrete even simulation model [75, 76]. The software data requirement is an advantage and disadvantage simultaneously. Positive is that the numerous data input into the simulation model increases the level of reflecting the reality. However this implies that the conformity of the model is significantly captured in proper input data. Hence this detailed requirement is a disadvantage as well. In order to serve the purpose of this study the 80/20 rule is applied. This entails that 80% of the possible procedures, rationale or habits is incorporated. This is conform the Lean Manufacturing VSM objective as described in Chapter 2.

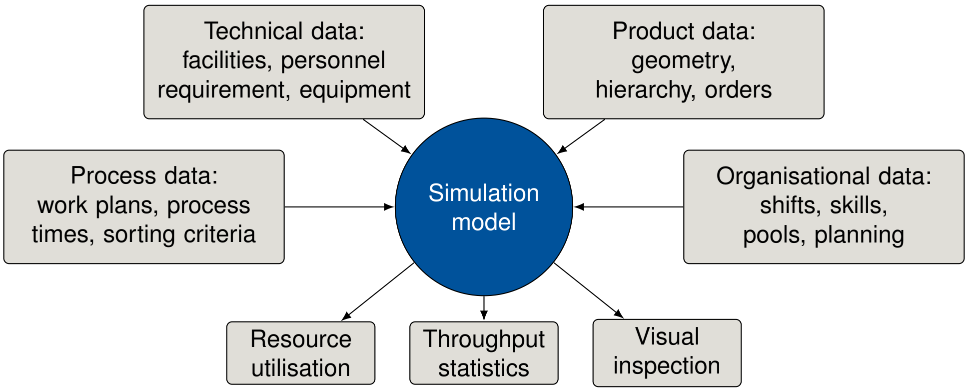


Figure 4.1: Simulation model input data [76]

For the purpose of this study the current situation is jointly described within Damen. The technical and process data are already introduced in Chapter 3. The entire ‘process model descriptions’ are documented and included in Appendix B and Appendix C. They are reviewed by Damen employees which are involved in the process. This is further described in Section 4.4. First the model boundaries are discussed.

4.2.2. Boundary description

Within the simulation model the front-end boundary is easily considered by modelling the shop primer facility as a single source. A push approach mitigates induced waiting times.
The end buffers are the interface between the pre-processing and assembly processes. Such they are the rear-boundaries. As their positions are known the approach is straightforward. Whether the pre-processing process can store parts in the end buffer depends on the available capacity, which is affected by the assembly processes as well. Within the model this capacity is assumed to be enough, which is reasonable because the reserved spaces are large.

The main difficulty is in the part processing spaces because the sub panel assembly is included in that as well. This process has an implication on the crane requirement and the duration. Due to the interaction both processes cannot easily be replaced by some correction factors. For this reason it is not considered. This also applies for the other crane handling.

Consequently the part processing spaces are occupied less than in reality. As a result more sections can be pre-processed in a shorter period of time, which has an effect on the intermediate buffer. Hence the inventory waste type is defined too positive. Since there is no accurate information available about the sub panel assembly durations no proper estimation of the 'error' can be made.

The combination of the grinding work step and the sub panel assembly also has an effect on the deployed workforce. In the model the entire work force is still deployed. For the purpose of grinding only this is too much. Therefore it will reasonably not become a bottleneck. In essence it is straightforwardly solveable, by reducing the number of workers. No stringent consequences for the man hour determination surfaces as for that the pre-processing and sub panel assembly hours are separated.

4.2.3. Model overview

Several sub models are programmed and combined in a master model. The S1 model is programmed by Kees van Ekeren, the author of this study. The plate related parts of the S1a model is programmed by Timo Kreule. In Figures 4.2 and 4.3 overview Figures are provided of both models.

The layout as described in Chapter 3 is clearly recognised. Also the positions and orientations of the cutting machines and presses are presented.

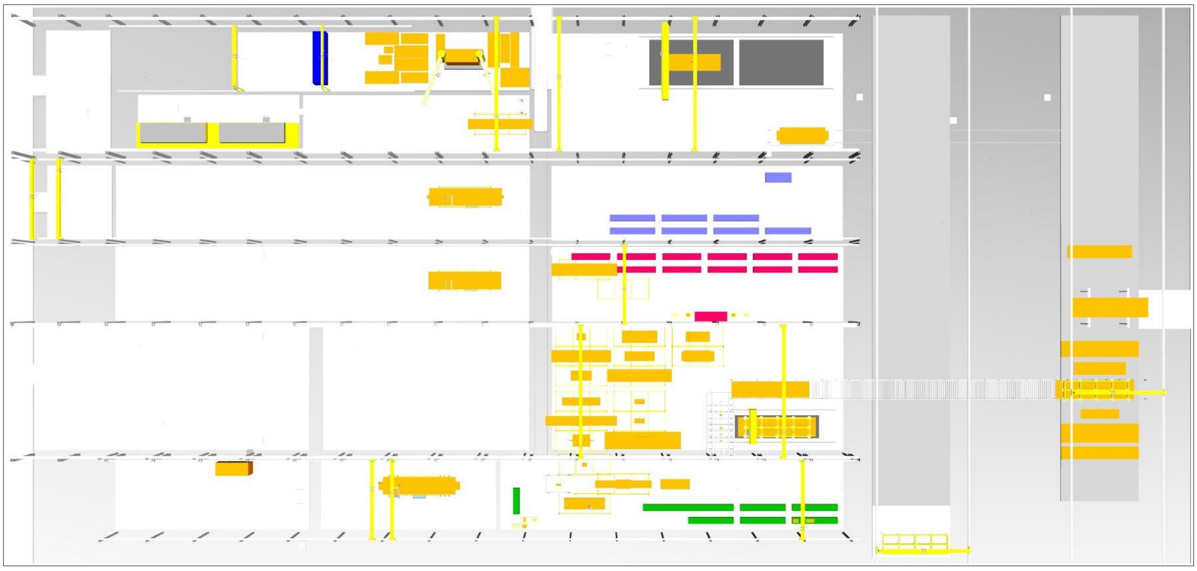


Figure 4.2: Preview model S1

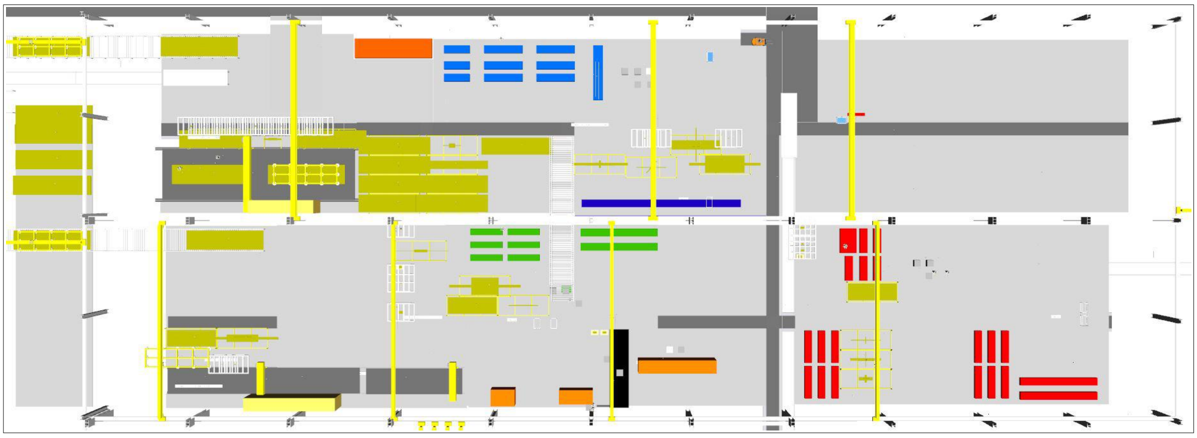


Figure 4.3: Preview model S1a

4.2.4. Deterministic model property and simulation runs definition

For appropriate use of the model it is essential to understand its behaviour [71]. Globally two model types exist, namely deterministic and stochastic models [68]. A deterministic model always produces the same output from a given starting condition or initial state. Contrary stochastic simulation, which includes random variables, does not provide this relation. Hence for stochastic simulation a number of simulation runs are required for each starting condition to provide a stable output. Hence for the constructed discrete event simulation model the behaviour is determined to determine the number of simulation runs required to provide a stable output.

Random distributions are mainly used to approximate resource failures and unforeseen daily events [75]. For each equipment the failure rate can be included, based on statistic distributions. Including much randomness complicates distinguishing whether an observation is a result of system interrelationships or randomness [71].

In the DSGa pre-processing simulation model no random variables are included, conform the model objective, resulting in a deterministic model. Furthermore no internal random assignments of cutting groups and sections are applied or random variations of process times. Hence the effect of interrelationships is less ambiguous. This does not imply that the input data cannot be random. Since a deterministic model can have different starting conditions.

Apparently those are random, since the sequence of cutting the cutting groups and the assignments of sections to processing spaces is random. Hence a number of runs is required to generate a stable data set. It is expected that only a limited number of runs is convenient since only 9 (2 for ASD, 7 for PSV) different cutting groups are cut. Furthermore there are only 3 different part processing spaces, from which several are more or less symmetric. For future states this has to be reconsidered.

The number of replications (N) determines the width of the confidence intervals (reduces variance). The limiting factors are be computing time and expense [66]. However, performing fewer than N replications could lead to inaccurate results and thus to incorrect decisions being made.

In literature three main methods are found in literature for choosing N: Rule of Thumb, a simple Graphical Method and the Confidence Interval (with Specified Precision) Method [67]. The Rule of Thumb actually states that relying on one run is unwise and recommends to run at least 3 to 5 times [66]. Whether it is adequate depends on the individual models.

In the simple Graphical Method a user carries out a series of replications and plots the cumulative mean of a chosen output variable against N (the number of replications). The user can then visually select the point on the graph where the cumulative mean line becomes ‘flat’ and use this as the number of replications. This method has the advantage of being simple to understand and perform, as well as utilising the output of interest in the decision made [67].

The Confidence Interval (with Specified Precision) Method interval increases the number of runs until the confidence intervals are within the user specified precision. The simplest method is to stop as soon as the stopping criteria is first found to be less than or equal to the user defined desired precision, and to recommend that number of replications to the user [67]. In order to asses premature convergence Robinson [67] advises to run at least five additional runs.

Within this study the first and second method are applied to assess the variations of the model inputs. In Section 4.4.2 this is further elaborated on.

4.3. Model verification

To enhance the conformity of the software model with the process model descriptions verification takes place. First the verification process is described, followed by a test plan explanation.

4.3.1. Verification process description

Verification is 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. It is a static practice of verifying documents, design, code and program. [71, 81] Hence the correct bridge between the process model description and the software model is enhanced by model verification. This link is illustrated in Figure 4.4.

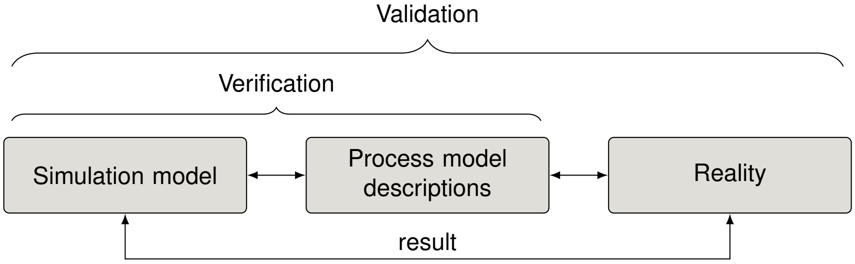


Figure 4.4: Verification and validation process

Verification is possible by walk through and inspection/review [76, 81]. Walk through entails guiding participants through the document to achieve a common understanding and to gather feedback. It is particularly useful for the people if they are not from the software discipline, who are not used to or cannot easily understand software development process. This step is executed in close cooperation with the people from the Damen Yard Support department.

Inspection/review entails the examination of code and fixing any defects in it. In a code review, a defect is a block of code which does not properly implement its requirements. This step is executed in close cooperation with Timo Kreule and Dirk Steinhauer on a regular basis. In the next Section the definition and execution of a test plan is defined, which is followed during the regular meetings.

4.3.2. Test plan definition

Several model aspects require specific emphasis due to their case specifics and programming assumptions. These events have a particular influence on the objective of the simulation model. They are listed in a test plan, which is incorporated in Appendix E.

1. Sequentiality of loading and unloading (FIFO, LIFO or with priority)
2. Change overtime implementation
3. Worker dependency
4. Maximum capacities
5. Different processes for small and large parts
6. Different means of transportation
7. Bundling of parts or containers

In order to verify the simulation model several test procedures are presented, from which a short description is given below. They are inline with the proposes walk through and inspection/review approach. Each test is executed from which prove is included in Appendix E. Whenever the test failed at first the model is adapted until it meets the process model descriptions. The completion of the test plan test provides a proper model verification since the reflection of the process model description and simulation model is found.

1. Sample test: checks a random number of parts and verifies sorting criteria and batch definitions.
2. Cumulative number test: checks the total numbers and compares it with the input data. It is used to support the sample tests.
3. Track and trace test: follows individual parts to check whether the flow is conform requirements.
4. New call chain analysis: checks the sequence of executing rules and processes and is mainly used for follow up processes.
5. Visual inspection: verifies the expected behaviour by assessing the graphics. This test is appropriate for checking the transportation means.
6. Block settings and trace functionality test: verifies the dependency on resources and settings. It is useful for checking the programming of worker, carriage and crane requirements.

4.4. Model validation

In order to ensure the link between the software model and the reality validation is required. First the approach is described. In Section 4.4.2 the model behaviour is studied in order to provide stable validation tests results. The results are presented in Section 4.4.3 and Section 4.4.4

4.4.1. Front-end and rear-end validation

Validation is the process of evaluating the final product to check whether the software meets the customer expectations and requirements. Front-end and rear-end validation are recognised (Figure 4.4). On the front-end the process model descriptions are valued/discussed by the process owners, which is performed by the Damen yard support department and pre-processing foremen. Both parties have the authority to know the process. Therefore this validation step is appropriate. This step is executed in the initial phase of the model construction process. Whenever additional insight was gained the process model descriptions were updated and software model modifications implemented.

On the rear-end the modelled performance of the yard is compared to the real performance. This is done on a more global level. Detailed validation is delicate because the yard does currently not monitor the yard performance on a detailed level. Two measures are considered: man hour registration and annual throughput. Man hour registration enables validation of the process and logistics durations.
Man hour registration for cutting is available on cutting group level (plasma cutting) or ship level (oxy acetylene cutting). Tapering is not registered at all, since it is controlled by the grinding foremen. Hours for forming and flanging are written on ship or cutting group level. Grinding is registered on section level and is separated from sub panel assembly. Data of several vessels is available. The average is considered, because significant spread is observed between the different projects per vessel type.
Based on the simulation model man hours can be derived as well. Only the active time is considered. The worker waiting time is not included. When writing them per ship, cutting group or section comparison with the real situation data is enabled. The results are presented in Section 4.4.3. Furthermore the simulation model yard capacity and the real world can be compared. Appropriate measures for this are the number of ships and processed tons. The results are presented in Section 4.4.4.

4.4.2. Simulation result definition

In Section 4.2.4 the deterministic model behaviour is discussed. Based on the input data randomness several simulation runs are required to generate a simulation output data set whose occurrence is likely and stable. Randomness is introduced by the sequence of cutting different cutting groups and processing sections. For the latter attention is paid to a levelled assignment since it is not realistic that multiple part processing spaces are waiting whilst the other has a queue of several sections.
Conform the portfolio defined in Section 2.3.1 12 tugs and 6 PSV's are included in the portfolio. In each cutting station (S1-L2, S1a-L2 and S1a-L3) both vessel types are cut. The cutting group planning is determined by a push approach, due to cutting group size variation. On a lower level it is assumed that in S1 and S1a the ratio between tugs and PSV's is the same. The cutting group distribution over S1 and S1a is based on the available man hour distribution, which is in the order of 30-40/60-70 percent for S1 and S1a respectively. Because the annual constraint is met the deviations might only concern monthly differences.
The occupation build up is shown in Figure 4.5. The implication is that about 5% of the parts and about two weeks are not considered. The moment is indicated by the black vertical line in Figure 4.5. The cutting process starts almost directly. After the cutting group is finished at least all part processing spaces are deployed. Whether the flanging or forming station are deployed depends on the section types. For this reason they are being idle from that moment, establishing the assumption. In order to obtain annual measures those two weeks are extrapolated.
The simulation run lasts one year. One year is approximately equal to the time to process all parts of the given input batch. Additional vessels are included in the input data set to prevent occupation reduction at the end of the year.

Multiple simulation runs are executed, from which for each the cumulative mean and standard deviation of the entire process duration and all parts is derived. They are normalised on the cumulative average of 10 runs. They are plotted with a 99% confidence interval.

Using the Rule of Thumb method to determine the number of simulation runs for the current state simulation model 5 runs show an accurate mean. This result could also have been determined with the simple Graphical Method or the Confidence Interval (with Specified Precision) Method. The specified precision could than be within a 0.1%, which is acceptable small. In retrospect deriving only 5 simulation runs would suffice.

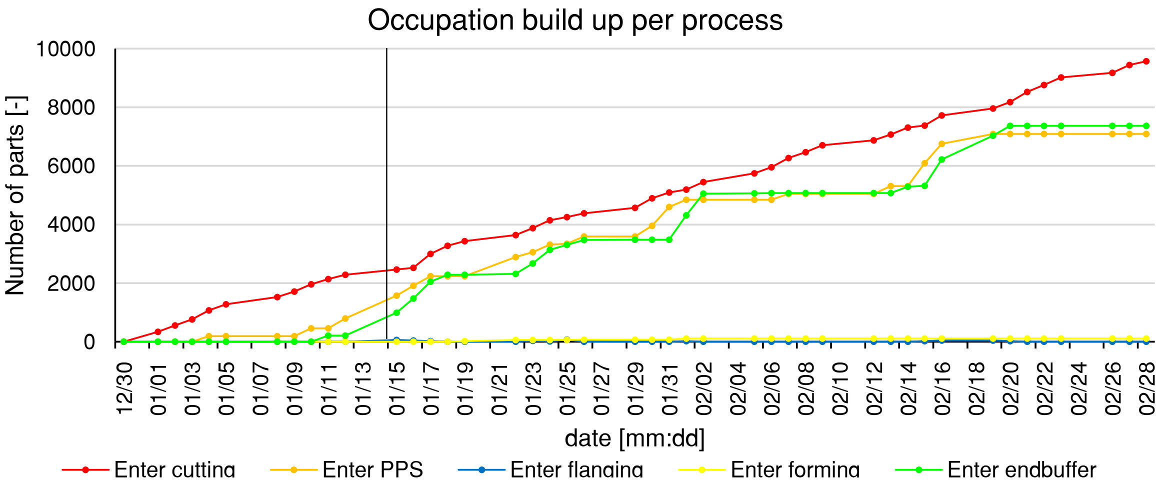


Figure 4.5: Occupation build up per process

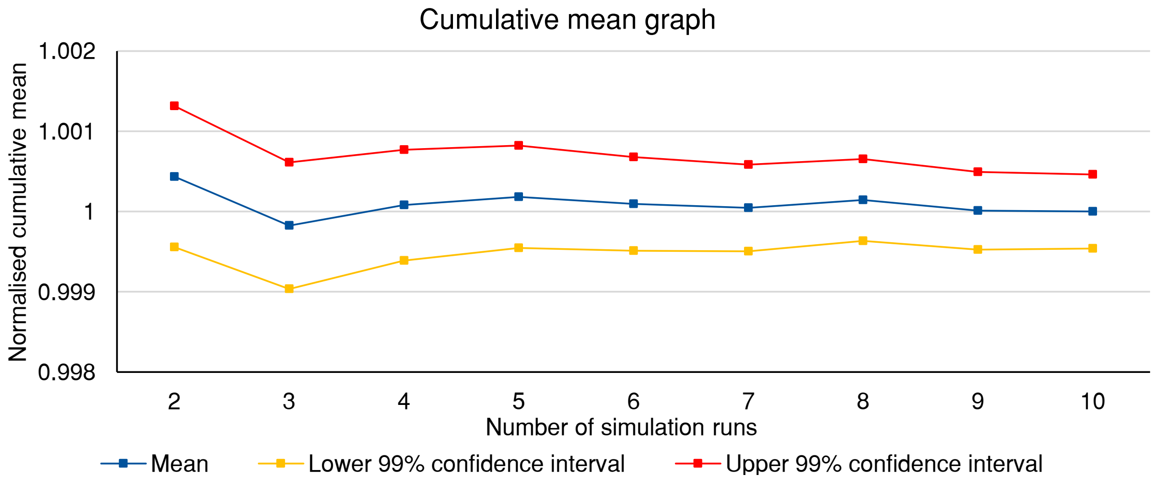


Figure 4.6: Plot of cumulative mean and 99% confidence lower and upper limit

This phenomena is explained by the deterministic character of the model, enhanced by the definition of the input data, which is build up from only 2 ships and 9 unique cutting groups only. Most likely only the interaction between the different batches has a varying influence on the processing times.

Since the 10 simulation runs results are available now, these are used for definition of KPI_5 to KPI_9 in Chapter 5. Due to the averaging the specific cutting group related phenomena will disappear. For that reason single run results are assessed as well. First the model validation results are presented.

4.4.3. Validation man hour registration

The real world data contains the hour registration of 10 ASD vessels and 5 PSV vessels. The same number of ships are processed by means of the simulation models in a random order. The hours are registered similar to the real world data. The man hour registration is done for S1 and S1a individually at first. The hours of all simulation runs and ships are averaged per ship. Those averages are compared. A comparison on ship level is made because the real world data shows significant differences between the registered hours on section level. Secondly the S1 and S1a results are averaged, since the real world data also contains data of the combined facilities.
In Figure 4.7 and Figure 4.8 the normalised man hour registration of the entire DSGa pre-processing is presented for the ASD and PSV ship type respectively. The results for the individual pre-processing facilities is presented in Appendix E.2. The results of both facilities are averaged. The real world data is is normalised on the model data and presented as well.

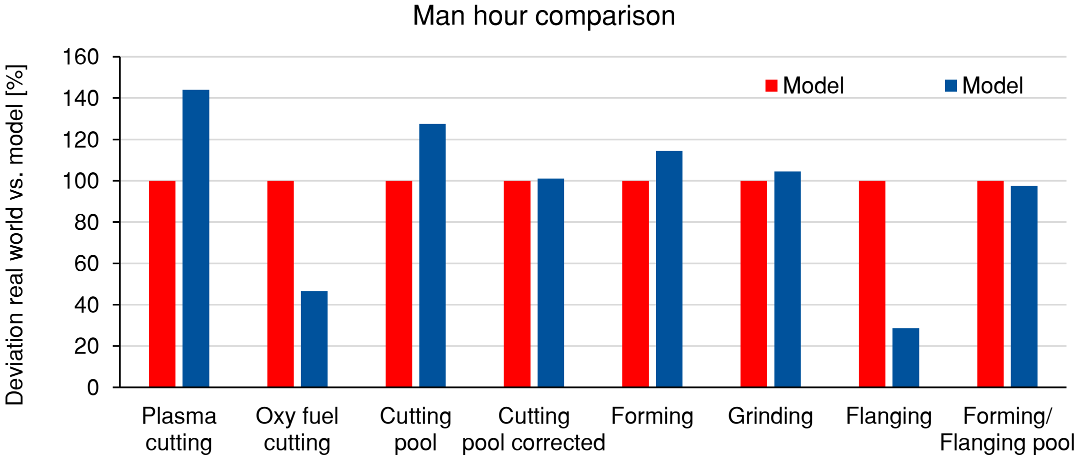


Figure 4.7: Man hour determination difference model and real world ASD ship type

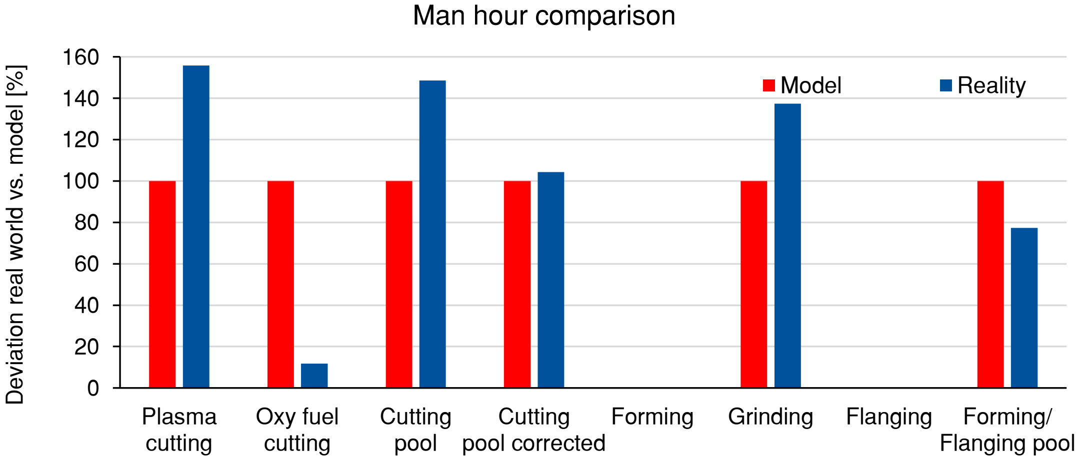


Figure 4.8: Man hour determination difference model and real world PSV ship type

The individual results per pre-processing facility shows the same behaviour for the cutting, forming and flanging stations. For the grinding stations the S1 model performs better than the S1a model. Discussion on this topic is given below.

The plasma and oxy fuel hour registrations show counteracting results, which is explained by imprecise hour registration of the outside steel storages. This can originate from both the simulation model data as well as the real world data. Imprecision is likely since the boundary between both is vague because the plates and workers belong to the same cutting group and workers pool respectively.
For this reason both cutting registrations are jointly presented as well. Still a large difference between the real and model registration is observed, which can be explained by the cutting registration procedure in the simulation model. When a plate is cut only the operator is active and therefore writing hours. However in reality the sorting assistant is also ‘active’ during cutting. When considering this ‘activity’ as well the difference becomes considerably small. The corrected result is presented in Figure 4.7 as well. It is very positive that the result shows good, explainable matching behaviour.

The forming and flanging stations of both facilities show very similar behaviour. The forming station registration is positive (15%) in the simulation model. Contrary the flanging station shows a negative result (70%) compared to the real data. The combined result shows a matching behaviour. For the PSV no separate forming and flanging data is available. Uncertainty exists about the origin of this difference. It could very well be that the real world data determines the difference, since the workers belong to the same pool. The ASD hour registrations show better agreement with the simulation results than the PSV ship type.

The grinding man hour registration is build up by many contributions due to the number of parts processed and shows also a slightly positive result for the S1 facility. A negative result is observed for the S1a facility. Due to averaging the combined result shows a matching behaviour. Grinding involves much walking, which is difficult to capture in the simulation model. Moreover the repetitive character of the process enhances inefficient processing due to human factors.

Finally it is concluded that the man hour validation shows a rather good matching behaviour. This increases the acceptance of the simulation results and trustworthiness of the KPI results. Still some deviation exists which mainly shows a non beneficial effect. Hence the current state is not overestimated.

4.4.4. Validation annual throughput

Based on the annual portfolio, determined in Section 2.3.1, and the product data per ship type the ‘real’ annual throughput is determined. Several aspects are noteworthy. In the current state both plates and flat bars are cut from plate. So when considering the plate pre-processing also part of the profiles need to be encountered. Moreover the scrap percentage needs to be incorporated. In Table E.2 the derivation of the entire plate pre-processing process throughput is presented. Hence KPI_6 is derived:

$$\mathrm{KPI}_{6,\mathrm{real}} = \text{maximum throughput per year} = 9275 \text{ [ton]}$$

Based on the simulation model throughput the same figures can be observed. Initial simulation attempts provide feedback on the performance of the system. Hence finally the following KPI is defined. This result is obtained using the approach described in Section 4.4.2. The cumulative of all cut parts is derived per simulation run. Subsequently the average of all runs is considered. A reasonably small difference is with $\mathrm{KPI}_{6,\mathrm{real}}$ is found.

$$\mathrm{KPI}_{6,\mathrm{modelled}} = \text{maximum throughput per year} = 9250 \text{ [ton]}$$

The throughput is enabled by the joint processing of S1 and S1a. Slightly more than 60% of the throughput is processed in S1a. The rest is processed in S1. This result is conform expectation as well. The behaviour of the S1 and S1a processes is studied by plotting the distribution of all individual process times of each part in Figure 4.9. The cumulative distribution function of the S1 process is slightly steeper than the distribution of the S1a process. Hence the S1 process is slightly faster. This is conform expectation as well. In the S1 process one cutting station is deployed contrary to S1a. However in both facility one flanging and forming station are present. Hence more waiting is involved with the S1a process compared to the S1 process, elongating the individual part durations.

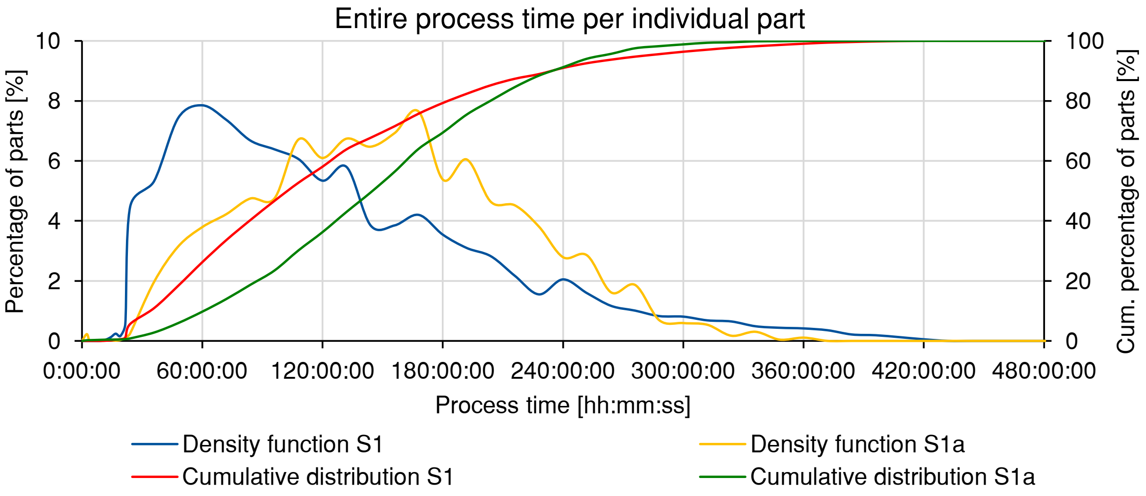


Figure 4.9: Process time: entire process per individual parts

Both results are conform expectation. Hence also for the annual throughput the acceptance of the simulation results and trustworthiness of the KPI results are enabled. Hence the reliability of the study’s outcome is improved.

4.5. Summary

In this Chapter the process of constructing a simulation model is described. The objective of this simulation model is to obtain the time related key performance indicators (KPI). Those are defined to quantify the waste analysis and enable comparison between the current and future states. Subsequently it addresses the second research question.
What is the quantitative performance of the current pre-processing process obtained by means of dynamic simulation analysis?

In order to scope and program the simulation model objective is defined as follows: ‘Providing insight in the effect of dynamic, dependent resources on throughput and resource utilisation, to quantify waste in the DSGa pre-processing process and enable comparison between current and future states by obtaining KPI results’.

Subsequently the required input data is listed and structured in a way that front-end validation is enhanced. The model boundaries are described, being the raw plate source, end buffer space and the part processing spaces. For the source and end buffer spaces this is straightforward since the positions are known and reasonably enough capacity is available. For the part processing space no interaction effects can be incorporated due to the absence of detailed sub panel assembly process information. Hence this boundary results in too positive inventory measures as the throughput is fastened.
The simulation model has a deterministic behaviour as no internal randomness is incorporated. A number of simulation runs is required to mitigate the randomness due to input data sequentiality. For prediction of the number of simulation runs the Rule of Thumb and Graphical Method are appropriate.

The translation between the process model descriptions and the software model is enhanced by model verification. Walk through and inspection is executed by those involved with the process model descriptions and modelling software. Several model aspects require specific emphasis due to their particular influence on the model objective, case specifics and programming assumptions. Those events are listed in and check by means of a test plan.

Front-end validation is accomplished by valuing and discussing the process model descriptions with the process owners. Rear-end validation is carried out by comparing the man hour registration and annual throughput capacity.
Multiple simulation runs are executed to study the output variability. The combination of the deterministic model property and input data variation results that the output variation after 10 simulation is neglectable small.
Man hour comparison is executed. Concerning cutting a minor difference (0-2%) in man hour registration is observed when comparing all cutting related hours and including the waiting hours of the assistant when the operator is executing the cutting program. The joint comparison of the forming-flanging cutting pool shows rather good results (0-15%) as well. The ASD hour registrations show better agreement with the simulation results than the PSV ship type. The S1 and S1a simulation model grinding man hour registration are respectively too positive and too negative compared to the real world data. This is explained by the high number of parts and involved human factors. The average shows a matching result.
The annual throughput measures are derived based on the annual portfolio and product data and the simulation model. Initial simulation attempts provide feedback on the performance of the system. Finally a reasonably small difference is found. Facility S1 and S1a show similar, expected behaviour. S1 is slightly faster compared to S1a.

Resuming, a simulation model is constructed which is able to properly capture the real world. The simulation results are addressed in the next Chapter.

5

Current State performance analysis

In Chapter 4 a simulation model is constructed to quantify waste in the DSGa pre-processing process and enable comparison between current and future states by obtaining KPI results. In this Chapter the question what the performance of the current state in terms of throughput is, is addressed.
What is the quantitative performance of the current pre-processing process obtained by means of dynamic simulation analysis?

First the part throughput performance is dealt with. Then the yard throughput is dealt with which deals with the station/yard occupancy. Moreover the utilisation of the resources is described. A structure overview is presented in Figure 5.1, which also shows the relation to the defined KPI's (Section 2.3.4).

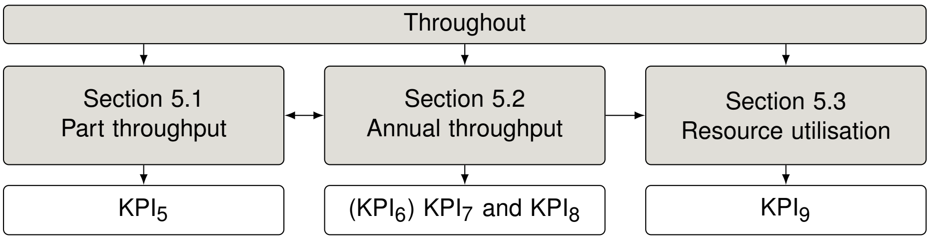


Figure 5.1: Structure throughput description

5.1. Part throughput analysis

Here the time that a individual part moves through the process is under consideration. First the entire process is concerned in Section 5.1.1, followed by the individual work steps in Section 5.1.2.

5.1.1. Part throughput entire process

In Section 2.3.4 the process is defined as the time between a raw plate entering the facility on the infeed conveyor and the processed part entering the end buffer. The hour determination is based on the actual working hours, based on two shifts. So the weekends and nights are excluded. The percentage of parts per specific time 'in the process' are plot in Figure 5.2. The horizontal axis shows the time. On the left vertical axis the probability density function is plot. On the right vertical axis the cumulative distribution function is plot. The combined S1 and S1a results of multiple runs are presented.

In order to capture the result in single, comparable figures the following KPI is defined. KPI_5 equals the mean of the distribution plot in Figure 5.2. This KPI is also defined for the strictly value adding activities. For cutting this time is defined as the cutting program duration. The KPI is presented below.

$$KPI_5 = \text{time average of 'entire process time' per individual part distribution} = \bar{x}_{time}$$

$$KPI_5 = 141{:}14{:}00 \text{ [hh:mm:ss]}$$

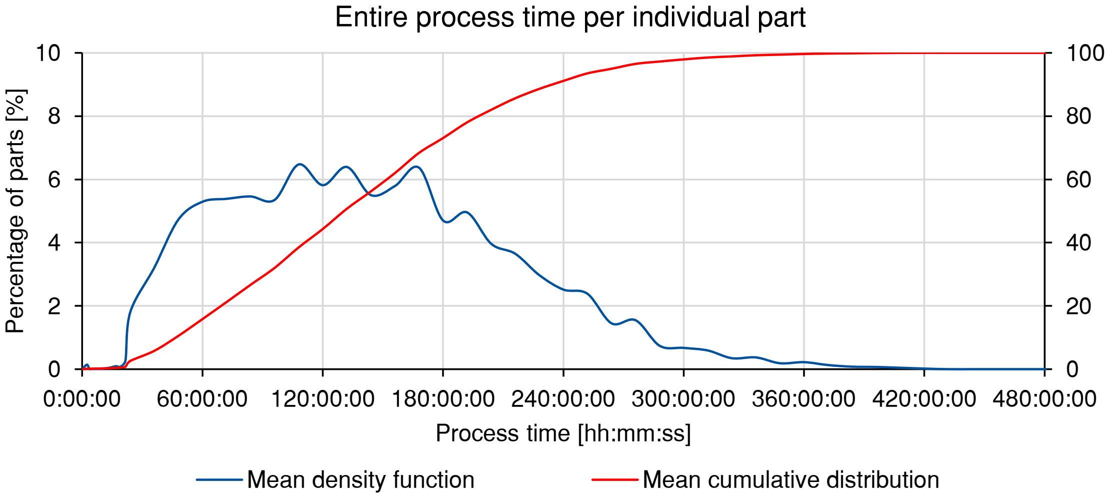


Figure 5.2: Cumulative number of parts per entire process duration

$$\text{KPI}_{5,\text{value added}} = 1{:}14{:}00 \text{ [hh:mm:ss]}$$

In Figure 5.3 shows the simulation results of a single simulation run. Plotting the data on time sequence clearly shows the effect of the cutting batch sizes, which are included on the secondary axis. The positive sloped behaviour is explained by the batch packing and delivery.

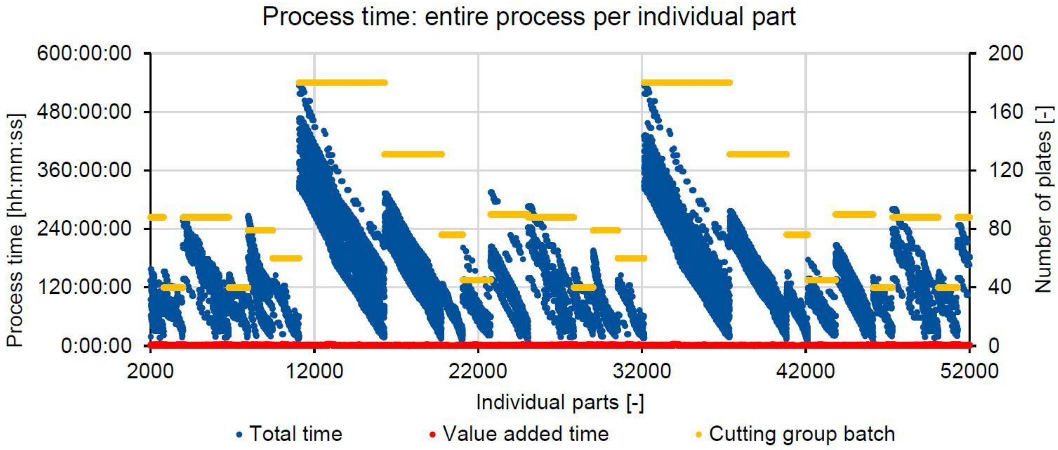


Figure 5.3: Process time: entire process per individual parts (parts are ordered in sequence of cutting)

Conclusively the ratio between value-adding activities and non-value-adding activities can be determined, which is approximately a factor 110. Clearly a large portion of the time is spend on non value adding activities. Furthermore the 'entire process time' is positively related to the cutting group batch size. This underlines the batch size observations of Section 3.2.2. Next the part throughput is considered per work step.

5.1.2. Part throughput individual processes

The individual work steps are more specifically considered. The combined results of facility S1 and S1a are presented, since both facilities show similar results. The tapering work step is excluded because its contribution is minor and it takes place at the start of the grinding work step. The exact state changes at which the time is measured are presented in Appendix F.1. A brief description is given below. The results are presented in Figure 5.4. The vertical axis shows the probability density functions.

The cutting process starts when a raw plate enters the facility. When the plate is cut the cutting process ends and the sorting process starts. When the cutting group is finished the sorting process ends and the transport (intermediate buffer) processes to the part processing spaces (PPS) or forming infeed buffer start. When the parts arrive, those end and the 'PPS process' and forming process start. Then the parts enter the end buffer those processes are finished as well. In between the flanging process can be executed which is measured by the time the parts enter or leave the in/outfeed buffer.

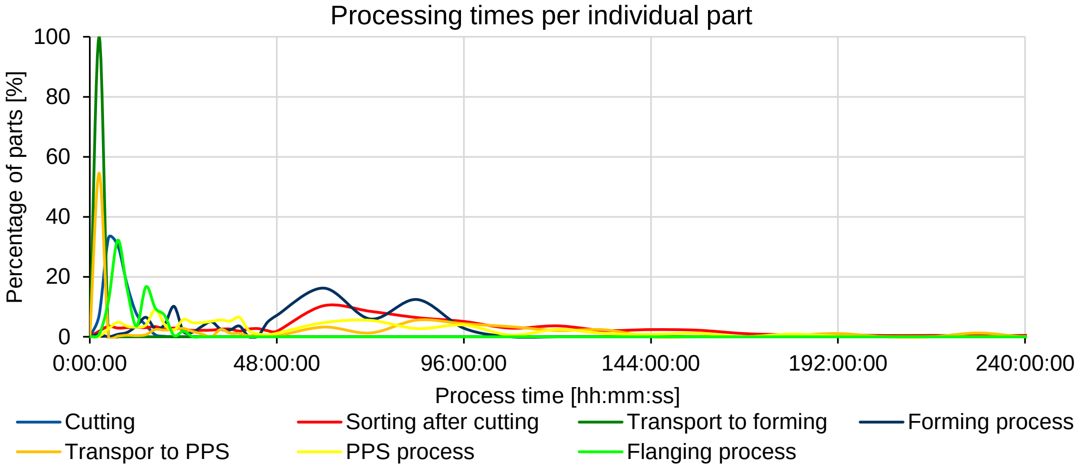


Figure 5.4: Process time: forming, grinding and flanging process

The cutting distribution shows a reasonable peak at 5 hours, which is mainly caused by the input batch delivery of approximately 4 plates. Sorting significantly contributes to the entire part duration. Since the parts only leave when a container is full or the entire cutting batch is finished, significant inventory is build up here. The effect of the batch size is underlined in Figure F.1.
Concerning forming: The transport to forming process is negligible compared to the total forming process. The fact that all to be formed parts are moved directly to the forming station (large dark green peak near 1 hr) is enabled by the large forming sorting space acting as an intermediate buffer. Due to the relatively long individual part process time and the batch existence the entire process takes much longer, which is observed by the larger peaks between 48hr and 96hr. The implication of the latter is that inventory is building up. Furthermore it has an implication on levelness of the resource utilisation, which is further assessed in Section 5.3.
Concerning grinding much time is spend for transport time to the part processing spaces, which is mainly spend in the intermediate buffer. It clearly reflects the inventory waste found in Chapter 3, by 'nesting of several sections in cutting group'. Moreover the parts stay a long on the part processing spaces, as shown in Figure F.2. This results from the batch handling and clearly is a inventory waste.

Conclusively the individual processes which are involved with large batches and long processing times are more susceptible for inventory building up. This concerns the sorting process, part processing process and forming process.

5.2. Annual station throughput analysis

The difference between the part and annual throughput is that the first concerns the time it takes to finish the process whilst the latter concerns the number of parts a station processes. First the annual yard throughput is discussed. Then the station throughput measures are presented.

The entire annual pre-processing throughput is already discussed in Section 4.4.4, where this KPI is used to validate whether the model is conform reality. Hence only the result is presented here.

$$KPI_6 = \text{maximum throughput per year (weight)} = 9250 \text{ [ton]}$$

KPI_7 and KPI_8 capture whether the work stations have a levelled throughout, as described in Section 2.3.4. This property is based on the Lean Manufacturing focus concerning levelled flows. KPI_7 distinguishes the ratio between idle and occupied time of each work station. The unit weight is used in order to incorporate the difference between parts. Since the entire station is considered insight in the in/outfeed buffer loading is obtained. KPI_8 distinguishes the degree of occupancy when being occupied.

$$KPI_7 = \text{station occupancy rate} = \frac{x_{all}-x_{idle}}{x_{all}} \text{ for } \begin{cases} \text{Cutting} \\ \text{Forming} \\ \text{PPS} \\ \text{Flanging} \end{cases}$$

$$KPI_8 = \text{active station occupancy variability} = \frac{\sigma_{occupancy}}{\mu_{occupancy}} \text{ for } \begin{cases} \text{Cutting} \\ \text{Forming} \\ \text{PPS} \\ \text{Flanging} \end{cases}$$

As described in Section 2.3.4, for a Lean, levelled flow KPI_7 and KPI_8 need to be close to 1 and 0 respectively, since this means that the station load is equally spread per time unit.

For data set determination the same state changes as used for the part throughput are used. The cutting and sorting process take place at the cutting station. The in- and output concerns raw material entering on the conveyor and parts leaving the sorting space. The in- and output of the forming station concern parts arriving from the cutting sorting space and containers leaving to end buffers respectively. The same applies to the part processing spaces. The flanging station in- and output concern parts arriving from the part processing spaces in the infeed buffer and leaving of parts from the outfeed buffer.

Per workday the in- and output flow of each station is determined (blue and red bars in Figure 5.5). The difference indicates the ‘work in progress’ (green line in Figure 5.5). In Figure 5.5 the results are plot for the S1 cutting station on an entire calender year scale, on a workday basis. For the other stations the results are included in Appendix F.3. The part processing are jointly described, for mitigation of assignment effects. KPI_7 and KPI_8 numerically captures the occupancy (cumulative line) being zero and the variation in peaks respectively.

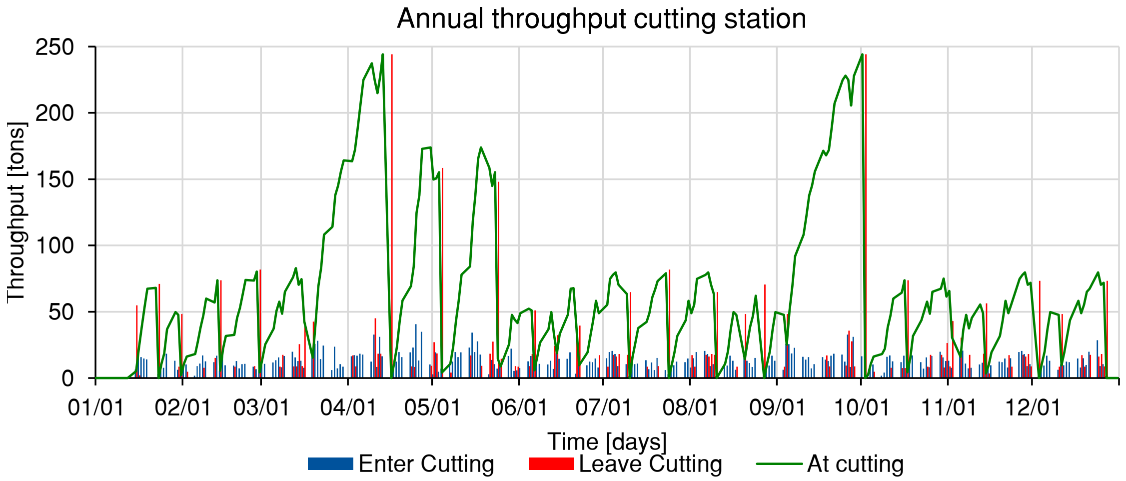


Figure 5.5: Throughput S1-L2 cutting station per year

Contrary to Figure 5.5, the KPI’s are based on multiple simulation runs since they are based on the comparison of all day based results. For the definition of the KPI’s the occupancy build up period, as discussed in Section 4.4.2, is essential. Hence that period is excluded from the calculation of the KPI’s. KPI’s are presented below.

$$\text{KPI}_7 = \text{station occupancy rate} = \frac{\text{x}_{\text{idle}}}{\text{x}_{\text{all}}} \text{ for } \left\{\begin{array}{c} \text{S1 Cutting} \\ \text{S1 Forming} \\ \text{S1 PPS} \\ \text{S1 Flanging} \\ \text{S1a Cutting} \\ \text{S1a Forming} \\ \text{S1a PPS} \\ \text{S1a Flanging} \end{array}\right. = \left\{\begin{array}{l} 1.00 \\ 0.52 \\ 0.89 \\ 0.40 \\ 1.00 \\ 1.00 \\ 1.00 \\ 0.89 \end{array}\right.$$

$$\text{KPI}_8 = \text{active station occupancy variability} = \frac{\sigma_{\textbf{occupancy}}}{\mu_{\textbf{occupancy}}} \text{ for } \left\{\begin{array}{c} \text{S1 Cutting} \\ \text{S1 Forming} \\ \text{S1 PPS} \\ \text{S1 Flanging} \\ \text{S1a Cutting} \\ \text{S1a Forming} \\ \text{S1a PPS} \\ \text{S1a Flanging} \end{array}\right. = \left\{\begin{array}{l} 0.84 \\ 0.60 \\ 0.66 \\ 0.56 \\ 0.68 \\ 0.57 \\ 0.62 \\ 0.74 \end{array}\right.$$

Several conclusions are drawn. The cutting stations are occupied for 100%, which is conform the definition of the experiment. Significant spread for the sorting space occupancy appears. The latter clearly underlines the “nesting one cutting group” waste. Since in S1a two cutting stations exist the S1a result is even more stringent.

The batches of parts entering and leaving the forming station are clearly observed. Furthermore the demand and supply variability (Section 3.4.2) is underlined by KPI_7 and KPI_8 being low and high respectively. Since sorting for end buffers takes place the batches leaving forming are smaller. Due to the larger supply of parts the S1a forming station has a higher occupancy rate, compared to the S1. Moreover due to its inefficient forming process the in- and outfeed buffers are larger.

The occupancy rate of the part processing spaces is also significant high. From a levelling perspective this is positive. However apart from being active also a lot of inventory is build up (Figures F.4 and F.8), which is underlined by a high occupancy variability.

For the flanging stations the occupancy rate is lowest. S1a has, compared to S1, a higher occupancy rate since the part supply is higher as well. However when it is active still a high occupancy variability is observed. In the next Section the resource utilisation is assessed to check whether the resources are a limiting factor, in the case that station is occupied and the occupation is high.

5.3. Resource utilisation analysis

In order to determine the utilisation of resources like cutting machines and presses the simulation model is used, as discussed in Section 2.3.5. KPI_9 is defined as the ratio between utilised and total time. Whether the utilised time is also value-adding time is resource specific.

$$\text{KPI}_9 = \text{resource utilisation} = \frac{\text{utilised time}}{\text{total time}} \text{ for } \left\{\begin{array}{c} \text{Cutting machines} \\ \text{Presses} \\ \text{Cranes} \\ \text{Carriages} \end{array}\right.$$

The cutting portals and forming/flanging presses are resources which directly enable value adding activities. High utilisation diagrams for those resources implies more value adding activities are going on, which is positive. Furthermore significant utilisation of expensive resources is advantageous from investment perspective. From that perspective KPI_9 should be high for those resources as well. The drawback of high utilisation diagrams is that the resource is sensitive to becoming a bottleneck.

Concerning the other resources (cutting beds, carriages and cranes) the KPI’s should be such that they do not form a bottleneck. For the cutting beds KPI_9 should equal the KPI of the cutting portal since then it is dedicated to value adding activities most. The KPI’s for the cranes and carriages should be low. For layout redesign this statement should be reconsidered since low utilisation implies more deployed resources, which effects investments.

For the determination of the KPI's the software build in functionality is used. The results of all simulations runs are averaged and presented in Table 5.1. The naming of the cutting portals and cutting beds is done from left to right, but actually does not matter since a similar result is observed within a cutting station. The naming of the cranes is conform the definition made in Figure 3.24.

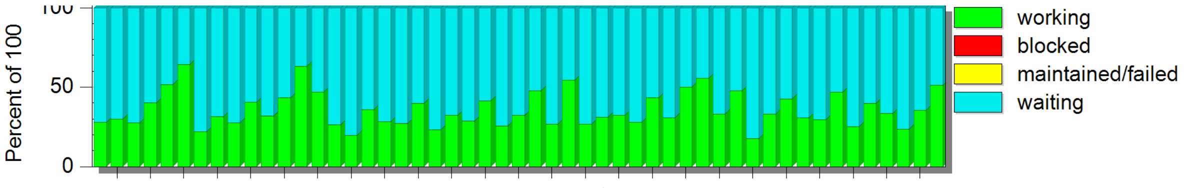
Table 5.1: Resource utilisation (KPI_9) results

Resource name	Util. [-]	Resource name	Util. [-]	Resource name	Util. [-]
Cut. portal S1-L2	0.53	Crane S1-L1-a	0.74	Crane S1a-L2-a	0.31
Cut. bed S1-L2	0.95	Crane S1-L1-b	0.09	Crane S1a-L2-b	0.51
Cut. portal S1a-L2-a	0.3	Crane S1-L2-a	0.26	Crane S1a-L2-c	0.41
Cut. portal S1a-L2-b	0.3	Crane S1-L2-b	0.38	Crane S1a-L2-d	0.59
Cut. bed S1a-L2-1	0.61	Crane S1-L3-a	0.45	Crane S1a-L3-a	0.26
Cut. bed S1a-L2-2	0.61	Crane S1-L4-a	0.63	Crane S1a-L3-b	0.52
Cut. bed S1a-L2-3	0.61	Crane S1-L5-a	0.11	Crane S1a-L3-c	0.37
Cut. portal S1a-L3	0.35	Crane S1-L5-b	0.15	Brake press S1a	0.4
Cut. bed S1a-L3-1	0.63	Crane S1-L5-c	0.17	Roller press S1a	0.6
Cut. bed S1a-L3-2	0.63	Brake press S1	0.24	Line heating station S1a	0.7
Carriage S1	0.28	Pressure press S1	0.68		
Carriage S1a	0.3	Roller pressure press S1	0.26		

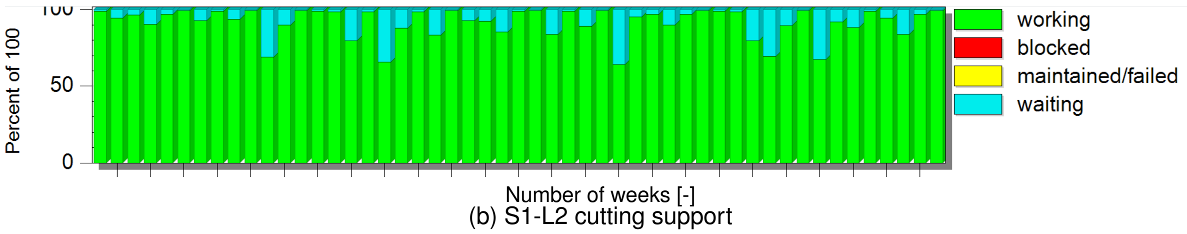
The KPI´s are defined in line with the objective of the simulation model. This KPI´s enable comparison with future states. Furthermore some discussion on waste quantification is presented. For the latter also some date based utilisation diagrams are provided. This is done per resource group.

5.3.1. Cutting resources

In Figure 5.6 the utilisation diagrams of the cutting portal and cutting bed are presented of cutting station S1-L2. In Appendix F.4 the diagrams of the other two plate cutting stations are provided in Figure F.10 and Figure F.11. The diagrams are based on single simulations runs in order to incorporate the day based effects. The data of an entire year is plot per week.



(a) S1-L2 cutting portal



(b) S1-L2 cutting support

Figure 5.6: Date based utilisation diagrams S1-L2 cutting station

The green contribution in Figure 5.6 indicates the time that the resource is active and executing its process. For the cutting portals this equals the time cutting. The cutting beds are working during all activities which occupy the bed, namely the entire cutting, signing, scrap cutting and sorting process. In Figure 5.6 the difference between the utilisation of the portal and bed is explained by the signing, scrap cutting and sorting actions. The results confirm the qualitative statements (cutting bed size) made in Chapter 3. The cutting portal is waiting for more than 40% of the time, due to the occupation of the cutting bed, which is wasteful. Moreover part of the waiting is explained by the outfeed of main panel plates via the infeed conveyor, which explains the regular utilisation drops of the cutting bed.

For the S1a cutting stations the ratio between the portal and bed utilisation is better, as shown in Table 5.1. This is underlines the statements made in Section 3.2.2. For the S1a-L3 cutting station the relation is best, which is conform expectation. The overall utilisation of the S1a cutting stations is relatively low. This is explained by the fact that the sorting spaces, acting as an intermediate buffer, are blocking further processing. Due to the same number of part processing spaces in S1a the process is much more strained, initiating waiting waste.

5.3.2. Forming resources

The next very resource dependent work step is the forming work step. The utilisation diagram of the pressure press, which is positioned in S1, is presented in Figure 5.7. The resource utilisation diagrams of the other presses and the line heating station are presented in the Appendix (Figure F.12). The pressure press and roller press are occupied more than the roller pressure press because there are parts which require a 2D form only as well.

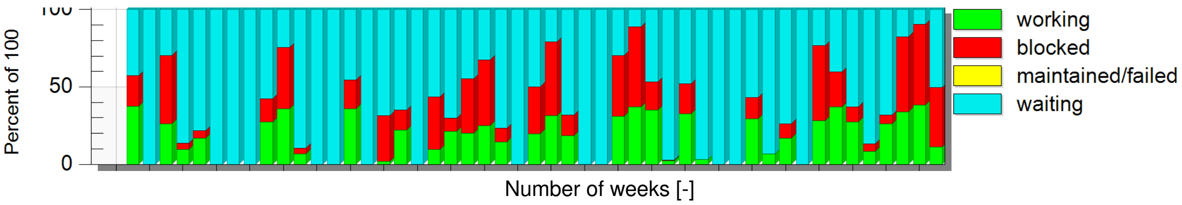


Figure 5.7: Date based utilisation diagram S1-L5 forming pressure press

Remarkable is that both process are waiting for personnel or blocked substantially, indicated by the red contribution in Figure 5.7. For a forming operation both an operator, assistant and crane are required. However the assistant is also active (off) loading the parts from the containers on the infeed/outfeed buffer. Furthermore the operators can also be involved in line heating.

This observation is explained by the absence of clear activity prioritisation or not enough personnel assigned. This phenomena is specifically verified in the verification test plan which is included in Appendix E.1 (Table E.1 test 42). In S1 the presses are never fully occupied (blocked or working).

In S1a significant deployment of the roller press and line heating station is observed, which explained by the higher supply of parts in the S1a facility. Furthermore there is a large difference in resource loading. This was already found by the station occupancy in KPI_7 and KPI_8 respectively. Hence a quantitative argument is presented for the demand and supply variability notion made in Chapter 3. The S1a forming station is not subjected to waiting for personnel since the forming workers pool contains more workers. However some blocking due to unfulfilled crane requests occur.

5.3.3. Part processing space resources

Concerning the part processing spaces no significant resources are deployed. The utilisation of the part processing space cannot be measured. As discussed in Chapter 4 the number of workers is implemented conform the reality. However in the pre-processing process simulation model there is not sub panel assembly included. Hence the workers of the part processing spaces are less busy. The utilisation will therefore not show a bottleneck. This also applies to the tapering station, which is controlled by the part processing spaces (Appendix B).

5.3.4. Flanging resources

The flanging processes are again more resource driven. The utilisation diagram of the S1a brake press is presented in Figure 5.8. The results for S1 brake press is included in Appendix F.4 and shows similar behaviour. The utilisation diagram, shows the utilisation of the brake press per week. Because sorting at flanging and the flanging process take place at the same time waiting for personnel and blocking of cranes occurs. The implication of no dedicated working cranes for flanging, introduced in Chapter 3, appears here. No apparent bottleneck is observed.

5.3.5. Carriages and cranes

In the Appendix the utilisation diagrams of the carriages and cranes are included. The KPI_9 show no high utilisation results for the cranes or carriages.

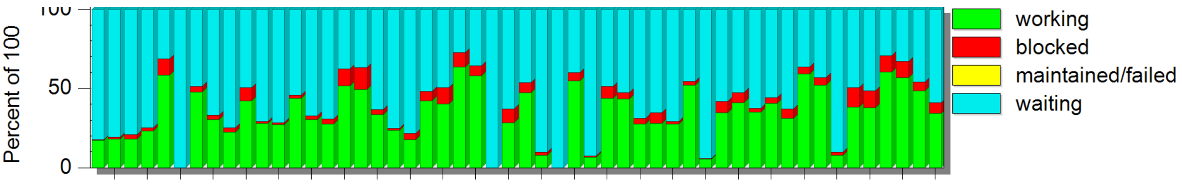


Figure 5.8: Date based utilisation diagram S1a-L2 flanging brake press

Concerning the cranes; only the considered pre-processing portals are considered. Particularly the cranes operating in the grinding areas are 'high' utilised. As the presses have their own working cranes the transport cranes are deployed to a smaller extent. The date based diagrams show some temporary peaks for the cranes deployed at the part processing spaces. However no stringent phenomena are presented since they only take a short time.
The carriage is used for about 30%. More detailed the loading activity takes most of the time. The root cause of this is the time it takes to fasten the container onto the carriage. Furthermore waiting for the right operators is included in the loading time. The utilisation is not too high to be an apparent bottleneck.

5.4. Summary

In this Chapter the second research question is addressed, which deals with the definition of the 'time' related KPI's. The second research question is stated: *What is the quantitative performance of the current pre-processing process obtained by means of dynamic simulation analysis?*

By means of the simulation model, constructed in the previous Chapter, the process is modelled and analysed. For the determination of the part throughput the defined output data set is used, based on multiple simulation runs. The distribution of the entire process duration of all individual parts is determined, which shows that the parts are on average approximately 140 hours 'in the process', from which on average only 1.25 hours is value adding. The time on the sorting space after cutting and the intermediate buffer before processing contribute to that significantly. This time in the process is positively related to the cutting group batch.

Furthermore the maximum annual throughput is determined, which equals 9250 ton. It is captured whether the stations have a levelled throughput by the occupancy rate, distinguishing the difference between idle and occupied time and the active occupancy variability, distinguishing the degree of occupancy when being occupied.
The cutting stations are significantly occupied, which is expected conform the push approach of the simulation runs. Significant active station occupancy variability is observed, which is explained by the processing on cutting group level. The resource utilisation analysis shows a low ratio between cutting portal- and bed utilisation. Hence the portals are significantly waiting for the sorting process of the cutting beds. The overall utilisation of the S1a cutting stations is relatively low. The sorting spaces, acting as an intermediate buffer, are blocking further processing. Due to the same number of part processing spaces in S1a the process is much more strained, initiating waiting.
Concerning forming and flanging the occupancy rate and active occupancy variability show low and high results respectively. This underlines the outlined 'supply and demand variability' waste. This result is also obtained from the resource utilisation analysis. The part processing spaces also show a high active station occupancy variability, which indicates significant inventory building up.

Resuming the inventory, transport and waiting waste types found by the waste analysis are quantitatively described. The effect of cutting in large groups is underlined by quantitative analysis. The supply and demand variability of the forming station is recognised by KPI_7, KPI_8 and resource utilisation diagrams. The resource utilisation diagrams clearly show the waiting wastes of the cutting beds and presses. Concerning cutting this is due to inefficient sorting routines and ratio between portals and supports. Concerning the presses this is partly caused by the absence of personnel or working cranes.

6

Improvement strategy development

In the previous Chapters the current pre-processing process of Galati is considered. In this Chapter qualitative improvement concepts are developed to improve the current state.
The objective is the improvement of the ratio between throughput and space utilisation, such that the S1 and S1a facility can be merged in S1a. Doing so the S1 facility is freed for execution of other operations and the yard's performance meets industry peers. In Section 1.2.2 the DSGa management's ambitions to dedicate the freed space in facility S1 is to aluminium processing discussed.

Following the five principles of implementing Lean Manufacturing the next steps are: 'create flow' and 'establish pull' (Figure 6.1). To obtain a clear understanding about the flow related Lean Manufacturing principles literature is reviewed, in Section 6.1.

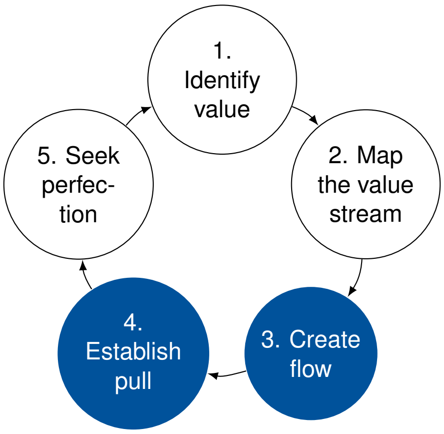


Figure 6.1: Principles of Lean

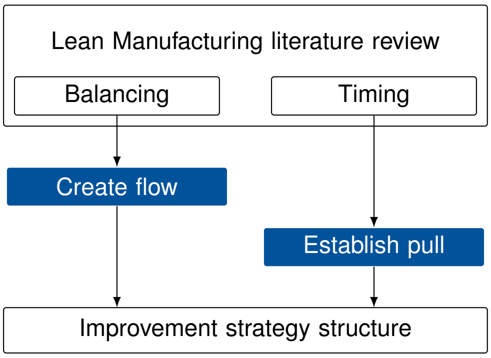


Figure 6.2: Summary approach Chapter 6

In Section 6.2 and Section 6.3 the balancing and timing of flow are discussed respectively. Balancing concerns the design of a process such that the flows are balanced. Timing concerns the control of the flow such that the balancing character is enhanced. The relation with the Principles of Lean is shown in Figure 6.2. It is investigated what strategies are feasibly and promising and which are not. In Section 6.4 these notions are converged in the development of improvement options. Doing so the second research question is addressed:
What process improvement strategies can be proposed, for redesigning process, based on the Lean Manufacturing framework?

6.1. Lean Manufacturing framework description

First general notions about the flow related Lean Manufacturing framework are made. Then two specific topics, applicable for shipbuilding, are dealt with in more detail, namely balancing flow and timing flow.

6.1.1. Flow focused Lean Manufacturing framework

Several flow related principles are determined within Lean Manufacturing, namely: continuous flow, one-piece flow, pull flow, levelled flow and takt time. Literature related to their applicability in shipbuilding is addressed secondly.

Flow principles description

Liker and Lamb [49] state that the continuous flow principle is about the shift from a traditional mass production to the non-batch, highly value added, continuous flow. The amount of time that any work project is sitting idle or waiting for someone to work on it, must be cut back. According to Hines and Rich [35] not the productivity of the worker, but the processing of the work piece is the main concern.

Therefore in Lean thinking the ideal batch size is one [87]. Benefits of one-piece flow are: build in quality (each peace is considered separately), create real flexibility (no huge batches pressing), create higher productivity (no unintentional attention to overproduction), frees up floor space (less material around), improves safety (less movement), improves moral (personal commitment) and reduces the cost of inventory (free capital by de-investing in stock) [50]. Furthermore, when having continuous flow it becomes immediately apparent where the bottleneck operation is and efforts can focus on that operation [49]. As this is not always practical, the size may increase [44]. Koenig et al. [40] propose that when a one-piece flow is not possible then the next best thing is to set up a small controlled buffer of inventory that is replenished based on pull signals.

The pull system is about the pull of material and resources by subsequent stages from the previous stages [44]. It is expanded until the customer. A derivative of this pull system is the *Just-In-Time* (JIT) principle. It also affects warehousing of inventory by stocking only small amounts of each product and frequently restocking, based on what the customer (production stage) actually wants [50, 87].

Machine setup time reduction is the main argument for batch production [35]. The machine setup time becomes more critical in an one piece flow. Within Lean Manufacturing this is encountered by levelling the flow irregularity, comprised in the Japanese word *Heijunka*. [50, 87]

Liker [50] notes that in order to make material flow through manufacturing processes at the rate needed to match customer demand, targeted production pace is required. Within Lean Manufacturing this is called *Takt time*. According to Phogat [61] it is also referred to as the ‘Customer Demand Rate’ and is measured as the total available production time/total customer demand for some period of time. *Takt time* is the target and should be the driver in developing the way the product is scheduled and the way material flows through the system. Liker and Lamb [49] underline the effect on the waste types as running faster than the *takt time* generates inventory, somewhere in the system. Running slower than *takt time* will generate the need for accelerated production, overtime and/or excess inventory.

Application for shipbuilding

Liker and Lamb [49] state that shipyards do not use all Lean Manufacturing principles. However many shipyards apply some flow related principles. Those include Just In Time deliveries and using takt time. Moreover staged materials and dedicated process lanes for major processes like flat and curved blocks, are recognised.

Comprehensively Storch and Lim [79] and Koenig et al. [40] state that the two basic concepts for Lean ship production process flows are perfect balancing and timing. Their definition is as follows:
Balancing means balanced work loads within manufacturing levels for producing needed interim products, in terms of working times, not in terms of man-hours. Balancing will require ‘appropriately sized’ work breakdown and corresponding resource utilisation. Basically, balancing will prevent overflow and guarantee uniform process flows.
Perfect timing means maintaining the status of having exactly needed work (completed interim products) at exactly needed times within the manufacturing levels. This corresponds to the JIT concept. Basically, perfect timing prevents unnecessary interruptions or waiting, and guarantee continuous flow.
Conclusively, when these concepts are realised together uniform and continuous process flows will be established. This will significantly improve throughput and reduce work-in-progress. Because that is the objective of this Chapter, these two concepts are discussed in Section 6.1.2 and Section 6.1.3.

6.1.2. Balancing flow in shipbuilding

Liker and Lamb [49] observed that the Shipbuilding process is traditionally organised by functions. Examples of functions are: cutting, forming, grinding, panel building or section building. Liker and Lamb [49] propose a process redesign to an organisation by product line. Under product line not the separation of ships rather similar part families is understood. Examples of such product lines are: T-beams, sub-panels, flat blocks or curved blocks. In this case flat blocks go through one set of processes and a separate set of processes are reserved for curved blocks.

This concept is also acknowledged by Storch and Lim [79] (and Kolić et al. [41]), describing that 'the basis for the establishment of Lean thinking in shipbuilding is the appropriate application of group technology through the use of a product-oriented work breakdown structure'. Group Technology (GT) is a technique for identifying and bringing together related or similar parts in order to take advantage of their similarities by making use of, e.g. the inherent economies of flow-production methods [30, 79]. Its adoption results in the definition of process lanes using standard work processes for the different part groups. Those appropriate manufacturing cells are totally responsible for the manufacturing of the grouped parts [42, 79]. Related is the required equipment to enable the work processes [49, 56].
Liker and Lamb [49] address the thought that the segregation by product families requires the duplication of some resources, which would also take more space. Yet the experiences of Lean Manufacturing have shown that a great deal of space is actually freed up by becoming Leaner. This is mainly caused by the dramatic reduction in inventory. The space used for storing and moving often takes as much space as the value adding processes.

Within shipbuilding the part groupings are based on size, material or similarity of geometry. However, it should also be based on the nature of interim products and their process flows in succeeding manufacturing stages [41, 79]. The choice of specific interim products and work centres is highly dependent on the characteristics of a particular shipyard [79]. They depend on the build strategy, product mix, existing facilities and size, work force skills.

6.1.3. Timing flow in shipbuilding

According to Koenig et al. [40] the production of investigated Japanese Shipyards is driven by pull at the top, and fixed schedules at the lower level. Besides it mainly concerns the assembly processes. This is different to the automobile industry and Lean Manufacturing theory. The pull concept at the top prevents from overproduction, as production is matched with customer demand. The fixed schedules at the lower level do not allow, in a case of production problems, upstream schedule to slip in, or halt the downstream production.

While strict one-piece flow is not feasible, smaller batch sizes are more ideal from a Lean Manufacturing perspective [49]. This can be addressed by shifting the organisation to a more product oriented process, as described in Section 6.1.2. The one-piece flow batch size is to be coupled to the customer demand batches, because in shipbuilding often a lot of parts are demanded in batches.
The advantages of JIT flow, described in Section 6.1.1, are applicable to shipbuilding as well. Especially the inventory cost, build in quality (less modifications) and part trace-ability are applicable.
Furthermore the productivity is improved by creating a Lean flow by reducing the non value added time. Moreover productivity is increased because identifying problems and solving them in real time takes less labour hours than finding and fixing problems that have accumulated over weeks [49].

Applying the *takt time* principle to the shipbuilding processes is less obvious. Storch and Lim [79] state that it generally does not make sense to treat an individual ship as a single unit of output. However, Liker and Lamb [49] state that a ship consists of many interim products (like blocks and sections) for which *takt times* might be applicable. Within literature the application of takt times mainly concerns mayor processes like the assembly process, instead of the pre-processing process.

6.2. Step 3. Create flow

In Chapter 3, where the flow in the current situation was described, it is clearly recognised that the current process is functionally organised. For initiating the shift from a process organised by functions to a process organised by product lines product line definition is proposed. GT application results in the definition of process lanes using standard work processes for different part groups, which can be interpreted as the routines. Besides they can be determined based on part attributes like geometry, weight and grinding length. Third, the customer demand can be incorporated into the product lines. Those possibilities are summarised in Figure 6.3. Hence the Section objective is to investigate what possibilities exist to define different flows based on different product lines.

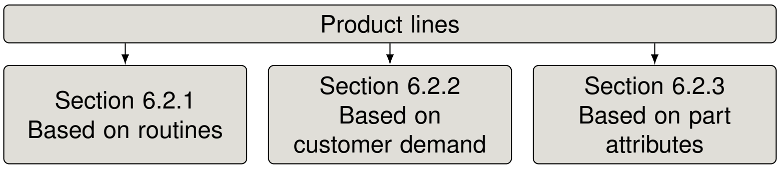


Figure 6.3: Possible product line definitions

Section 6.2.1 and Section 6.2.2 dealt with the approach to use routines and customer demand to define product lines respectively. Section 6.2.3 focuses on product lines based on part attributes.

6.2.1. Product lines based on routines

The routines, displayed in Figure 6.4, are already introduced in Section 2.2.2, and therefore do not require much explanation. The contribution of this approach is the arrangement of a specific flow dedicated to a specific product requirement (routine). Hence it is clear which subsequent process is required. A direct input-output relation stimulates a more continuous flow and reduces sorting.

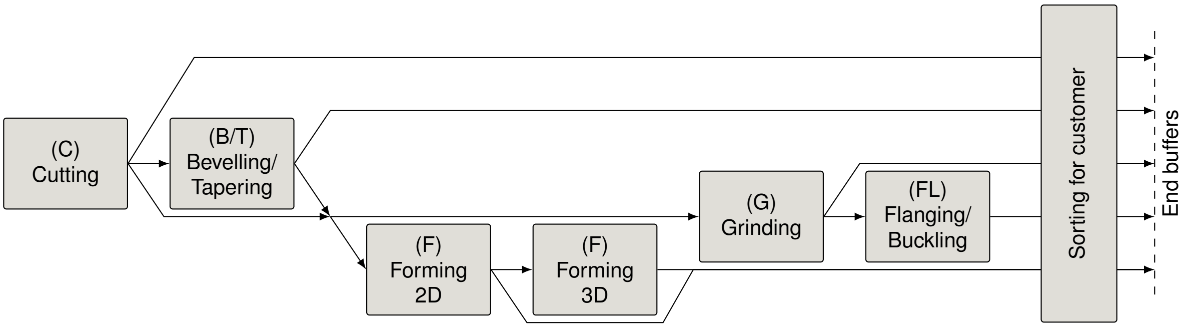


Figure 6.4: Part routing in the pre-processing process

Essential to achieving product lines and linking them to a layout is the use and availability of resources. Numeric estimations of cutting and forming machines are presented. For bevelling/ tapering and grinding the required work bench area is assessed. Last the number of brake presses is questioned.

Number of cutting machines

The assignment of one cutting machine to each flow would result in under utilised machines and significant additional investments. Hence this approach is not feasible. Currently cutting machines with an extensive bevelling functionality exist [55]. Hence it can be decided to invest in such a cutting machine and eliminate the bevelling step, reducing the number of flows. Consequently the cutting program becomes longer and investment is increased. Still the to be tapered parts require tapering. The bevelling/tapering flows only contribute a few percent (Section 2.3.2). Besides better integration of bevelling/tapering in the grinding work step is feasible. Hence investing in additional bevelling functionalities will contribute only minor to the total process performance.

Based on the annual throughput and cutting speed (tons per cutting cycle) the number of cutting machines is estimated. The detailed analysis is included in Appendix G.1. Based on the available product data the total time for cutting a plate is determined. The time for marking and cutting is not changed as the cutting machine performance cannot be changed [28, 55]. However automatic signing can be included instead of manual signing. Based on initial estimations of the improved logistic flow for on/off-loading the cutting cycle time is derived.

Following the ship delivery driven throughput determination three cutting machines suffices. A detailed calculation is provided in Appendix G.1. In the objective of this study it was hypothesised that the throughput can be increased to obtain a ratio between throughput and required gross area. Therefore the number of cutting machines is slightly over estimated to four cutting machines.
The drawback of this approach is that it is based on averages only. Two kinds of averages are observed, namely, based on plate thickness and based on nesting files. Still the analysis provides a well educated guess on the number of cutting machines. Final analysis has to provide feedback on the feasibility and utilisation of the provided predictions. Conclusively four cutting machines are to be deployed.

Size of the forming station
For routines involved with forming the implication of defining different product lines is large as less flexible equipment and more investment is involved. Hence creating multiple forming stations is not straightforward. Besides the current deployed forming machines complement each other as they are all three different (pressure press, roller press and roller pressure press).

Based on the DSGa portfolio the number of to be formed parts can be derived and the related process times. Accumulation of the process times shows an occupation of approximately 1800 hours. Hence with a 45% utilisation of the roller press only one 2D forming machine is required. This is feasible although the setup and (off) loading times are not yet included. Number wise the pressure roller press should be able to cope with all 3D curved plates. Conclusively the deployment of the roller press and roller pressure press should be sufficient. The roller press requires a work space of 5x12m. The roller pressure press requires a work space of 3x24m. Capacity increase and down time due to logistic implications might initiate the need for a third press. A pressure press is well suited due to its ability to form both 2D and 3D curves. Moreover it is able to form 3D curvatures for thick plates.

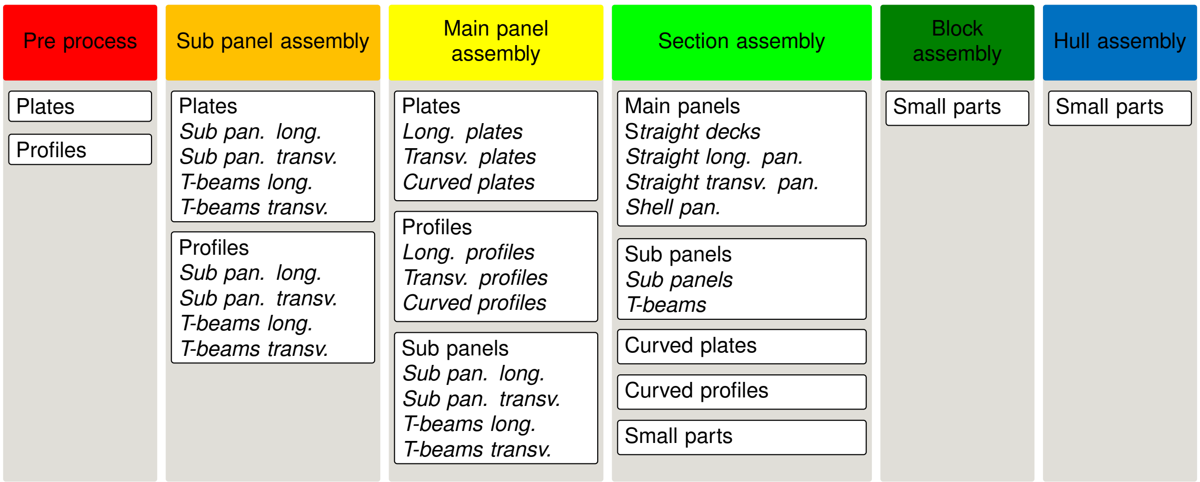
Number of grinding resources
For grinding the resources can easily be re-positioned and duplicated, as the only equipment involved are grinding tools and work benches. This would be more stringent when automatic systems are implemented. The application of (semi-) automatic systems for grinding makes sense as grinding is a rather repetitive process which does not entail difficult working procedures or craftsmanship, like for example forming [86]. With the use of robots more investment is involved. Valuing the investments on basis of the current work force deployment robotic grinding is currently not very promising. Also because machine efficiency starts to play a role then, reducing the work steps flexibility.

The determination of the required area for the grinding operations is delicate for several reasons. It is difficult to determined the additional factor for worker movement, for both small and large parts. The supply of parts is not levelled due to the intermittent character of the cutting process. Furthermore crane requirement plays a role in the duration of the work bench occupation.
For this reason the area can be determined by means of simulation attempts/iterations. This also applies to the bevelling and tapering work steps which are also work bench area driven.

Number of flanging resources
Merging S1 and S1a results in possible duplication of resources. This is especially true for the brake presses for flanging. The resource utilisation analysis in Section 5.3 shows that enough capacity is available when deploying one brake press since both presses are jointly utilised for 65% (Table 5.1). Hence with the duplication of resources definitely enough capacity is available. Furthermore it enables much more flexible operations and higher availability.

When a product reaches the end of the dedicated flow still sorting for end customer is required. Those end customers are specifically addressed in the next Section. There also the quantitative contribution is presented, in Table 6.1.

6.2.2. Product lines based on customer demand
This approach is focused on the successor process input requirements. For each shipbuilding sub process the product input entities are presented in Figure 6.5. They are described below. After that their use-fullness for establishing a product line is considered. The useful ones are quantitatively described.



Pre process	Sub panel assembly	Main panel assembly	Section assembly	Block assembly	Hull assembly
Plates	Plates *Sub pan. long.* *Sub pan. transv.* *T-beams long.* *T-beams transv.*	Plates *Long. plates* *Transv. plates* *Curved plates*	Main panels *Straight decks* *Straight long. pan.* *Straight transv. pan.* *Shell pan.*	Small parts	Small parts
Profiles	Profiles *Sub pan. long.* *Sub pan. transv.* *T-beams long.* *T-beams transv.*	Profiles *Long. profiles* *Transv. profiles* *Curved profiles*	Sub panels *Sub panels* *T-beams*		
		Sub panels *Sub pan. long.* *Sub pan. transv.* *T-beams long.* *T-beams transv.*	Curved plates		
			Curved profiles		
			Small parts		

Figure 6.5: Specified product line based on hull breakdown [10]

Process product input entities

According to the Blueprint Production [10] there are two types of sub panels. The first type is composed out of one plate and one profile, further noted as T-beam. The second type is composed out of one plate and several profiles, further noted as plate-sub-panel. In Figure 6.5 an additional division is made between longitudinal and transverse T-beams and sub-panels.

According to the Blueprint Production [10] a main panel consists out of several panels, several profiles and some sub panels. In the current situation both a line setup, having six stations, and areas for classical main panel assembly are present. The question which setup is more efficient is left out of scope in this report. At both assembly stations several works steps can be recognised, namely [2]:

1. One-sided welding
2. Cutting / marking / blasting
3. Profile mounting
4. Fillet welding
5. Web mounting
6. Web welding

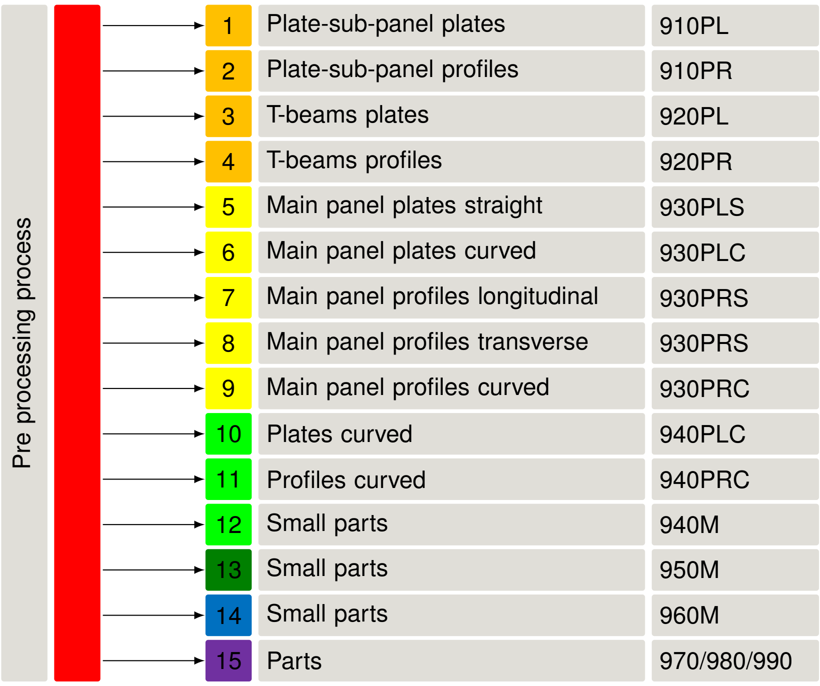
At work step 1 main panel plates are required. At work step 3 longitudinal profiles are required, on cassettes/racks so that the profile mounting gantry can easily place them. At work step 5 the transverse profiles are mounted. Hence a distinction in longitudinal and transverse profiles is required as they are mounted on different locations and with different procedures. Moreover the sub panels are mounted at this work step.

Figure 6.5 distinguishes also a difference in longitudinal, transverse and curved main panels. This takes into account the current DSGa job preparation performance, because in the current situation some main panels are defined such that transverse welds need to be made, which cannot be done on the main panel line. Those main panels are then assembled on the classical panel line. Curved main panels are currently assembled in both main panel assembly (classical way) and section assembly.

In section assembly the sub and main panels are assembled to sections. Several sections types exist such as closed/open and straight/curved. This implies that not all section assembly processes require curved parts. If they are required they are considered to be product input, according to the Blueprint Production [10]. The last distinguished group contains all “small” parts mounted on the connections of the assemblies. All parts need to be arrived before section assembly can start due to the absence of clear mounting constraints.

Lean Manufacturing review

From a Lean Manufacturing perspective the definition of product lines based on customer demand is promising as it relates the distinction of product lines to the next process part demand. The feasible options are summarised in Figure 6.6.



1	Plate-sub-panel plates	910PL
2	Plate-sub-panel profiles	910PR
3	T-beams plates	920PL
4	T-beams profiles	920PR
5	Main panel plates straight	930PLS
6	Main panel plates curved	930PLC
7	Main panel profiles longitudinal	930PRS
8	Main panel profiles transverse	930PRS
9	Main panel profiles curved	930PRC
10	Plates curved	940PLC
11	Profiles curved	940PRC
12	Small parts	940M
13	Small parts	950M
14	Small parts	960M
15	Parts	970/980/990

Figure 6.6: Defined product lines

The distinction in longitudinal and transverse profiles for main panel assembly make sense because they are mounted in different phases of the assembly. However since no part information is available implementation is not possible. As the sub panels are mounted within the same work step there is no specific need to separate the longitudinal and transverse ones. By the nature of the product advocates for the distinction of plate-sub-panel and T-beam demands. It was already described that the distinction between longitudinal and transverse main panels is driven by improper job preparation mainly. When applying proper Design For Production this distinction disappears [2]. Hence it is not a promising concept for further implementation. Following the GT idea the distinction between straight and curved parts is favourable. This applies for both the demand from main panel assembly and section assembly.

The feasible options are listed and coded as depicted in the Figure. The supplements PL and PR indicate plate and profile parts respectively. The supplements S and C indicate straight and curved parts respectively. The supplement M indicates small parts. The parts for outfitting have either code 970 (small steel workshop), 980 (mechanical workshop) or 990 (subcontractors). 970/980/990 parts are not pre-processed in the regular process.

Quantification of product line contribution

Appendix G.2 the approach to obtain the contribution of each product line is described. In Table 6.1 the normalised product lines based on routines and customer demands are presented.

In shipbuilding the size of the parts can differ significantly. For this reason a closer look is taken at small and large parts individually. Insight in the contributions of small and large parts is given in Tables G.2 to G.4. Whether additional distinctions can be made on part attributes is discussed in the next Section, Section 6.2.3.

Creating a individual flows for each customer is not feasible, because of minor contribution of some flows. A lot of resource duplication would be required. More important the nesting of the parts becomes critical. For nesting small parts and large parts need to be combined in a plate to improve the scrap ratio. Subsequently it is promising to combine some product lines based on the part size. For example the large main panel plates can be nested together with all smaller parts for the sub contractors. Similarly the product lines of curved parts (930PLC and 940PLC) can be combined.

Table 6.1: Product line quantification, all parts

ALL PARTS NUMBER NORMLISED																	
Routing/Endbuffer	910PL	910PR	920PL	920PR	930PLS	930PLC	930PRS	930PRC	940PLC	940PRC	940M	950M	960M	9++PL	9++PR	9++SM	Total
C	0.01	0.11	0.01	0.02	0.02		0.00				0.03	0.00	0.01	0.00		0.02	0.24
C-B/T	0.00				0.00						0.00			0.00			0.00
C-B/T-F						0.00			0.00								0.00
C-B/T-G	0.00		0.00											0.00			0.00
C-B/T-G-Fl																	
C-F	0.00					0.01			0.01					0.00			0.02
C-F-G								0.02	0.00	0.01							0.02
C-G	0.06	0.09	0.01				0.10				0.35	0.00	0.07	0.01		0.00	0.69
C-G-Fl	0.00										0.01		0.00				0.02
C-Fl	0.00	0.00		0.00			0.00				0.01	0.00	0.00	0.00			0.01
Total	0.08	0.20	0.02	0.02	0.02	0.01	0.10	0.02	0.01	0.01	0.39	0.01	0.08	0.01		0.02	1.00

ALL PARTS WEIGHT NORMLISED																	
Routing/Endbuffer	910PL	910PR	920PL	920PR	930PLS	930PLC	930PRS	930PRC	940PLC	940PRC	940M	950M	960M	9++PL	9++PR	9++SM	Total
C	0.06	0.02	0.01	0.01	0.32		0.00				0.06	0.00	0.00	0.00		0.01	0.48
C-B/T	0.00				0.01						0.00			0.00			0.01
C-B/T-F						0.00			0.00								0.00
C-B/T-G	0.00		0.00											0.00			0.01
C-B/T-G-Fl																	
C-F	0.00					0.08			0.05					0.00			0.14
C-F-G								0.01	0.00	0.00							0.02
C-G	0.14	0.02	0.01				0.05				0.08	0.00	0.00	0.00		0.00	0.32
C-G-Fl	0.01										0.00		0.00				0.01
C-Fl	0.01	0.00		0.00			0.00				0.00	0.00	0.00	0.00			0.01
Total	0.22	0.04	0.03	0.01	0.32	0.09	0.05	0.01	0.05	0.00	0.14	0.00	0.01	0.01		0.01	1.00

6.2.3. Product lines based on part attributes

Generally the following part attributes can be thought of, weight, dimension, part type, processing type (bevelling, tapering, forming 2D, forming 3D, grinding and flanging). They are addressed.

Weight attribute

A feasible and promising option is to make different product lines for parts under and above 20kg, because of the logistic implication. In Figure 6.7 the cumulative number of parts versus weight is plotted, which shows that 71% of the parts have a weight less/equal than 20kg. This concerns the cutting - grinding (C-G) routine mainly. Hence it makes sense to delineate that as a separate flow.

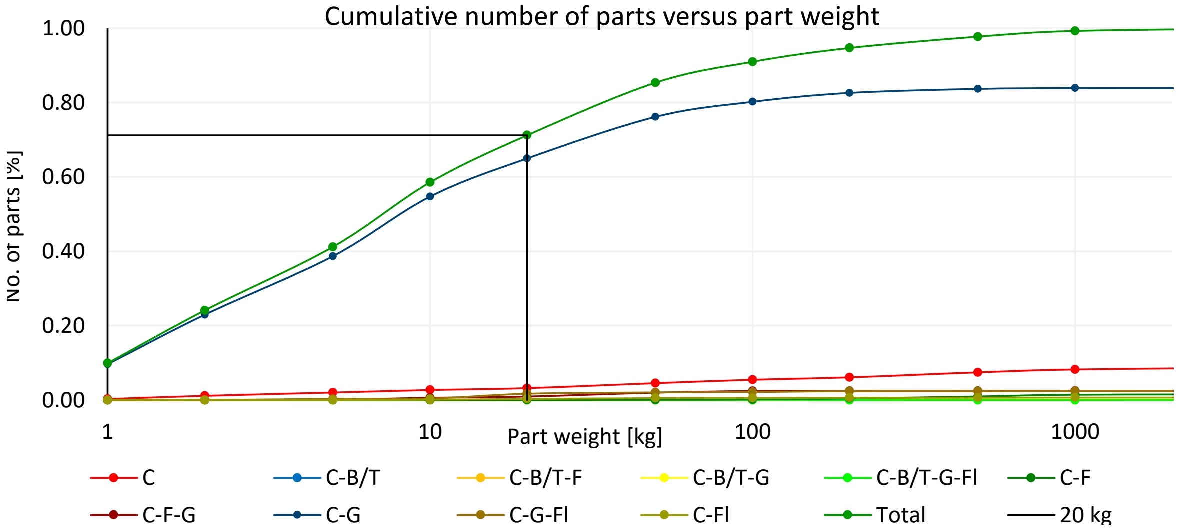


Figure 6.7: Cumulative parts mass distribution - as is process

Theoretically a part of twice that weight could be carried by two workers. This possibility is concerned not to be very likely in DSGa pre-processing and therefore excluded. For parts above 20kg lifting mechanisms are required like cranes.

Part type attribute

It is surfaced that flat bars can be cut from both steel plate and profiles. When flat bars are cut from profiles less grinding is required as the profile cutting robot already grinds the edges automatically (Section 3.5.2). The current profile cutting robot has enough capacity to cut the flat bars as well, as defined in Appendix G.3. It should be noted that the raw material is more expensive when cutting flat bars from profiles instead of plates. The logistic advantage makes it a promising option.
About 20% of the parts do not require grinding anymore, and can directly be sorted after cutting. Hence the number of grinding meters can be reduced by 40%. A detailed Figure is presented in Figure G.1. Flat bars do not require forming as they are hardly used in curved areas, since they are most often used in double bottoms or as t-beams. So only the C-G contribution changes.

Processing type attribute

Analysis of the bevelling and tapering part attributes points out that less than 1% of the part require bevelling or tapering. All of these parts are heavier than 20kg. About half of these parts are thick parts. Consequently it can be stated that the contribution of these flows is rather minor. Furthermore it is a work step which does not require significant fixed resources.

The distinction between curved and straight panels was already introduced in Section 6.2.2, which also is a distinction based on the routines and part attributes. A 2D or 3D form requirement initiates the separation of product lines. The drawback is that duplicate resources are required for obtaining a 2D form. This has an implication on the investment side, but also on the space utilisation aspect, because forming machines require much work space.

Concerning flanging about 70% of the parts is lighter than 20kg, which is illustrated in Figure 6.8. These parts can be loaded on the brake press more easily. Based on this attribute a separation of both flows can be advised. As said the duplication of resources is less an issue. The difference between flanging and buckling has an implication on the process times only.

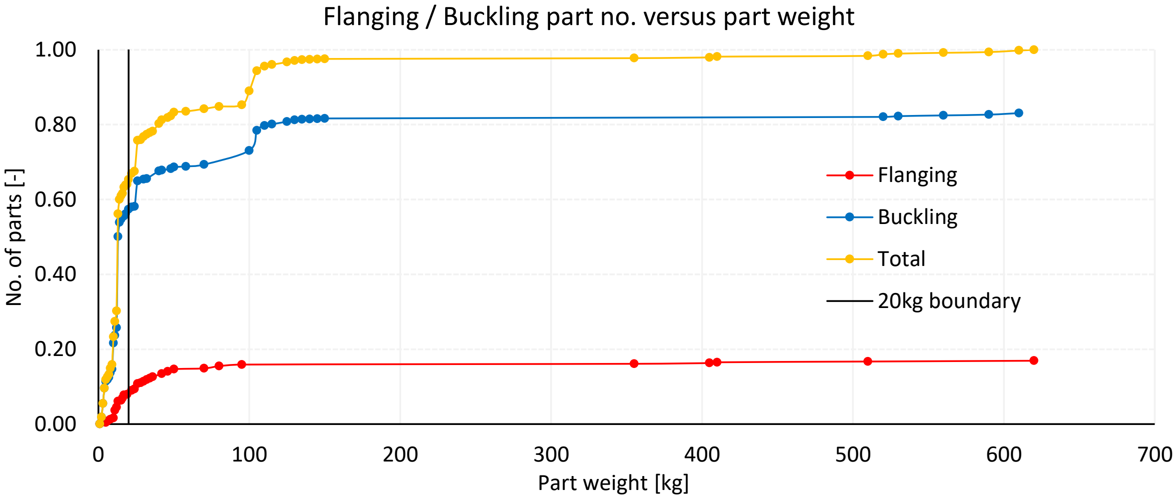


Figure 6.8: Cumulative parts mass distribution - part for flanging/buckling

6.2.4. Summary

Three different approaches to define product lines are described, based on routines, customer demands and part attributes. The application of all product lines is not entire feasible or advisable. When combining the product lines on customer demand a balance between small and large parts need to be enhanced, else the nesting efficiency will definitely drop significantly.

The bevelling/tapering flows contribute only minor and do not require very fixed resources. Hence it is a good option to integrate it in either cutting or grinding. Because grinding does not require much fixed resources either it can be easily separated for different product lines. Concerning grinding the separation between light and heavy parts makes, because of the handling implication.

The analysis of product lanes based on routines showed that the grinding-flanging routine occurs often. Hence it makes sense to combined them. As there are several brake presses available it possible to define such a station for different combinations of product lines. For flanging the product line on weight attributes makes sense as well because the both flows are relatively large.

It does not make sense to create two forming stations, because forming resources are expensive and the flow is numerically rather small. This drives product line combination as well.

For the product lines bases on routines the sorting takes place at the end of the pre-processing process. Contrary for product lines based on customer demand the sorting takes place directly after cutting. For a combination of both product lines different sorting points are required.

6.3. Step 4. Establish pull

In Section 6.1.3 Lean Manufacturing framework principles related to the timing of flows in shipbuilding are described. Three main principles are introduced. These are summarised in Figure 6.9 and described in the presented Sections.

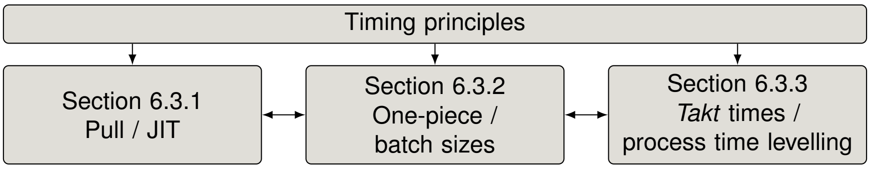


Figure 6.9: Structure description timing principles

6.3.1. Establish Just In Time arrival

The current state analysis in Chapter 3 shows that the current process functions far from Just-In-Time. For improvement the moment of customer demand is required. Attempting to enable the proper definition of customer demand scope limitations are observed. Furthermore some limitations by the current yard production planning are present. They are described first. Secondly a pragmatic approach to enable a JIT flow for quantification purposes is proposed, for the purpose of this thesis.

Scope and yard production planning limitations

The moments of customer demands are linked to each other and come together in the finalisation of the entire hull. It is best to delineate all customers demand moments from that point. In Section 1.2.2 it is outlined that only the pre-processing process is concerned as that process is the first in line. When applying the Lean Manufacturing framework this is a significant drawback. Hence a clear limitation of this scope is observed.

In order to pre-process the parts conform the customer pull, the 'pull point in time' needs to be known. For this the current production planning can be used. According to the Damen Yard Support department [17] this option does not suffice as DSGa does not work with yard production plannings but with individual project production plannings. Furthermore these plannings contain planned imputed, waiting times, making duration determination critical [22]. The drawback of using these to define the customer demand is that a non-optimised situation is taken as pull reference.

Based on planning and production logic a fictitious planning can be determined. Doing so the imputed waiting time issue can be mitigated. However this approach relies strong on the definition of all processes or work steps. Those processes cannot be defined precisely within the scope of this study, hence using them to derive a very detailed planning creates uncertainty about being realistic.

Pragmatic approach for JIT arrival

The JIT principle entails two aspects. The first aspect concerns the process of the customer. That process can only start when all parts are arrived. As explained difficulty exist to define that process. An approximation based on annual measures could be made. Annual measures show that approximately 500 ship sections are assembled each year [19]. In other words each shift a section needs to be produced and that in each shift a number of sub panels needs to be generated. The section size and characteristics should be incorporated since those effect the demand of specific parts (formed/main panels etc.). The start point of this approach is a levelled flow of the customer processes as well.
The second aspect concerns the process of the supplier. That process is only delivering just in time when all parts of a customer demand batch are finished and collected. This second aspect is focused on in this study. Hence the assumption is made that the next process can start when the entire customer demand batch is finished and entered the end buffer. The drawback of this approach is that the customer process performance also has an influence on the buffer space.

6.3.2. Establish one piece flow

This Lean principle is also related to the timing of flow because it concerns the way parts are created, transported or arriving. First the batch sizes of the part processing and plate cutting are dealt with. Then the profile cutting batch size is dealt with. Fourth the customer demand batch is discussed. Related to that are the different part thicknesses within a customer demand point are discussed.

Processing batch size

In Section 3.2.2 and Section 3.5.2 it is acknowledged that cutting in cutting groups and processing on section level implies a significant amount of inventory waste. Mitigating this type of waste is enabled by implementing the one piece flow paradigm.
First the processing batch is considered since it is closest to the customer. Batch processing implies that the first parts have to wait until the entire batch is processed before they can move to the next process. This waiting is wasteful and can be reduced by reducing the batch size.
To what extend they need to be reduced depends on the supplying work step as well. For the transfers between bevelling, grinding, and flanging the batch size can be theoretically and practically be one, because the parts are processed individually.

When the batch size is reduced significantly the transport requirements increase, because more moves are performed. Hence an implication on the transportation resources arise, making the transport distances and transfers more stringent. A balance needs to be found.

Plate cutting batch size

In the current situation parts are cut in cutting groups of about 100-400tons. Section 5.1 already underlined the effect on the waiting and inventory waste. In a cutting group the parts for several sections are cut at the time. Hence much sorting space is required to store all transport entities for all sections. Three options are foreseen to reduce the cutting batch:

1. *Less sections in a cutting group:* When less sections are cut in a cutting group less space is required for sorting after cutting. From a space utilisation perspective this is positive. Furthermore sorting can be done faster because there are less part destinations, enabling more parallel sorting. Cutting less sections in a cutting group has a negative effect of the quality of the nesting.
   The processing stations still receive a batch of all parts of a section. This is not preferred because then still the batch size flow in the processing stations is not improved, as stated above.
2. *Less plates in a cutting group:* When the number of plates in a cutting group is reduced the waiting time before the entire batch is cut becomes shorter and inventory is reduced. Furthermore the nesting does not need to be changed. However the space utilisation is not necessarily reduced because the same number of sections can be cut, resulting in the same number of transport equipment on the sorting space. Still the throughput can be significantly increased because the parts move to the next station faster.
   The batch size of the subsequent processing stations is decreased, which has a positive effect on their performance. Reverse reasoning from the reduction of processing batch sizes makes the reduction of cutting batches (entire section) logic. This option can ultimately be reduced to the number of parts which originate from one plate. That implies that one plate is cut and the generated parts directly move to the next stations.
   Even the size of the plates can theoretically be reduced. Traditionally the raw plate size is chosen to be as big as possible in order to enable larger sized parts. This is preferred from assembly perspective. When the parts are larger less parts need to be assembled, less welding hours are required, etc. Furthermore nesting can be done more efficient when compared to smaller plates. For having an effect on the means of transportation the parts should become lighter than 20kg. This is not very likely. Therefore the plate size is not concerned as a variable parameter in this study.
3. *Less sections and less plates in a cutting group:* This option is a combination of option 1 and 2. It enables improved throughput as the batches are smaller and move faster. Besides it requires less space because only a few sections are cut in a cutting group. The main drawback is that the nesting efficiency can drop.

The current plate nestings contain on average about 30 parts per plate. At maximum about 200 parts can originate from one plate. Hence reducing the batch size to the number of parts which can be cut from one plate does not result in a stable levelled flow because the parts differ in size.
The variability is influenced by proper nesting. This makes nesting the most effective (but also delicate) part of reducing the batch sizes. The number of parts cut from one plate also affects the cutting program duration, because the cutting program duration is positively related to the number of parts cut from one plate. Keeping the number of parts from one plate more constant the program duration will be more constant too. This is related to the Lean takt time principle, which is described later.

Profile cutting batch size

The notions above can be applied to the profile flows too. When limiting the batch size to the number of profiles which can be cut from one profile the batch size is also significantly reduced. However also the implication on the transport increases. On average seven profiles are cut from a raw profile. At maximum about 30 parts are cut.
The profile batch is smaller much smaller than the plate cutting batch. Furthermore the profile cutting program is about 5-6 times shorter. Smaller batches sizes introduce more flexibility. The higher flexibility of profile cutting can be used to enable the JIT principle application. Whether this flexibility is required is driven by the customer demand. Hence specific attention is paid to that in the next paragraph.

Customer demand batch

The customer demand batches are different from the part generation batches. Furthermore they differ per customer. In Figure 6.10 the number of plate parts per customer demand point are plot. The customer demands are defined by section, panel name and end buffer. The unit on the horizontal axis is number of customer demands for one ASD and PSV. The entire portfolio can be build up out those customer demand points. The similarity of the some data points (1000-2900) originates from the definition of the PSV data set, which is specifically described in Section 2.3.1 and Appendix A.2. The colours of the data point related to different customer demand group, being in order: plate-sub-panel-, t-beam-, main panel-, section-, block-, hull assembly and external outfitting demands.

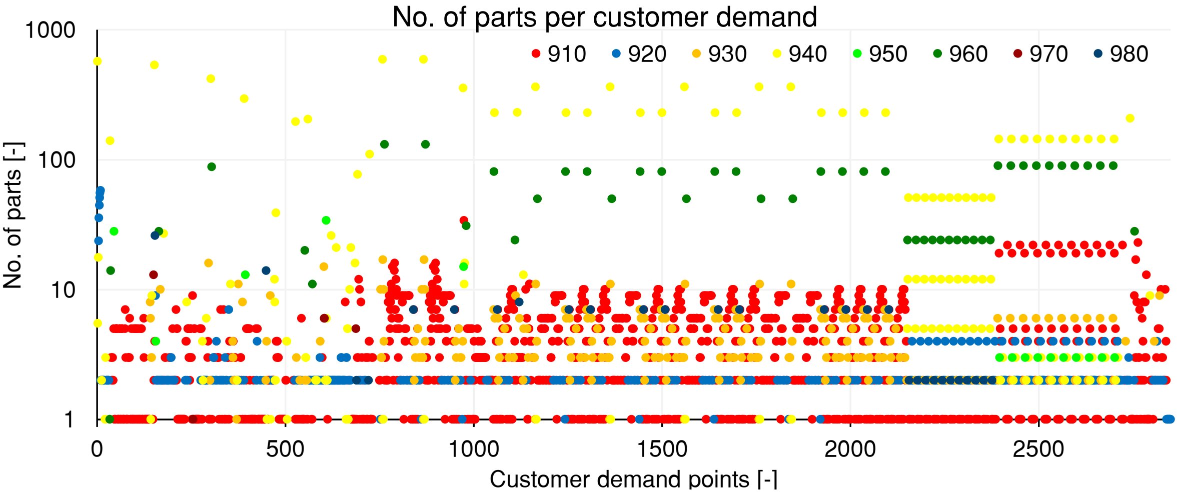


Figure 6.10: Plot of number of parts per customer demand

The results are conform the definitions of the end buffers in Section 6.2.2. The section assembly (940) batches are especially large, because there are no specific assembly constraints and thus all parts are required at once. Such there is no specific need to enhance a specific 'one-piece-flow' variant.
To provide a coherent overview also the cumulative weight of the parts per customer demand are plot, in Figure G.2. The cumulative weight is positively related to the required plate area.

Whether all parts for one customer demand point can be generated from the same raw plate/profile depends on the available nest-able area, material grade and the part thicknesses. This question makes sense as it limits the minimum batch size.

1. The first notion is a capacity problem. For even the thinnest plate thickness still all parts for sub panel assembly (910/920) can be cut from one plate, weight wise. This also applies the block assembly (950) code and higher. The customer demands for main panel and section assembly can weight wise not be cut from one single plate. The area wise question cannot be addressed because insufficient information is available in the product data.
2. Concerning the material grade; product data analysis shows that the vast majority of parts has material grade A. The other parts are thick plates (>30mm), which are only a few whatsoever. Therefore also this notion is not critical.
3. The third phenomena (thickness) is inevitable due to the physical characteristics of the parts. Therefore specific attention is paid to this notion.

Different part thicknesses within customer demand

In Figure 6.11 the number of part thicknesses per customer demand are plot. On the horizontally axis the same data is plot as in the Figure above. On the vertical axis the number of part thicknesses per customer demand are plot. Only the parts which are cut from plate are considered in this analysis, because of cutting batch flexibility.
Especially the customer demands for with the thickness is the only limiting factor are considered (910/920). About half of the customer demands require parts with more than one thickness. Waiting is induced as not all parts can arrive at the same time (JIT).

Figure 6.11: Plate nestings of plates and profiles (Flat bars) - As-Is situation

From a Lean Manufacturing perspective it is preferred that all parts for a customer are nested in the same raw plate so that sorting and transport becomes more straightforward and less intermediate inventory is required. The fact that a customer demand point requires parts with several thicknesses complicates the nesting significantly.

Applying 'Design For Production' can solve this, by reducing the number of thicknesses in a customer demand batch. Within the scope of this research this option is not concerned. It is recommended to further study the implication of such a decision.

Another solution is found by studying the possibility to cut flat bar plate parts from raw profiles. The cutting time of a profile is shorter (factor 5/6) than the cutting time of a plate so different thicknesses can be cut in the same plate 'instant'. Furthermore the implication on nesting is expected to be minor, since flat bars are small and the size is not flexible. The drawback is that more flows are created as the parts are now cut at different stations. In Figure 6.12 the number of part thicknesses per customer demand points are plot again. However now the flat bar parts are excluded from the data set.

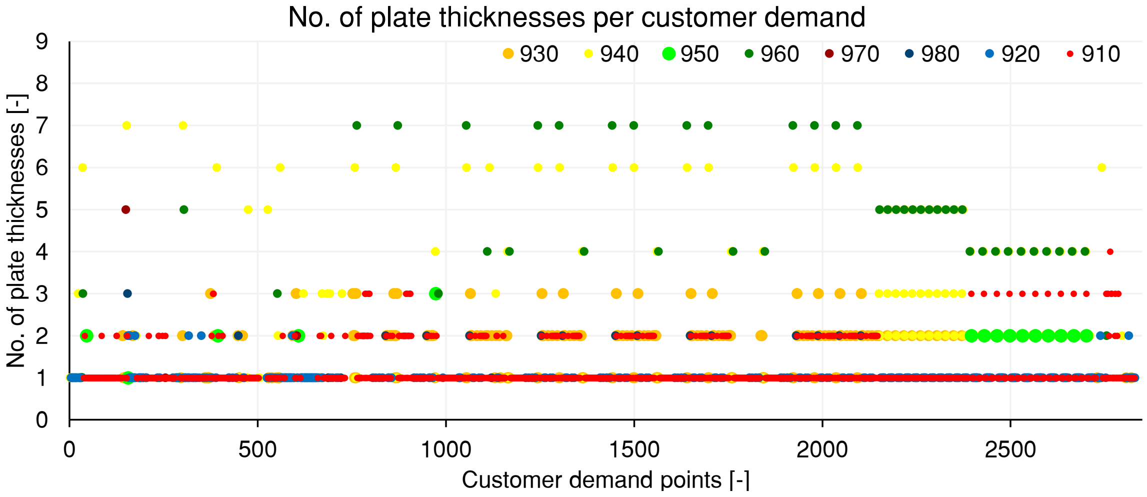


Figure 6.12: Plate nestings of plates only

A significant reduction (40%) of part thicknesses per customer demand is gained. Hence with cutting flat bars on the profile cutting line, nesting of plates becomes much less critical when generating all customer demand parts instantaneously.

Conclusively, it is theoretically possible to ensure JIT arrival of all parts for a sub panel. Whether this works in practise depends on the correct implementation. Furthermore it needs to be investigated what the effect on the transport is. It is expected that this is extensive because the number of transports increases significantly. This drives a new layout design. Furthermore still some demands with several plate thicknesses exist. Ideally they should be cut one after the other, in order to minimise the time difference between the generations. Cutting different thicknesses after each other implies more changeover time. When a cutting station contains different cutting machines this can be more easily mitigated. Recalling the flexibility of the profile cutting line compared to the plate cutting stations recalls the notion of *takt times*. That is described next.

6.3.3. Establish takt times

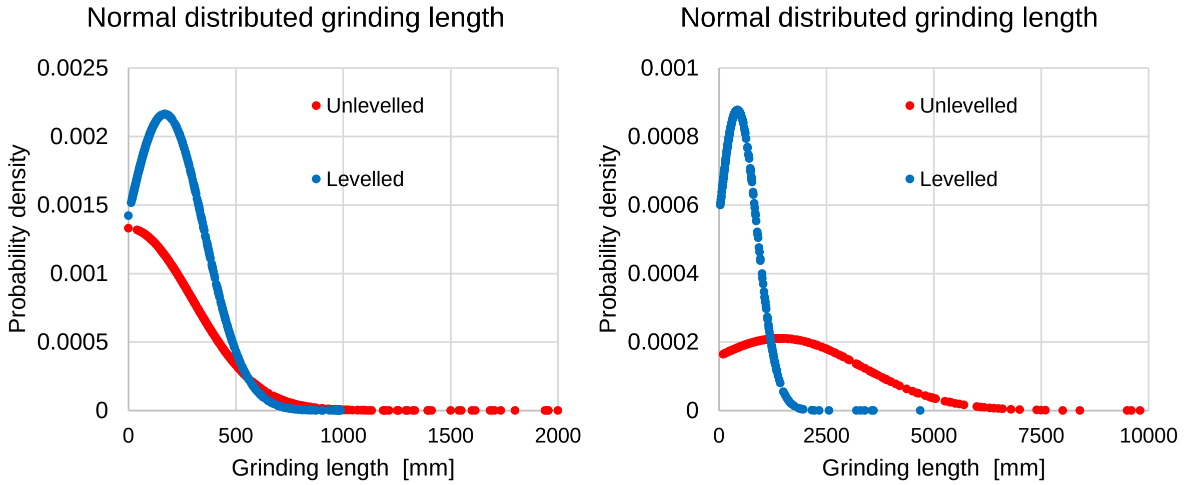
The takt time sets the pace at which parts are generated and processed. The principle can be implemented on several process organisation levels. The lowest possible level for applying is the part level, which is described first. Subsequently options to combine takt times to batches are discussed.

Part level

Applying takt times on part level implies that each part is processed for the same time. By specific allocation of resources the process time variability can be reduced. This is only possible when the process time can be speed up by parallel working.
As the forming and flanging process concerns the deployment of a specific machines these work steps cannot be accelerated, without duplicating the number of brake presses. This would have a relative large effect on investment figures. Hence applying takt times for these work steps is mainly possible by the rate at which the parts are supplied. This can mainly be determined by the pace at which parts are cut. Such Takt times can be approached by levelling the part generations.

The bevelling and tapering processes could be speed up by deploying more semi automatic tractors. The effect of a proper takt time implementation for the bevelling/tapering process is expected to be rather minor as only a very limited amount of parts are to be bevelled/tapered. The grinding work step could be speed up by deploying more workers to one work piece. As this flow is rather significant it is investigated whether takt times can be applied here.

Because the grinding setup times are negligible small the grinding length is the main attribute contributing to the total value added time. Also a logistic contribution is observed, because small parts can be easily turned, compared to large parts. In Figure 6.13 the normal distribution of the grinding lengths are plot. This is done for the small and large parts separately in Figure 6.13a and Figure 6.13b respectively.



(a) Small parts data set

(b) Large parts data set

Figure 6.13: Normal distributed grinding length plotted for data sets

Conform Lean Manufacturing principle, outlined in Section 6.1 the flow can be levelled by applying more resources. Specific to grinding it applies that more worker can be assigned to one part. The possible assignment of workers is dictated by the grinding length and limited by the part area [80].
For the small parts data set one or two workers can be assigned to one part. For the large parts data set three to six workers can be assigned to one parts. These assignments are based on safety measures [80]. Based on these assignments the grinding lengths are adapted. The normal distribution of the adapted values are presented in Figure 6.13 in blue.
Conclusively, the blue distribution shows a significant peak increase compared to the red distribution, which is implies more levelling. The effect is largest for the large parts because more workers can be assigned to one part as the area constraint plays a smaller role.

As said earlier the customer demand batch needs to be considered when defining batch sizes. In Figure 6.14 the number of parts per end buffer for the two sets are counted. The parts in the small parts data set mainly go to section assembly end buffer 940M. This end buffer has a batch requirement as explained ealier. Hence the requirement for takt times to the small parts data set is less stringent.

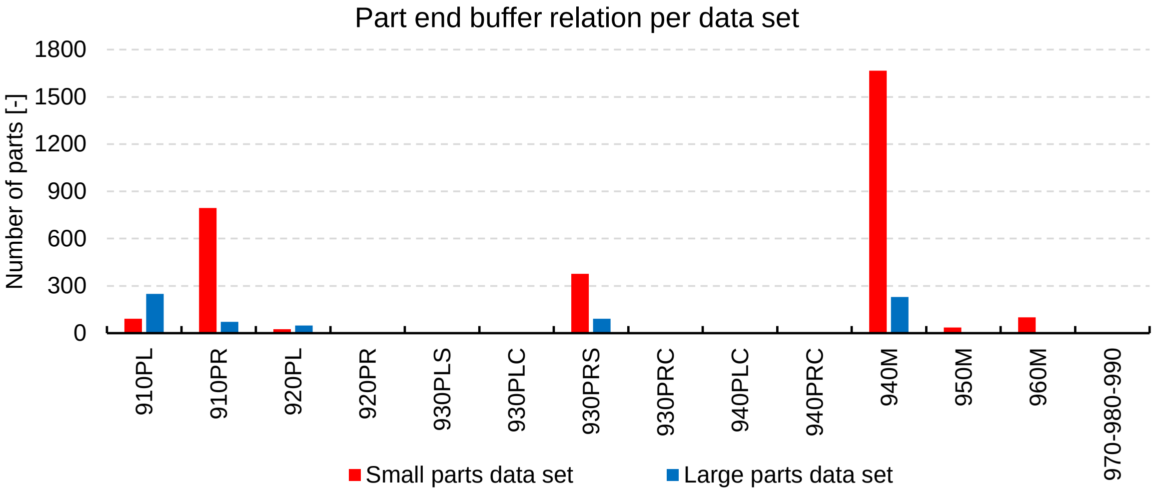


Figure 6.14: Data set end buffer relation

Resuming, when checking the ability to level the flow by implementing takt times on part level, it outlined that this is mainly possible for large parts which require grinding. For the other pre-processing processes the establishment of takt times is less obvious. For forming and flanging a levelled production flow can be better established by a levelled generation of parts. Whether takt times can be applied to batches is discussed in the next Section.

Combining takt times to batch sizes
The cutting time is positive related to the number of parts cut from a plate. From that perspective it is advocated to cut an equally number of parts from a plate. The number of parts is not the only parameter in the cutting program duration, because also the cutting length plays a large role.
Cutting an equal number of parts is, due to the high part variability, not entirely feasible. Still it should be one of the conditions when nesting the parts. The variability of plate cutting durations can be levelled over a number of plates. Doing so longer and shorter durations are levelling each other.

The generation of pace of plate parts and profile parts has to be related in order to enhance the JIT principle, as noted in Section 6.3.2. Such relation can be found in the establishment of takt times. Hence takt times can also be applied on higher hierarchical levels.
Forming 3D curved plates takes about 40 minutes per part [59]. Hence the pace of processing to be formed parts is unequal to the takt time at which parts are generated (approx. 1 hour per plate). In order to combine both takt times of the cutting stations and the forming stations not all plate nestings should entail to be formed parts, in order to not let them waiting. When nesting the parts the takt times of the subsequent stages need to be incorporated.

6.3.4. Summary

The application of the JIT principle is investigated. Using the current yard production planning for applying the pull mechanism is not useful. For quantifying the performance increase when applying JIT, the pre-processing aspect is concerned mainly. Related to the JIT principle is the batch size in which the parts are demanded. Different batch sizes are defined by the generation of parts and the demand of parts.

Reducing the cutting group batch size is a promising concept to reduce the inventory waste. Theoretically the lowest level of reducing the cutting group batch size is the size of one plate. However this has an implication on the transportation requirement. Hence a balance needs to be obtained. The profile cutting station generates parts in smaller batches than the plate cutting stations. Hence it is better able to enable the JIT principle.
The customer demand batches are different from the batches in which they can be generated. The plate capacity and thickness play the main role in the batch in which parts are generated. By cutting flat bar profiles on the profile cutting line the flexibility of the profile cutting line can be used and the implication of different thicknesses is reduced significantly.

Related to this flexibility is the takt time principle, which is discussed third. First this application on part level is discussed. Assigning multiple resources in order to create a stable takt time only makes sense for the grinding work step of large parts. Then the takt time application is related to the batch sizes. It is found that coordination of more flexible stations is required in order to match them with the pace of the other stations. The basis of proper takt time establishment in found in the nesting of parts.

6.4. Improvement strategies delineation

The reasoning discussed in the previous Sections comes together in order to extract practical improvement strategies. This is visualised in Figure 6.15. The points of interest resulting from the previous discussion are listed. Global, Lean improvements are initiated by means of the flow related notions. Those concern the reduction of batch size and establishment of product lines mainly. Those will be leading in the next Chapter. Other, more local applicable notions are listed as well, which for example concern the improvement of the cutting or forming program duration. Obviously the local applicable notions can also be introduced solely and will result in an improved state.

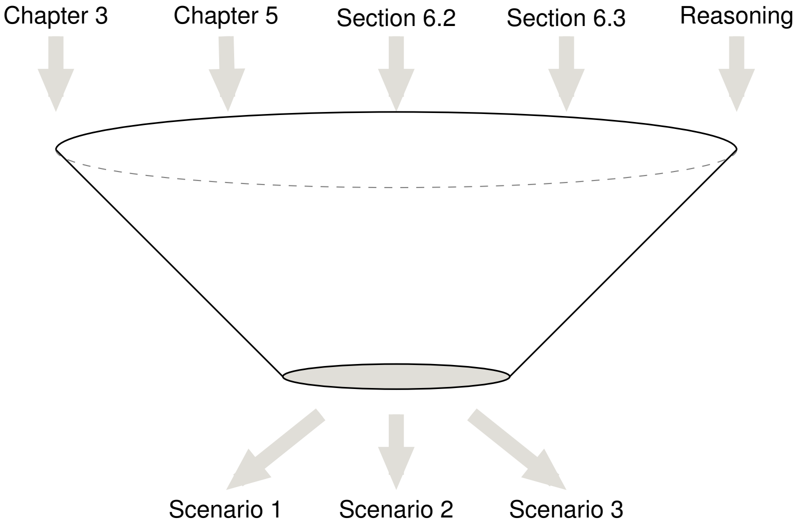


Figure 6.15: Converging step

First notions concerning the organisation of the process are made as they are key for all flows. Then notions concerning cutting and processing stations are presented, followed by those concerning buffer space and facility layout constraints. Last a summary of the related investment figures is presented.

Noteworthy is that not all improvements are directly related or initiated by the Lean Manufacturing framework. For each notion it is indicated whether they are directly linked (L), derived (D) or based on logic reasoning (R). These indicators are indicative only. Furthermore for some notions the supplement '-G' is provided to underline that it concerns a global effective improvement notion.
In the next Chapter most of the items are used for the definition of layouts and scenarios, starting with the improvement notions related to flow. Those lists will be referred to then. Moreover the investment figures will be used to define the investment related KPI's.

Concerning batch sizes

1	L-G	Maximum cutting group size	In order to minimise buffer space, decrease inventory, reduce sorting time, and create one-piece and pull flow the batch size in which the parts are 'generated' need to be reduced significantly. The minimum batch size is the number of part generated from one raw plate.
2	L-G	Nesting on customer demand	All parts of a customer need to be generated in a relative short period of time. So all parts for a sub panel customer demand should be cut from one plate (or two subsequent ones). Hence different plate thickness can be cut after each other, despite the increase in changeover times. Another notion is that the parts should be nested conform the pace of the subsequent processes. So not all to be formed parts in one nesting, as parts generation takes less time than forming.
3	L-G	Nesting levelled plates	The cutting program duration is positive related to the number of parts cut from one plate. For the creation of a levelled flow perspective it is advocated to cut an equal number of parts from one plate, so that the cutting program duration is more levelled. This also affects the arrival of parts at the other stations.
4	D-G	Combine product lines	Which customers need to be included into the plate nesting depends on the flows starting from the cutting stations. These flows are to be determined based on routines and customer demand. Table 6.1 provides a good overview concerning the contribution of each flow.

Concerning profile cutting and sorting

5	D-G	Cutting program duration	The cutting time of one profile on the profile cutting line is much less than cutting an entire plate at the plate cutting stations. Hence the profile cutting line can be used to enable the JIT principle much better than the plate cutting stations because it is more flexible. This effect is enhanced by the following notion.
6	D-G	Cutting flat bars from raw profiles	By cutting flat bar profiles from raw profiles instead of raw plates the number of to be grinded parts can be reduced by 20%. This implies that the cumulative grinding length can be reduced by 40%. Secondly, when cutting flat bars from raw profiles the just in time arrival of parts for sub panel assembly can be much easier enhanced. Doing so all parts for a sub panel assembly customer demand can be cut in same 'instant'. The instant length is then determined by the plate cutting station.
7	R	Profile cutting line infeed outside	The profile cutting line infeed can be moved outside so that less transport handling is required to infeed the raw profiles.
8	L	Profile cutting line near end buffer	It observed the processed profiles are transported much to their customers. As the number of transports increases, by reducing the batch sizes, the transport transfers and distances need to be shortened.

Concerning plate cutting and sorting

9	L	Using present cutting machines	The waste analysis performed in Chapter 3 showed that rather much waste is present in the operation of the S1a-L3 cutting station, due to the synchronous cutting and water bed functionality. This last argument also applies to the S1a-L2 cutting station. Furthermore these cutting machines require relatively much space, when compared to newer cutting machines (e.g Microstep in S1). Balancing this drawback and the investment side is required.
10	D	Bevelling	Currently on the new cutting machines a bevel functionality is possible to bevel all kinds of bevels. The consideration to invest in additional bevelling functionalities will contribute only minor to the total process performance. Such additional bevel functionality costs about 75k euro [55].
11	L	Relation portals and cutting beds	The cutting bed size waste analysis and utilisation showed that the cutting beds are occupied by crane handling, scrap cutting and sorting by about 60%. In order to reduce this occupation percentage several options are possible. More cutting beds can be applied in order to increase the performance of the cutting portal.
12	R	Sorting beds	Elaborating on the previous point, the parts can also be directly offloaded from the cutting bed by a detailed magnetic yoke or gripper. Then the scrap can be cut and the parts sorted from that sorting bed.
13	R	Scrap cutting	The scrap cutting grid lines can be incorporated in the nesting files. This way the scrap can be directly picked up and loaded onto the scrap containers. This option requires handling by workers. Another option is to not cut the scrap grid at all but pick it by the crane and remove it as one piece. For this option the crane is used. Moreover the scrap stack occupies more space that the scrap containers.
14	D	Automatic signing	Conform the waste analysis in Chapter 3 automatic signing is to be incorporated in the cutting program. It enhances the generation of value. Besides it is faster than hand signing.
15	R	Automatic cranes	For (off) loading the plates onto the cutting bed an automatic crane can be used. The advantage of this it is less dependent on the human factor. Consequently less waiting is involved. The drawback is that financial figures are involved. An automatic crane cost about 750k euro [43].
16	D	Cutting machines positioning	Transverse transport of parts is to be avoided. Hence all parts which are generated in a S1a lane are to be processed in a S1a lane. Subsequently the question where to position the cutting machines depend on the customer demand per batch. Also the number of cutting machines per lane depend on this question.
17	R	Part sorting	When only a limited number of different flows are supplied per plate arrived on the sorting bed, sorting can be done easier. This way the crane can bring several parts at once to the correct destination. Besides less mistakes can be made when manually sorting.
18	R	Oxy fuel / plasma combination	Current cutting machines can be equipped with both an oxy fuel cutting and plasma cutting torch. Hence this machine can be used for double operations. This way flexibility is gained.

Concerning the forming station

19	R	Position roller press	The roller press in S1a is rather fixed foundation and is therefore expensive to move. Moving and re installing such a machine cost in the order of 100k euro [63]. The press requires a crane for unloading the parts.
20	R	Roller press work space	In order to form large plates the roller plate requires a work space of about 12x5m (width wise).

21	D	Roller pressure press re-positioning	The roller pressure press turns out to be a Lean replacement for the line heating station. This press is especially of use for forming 3D curvatures and needs to be replaced to the proximity of the roller press. This machine requires working cranes during the forming execution.
22	R	Roller pressure press work space	In order to form large plates the roller pressure press requires a work space of about 3x24m (length wise as perpendicular curvature is concerned).
23	R	Pressure press	This press is currently located in S1. The need to replace to S1a is determined by the performance of the S1a forming station. A combination of roller press and roller pressure press should be sufficient. This machine can be used for creating more forming capacity.
24	L	Different product lines	Defining different product lines for 2D and 3D curved plates result in the duplication of resources.

Concerning the grinding work step

25	L	Levelling of grinding work step	Section 6.2 shows that the processing time levelling of the grinding work step is possible for large parts by applying resources assignment.
26	L	Levelling of individual part transport	Section 6.2 shows that a distinction on part weight makes sense, as distinction whether or not to use cranes has an implication on the handling time.
27	R	Transport safety	Concerning transport in the grinding station is should be noted that no transportation is allowed above the worker's heads.
28	R	Cell structure	Bevelling and tapering are, similar to grinding, work bench driven processes, which do not required very specific resources. Furthermore those work steps are often required for the same parts. Hence combining the three work steps in a cell is appropriate.
29	R	Automisation	The grinding work step is an appropriate step for automisation. However the application of such systems needs to be balanced with the flexibility loss and investment side. Valuing the investments on basis of the current work force deployment costs automatic grinding is currently not very promising.

Concerning the flanging station

30	D	Resource duplication	Many customers demand flanged parts. As a result of that a number of flows contain the flanging work step. In S1a and in S1 a brake press for flanging is present. Hence brake presses can be dedicated to specific flows, to create a direct input - output relation. The investment cost of brake presses is in the order of 50k euro [26].
31	D	Crane requirement	For large parts working cranes are required to load the parts into the press. When dedicating specific cranes to the brake presses the idle time due to waiting can be reduced.

Concerning customer demand / end buffers

32	L	Infeed sub panel assembly (910/920)	The size is related to the extend nesting can be optimised. Ideally when applying the JIT principle to the sub panel assembly part requirement, the infeed buffer should be large enough to store all parts from two plates. This is because only the capacity problem is to be covered, as denoted in Section 6.3.2. Because of different thicknesses in a demand batch (non-ideal case) more space is required. Since they are small less stacking is possible and more floor space is required.
33	D	Infeed plates main panel (930PLS)	A larger infeed buffer for straight main panels (MP) is required because collecting a demand batch takes longer and they are relatively large. The plates for one main panel can be stacked.

34	D	Infeed curved plates main panel (930PLC)	Curved main panels require their own classical panel line. These areas can be shifted from the current section assembly facility to the freed space in the pre-processing facility.
35	D	Infeed profiles main panel assembly (930PRS)	The profiles for the main panels also need to arrived just in time. The position of the profile infeed buffer requires to be in the proximity of the main panel profile mounting station (about half way).
36	R	The main panel line re-positioning	Main panel line can be shift to the left, but cannot be shifted to another lane due do the section assembly logistic requirement.
37	R	End buffer section assembly (940)	Previous analysis showed that the customer demand of the section building process is a batch of parts. Hence more space is required for this specific end buffer.
38	R	End buffer block and hull assembly (950/960)	These parts are required in the block and hull assembly work steps and therefore require transportation to these facilities.
39	R	End buffer workshops	The parts for the mechanical workshop, small steel workshop and external suppliers are sorted for end buffers directly after cutting.

Concerning facility layout constraints

40	R	Width lanes in S1a	The width of the lanes in S1a is 28m. From a crane operating perspective this is a drawback. As the safety distance between two portals is about two meters only one crane can be operated on an area of 2x28m. Hence the proposition of half gantry cranes which cover only part of the lane width make sense.
41	R	Length lanes in S1a	The length of the lanes in S1a is 100m, which induces significant longitudinal movement. To limit the longitudinal transport and enhance the one piece principle is is beneficial to assembly parts as close to the origination position. Still longitudinal transport is required. Some possibilities are listed below.
42	R	Roller conveyor	Roller conveyors can be used to longitudinally transport parts/containers. The advantages of using roller conveyors are; that they can be used as intermediate buffers, that they do not intersect crane movements. Drawback are: space cannot be used else and intersection of conveyors is more difficult.
43	R	AGV's / carts / quick lifters forklifts	Carts can be used for more flexible longitudinal movement. Advantages are flexible transverse transport (across lanes), overtaking of parts, and temporary space use. Disadvantages are that they cannot be used as intermediates storages and more safety issues might be involved. To enable this the floor must be equalised.

Investment figures overview

The implementation of some improvement notions require financial investments as resource purchases or replacements are involved. In Table 6.2 the resource related investments are listed to enable better improvement notion selection and enable comparison between the current and future state. Only indicative measures are presented, based on educated approximations originating from contact with resource suppliers.

Table 6.2: Overview investment figures

Item	Investment [k€]	Item	Investment [k€]
Cutting machine	≈ 500	Transport crane	≈ 500
Working crane	≈ 200	Transverse conveyors	≈ 20
Longitudinal conveyors	≈ 20	Forming roller press replacement	≈ 100
Hand tool equipment	-	Workbenches	-

For the cutting machine figures the suppliers ESAB [27] and MicroStep [54] are contacted. Concerning cranes Konecranes [43] is approached. Furthermore companies involved with conveyors systems [74] and machinery re-installation [63] are contacted to obtain figures for investments in conveyors and re-installation of the roller press respectively. Detailed information would provide full commitment of suppliers and detailed requirement definition as well and is therefore to extensive for the purpose of this study.

6.5. Summary

In this Chapter the following research question is addressed: *What process improvement strategies can be proposed, for redesigning process, based on the Lean Manufacturing framework?*

The redesign element is based on the analysis presented in Chapter 3 and Chapter 5. Different deficiencies and waste types are outlined there. Literature poses several improvement options. Whether these are feasible and applicable for the DSGa case is determined subsequently in this Chapter. The concepts are either further outlined or abandoned. Finally the concepts and notions are collected and listed.

Product lines need to be defined in a way that both provides the benefits of mass production by repeated manufacturing of interim products and balances process flows by facilitation of continuous and uniform flows within manufacturing levels. The main drivers are the batch generation and demand, significant part variability and sorting routines reduction.
Product lines can be based on routines, customer demands and part attributes. It is not feasible to implement all of them due to implications like resource duplication and flow contributions. A distinction based on part weight makes sense for grinding and flanging. Merging several customer demand flows in a tapering-grinding-flanging routine flow succeeds. Positioning the specific customers close by enhances transport reduction.

It was already acknowledged that cutting and processing in large batches implies a significant amount of waste. Particular emphasis is put on the batch size reduction. For the transfers between bevelling, tapering, grinding and flanging the batch size can be reduced to one. By the nature of cutting this not possible. The number of sections and customer demands cut from one plate must be reduced to reduce the required sorting space and enable smooth flows. The ‘one-piece’ flow and Just-in-Time principle drive the instantaneously collection of a customer demand batch. The customer demand batches are different from the part generation batches because of nest-able area and part thicknesses. Especially the part thickness plays a large role because of the high number of related customer demands. Improvements are foreseen by cutting flat bars from profiles instead of plates. The flexibility of the profile cutting line compared to the plate cutting stations can be used to enable Just-in-Time deliveries.

Hence the implementation of the flow and timing principles is directly related to the parts generation, which makes part generation key for improvements. The implementation of these principles results in additional constraints on the nestings. Batch size reduction poses logistical implications, which effects need to be further analysed, because it enables the approaching of a true continuous flow. Furthermore local improvement notions are listed.

7

Scenario definition approach

In the previous Chapter several improvement strategies are outlined, resulting in a list with feasible advised notions. Specific attention is paid to global effective improvements in this study to enable process redesign, since they initiate major improvements.
The main contribution of this and the following Chapters is to provide quantitative argumentation about the effect of the flow improvements by implementing 'improved' nestings which initiate layout redesigns. For this purpose scenarios are defined which build on the improvement notions (global and local) resulting from Section 6.4. Hence the fourth research question is addressed: **What is the quantitative effect of the proposed improvement strategies in terms of space utilisation and throughput?**

First the effect of batch size reduction on the current situation is studied in Section 7.1, to provide insight into the effect of possible layout redesign choices and the related logistic implications. In Section 7.2 the feasibility of the additional nesting constraints is assessed qualitatively. Based on the feasibility three scenarios are defined, which are described and analysed in Chapter 8, Chapter 9 and Chapter 10 respectively. For those scenarios the output from Chapter 6 is used, which is shown in Figure 7.1.

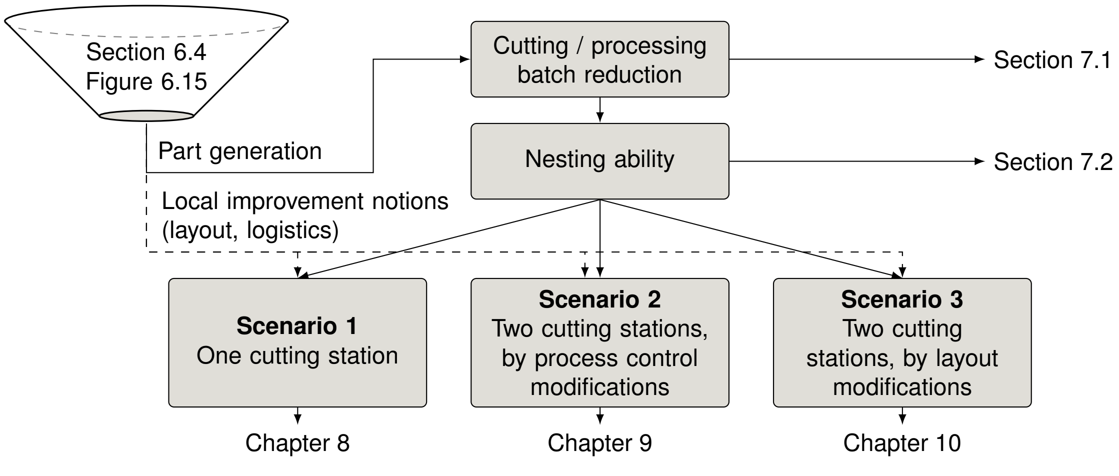


Figure 7.1: Flowchart of scenarios approach

7.1. Cutting group batch size experiment

The effect of reducing the batch size is studied to gain insight into the implication of the cutting group batch size on sorting inventory and transport. Moreover insight in the performance of the current state versus the future state layouts is provided. An experiment is described and its results are discussed.

7.1.1. Simulation experiment approach

In the current situation the cutting groups can contain 50 to 400tons, which is about 40-180 plates. Generally the larger cutting groups are of the PSV. Within this experiment the number of plates in a

'cutting group' is systematically reduced to: 40, 30, 20, 10, 5, 2. Since the nestings are not changed the processing batches are reduced as well. The sorting of customers is unleashed since the customer demand batches do not change. Such the processing process is estimated too positive, as some waiting is excluded. This is accepted because in future scenarios parts should be demanded in smaller batches as part of the pre-processing aspect of JIT implementation (Section 6.3.1).
The process is divided in two main processes namely; cutting-sorting and processing process. Their definitions are similar to the approach described in Section 5.1.2. In the processing process the work steps bevelling/tapering, grinding, flanging and forming are included. For this experiment those processes are not changed. The processing batches are randomly assigned to the part processing spaces. Attention has been paid to a performance based levelling of the workload.
For the purpose of this experiment the S1 model is used only. It shows a more direct relation between a cutting station and the processing work steps, is computationally faster than the S1a model and programmed by the author. For each experiment the number of required simulation runs should be repeated . Since that is time consuming only five runs are performed and averaged per experiment.

7.1.2. Simulation results

The mean process times are plot per experiment (similar to KPI_5 as defined in Section 2.3.4) in Figure 7.2, since this KPI captures the extend to which a continuous flow is approached. Horizontally the experiments are plot. Vertically the experiment mean process times are plot. Although the data has a large spread no outliers are observed. Therefore the mean is appropriate. On the secondary axis the number of 'processing batches' resulting from the cutting group reduction is given.

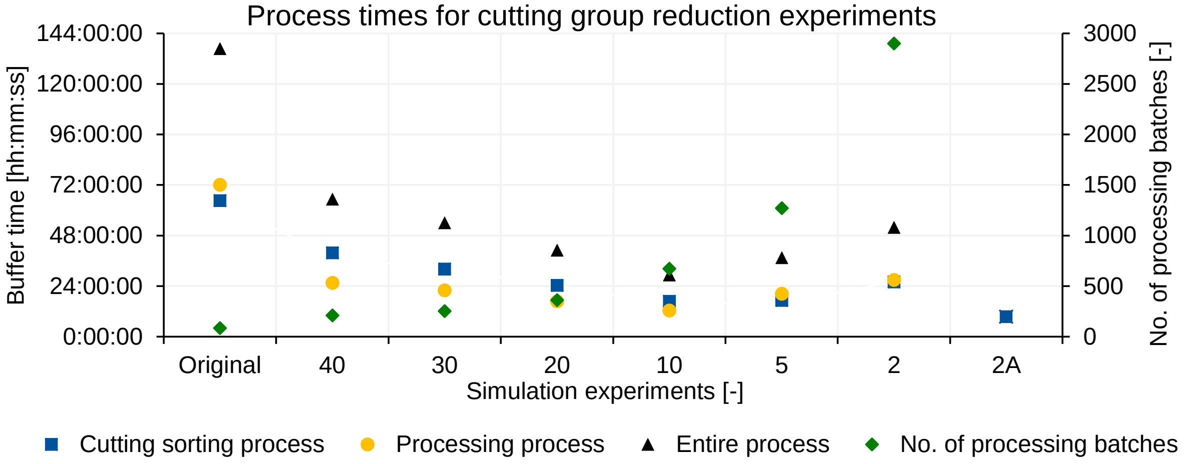


Figure 7.2: Process times for cutting group reduction experiments

The mean process times can be reduced significantly by reducing the cutting group batch size. Reducing the batch size smaller than 10 plates results in a relative increase again. For these experiments (5 and 2) the processing phase duration increases more than the cutting sorting phase duration, because of the logistic implications due the increase of number of transports. The increase of number of transports is derived from the number of processing batches (Figure 7.2). The transport resource utilisation are increased which is most stringent for the transverse carriage. The course of the experiments is presented in Figure H.1. The cutting-sorting phase duration is increased as well since the intermediate buffer is overloaded. Figure H.1 shows that due to increased transport requirements the time to finish the entire simulation increases, because more waiting occurs.

An additional simulation run (labelled experiment 2A in Figure 7.2) is performed to study the cutting sorting phase solely, by increasing the intermediate buffer capacities. The processing phase is not shown as it becomes disproportionately large. The cutting sorting phase duration declined further.
Conclusively, the reduction of the batch size is effective not only for the cutting station but also for the processing processes. A part throughput increase of factor 4 is enabled. The ability to reduce to cutting group batch size very much depends on the logistic flows. Finally, the sorting space is still significantly occupied as the same sorting on section level takes place, resulting from the current nestings.

7.2. Nesting implications

In Chapter 6 it is concluded that the implementation of Lean Manufacturing starts with the parts generation. The batch size experiment underlines this. For that reason particular attention to the feasibility of the nesting constraints is paid. First the additional constraints are summarised in Section 7.2.1. Then in Section 7.2.2 a qualitative feasibility check is performed. Based on that scenarios are defined.

7.2.1. Additional constraints on nesting

Several notions are listed in Chapter 6:

1) Conform the ‘one-piece’ flow principle, the number of different sections per end buffer nested in one plate should be reduced. It will result in reduced sorting time, less buffer space requirement and shorter finalisation of one customer demand batch (more continuous).

2) In order to enhance flow and reduce buffer space all parts for a customer demand batch need to be cut ‘instantly’ (small period of time). This is most stringent for the sub panel customer demands as those batches are small and therefore require more space (less stacking).

3) The parts should be nested conform the pace of the subsequent processes (forming, grinding, flanging, sub panel assembly, etc.), in order to reduce buffer space requirement and enable proper occupancy. This is supported by the JIT principle which links the generation batches to the demand batches. Applied to the part generation (cutting work step) this means that all parts for one customer demand point are to be cut out of one (or two subsequent) plate. Due to the number of customer demands in time this is most stringent for sub panel assembly, followed by main panel assembly.

4) Only specific customer demand product lines need to be assigned to a cutting station by limiting the number of product lines originating from one plate. Hence the cutting station can then be positioned more favourable on a layout diagram.

5) For levelling the cutting program duration an approximately equal number of parts or cutting length has to be cut from each plate.

6) Flat bars are to be nested from profiles. This improves the processing work steps and has a positive logistical implication. Moreover the generation becomes much more flexible.

7.2.2. Feasibility check

The feasibility of the conditions is qualitatively considered. The product data is not comprehensive to do this quantitatively. Part area approximation is too positive since the the part length and width are approximated based on a rectangular shape. Hence using any nesting software or algorithms to nest the parts does not suffice. The implementation of additional constraints will reduce freedom and possibly increase the scrap rate [48]. Some constraints are more susceptible for this than others:

1) The first constraint is feasible when about 3-4 sections are nested per plate, because this number is close to the current practise and excludes the excessive cases. Since currently on average 5.5 sections are nested per plate this is a significant reduction. Left over plates are mitigated and nesting freedom is introduced by nesting the parts as an infinite sequence instead as a groups.

2/3) The second constraint is also expected to be feasible, especially for the forming process. However nesting freedom is limited, increasing the probability of scrap rate increase. This also applies to the third constraint. Concerning the third constraint also the plate thickness plays a role. Data analysis shows that the number of sub panel assembly demand points differ per plate thickness. Hence from each plate no equal number of customer demand points can be generated. However, when levelling the number within each plate thickness the peaks can be removed.

4) When applying the fifth condition the nesting freedom is reduced, which has a direct effect on the scrap result. However, because a large percentage of the parts is relatively small the effect is expected to be rather minor. When including different product lines in a nesting attention a numeric relation between small and large parts needs to be enhanced.

5) This condition cannot be met. There are large plates which cover almost the entire plate. However a limit on the maximum number of parts can be set. Reducing the number of parts cut from one plate has a direct influence on the scrap percentage. This influence needs to be determined carefully.

6) The last condition is expected not to be problematic, although much small parts are excluded also long shapes are excluded.

7.2.3. Further approach

The ‘cutting less section from a plate’ (1) and ‘cutting less product lines from a plate’ (4) constraints show feasible, global effective potential for further batch size reduction and logistic flow improvement, contrary to the other constraints. Scenarios are defined to check the effect of these constraints:

1. Scenario 1: The ‘cutting less section from a plate’ constraint is implemented in scenario 1. Consequently the sorting space can be significantly reduced. However as all flows can originate from one plate a central cutting station is required.
2. Scenario 2: The ‘cutting less product lines from a plate’ constraint is additionally implemented in scenario 2 in order to pull different flows apart. The same layout is used to specifically study the effect of the addition of this constraint.
3. Scenario 3: The implementation of the ‘cutting less product lines from a plate’ constraint allows more design freedom. Within this scenario this freedom is assessed in order to define two, instead of one, cutting stations.

Based on those scenarios layouts can be defined. No overall algorithm exists for the definition of locations, configurations and dimensions [29]. Layout proposition is a cascading process, as subsequent steps follow from the start assumptions [29, 36, 73]. This process is described in the next Chapters. The improvement notions defined in Section 6.4 are incorporated. For each scenario a more detailed overview of the application is provided. Moreover for each scenario a simulation model is constructed and analysed. This approach is graphically described in Figure 7.1.

In the project statement of this study it is hypothesised to merge both pre-processing facilities in facility S1a, based on the performance of industry peers. Hence the layout redesign concerns the S1a facility. For the redesign of the pre-processing layout the hypothesis stated in Section 1.2 is considered. Hence the objective of studying the scenarios is:
Quantifying the effect of flow improvements by implementing additional constraints to part generation, namely ‘less sections from a plate’ and ‘separate product lines per cutting station’.

The nesting quantification for the purpose of this study makes as much as sense as the definition of the portfolio from two vessels and the definition of a PSV from several indicative sections. In the future outlook of this study (Section 13.3) it is recommended to further investigate this quantification.

7.3. Summary

Specific attention is paid to global effective flow improvements in this study to enable process redesign, since they initiate major improvements. The main contribution of this and the following Chapters is to provide quantitative argumentation about the effect of the flow improvements by implementing ‘improved’ nestings which initiate layout redesigns. Hence the fourth research question is addressed:
What is the quantitative effect of the proposed improvement strategies in terms of space utilisation and throughput?

An experiment shows that batch size reduction is promising for enabling a continuous flow. However logistic implications increase when one-piece flow is approximated and sorting space utilisations are not necessarily reduced. Therefore specific attention is paid to the feasibility of nesting improvements. Several additional nesting constraints are extracted from Chapter 6 in order to improve the subsequent process. Generally they are related to the Lean Manufacturing principles ‘one-piece’ and ‘levelled’ flow. An initial qualitative feasibility check shows that some are expected to be feasible whilst other are not. Further research is required to quantify these expectations.
The ‘cutting less sections from a plate’ (1) and ‘cutting less product lines from a plate’ (4) constraints show a feasible, global effective potential for further batch size reduction and logistic flow improvement, contrary to the other constraints. Different scenarios are defined to check their effect in the next Chapters. Scenario 1 will deal with the implementation of the first constraint. In scenario 2 the fourth constraint is additionally implemented, by means of process control modifications. In scenario 3 both constraints are implemented as well, and layout modifications are introduced.

8

Improvement scenario 1 analysis

In the previous Chapter several scenarios are defined to quantify the flow improvements by implementing additional nesting constraints. Here the first scenario is further explained and analysed. The scenario entails the following concepts: nesting is changed by reduction of the number of sections cut from one plate and a central cutting station is defined.

First the scenario design, including layout resource allocation and investments, is described, addressing KPI_1 to KPI_4 and KPI_{10}. Second the simulation model construction is discussed. In Section 8.3 the throughput measures are presented, addressing KPI_5 to KPI_9 and KPI_{11}.

8.1. Scenario description

First the layout and crane allocation is explained in Section 8.1.1 and Section 8.1.2. Finally some investment figures are presented in Section 8.1.3.

8.1.1. Layout explanation

The process of defining and proposing layout scenario 1 is explained below. The thought steps are summarised in Figure 8.1, where the dark grey frames indicate the decisions and the light grey frames indicate the logic consequence. Figure 8.1 is linked to the list with improvement notions provided in Section 6.4 by referring to the specific notions. Moreover Figure 8.1 is linked to the layout which is enclosed in Figure 8.2. The concerned areas are linked to the decisions.

1) The start point for this scenario is the definition of one cutting station, which is positioned in lane 2 to minimise transport to the other lanes (Figure 8.2 - 1). Because a dense sorting space arises the cutting bed loading and sorting actions are separated, by means of outfeed conveyors from the cutting supports, which enables a clear distinction in crane assignments for both activities.
The resource prediction (Section 6.2.1) shows that three cutting stations suffice. A fourth cutting machine is deployed, equipped with an oxy fuel/plasma portal to provide this functionality and enable possible throughput increase. (This cutting machine is illustrated by the diagonal in Figure 8.2).
After cutting the parts move per cut plate to the sorting space by the conveyors. Therefrom they are sorted and moved to end buffer containers or processing stations, creating a more continuous flow.

2) Because of the dense sorting area the relocation of the plate roller, to a position closer to the sorting space, becomes less obvious. To avoid additional investments it is not relocated. A roller conveyor is used for the longitudinal lane transport. Benefits are the independence of cranes and the function as infeed buffer. A roller conveyor is enables prioritisation by its FIFO characteristic and size. The roller pressure press is positioned next to the roller conveyor. As it has its own working crane it is able to operate independently from the overhead transport cranes. On the layout the additional pressure press is already conceptually indicated. At first it is not deployed.

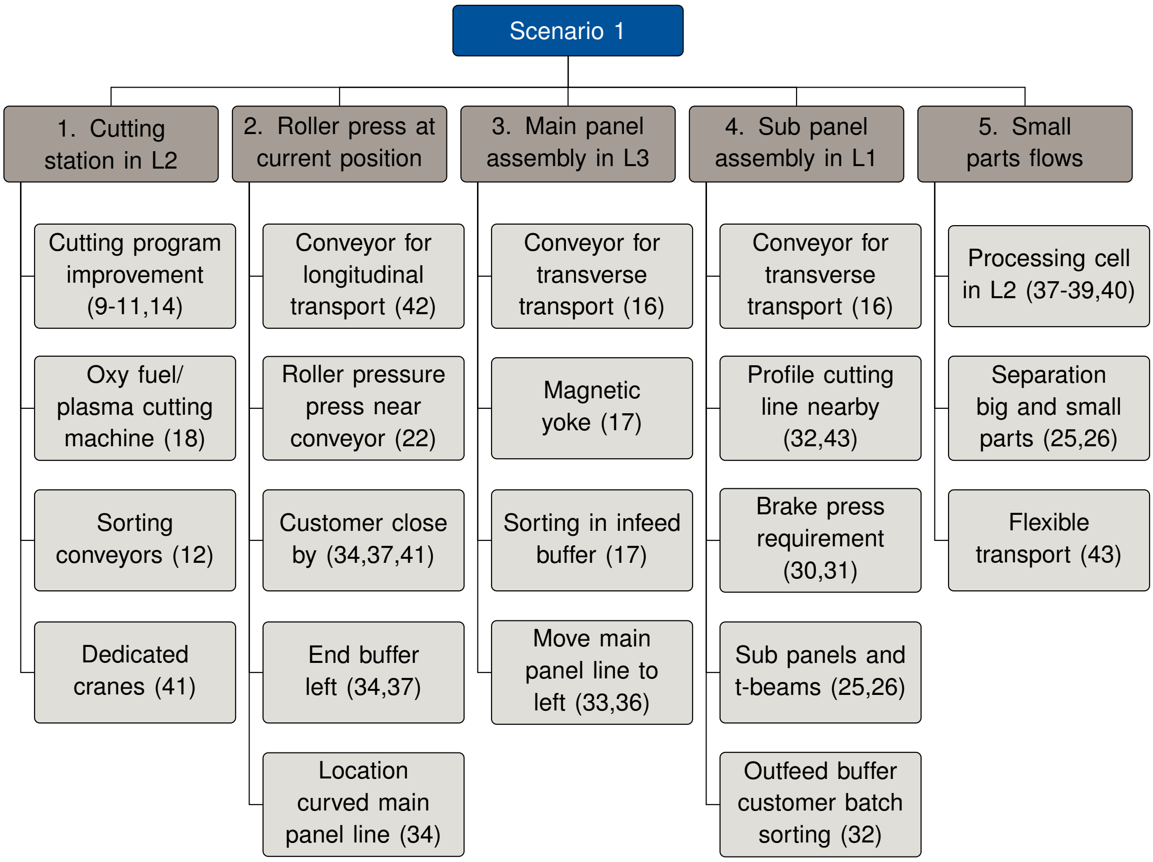


Figure 8.1: Scenario definition structure, link to improvement notions from Chapter 6

Left of the forming centre the outfeed buffer is positioned, such that it can directly function as infeed buffer for the curved main panel process (930PLC). Moving the curved main panel process closer to the forming station is driven by the freed space utilisation and transport distances. The formed parts for section building (940PLC) can be moved out via a truck to the section building hall.

3) Using a transverse conveyor main panel parts (930PLS) are easily moved to the next lane. From there they are loaded into the main panel assembly line infeed buffer. Using a magnetic yoke all parts for the main panel end buffer are moved at once from the sorting conveyor to the transverse conveyor. From the transverse conveyor they are directly sorted and stacked per panel name. The freed space drives the decision to replace the (classical) main panel line entirely into the pre-processing facility. Subsequently additional space is freed in the section assembly facility as well.

4) A third flow from the sorting space is the flow of sub panel parts (910PL and 920PL). Positioning the sub panel assembly processing station and outfeed buffer in the proximity of the profile cutting line is straightforward since it requires a high number of small profile batches. They can require grinding and/or flanging (Table 6.1), which drives positioning a brake press in lane 1. Significant outfeed buffers space is required due to the sorting for customer demand batches. Expectantly there enough space is available in lane 1, based on current state estimations. T-beams and plate-sub-panels assembly is separated.

5) Some other flows need explanation, namely the flows with parts for section- (940M), block- (950M), and hull (960M) assembly and the parts for external contractors (970/980/990). The parts for external contractors does not require pre-processing and are only relatively small. Hence they can be directly sorted in a small container on the sorting space. Table 6.1 shows that about 60% of the other flows contain parts which require processing. The other 40% can be directly sorted in containers. This underlines the need for a processing station close by the sorting space. The left over space in lane 2 is used for this.

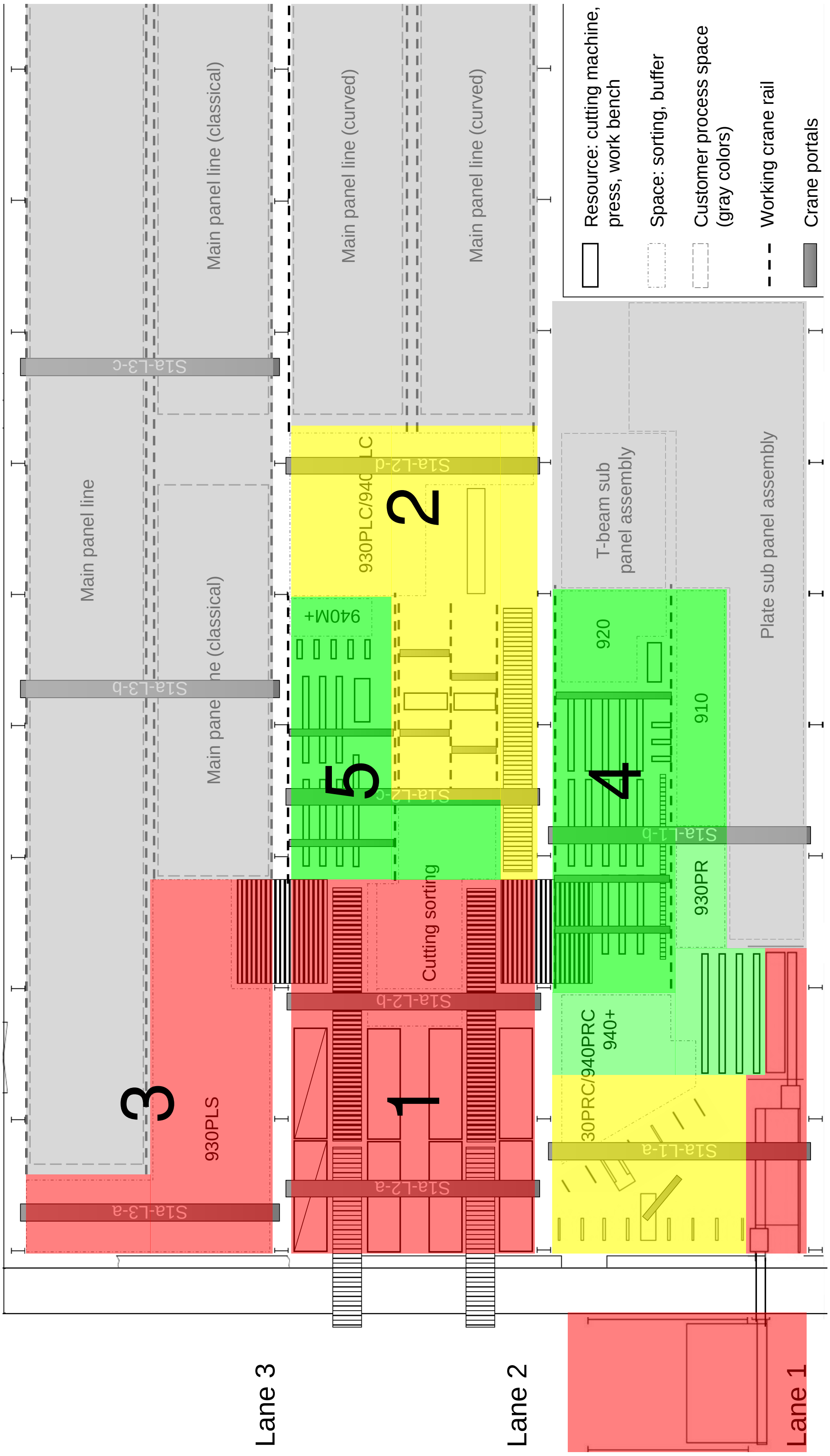


Figure 8.2: Concept layout, scenario 1

As (1) number wise the small parts contribute significantly, (2) they are required in batches and (3) are easy to handle they are first sorted per customer in a small container. Then they are moved to a small parts processing station, processed and transported to the end customers. Transport is most flexible by forklift. The larger parts are directly moved to the processing work station or the end buffer containers. Once processed they are also moved to the end buffer containers. Once the end buffer container is ‘full’ it is moved to the end buffer.

Table H.1 entails a overview of the utilised space per work station, which is derived based on rough area estimations. The same area which was occupied by the pre-processing activities in redesigned. Particular attention is paid to the assignment of vacated space, which is presented as well. Between pre-processing and assembly workstations out/infeed buffers are presented. In the Table they are included as pre-processing outfeed buffers.
For comparison with the current state the KPI’s are defined based on the data provided in Table H.1. Furthermore the improvement ratio (IR) relative to the current state is derived. They are defined positive, meaning that an increased ratio implies an improvement.

$$\mathrm{KPI}_1 = \mathrm{Area}_{\mathrm{total}} = 5530\ [m^2] \qquad \mathrm{IR}_1 = 2.3$$

$$\mathrm{KPI}_2 = \frac{\text{Process space}}{\text{Total space}} = 45\ [\%] \qquad \mathrm{IR}_2 = 2.0$$

Conclusively the required area to execute the pre-processing process can be significantly reduced. The increase of KPI_2 shows that this is mainly enabled by a in/outfeed space reduction.

8.1.2. Transport allocation

Currently in lane 1, lane 2 and lane 3 have two, four and three overhead transport cranes are deployed. Each is assigned to a specific task and area in order to minimise interaction between cranes. Furthermore additional working cranes are listed. The portals are indicated and labelled in Figure 8.2.
Like in the current situation small parts (≤20kg) are carried by hand. Small containers or pallets (≤2tons) are moved by fork lifts. Large containers are moved by either truck or crane.

- Transport crane S1a-L1-a is required for the operation of the profile cutting processes.
- Transport crane S1a-L1-b is used for the offloading and sorting of parts from the grinding workbenches at the outfeed buffers.
- The grinding-bevelling-flanging station in lane 1 is deployed with working cranes for offloading the parts from the transverse conveyor, the turning of the parts during the grinding process or the support of the flanging process. (2 portals for grinding, 1 portal for grinding-flanging)
- The sub panel assembly processes have their own working cranes, those are not included.
- Transport crane S1a-L2-a is assigned to loading and emptying the cutting supports.
- Transport crane S1a-L2-b is assigned to the sorting activities. The parts for the main panel line, forming station and sub panel assembly can all be moved at once as the entire yoke can be emptied on the subsequent conveyors. It loads the large parts for section-, block- and hull assembly either on the grinding workbenches or on the end buffer containers.
- Transport crane S1a-L2-c is assigned to the sorting after grinding activities and the loading of the end buffers containers onto the truck.
- Transport crane S1a-L2-d is assigned to the forming station, supplying the roller press and sorting the parts on the end buffer containers or stacks.
- The forming roller pressure press and the pressure press require their own working crane, like in the current situation.
- Also the lane 2 grinding-flanging station should be deployed with working cranes for the same reasons as the working crane in lane 1. (1 portal for grinding, 1 portal for grinding-flanging)
- In lane 2 space is freed for the curved main panel line. Therefore dedicated working cranes are required. Hence no additional transport crane needs to be invested in.
- Transport crane S1a-L3-a is assigned to the transport of main panels from the transverse conveyor to the main panel end buffers stacks.
- Transport crane S1a-L3-a and S1a-L3-b can be used for classical main panel assembly.

- In lane 2 space is freed for the curved main panel line. Therefore dedicated working cranes are required. Hence no additional transport crane needs to be invested in since the current transport cranes are able to support transport to the classical main panel assembly stations.

Likewise in Chapter 3 the KPI's for transport distances (KPI_3) and number of transports (KPI_4) are defined below. In Appendix H.2.2 and Appendix H.2.3 the detailed assessment is shown per product line and routine. The transport distances for different routines do not significantly differ due to the layout design based on multi-routine cells.

$$KPI_{3,number} = 144\ [m] \qquad IR_{3,number} = 2.4$$

$$KPI_{3,weight} = 134\ [m] \qquad IR_{3,weight} = 3.6$$

$$KPI_{4,number} = 5.6\ [-] \qquad IR_{4,number} = 3.5$$

$$KPI_{4,weight} = 5.2\ [-] \qquad IR_{4,weight} = 4.0$$

The difference between KPI_3 on part number and part weight is explained by the main panel (930PLS) and small parts (940M, 950M, 960M) flows. Due to the elimination of S1 and the dense organised processes the mean transport distance is reduced significantly.
The reduction of the transport distance is mainly enabled by the reduction of transports rather than the reduction of the distance per transport. Actually the distance travelled per transport increases. The reduction of the number of transports reduces the sensitivity for waiting, which is positive.

8.1.3. Investment overview

KPI_{10} concerns the required investments to obtain the future state and is defined below. In this scenario four new cutting machines are implemented. Chapter 3 states that the S1a plate and oxy acetylene cutting machines approximately reached their economic lifetime. Moreover the lack of extensive bevelling and singing functionalities advocate the investment in new machines.
Some additional half gantry working cranes are required for the operation of the grinding cells. Such working cranes are particularly proper since the lane width issue (improvement notion 40) and crane clashes are mitigated. A detailed information is given in Table H.9.

$$KPI_{10} = \text{required investments} = 2.5\ [M€]$$

The required investment is compared with the annual yard turnover, which is 114 M€ [13]. The required investments involves a modest 2.2% of the annual throughput.

8.2. Model construction

Similar to the current state approach a simulation model is constructed to obtain the defined (Section 2.3.4) KPI's for scenario 1. The model construction and behaviour are discussed.

8.2.1. Model construction

The layout and crane allocation is translated to a simulation model. Whenever possible the model assumptions are the same as in the current situation. This mainly implies the transport equipment, setup and changeover times of machines, personnel requests and handling by hand. The cutting program is slightly changed since automatic signing is deployed (Figure 8.1). Furthermore the technical data of cranes and conveyors is duplicated. For the new working cranes the same properties as the current working cranes are provided.

By means of a iterative simulation process the sorting space requirement is defined, due to the area requirement posed by the part supply. At least eight containers need to be temporarily stored, since the containers for section-, block-, and hull assembly have to stay until the entire batch is finished. The crane operations in this area contribute to the cutting sorting space being a rather dense space.
The work bench area and end buffer space definition is based on bottleneck analysis and the layout, conform the upfront estimation dealt with in Section 6.2.1. For this reason the space in lane 2 is

rather confined. The workbench capacities are based on the ability to cope with peaks in supply. Peak in outputs are also observed. The outfeed buffer space is defined such that a feasible solution results, which is also able to cope with peaks. The current state simulation modelling showed that rare significant peaks can occur. For very rare peaks the outfeed buffer space (area wise) can be temporarily balanced with workbench area. The forming infeed conveyor very well acts as infeed buffer. Hence it serves a dual objective. The occupancy rate of the conveyor very much depends on the supply variability.

For model verification the method, introduced in Section 4.3.2, is applied to the scenario modelling as well. The micro routines (forming press requirement sequence and grinding turning process) are verified on the basis of their description in the process model descriptions (Appendix B).

8.2.2. Model behaviour

In Section 4.2.4 the need for understanding the model behaviour is discussed. Several simulation runs are required. In Section 4.4.2 the Graphical Method [67] is applied on the current state to determine the number of simulation runs required. For the current state five simulation runs already result is a precise ‘Specified Precision’.

The first scenario poses process control changes which have an effect on the process variability. Multiple simulation runs are executed, from which for each the cumulative mean and standard deviation of the entire process duration and all parts is derived. They are normalised on the cumulative average of the final run. They are plotted with a 99% confidence interval in Figure 8.3

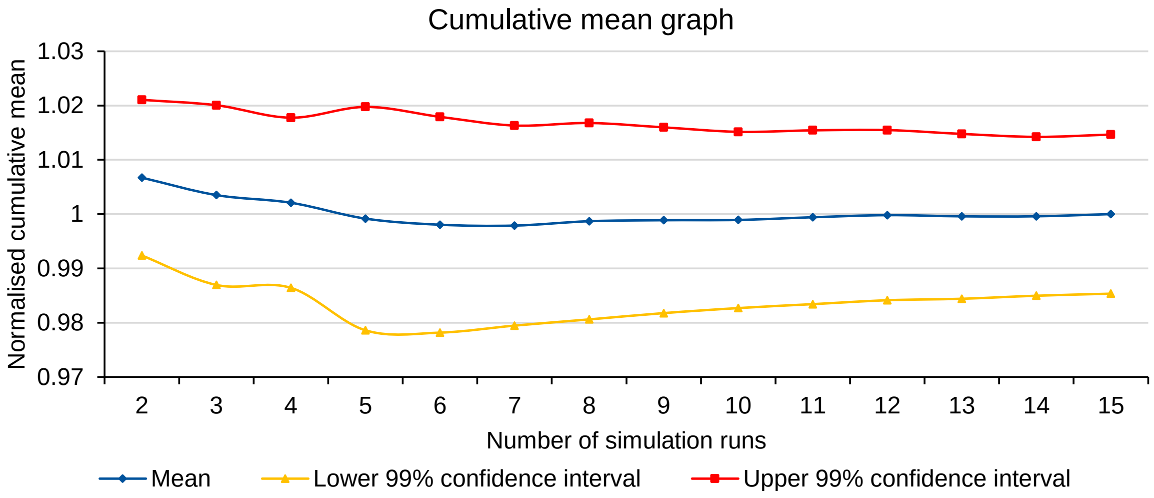


Figure 8.3: Plot of cumulative mean and 99% confidence lower and upper limit, scenario 1

Conform the simple Graphical Method the user can visually select the point on the graph where the cumulative mean line becomes ‘flat’ and use this as the number of replications[68]. After 10 simulation runs a stable cumulative mean value is observed. Five additional simulation runs, as recommended by Robinson [67], are performed to mitigate possible premature convergence. With 99% certainty the variation of the entire process duration of all parts is smaller than 1.5%, which is accepted. Hence the result of 15 simulation runs are used for the determination of KPI_5 to KPI_9.

Each simulation run takes an entire year. The same occupation build up period as the current state simulation is applied. This is valid because all parts are directly processed after cutting, so all stations are activated.

Because of data analysis limitations, the high number of parts and computational expense only one year is considered. Whenever annual measures are required the occupation build up period is not based on the data but extrapolated. Due to the high number of parts (≈200000) this does not result in much difference.

8.3. Throughput analysis

In Chapter 5 the throughput of the current situation is analysed. Moreover several KPI's are developed. The same approach is repeated in this Section for improvement scenario 1.

8.3.1. Part throughput

The entire process duration per part is measured, which spans the time between a raw plate entering on the conveyor and a customer demand batch being entirely finalised and collected. The start point is a matter of definition and is conform the current state analysis. The end point is measured under the assumption that a customer demand batch is directly used when finished and collected, conform the pragmatic JIT approach described in Section 6.3.1.

In Figure 8.4 the distribution of parts per specific time 'in the process' is presented. Part of the current state results are plot in the Figure as well. Based on the distribution KPI_5 is defined.

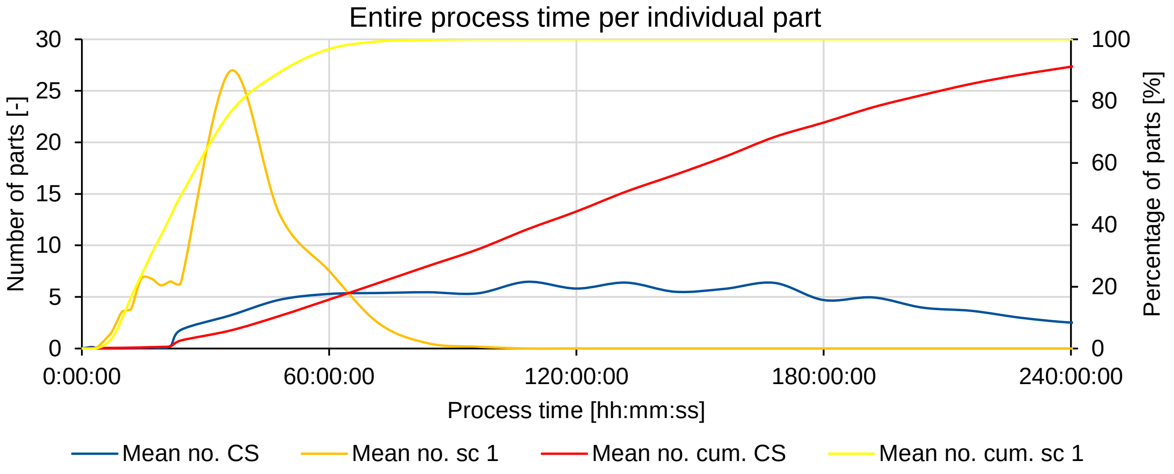


Figure 8.4: Cumulative number of parts per entire process duration, for scenario 1

The duration in the end buffer is related to the second additional nesting constraint: 'all parts for a customer demand batch need to be cut in a small period of time'. In order to study the effect of this the entire process duration is also determined including a modification for waiting in the end buffer. Hence two KPI's are defined, namely a original and modified one respectively.

$$KPI_5 = \text{time average of process time per individual part distribution} = \bar{x}_{time}$$

$KPI_{5,real} = 26{:}08{:}00$ [hh:mm:ss] $\qquad IR_{5,real} = 5.4$

$KPI_{5,modified} = 19{:}58{:}00$ [hh:mm:ss] $\qquad IR_{5,modified} = 7.1$

KPI_5 is improved with a factor 5.4 compared to the current state. Hence the flow has become much more continuous since the parts move much faster through the process. This factor is enabled by directly processing the parts after cutting and sorting for customers demand batches afterwards.

Compared to the experiment in Section 7.1 the part process time is reduced even further than the minimum of Figure 7.2. Hence it can be concluded that improving the logistics enables further reduction.

8.3.2. Annual station throughput

In KPI_6 the cumulative annual throughput is determined, similar to the current state analysis, based on the accumulation of all cut parts. The throughput is approximately equals the current state performance.

KPI_6 = maximum throughput per year (weight) = 9300 [ton] $\qquad IR_6 = 1.0$

KPI_7 and KPI_8 are related to the performance of the different stations and specifically explained in Section 2.3.4. This property is based on the Lean Manufacturing focus on levelled flows. Hence

KPI_7 and KPI_8 need to be close to 1 and 0 respectively to indicate an equal occupation in time. The measured state changes defined in Appendix H.4.1.
In scenario 1 no specific tapering and flanging stations are determined, but cells charged with performing those work steps are constructed. This new ‘station’ is abbreviated as TBGF. Both TBGB cells are described together because the same work steps are executed and personnel is deployed. Due to this comparison with the current state is not straightforward.

In the Appendix H.4.2, in Figure H.2 to Figure H.4 the throughput is plot per station. Per workday the input, output and difference is plot. These plots are based on the output of a single simulation run, since the dates matter here. The following KPI’s are defined, based on multi run results.

$$KPI_7 = \text{station occupancy rate for} \begin{cases}\text{Cutting}\\ \text{Forming}\\ \text{TBFG}\end{cases} = \begin{cases}1.00\\ 0.96\\ 1.00\end{cases} \qquad IR_7 = \begin{cases}1.00\\ 1.8\\ -\end{cases}$$

$$KPI_8 = \text{active station occupancy variability for} \begin{cases}\text{Cutting}\\ \text{Forming}\\ \text{TBGF}\end{cases} = \begin{cases}0.29\\ 0.69\\ 0.85\end{cases} \qquad IR_8 = \begin{cases}3.0\\ 0.9\\ -\end{cases}$$

The station occupancy rate shows that the stations are less unoccupied. From a levelling perspective this is preferred. The cutting station occupancy rate reduces significantly, since the parts leave the station much faster. This is reflected by the reduction in space utilisation as well as there is less space used for ‘being’ at the cutting station. Due to the introduction of a more levelled input of the forming station and the batch customer demand the occupancy variability is increased. Here a reduction of the improvement ratio is observed.

The daily station occupancy is related to the number of parts which originate from each plate, which is determined by the plate nestings. Due to the introduced nesting issues it can not be advocated that the relation between plates and parts is exactly true. This mainly concerns KPI_8.
The station throughput is related to the utilisation of resources because those can be throughput bottlenecks. Hence those are described in the next Section.

8.3.3. Resource utilisation

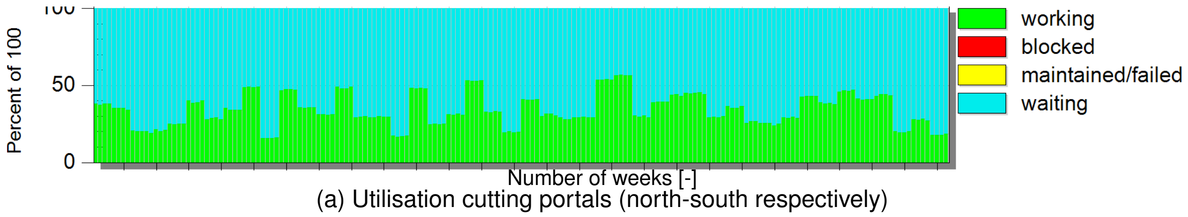
Last the utilisation of the resources is considered. In Section 2.3.4 the KPI is defined to be ratio between the time used and the total time. The resources are named as indicated in Figure 8.2. When more resources are deployed (cutting machines and crane portals) the labels -a to -b are provided from left to right. Only the pre-processing process related cranes are considered. The result is provided in Table 8.1.

$$KPI_9 = \text{resource utilisation} = \frac{\text{utilised time}}{\text{total time}} \text{ for } \begin{cases}\text{Cutting machines}\\ \text{Presses}\\ \text{Cranes}\end{cases}$$

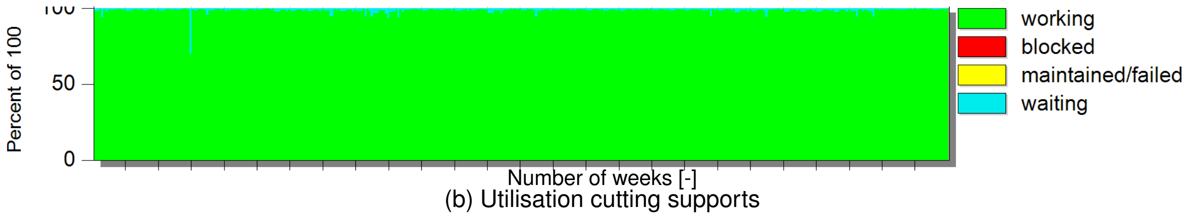
Table 8.1: Resource utilisation (KPI_9) results

Resource name	Util. [-]	Resource name	Util. [-]	Resource name	Util. [-]
Cutting portal 1	0.4	Cutting bed 1-a	0.98	Crane L2-a	0.25
Cutting portal 2	0.4	Cutting bed 2-a	0.98	Crane L2-b	0.58
Cutting portal 3	0.4	Cutting bed 3-a	0.98	Crane L2-c	0.2
Cutting portal 4	0.4	Cutting bed 4-a	0.98	Crane L2-d	0.15
Brake press L1	0.1	Cutting bed 1-b	0.98	Crane L3-a	0.1
Brake press L2	0.2	Cutting bed 2-b	0.98	Working crane L1-a	0.46
Roller press	0.68	Cutting bed 3-b	0.98	Working crane L1-b	0.36
Roller pressure press	0.38	Cutting bed 4-b	0.98	Working crane L1-c	0.37
		Crane L1-b	0.38	Working crane L2-a	0.4
				Working crane L2-b	0.35

Concerning the flanging and forming resources not stringent bottlenecks are observed. Conform expectation the roller press is significantly occupied. In Figure H.13 the diagrams are included.
In Figure 8.5 the date based utilisation diagrams of the cutting portals and beds are given. Although the relation between two beds and one portal is enhanced still the portals are significantly under occupied. A bottleneck on the sorting space is found. The cutting beds are continuously active but the portals are not entirely working, which implies that the cutting beds are not directly emptied.



(a) Utilisation cutting portals (north-south respectively)



(b) Utilisation cutting supports

Figure 8.5: Date based utilisation diagrams cutting stations scenario 1

This is illustrated by the utilisation of the sorting crane (S1a-L2-b), which is utilised significantly. Only one sorting crane is deployed because all flows need to be served from both conveyors and clashes are likely when two cranes are deployed. Furthermore working crane S1a-L1-a is reasonably active. This crane is responsible for offloading the parts from the transverse conveyor (Section 8.1.2). This activity is characterised by a batch to single flow phenomena. Hence a revealing bottleneck is observed by the transport sorting crane in lane 2 and the offloading of parts from the transverse conveyor.

Since the cutting portals are definitely not the bottleneck one could argue whether all cutting machines should be deployed. Cutting machines are expensive, value-adding resources which should therefore be reasonably utilised. Based on current result the number of cutting machines can be reduced. However the current process can be improved by improving the observed bottlenecks. Consequently the cutting machine utilisation will increase as well. This is not further considered in this study.

8.4. Summary

In Chapter 7 several scenarios are defined for quantifying the effect of flow improvements by implementing additional constraints to part generation. The first scenario concerns the first nesting constraint ‘cutting less sections from a plate’ and is applied and analysed in this Chapter. Doing so the fourth research question is addressed.
What is the quantitative effect of the proposed improvement strategies in terms of space utilisation and throughput?

The implementation of the nesting constraint advocates the definition of a single cutting station, which is used as main input for a cascading layout definition process. Based on layout and resource description the required investments are derived, which amounts 2.5 M€.
For the current state and scenario 1 the same KPI’s are determined. Comparison shows that the first scenario requires much less space to execute the same work steps (improvement ratio of 2.3). Moreover much more space is used for the actual value adding process instead of on buffer space (factor 3). The transport distances are mainly reduced (factor 3) due to the reduction (factor 4) of number of transports.

A discrete event simulation model is constructed for the definition of the time related resources. By means of simulation iterations the space requirements of the sorting space and grinding cells are determined. The spaces are defined such that a feasible solution results for rare cases as well. Verification is performed similar to the current state modelling process. The model behaviour is studied, which shows that 15 simulation runs are required to obtain a stable data set. With 99% certainty the variation of the entire process duration of all parts is smaller than 1.5%.

A more continuous flow is enabled by reduction of the individual parts duration in the process of a factor 5.4. Hence an annual throughput of 9300 [ton] is enabled, which equals the current stat throughput. The 'occupancy rate' and 'active cutting station occupancy variability' are improved reasonably. Resource utilisation shows that the sorting action is the flow bottleneck due to the high sorting crane and transverse conveyor off-loading crane utilisation. Hence the scenario can be further improved by improving these specific crane assignments.

Finally the ratio as defined in Section 1.1.2 is defined. At the expense of roughly €2.5 million the process can be improved by 2.6 times. This investment equal about 2.2% of the annual yard turnover. Part of the investment is due to the investment in new cutting machines, which approximately reached their economic lifetime. This reduces the additional (unforeseen) investment in 'improvements'. The question whether four cutting machines should be deployed depends on further scenario optimisation and is left open in this Chapter. That does have a significant implication on the required investment.
The implementation of the nesting constraint enabled a feasible scenario which requires much less sorting space and still meets the annual throughput capacity. Furthermore it enables a more continuous flow since the parts are shorter in the process.

$$\mathrm{KPI}_{11} = \frac{\text{Throughput}}{\text{Required space}} = 1.7 \qquad\qquad \mathrm{IR}_{11} = 2.6$$

9

Improvement scenario 2 analysis

In Chapter 7 several scenarios are defined to quantify the flow improvements by implementing additional nesting constraints to the parts generation. In this Chapter the second scenario is explained and analysed, which entails the allocation of only a few product lines per cutting station. Two cutting stations are defined and the layout from scenario 1 is used.

The analysis of scenario 1 shows that the sorting space after cutting is dense and that the sorting crane is highly utilised. The implementation of nesting constraint 'cutting less product lines from a plate' opens the possibility to assign more cranes since the flows are separated. Due to independent assignments clashes can be avoided. The implementation of an additional sorting crane is discussed when dealing with the layout and process design. However no reasonable KPI performance increase is found. Therefore it is not further considered in the model construction and analysis.

First the scenario design is described, initiating the definition of the design related KPI's. Subsequently the simulation model is discussed in Section 9.1.3. The throughput and resource utilisation related KPI's are defined, in Section 9.3.

9.1. Scenario description

This Section deals with the explanation of the defined layout (Section 9.1.1), crane allocation (Section 9.1.2) and investment figures (Section 9.1.3) respectively.

9.1.1. Layout explanation

The functional separation of the cutting machines does not have a meaningful implication on the layout, as no work stations are shifted layout wise. Since the layout is not changed KPI_1 and KPI_2 are not changed either. The diagram presented in Figure 8.1 is extended by the separation of the cutting station into two cutting stations in Figure 9.1. Explanation is given below.

2) Within this scenario different product lines are assigned to each of the cutting stations. Since cutting station 1 and 2 (defined in Figure 9.1) are located closest to the main panel assembly station main panel parts (930PLS) are cut there. To enhance feasible nesting also small parts need to be cut at this station. Therefore the small parts for section assembly (940M) and external subcontractors (970-980-990) are cut there as well. It has an implication on the crane allocation which is described in the next Section.

3) Cutting station 3 and 4 (defined in Figure 9.1) are in charge of cutting the to be formed parts and sub panel parts since those flows are closest to this cutting station. The parts for block (950M) and hull (960M) assembly are cut here as well, based on an area balance between both stations (1&2 vs. 3&4).

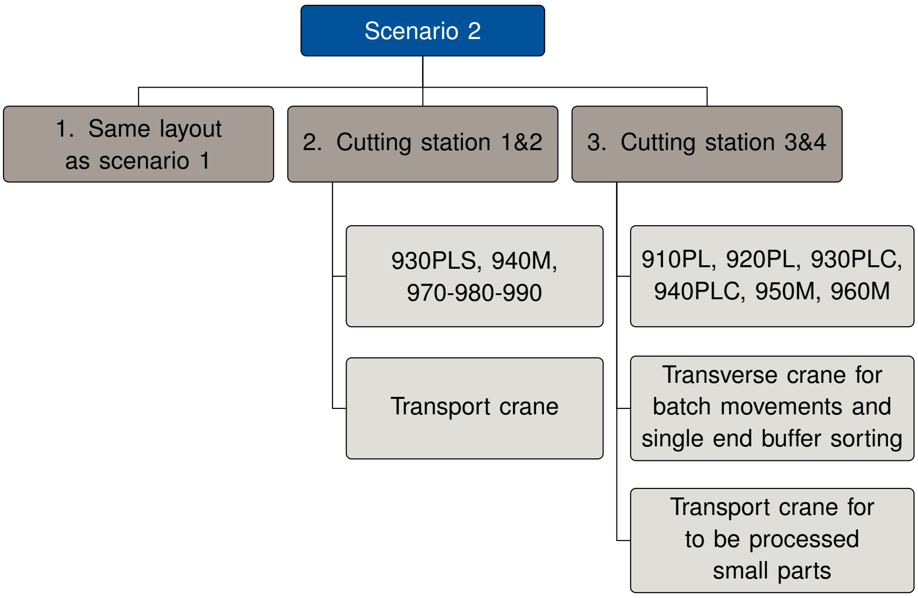


Figure 9.1: Scenario definition structure, extension of Figure 8.1

9.1.2. Transport allocation

In order to reduce the utilisation of and dependency on the overhead sorting portal in lane 2 an additional crane can be introduced. There are several options to position this crane, depending on the planned functionality. The current sorting crane is serving a rather large area, stretching from the sorting conveyor (entire width of lane) to the grinding workbenches. The following is proposed.

The crane is positioned in transverse direction (lane 1 side), serving the transport of the sub panel (910PL/920PL) parts to the transverse conveyor and the main panel (930PLC/940PLC) parts to the longitudinal conveyor. Furthermore it is able to sort the block- and hull assembly (950M,960M) parts. Only the 950M/960M parts which require processing need to be transported by the overhead sorting portal. The assignment of flows is presented in Figure 9.1. The crane is positioned transverse for better occupation of the sorting space. However for this a larger beam is required. The crane height is lower than the overhead transport cranes to allow overtaking.
Positioning the additional crane on the lane 3 side of lane 2 would result in in a large portal beam requirement or illogical positioning of the crane track. Furthermore clashes between the crane and the overhead sorting portal are expected due to the longer movement distance.
Dedicating a second additional crane to the 930PLS parts and 940M parts (which do not require processing) is not straightforward since the crane track would disorder the grinding-flanging station, or no limit the sorting capability. Furthermore significant investments are involved.
The transport distances of the parts is not significantly changed due the assignment of different cranes. Hence KPI_3 and KPI_4 are not changed.

9.1.3. Investment overview

The additional transverse transport crane is incorporated in the investment overview, which is included in Table H.10. The investments for a large beam portal equal the transport crane investments.

$$KPI_{10,\text{ incl. crane}} = \text{required investments} = 3000\ [k€] \qquad KPI_{10,\text{ excl. crane}} = 2500[k€]$$

9.1.4. Preliminary model analysis conclusion

Both the flow control and additional crane changes are implemented in a simulation model, which is further discussed in Section 9.2. Preliminary analysis shows that the implementation of an additional crane does not show a reasonable KPI performance increase. The resource utilisation of the initial sorting crane (S1a-L2-b) decreased to the same extend as the additional sorting crane utilisation increased.

Because of the poor performance increase and additional investment of 500 k€ the implementation of an additional sorting crane is irrational. Therefore it is not further dealt with. The model construction and throughput analysis in Section 9.2 and Section 9.3 concern the implementation of flow control changes only. Conclusively KPI_1 to KPI_4 are equal to the results of scenario 1. Besides KPI_{10} does not change since only flow control changes are implemented.

9.2. Model construction

The nesting constraint 'cutting less product lines from a plate' is implemented in scenario 2. First some model overview notions are presented, followed by a model behaviour study.

9.2.1. Model overview

Similar to the approach in Chapter 8 the same assumptions as in the current situation are followed. The assignment of customer product lines to cutting station is made by balancing small and large parts and the to be cut area. Hence two approximately equal flows are created.

Due to the more concentrated part supply other bottlenecks surface. Since all parts for forming and sub panel assembly are now cut from a smaller amount of plates, the average supply per plate increases. Since the system is not entirely levelled bottlenecks become more stringent as the input batches are larger. This is mainly the case for the transverse conveyor to sub panel assembly and the longitudinal conveyor to forming, supplied by the cutting station 3&4.

For model verification the method as introduced in Section 4.3.2 is applied to the scenario modelling as well. The micro routines (forming press requirement sequence and grinding turning process) are verified on the basis of their description in the process model descriptions (Appendix B).

9.2.2. Model behaviour

Due to the process flow control the process behaviour is changed. Multiple simulation runs are executed, from which for each the cumulative mean and standard deviation of the entire process duration and all parts is derived. They are normalised on the cumulative average of all runs. They are plotted with a 99% confidence interval in Figure 9.2.

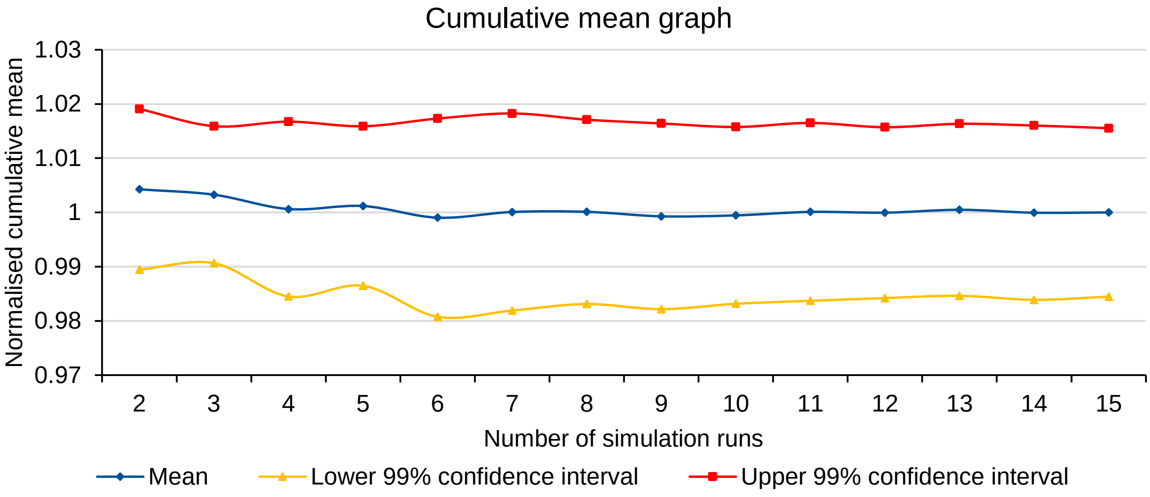


Figure 9.2: Plot of cumulative mean and 99% confidence lower and upper limit, scenario 2

10 simulation runs are performed, whereafter a stable cumulative mean is observed. Five additional simulation runs, as recommended by Robinson [67], are performed to mitigate the chance of premature convergence. Conclusively with 99% certainty the variation of the entire process duration of all parts is smaller than 1.6%. This variability is accepted. Hence the results of 15 simulation runs are used for the determination of KPI_5 to KPI_9. For the determination of annual measures the same procedures are followed as the previous scenario.

9.3. Throughput analysis

Subsequent to the description of the model its throughput performance is analysed. First the part throughput is dealt with. Then the annual and station related throughput are discussed. Last the resource utilisation is determined.

9.3.1. Part throughput

Based on the simulation runs the entire process time per part distribution is plot. The results of the current state and scenario 1 are plot as well. Visually again a significant reduction in individual part duration is observed. Since the distribution shifts to zero an improvement compared to the current state and scenario 1 is present.

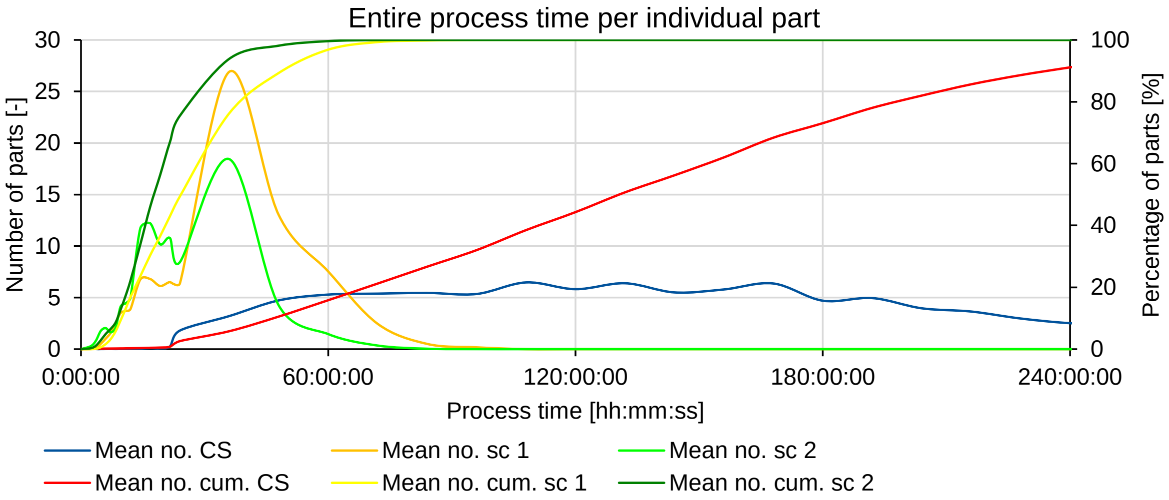


Figure 9.3: Cumulative number of parts per entire process duration, for scenario 2

A reasonably number of parts did not change. Mainly the part durations of the straight main panel parts (930PLS) and the small parts for section-, block- and hull assembly (940M/950M/960M) improved. Contrary the part durations for sub panel assembly (910PL/920PL) slightly decayed.

The 910PL/920PL flow is not reduced because the transverse conveyor to the sub panel parts processing station is occupied significantly. Furthermore the forming infeed conveyor is occupied as well. Both observations are explained by a more dense supply of parts. The resource utilisation of the cutting station 3&4 will further illustrate this.

The duration in the end buffer is related to the second additional nesting constraint: ‘all parts for a customer demand batch need to be cut in a small period of time’. Similar to the previous Chapter the entire process duration is also determined including a modification of waiting in the buffer, resulting in two values per KPI, namely the real and modified one respectively.

$$KPI_5 = \text{time average of process time per individual part distribution} = \bar{x}_{time}$$

$KPI_{5,real}$ = 19:09:00 [hh:mm:ss] $IR_{5,real} = 7.0$

$KPI_{5,modified}$ = 13:14:00 [hh:mm:ss] $IR_{5,modified} = 10.7$

Furthermore the improvement ratios (IR) are determined. Compared to the current state an improvement ratio of 7 is enabled. Hence the parts move much faster through the process. From Lean Manufacturing perspective this is favourable since a shorter process duration indicates a more smooth, value adding, continuous flow. Moreover the ability to enable the JIT principle is increased with a shorter entire process duration. The improvement is enabled by a combination of buffer (inventory) time reduction and process (inventory, transport) time reduction, which is found by comparison of the process times modified for buffer time. In the next Section it is obtained whether this also resulted in a throughput increase.

9.3.2. Annual throughput

In KPI_6 the cumulative annual throughput is determined. For consistency the similar approach as for the current state and scenario 1 is followed. The implementation of the nesting constraint ‘cutting less product lines from a plate’ enabled an annual throughput increase.

$$KPI_6 = \text{maximum throughput per year (weight)} = 9600\ [\text{ton}] \qquad IR_6 = 1.1$$

KPI_7 and KPI_8 are related to the occupancy performance of the different stations. Since no layout changes are implemented also in scenario 2 no specific tapering and flanging stations are determined, but (TBGF) cells charged with performing those work steps. Moreover since two cutting stations are defined, for each these KPI’s will be defined individually to provide more insight in their performance.
In the Appendix H.4.2, in Figure H.5 to Figure H.8, the throughput is plot per station. Per workday the input, output and difference is plot. These plots are based, contrary to the KPI’s, on the output of a single simulation run, since the dates matter here. The following KPI’s are defined.

$$KPI_7 = \begin{cases} \text{Cutting 1\&2} \\ \text{Cutting 3\&4} \\ \text{Forming} \\ \text{TBFG} \end{cases} = \begin{cases} 0.88 \\ 1.00 \\ 0.97 \\ 1.00 \end{cases} \qquad IR_7 = \begin{cases} 0.9 \\ 1.0 \\ 1.9 \\ - \end{cases}$$

$$KPI_8 = \begin{cases} \text{Cutting 1\&2} \\ \text{Cutting 3\&4} \\ \text{Forming} \\ \text{TBGF} \end{cases} = \begin{cases} 0.78 \\ 0.25 \\ 0.67 \\ 0.50 \end{cases} \qquad IR_8 = \begin{cases} 1.1 \\ 3.4 \\ 0.9 \\ - \end{cases}$$

For both cutting stations a difference in station occupancy rate and active station occupancy variability is observed. Cutting station 3&4 is much more levelled since the occupancy variability is much lower. Cutting station 1&2 is not always occupied. Besides, when it is occupied, much more output variation is observed. This phenomena is further studied by the resource utilisation results.

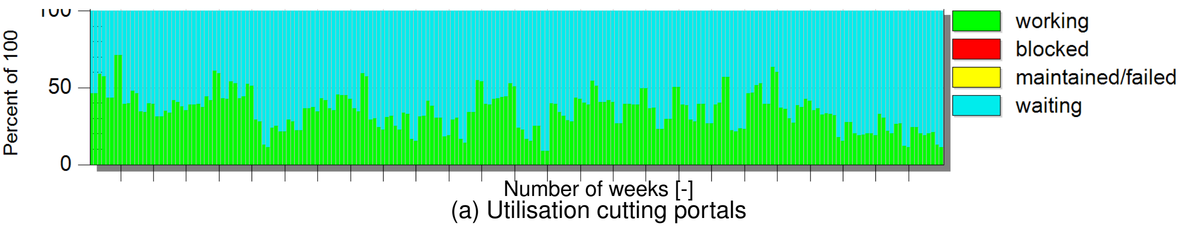
9.3.3. Resource utilisation

Finally the KPI’s related with the utilisation of the different resources are determined. The results are enclosed in Table 9.1. Furthermore date based diagrams are provided in the Appendix (Figure H.14). The utilisation diagrams of the presses show approximately the same results as the results of scenario 1. The utilisation results of the cutting portals and beds show noteworthy results.

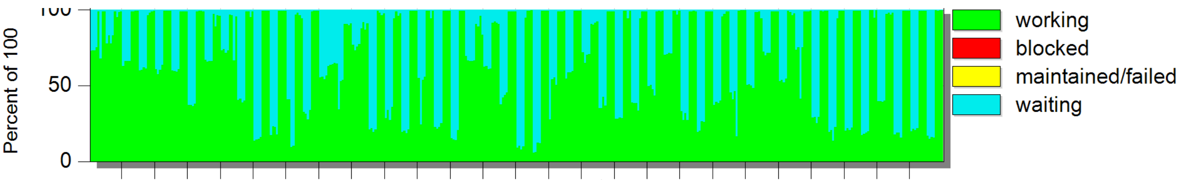
Table 9.1: Resource utilisation (KPI_9) results

Resource name	Util. [-]	Resource name	Util. [-]	Resource name	Util. [-]
Cutting portal 1	0.41	Cutting bed 1-a	0.46	Crane L2-a	0.24
Cutting portal 2	0.41	Cutting bed 1-b	0.46	Crane L2-b	0.53
Cutting portal 3	0.41	Cutting bed 2-a	0.46	Crane L2-c	0.21
Cutting portal 4	0.41	Cutting bed 2-b	0.46	Crane L2-d	0.18
Brake press L1	0.21	Cutting bed 3-a	0.97	Working crane L1-a	0.6
Brake press L2	0.11	Cutting bed 3-b	0.97	Working crane L1-b	0.55
Roller press	0.72	Cutting bed 4-a	0.97	Working crane L1-c	0.21
Roller pressure press	0.39	Cutting bed 4-b	0.97	Working crane L2-a	0.41
Crane L1-b	0.4	Crane L3-a	0.1	Working crane L2-b	0.36

In Figure 9.4 the date based utilisation diagrams of the cutting portals and beds are given. Compared to the cutting portal utilisation diagram of scenario 1 the result of scenario 2 (Figure 9.4a) is more fluctuating. At some days the utilisation of the cutting station 1&2 is nearly 50%, whilst on other it is hardly used. The utilisation drops in Figure 9.4a and Figure 9.4b correspond.
Due to the transverse conveyor between lane 2 and lane 1 and forming infeed conveyor being bottlenecks the cutting station 3&4 performs worse than the cutting station 1&2. Because the payload is based on an approximately equal amount of plates, the plates are released in batches per ship/nesting group and the cutting station 3&4 under performs the cutting station 1&2 is sometimes idle.



(a) Utilisation cutting portals



(b) Utilisation cutting support

Figure 9.4: Date based utilisation diagrams cutting stations scenario 1

9.4. Summary

In Chapter 7 several scenarios are defined for quantifying the effect of flow improvements by implementing additional constraints to part generation. The second scenario concerns the additional implementation of the nesting constraint “cutting less product lines from a plate” and is assessed in this Chapter. The fourth research question is addressed.
What is the quantitative effect of the proposed improvement strategies in terms of space utilisation and throughput?

The constraint is additionally implemented in scenario 2 in order to pull different flows apart. The same layout is used to specifically study the effect of the addition of this constraint.
The analysis of the previous scenario showed that the sorting crane is highly utilised. The implementation of the additional nesting constraints enables flow separation and therefore also more design freedom. Hence initially the effect of implementing an additional sorting crane is studied. Simulation model analysis showed that the implementation of an additional crane does not show a reasonable KPI performance increase. Hence the implementation of the additional sorting crane is rejected and only the flow control changes are implemented. Consequently the required investments amount the same as scenario 1, namely 2.5 M€. Furthermore since same layout is used the space related KPI’s are not changed either.

Due to the implementation of the flow control changes other system variability is introduced. Hence the model behaviour is studied again. This result is very similar to the scenario 1 result.

The assessment of the throughput and utilisation related KPI’s show that the flow of the cutting station 1&2 is significantly improved. Hence the individual part process duration reduces (factor 7) and annual throughput increases (1.1). The analysis of cutting station 3&4 shows that the related flows are partially blocked by the transverse conveyor output being a bottleneck. Because the payload is based on an approximately equal amount of plates, the plates are released in batches per ship/nesting group and the cutting station 3&4 under performs cutting station 1&2 is sometimes idle. Hence particular attention needs to be paid to the levelling of the working load over both cutting stations, else waiting and under utilisation is induced.

Finally the ratio as defined in Section 1.1.2 is defined. Hence it is concluded that at the expense of roughly €2.5 million the process can be improved by 2.7 times.

$$\mathrm{KPI}_{11} = \frac{\text{Throughput}}{\text{Required space}} = 1.8 \qquad\qquad \mathrm{IR}_{11} = 2.7$$

The implementation of the additional nesting constraint enables to improve the individual part process duration, which is favourable from Lean Manufacturing perspective. Special care needs to be paid to the levelling of the working load over both cutting stations, else waiting and under utilisation is induced.

10

Improvement scenario 3 analysis

Scenario 3 is a follow up of scenario 1 and 2. Where in scenario 2 a flow control modification is proposed, in this scenario a layout modification is proposed. The separation of product lines enables the definition of two separate cutting stations. This opens the possibility to locate both cutting stations in different lanes. The proposed layout change is also a reaction on the observations done in the previous Chapter, namely the transverse conveyors being a bottleneck.

In this Chapter the same structure is followed as in the previous Chapter. Since this scenario describes a different layout specific attention is paid to the layout description, resource allocation and investments, in Section 10.1. It addresses KPI_1 to KPI_4 and KPI_{10}). The simulation model construction is dealt with in Section 10.2. The throughput and resource utilisation related KPI's (KPI_5 to KPI_9) are discussed in Section 10.3. Finally KPI_{11} is defined and a summary is provided.

10.1. Scenario description

This Section deals with the 'design' of scenario 3. The layout, crane allocation and required investments are described respectively.

10.1.1. Layout explanation

The process of defining and proposing layout scenario 3 is explained below. In Figure 10.1 an overview of the thought steps is provided, including a link to the improvement notions listed in Section 6.4. Those will be specifically described below. The layout result in included in Figure 10.2.

1) The start point of this scenario is the definition of two separate cutting stations. The first cutting station is dedicated to cutting the parts for t-beam- (920PL), main panel- (930PLS) and section assembly (940M), which is different from the allocation for scenario 2. The allocation is again based on area definition and the balance between small and large parts.
The positioning of the cutting station is driven by the direct transport to the main panel line and the positioning of the profile cutting station in lane two (discussed in point 4). Hence the transverse conveyor for main panels is eliminated. The positioning of the t-beam pre-processing (green area in lane 3 in Figure 10.2) and assembly station is driven by the fact that t-beams need to be mounted on main panels later.
To minimise cutting bed occupancy specific sorting beds are defined, from which the parts for processing are directly picked by the working cranes. The parts for end buffers are directly sorted therefrom. Cutting parts for section building (940M) requires a reasonable amount of sorting space since the parts are directly sorted for end buffers after cutting and a larger number demands exists compared to the block- and hull assembly (950M/960M) demands.
From the sorting beds the parts for processing can be directly loaded onto the workbenches. Hence compared to the current state a more single flow like flow is created. This ability is described in Section 6.3.2. Again tapering, bevelling, and flanging are included in the grinding work step.

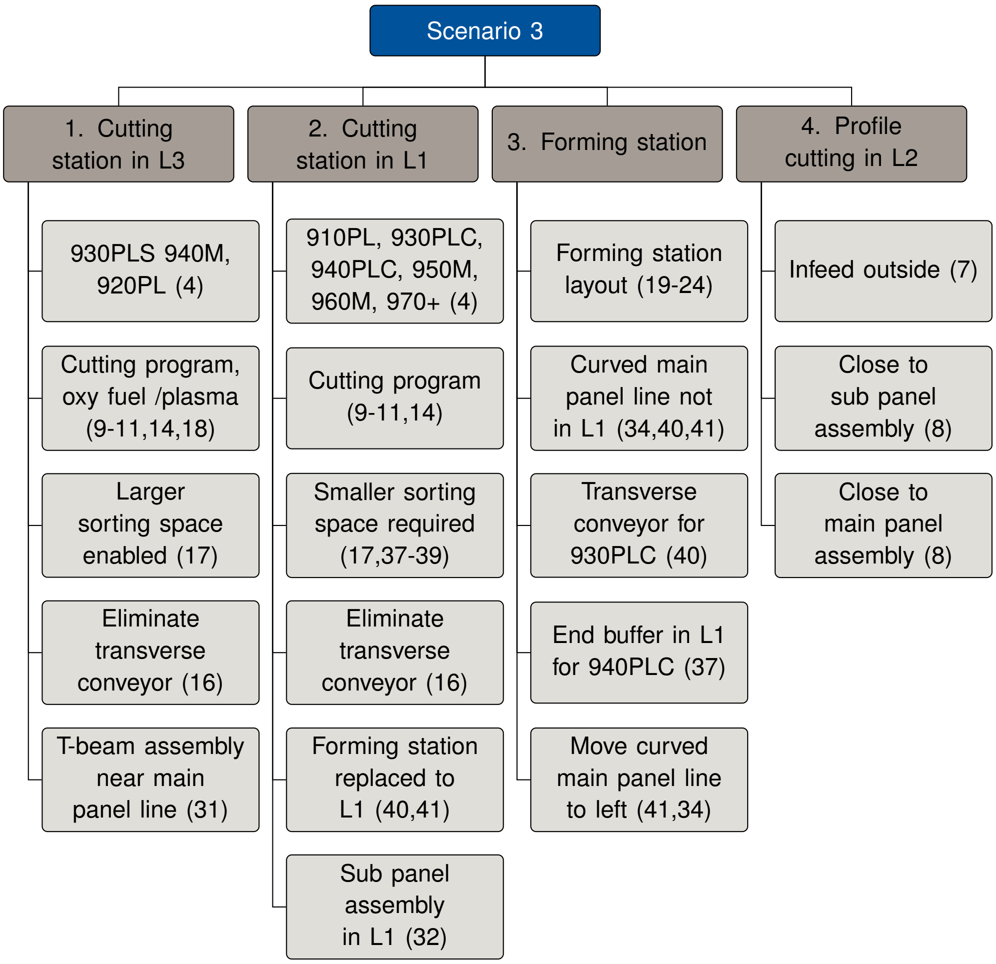


Figure 10.1: Scenario definition structure, link to improvement notions from Chapter 6

2) The second cutting station is dedicated to cutting parts for forming, sub panel-, block- and hull assembly and external contractors. Since the number of required containers is small (950M/ 960M) or the containers are small (950M/960M/970-980-990) a relatively small sorting space is required.

Direct transport to the workbenches is enabled by cutting and processing in the same lane. Due to the positioning of cutting station 2 in lane 1 the transport to forming becomes longer. Hence not only a longitudinal but also a transverse conveyor is required. This drives the re-positioning of the entire forming station close-by. Further attention to the forming station is paid in point 3. Positioning cutting station 2 in lane 2 is not possible since there would not be enough space for the assembly of sub panels then. The problem observed in Chapter 9 would then only be shifted.

3) For the forming station the press related work space is considered. The 930PLC parts need to be assembled on a curved main panel line, for which there is not enough space left in lane 1. Hence a transverse conveyor is used to transport the parts to lane 2. Because this flow concerns less parts and the parts are sorted for end buffers there the 'transverse conveyor problem' is less stringent.

The 940PLC, for section building, can be sorted for end buffers on containers in lane 1. Once finished they are moved to section building by truck.

Consequently to moving the forming station to lane 1 space is freed in lane 2. Hence the curved main panel line can be moved left, which is indicated in Figure 10.2 as well.

4) Due to the shifts of the plate cutting stations the profile cutting station is positioned in L2. For the transport of profiles to the t-beams and sub panel assembly stations, which main implies a high number of small batches, this is favourable. Furthermore the transport distance to the main panel line stations is improved. Small batches are easily transported by lift truck.

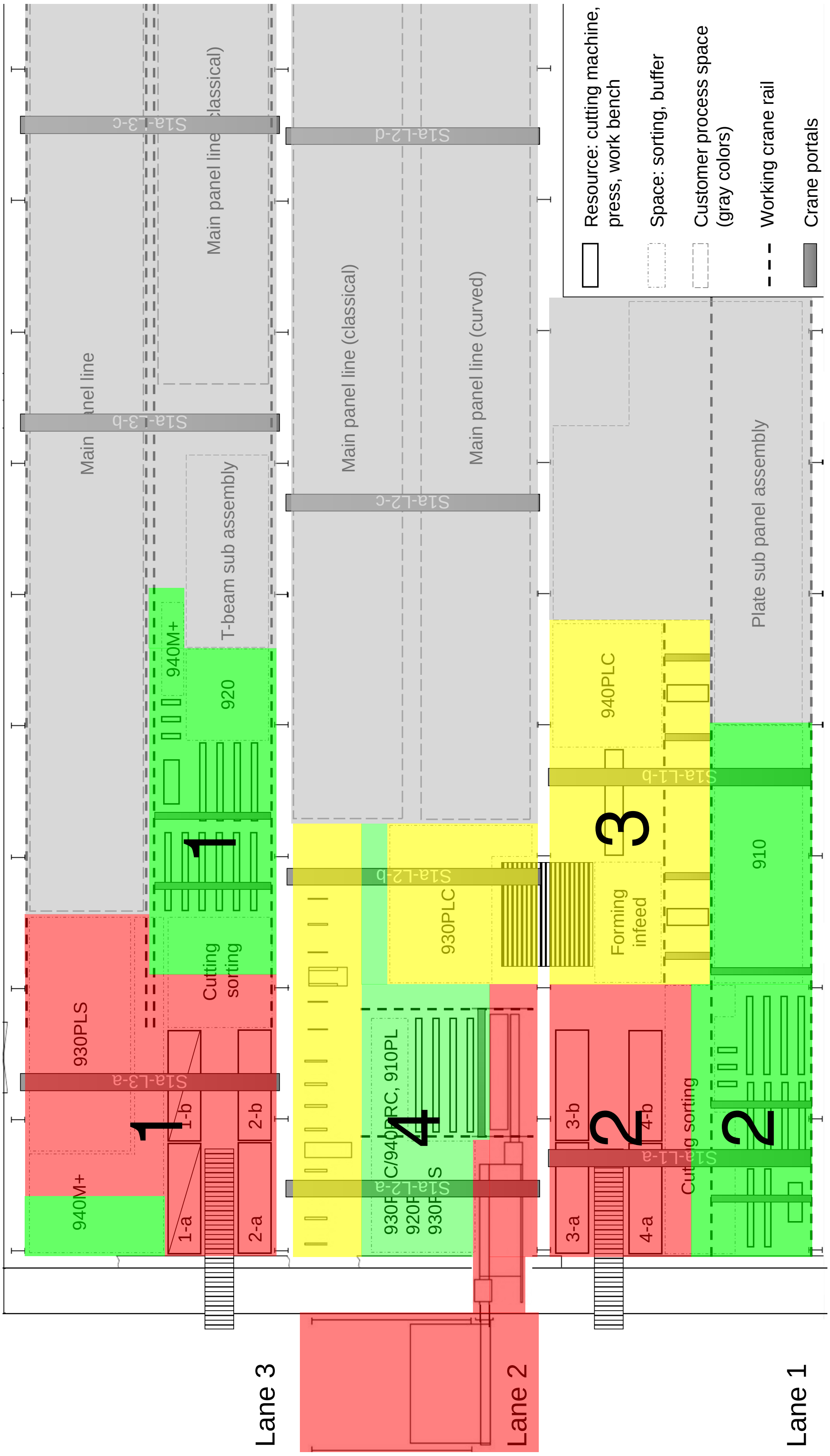


Figure 10.2: Concept layout, scenario 3

In Table H.2 a detailed overview of the utilised space of each work station is presented, which is derived based on rough area estimations. Similar to the approach described in Section 10.1.1 the area which was occupied by the pre processing activities and vacated is redesigned as well. Based on that the following KPI's can be defined. Moreover the improvement ratios (IR) are defined. They are defined positive which implies that an increase indicates an improvement.

$$\text{KPI}_1 = \text{Area}_{\text{total}} = 5040\ [m^2] \qquad \text{IR}_1 = 2.5$$

$$\text{KPI}_2 = \frac{\text{Process space}}{\text{Total space}} = 49\ [\%] \qquad \text{IR}_2 = 2.2$$

Conclusively the required area to execute the pre-processing process can be significantly reduced compared to the current state. Considering measurement deviations the difference between scenario 1/2 and 3 is minor. Compared to scenario 1 and 2 KPI_1 and KPI_2 slightly reduced and increased respectively. Both phenomena are positive since relatively more space is used for value adding processes.

10.1.2. Transport allocation

In this Section the crane allocation and transports are discussed. Similar to the previous scenarios the same transport rules concerning the transport of small parts, small containers and large containers are applied. The assignment of cranes to specific tasks and area is more specifically described below.

- Transport crane S1a-L1-a is required for the operation of the cutting station in lane 1. The operations include the loading of raw plates on the beds, the off loading of a cut plate in the sorting beds, the sorting of the parts from the sorting bed onto the containers, forming infeed or workbenches. Priority is given to loading a new raw plate on the cutting beds.
- Transport crane S1a-L1-b is used for the forming activities. The following operations are included: picking a part from the infeed buffer, loading the part on the roller press, off loading the part from the roller press and sorting it for end buffers (container or transverse conveyor to lane 2).
- The forming roller pressure press and the pressure press require their own working crane, as in the current situation. Since both presses are located in line the same crane track can be used. The cranes are indicated as well.
- The grinding-bevelling-flanging station in lane 1 is to be deployed with working cranes (3 portals) for the turning of the parts during the grinding process, the support of the flanging process and the sorting for end buffers.
- Transport crane S1a-L2-a is required for the operation of the profile cutting processes.
- Transport crane S1a-L2-b is assigned to the the sorting activities of the curved main panel parts. Furthermore it can be used for the infeed and transport of the curved main panel line.
- Transport crane S1a-L2-c is assigned to the main panel assembly process. Within this scenario some internal main panel assembly process part transportation is required. Hence additional transport cranes are assigned.
- Transport crane S1a-L2-d is assigned to the main panel assembly process.
- In lane 2 space is freed for the curved main panel line. Therefore dedicated working cranes are required, whenever the transport crane are not enough. This aspect is further not considered.
- Transport crane S1a-L3-a is required for the operation of the cutting station in lane 3, which include the loading of raw plates on the beds, the offloading of a cut plate in the sorting beds, the sorting of finished parts.
- Transport crane S1a-L3-b is assigned to the infeed of the main panel line.
- Transport crane S1a-L3-c is assigned to the main panel assembly process.
- Also the lane 3 grinding-flanging station is to be deployed with working cranes for the same reasons as the working crane (2 portals) in lane 1. The same activities are assigned.

The KPI for transport distances are defined based on product line and routine. Furthermore the number of transports are determined. The detailed results are enclosed in Table H.4 and Table H.7 respectively. The KPI's are defined below.

$KPI_{3,number}$ = 167 [m] $IR_{3,number}$ = 2.1

$KPI_{3,weight}$ = 112 [m] $IR_{3,weight}$ = 4.3

$KPI_{4,number}$ = 5.8 [-] $IR_{4,number}$ = 3.3

$KPI_{4,weight}$ = 4.7 [-] $IR_{4,weight}$ = 4.4

Similar to the KPI's of scenario 1 the difference in performance of the KPI's on part number and part weight is explained by the main panel (930PLS) and small parts (940M, 950M, 960M) flows. Compared to scenario 1 the main panel flow became much shorter. However the flows for small parts became longer. Hence the difference between the KPI on part number and weight becomes much larger. This is also illustrated by KPI_4. The reduction of the number of transports enables a more smooth flow, since waiting on resource availability is reduced or mitigated.

10.1.3. Investment overview

KPI_{10} concerns the required investments to obtain the future state. The investment overview is updated for the third scenario. Also in this scenario new cutting machines are deployed. The number of transverse conveyors is reduced to 1 and the longitudinal (sorting) conveyors do not appear anymore. The replacement of the roller press is included. Investment figures discussed in Section 6.4 are followed. A detailed information is provide in Table H.11. The required investments for scenario 3 and scenario 1 are approximately equal.

$$KPI_{10} = \text{required investments} = 2520\ [\text{k€}]$$

10.2. Model construction

Similar to the description and analysis of the current state and previous scenarios the construction of the simulation is described prior to obtaining the KPI results. First the model specifics are discussed. Moreover its behaviour is determined.

10.2.1. Model overview

Similar to the approach in Chapter 8 the same assumptions and verification approach as in the current situation are followed. For the new working cranes the same properties as the current working cranes are provided.

The assignment of customers to cutting station is made based on the balance between small and large parts and the to be cut area. Hence two approximately equal flows are created.

The customer demands are studied and resulted in a much smaller sorting space requirement for the cutting station in lane 1 compared to the cutting station in lane 2, since the block- and hull assembly demands are numerically less than the section assembly demands.

The number of sorting beds is determined by initial simulation runs and bottleneck analysis. Having more than one sorting bed the crane requirement and input flow can be more levelled. Since the cranes are used for several cutting station operations a priority is given to the re loading of the cutting support.

The work bench area and end buffer space definition is based on bottleneck analysis and the layout. Furthermore input from the previous scenarios is used.

10.2.2. Model behaviour

Similar to the previous scenarios process control changes are implemented, which have an effect on the process variability. Therefore the model behaviour of the third scenario is studied here. Multiple simulation runs are executed, from which for each the cumulative mean and standard deviation of the entire process duration and all parts is derived. They are normalised on the cumulative average of all runs. They are plotted with a 99% confidence interval in Figure 10.3.

10 simulation runs are performed, whereafter a stable cumulative means is observed. Five additional simulation runs, as recommended by Robinson [67], are performed to mitigate the chance of premature convergence. Conclusively in 99% of the runs the entire process duration of all parts is smaller than

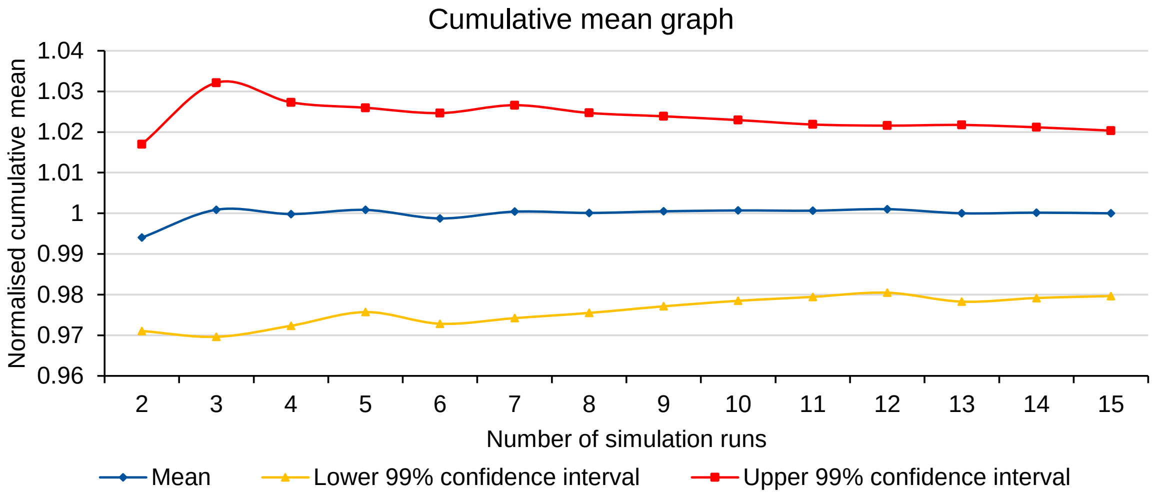


Figure 10.3: Plot of cumulative mean and 99% confidence lower and upper limit, scenario 3

2%. This uncertainty is larger than scenario 1 and 2. Nevertheless this variability is accepted, since an accurate confidence interval is used. Hence the result of 15 simulation runs are used for the determination of KPI_5 to KPI_9. For the determination of annual measures the same procedures are followed as the previous scenarios.

10.3. Throughput analysis

First the part throughput is dealt with. Then the annual and station related throughput are discussed. Last the resource utilisation is addressed. For each the KPI's are defined.

10.3.1. Part throughput

The entire process time per part distribution is plot based on several simulation runs, in Figure 10.4. Compared to scenario 1 and 2 the following phenomena are observed. The right part of the original peak becomes more slim. Besides on the left the new peak increases. In KPI_5 the time average of 'entire process time' per individual part is given. Moreover the KPI is determined when excluding the inventory time in the end buffer. Both results are presented respectively.

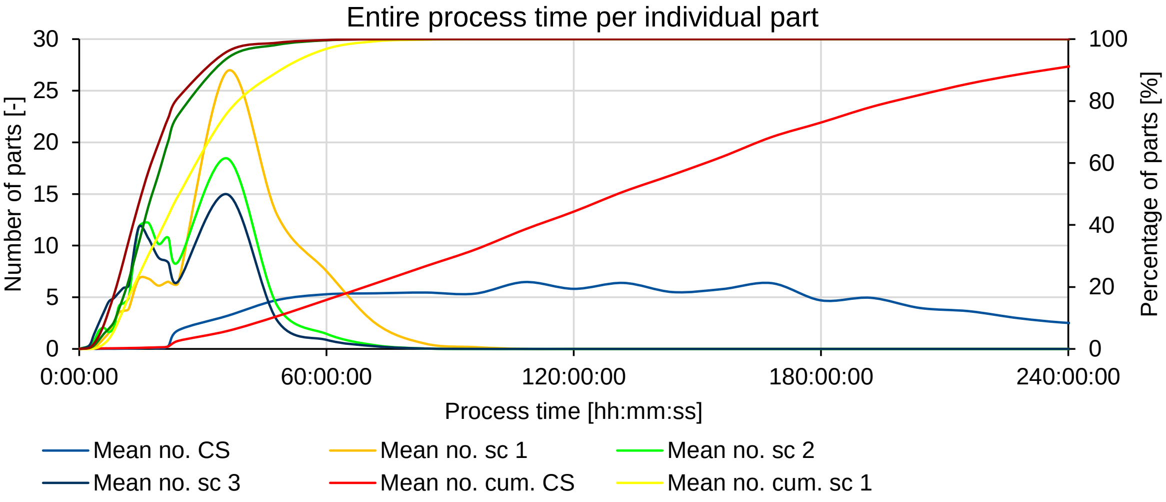


Figure 10.4: Cumulative number of parts per entire process duration, for scenario 3

$$KPI_5 = \text{time average of process time per individual part distribution} = \bar{x}_{time}$$

$$\mathrm{KPI}_{5,\mathrm{real}} = 16{:}58{:}00 \text{ [hh:mm:ss]} \qquad \mathrm{IR}_{5,\mathrm{real}} = 8.3$$

$$\mathrm{KPI}_{5,\mathrm{modified}} = 7{:}02{:}00 \text{ [hh:mm:ss]} \qquad \mathrm{IR}_{5,\mathrm{modified}} = 20.1$$

The entire process duration is reduced for all product lines. The largest improvements are observed for the sub panel assembly parts (910PL/920PL), which clearly underlines the effect of the layout redesign. Also significant improvements are found for the 94M/950M/960M product lines, which clearly underlines the effect of different crane assignments.
The potential effect of implementing nesting constraint “customer demand batch need to be cut in a small period of time” is shown. The presented KPI result is not entirely realistic some customer demand batches are large (section building). However the potential is proven.

10.3.2. Annual throughput

Second the annual throughput is presented. The cumulative annual throughput is determined in KPI_6. This value shows a reasonable increase compared to the KPI of scenario 1 and 2.

$$\mathrm{KPI}_6 = \text{maximum throughput per year (weight)} = 10350 \text{ [ton]} \qquad \mathrm{IR}_6 = 1.1$$

KPI_7 and KPI_8 are related to the occupation of the different stations. In scenario 3 also the tapering, bevelling, grinding and flanging activities are bundled in one cell because the product line contributions. In the Appendix, in Figure H.9 to Figure H.12 the throughput is plot per station. Per workday the input and output flow is described and the difference is plot. These plots are based, contrary to the KPI’s, on the output of a single simulation run, since the dates matter here. The deviations within the individual KPI results is small. KPI_7 and KPI_8 are derived:

$$\mathrm{KPI}_7 = \begin{cases} \text{Cutting 1\&2} \\ \text{Cutting 3\&4} \\ \text{Forming} \\ \text{TBFG} \end{cases} = \begin{cases} 0.90 \\ 1.00 \\ 1.00 \\ 1.00 \end{cases} \qquad \mathrm{IR}_7 = \begin{cases} 0.9 \\ 1.0 \\ 1.9 \\ - \end{cases}$$

$$\mathrm{KPI}_8 = \begin{cases} \text{Cutting 1\&2} \\ \text{Cutting 3\&4} \\ \text{Forming} \\ \text{TBGF} \end{cases} = \begin{cases} 0.60 \\ 0.30 \\ 0.60 \\ 0.70 \end{cases} \qquad \mathrm{IR}_8 = \begin{cases} 1.4 \\ 2.8 \\ 1.0 \\ - \end{cases}$$

It observed that the cutting station occupancy rates, compared to scenario 2, improved slightly. An explanation for this is that the 920PL parts are also cut in the cutting station 1&2 now. Hence the balance shifted from levelling on number of plates to required cutting time. The cutting station occupancy rates do not show much difference from the previous scenarios.
The active station occupancy variability (KPI_8) of the forming station equals the current state. Compared to scenario 1 and 2 this KPI is reduced, which is explained by the fact that parts move through the process faster so less inventory is building up at the stations. This inventory is captured by the active station occupancy variability, which consequently reduces.
The daily station occupancy is related to the number of parts which originate from each plate, which is determined by the plate nestings. Due to the introduced nesting issues it can not be advocated that the relation between plates and parts is exactly true. This mainly concerns KPI_8.

10.3.3. Resource utilisation

Last the utilisation of the resources is considered. The resource utilisation diagrams enable bottleneck identification, which provides information about the station occupancy rate and variability. The resources are named as indicated in Figure 8.2. When more resources are deployed (cutting machines and crane portals) the labels -a to -b are provided from left to right. The result is provided in Table 10.1, where only the pre-processing process related cranes are considered.

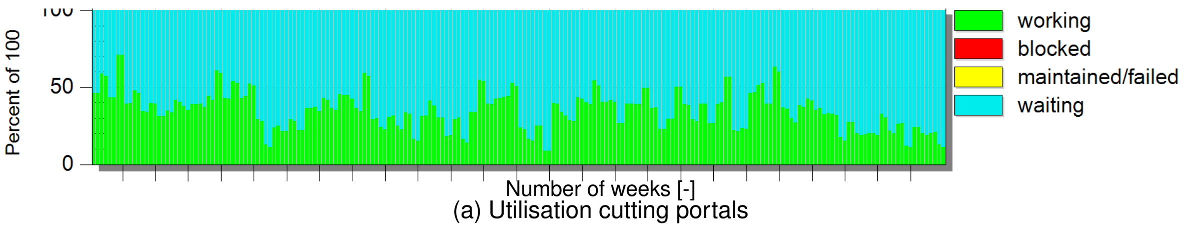
$$\mathrm{KPI}_9 = \text{resource utilisation} = \frac{\text{utilised time}}{\text{total time}} \text{ for } \begin{cases} \text{Cutting machines} \\ \text{Presses} \\ \text{Cranes} \end{cases}$$

Table 10.1: Resource utilisation (KPI_9) results

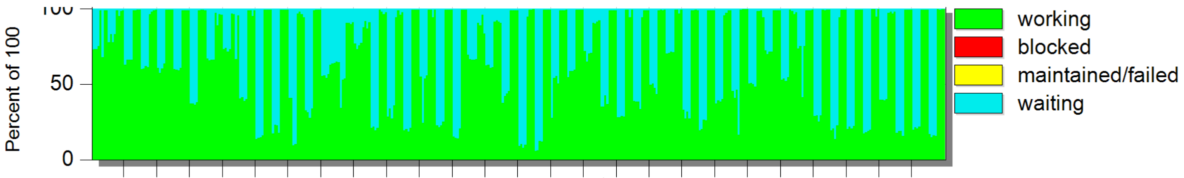
Resource name	Util. [-]	Resource name	Util. [-]	Resource name	Util. [-]
Cutting portal 1	0.44	Cutting bed 1-a	0.6	Crane L2-b	0.02
Cutting portal 2	0.44	Cutting bed 1-b	0.6	Crane L3-a	0.62
Cutting portal 3	0.43	Cutting bed 2-a	0.6	Working crane L1-a	0.38
Cutting portal 4	0.43	Cutting bed 2-b	0.6	Working crane L1-b	0.42
Brake press L1	0.22	Cutting bed 3-a	0.95	Working crane L1-c	0.42
Brake press L3	0.12	Cutting bed 3-b	0.95	Working crane L1-d	0.35
Roller press	0.74	Cutting bed 4-a	0.95	Working crane L3-a	0.27
Roller pressure press	0.4	Cutting bed 4-b	0.95	Working crane L3-b	0.18
Crane L1-b	0.18	Crane L1-a	0.68	Working crane L3-c	0.06

Concerning the flanging and forming resources not stringent bottlenecks are observed. In Figure H.15 the diagrams of the presses are presented, which show approximately the same results as the results of scenario 2. An increase in utilisation is observed due to the throughput increase. For the roller press this might become an issue with further throughput increase.

The resource utilisation diagrams of the cutting portals and beds, presented in Figure 10.5, show still a significant under utilisation of the cutting portals. Close comparison shows a minor improvement compared to scenario 1 and 2. For scenario 3 there is also room for improvement to further utilise delicate resources as cutting machines. On the other hand the number of cutting machines may be questioned.



(a) Utilisation cutting portals



(b) Utilisation cutting beds

Figure 10.5: Date based utilisation diagrams cutting stations scenario 3

Due to the layout redesign the sorting crane problem is assessed. When implementing the crane allocation, as discussed in Section 10.1.2, the cranes (S1a-L1-a/S1a-L3-a) supportive to the cutting operations are again highly utilised. These cranes are in charge of loading the raw plates, offloading the batch of cut plates and sorting all parts. Especially the last activity has an effect on the cranes utilisation since that operation is executed on part level. Hence the sorting operations within the third scenario also need to be subjected to further optimisation.

10.4. Summary

The third scenario focuses on the implementation of the nesting constraint 'cutting less product lines from a plate'. It allows layout redesign freedom, which is used to define two separate cutting stations. Hence the fourth research question is addressed. *What is the quantitative effect of the proposed improvement strategies in terms of space utilisation and throughput?*

In lane 3 a cutting station dedicated to cutting parts for t-beam, main panel and section assembly is included. In lane 1 a cutting station dedicated to cutting parts for plate-sub-panel, block and hull assembly is included. Hence more direct transport the to sub panel- and main panel assembly processes is enabled. Specific cranes are allocated to processes. Utilisation analysis shows that the sorting cranes are deployed significantly. Conclusively this scenario shows initial improvements but can be further improved.

Due to the layout redesign the total required area and the ratio between process and in/outfeed buffer KPI's improve, similar to the KPI's of scenarios 1 and 2. Also the transport distance KPI concerning part weight improves. This KPI on part number slightly deteriorates, which is not stringent because those parts are mainly transported in larger batches.

The individual part throughput improves significantly compared to current state (factor 8) and to scenario 1 and 2 (15% and 35% respectively). Hence the implementation of this nesting constraint and the introduced layout redesign enable a smooth, more continuous, one-piece flow. This has a positive effect on the cumulative annual throughput which also reasonably improves.
The cutting station occupancy rates do not show much difference from the previous scenarios. Due to the introduced nesting issues it can not be advocated that the relation between plates and parts is exactly true.

Finally the ratio between throughput and space utilisation is defined. It is concluded that at the expense of € 2520k the process can be improved by a factor 3.1. This investment equals 2.2% of the annual turnover of the DSGa yard. The same notions, concerning the investments, applicable to scenario 1 apply to scenario 3.

$$\mathrm{KPI}_{11} = \frac{\text{Throughput}}{\text{Required space}} = 2.1 \qquad\qquad \mathrm{IR}_{11} = 3.1$$

The implementation of the additional nesting constraint enables to improve the individual part process duration, which is favourable from Lean Manufacturing perspective. Special care needs to be paid to the levelling of the working load over both cutting stations, else waiting and under utilisation is induced.

11

Valuation metric comparison

In the previous Chapters, Chapter 8 to Chapter 10, different scenarios are described and analysed. For each the same key performance indicators are defined, in order to capture the result in single, comparable metrics. In this Chapter the metrics are compared and the differences are explained. First the design related KPI_1 to KPI_4 are described. Then (Section 11.2) the throughput related KPI_5 to KPI_9 are discussed. By explaining the metrics both positive points and point for improvement are derived. Subsequently in Section 11.3 the investment (KPI_{10}) and benchmark (KPI_{11}) related KPI's are discussed. Such the fourth research question is addressed: **What is the quantitative effect of the proposed improvement strategies in terms of space utilisation and throughput?**

11.1. Comparison layout related metrics

In Figure 11.1 the improvement ratios of the layout related KPI's of the scenarios versus the current state are plot. They are already introduced in Chapter 8. They are compared here. The differences between layout 1 (scenario 1 and 2) and 2 (scenario 3) are discussed.

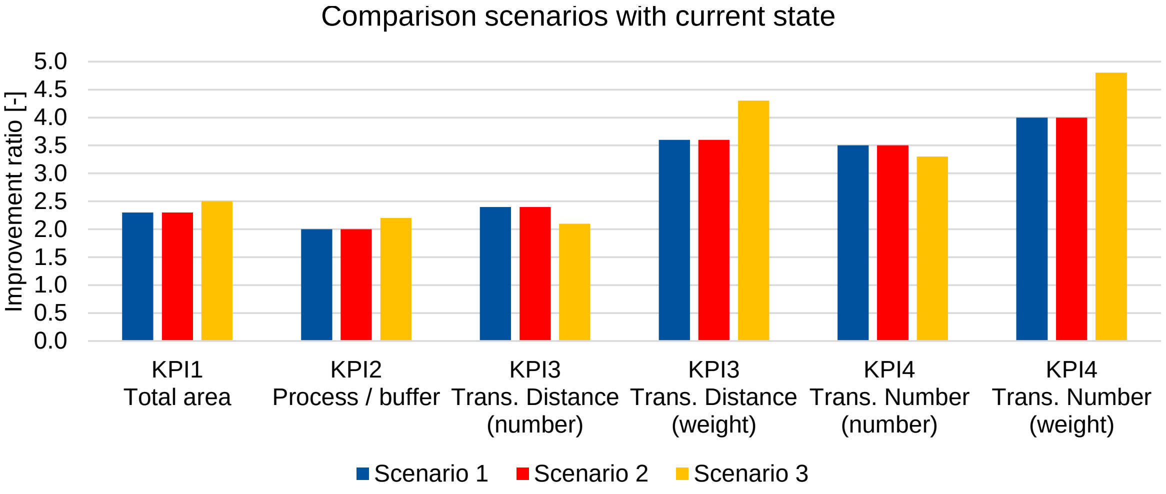


Figure 11.1: Improvement ratios of KPI_1 to KPI_4 of scenarios versus current state

Layout 2 shows an improvement of about 10% in terms of total available area (KPI_1). KPI_2, which captures the percentage of space used for value adding activities, shows that this is initiated by a reduction in buffer space mainly, because its improvement ratio increased. Since buffer spaces do not directly generate value this is positive. The improvements result from the definition of two cutting stations instead of one. Such they are better and directly reachable. Less conveyor systems are applied and the area required for transportation is reduced. Furthermore some areas might be better utilised in layout 2. Hence using two cutting stations is favourable from space utilisation perspective.

Concerning the transport distances (KPI$_3$) and number of transports (KPI$_4$) also improvements between layout 1 and 2 are found, despite the allocation of flows changed. Compared to the current state the improvements are enabled by the exclusion of the S1-S1a transport and a transport reduction of the main panel (930PLS) and small parts (940M, 950M, 960M) flows. Layout 2 enables a shorter main panel parts flow, compared to scenario 1. However the small part flows become longer. This corresponds to the difference between the improvement ratios on part number and weight and concerns to both the transport distance and number of transports (Figure 11.1). The reduction of the number of transports enables a more smooth flow, since waiting on resource availability is reduced or mitigated.

The analysis of the scenarios in Chapters 8 to 10 show KPI$_4$ results in the order of 5-6. Chapter 3 learns that KPI$_4$ for the necessary-non-value adding transports is in the order of 5 moves. Conclusively the transport is significantly improved and is reaching an ideal situation. It is explained by the introduction of much more one-piece, continuous flow and re-positioning of the processes on the layout.

11.2. Comparison throughput related metrics

First the part throughput and maximum annual throughput are discussed. The station throughput is considered in Section 11.2.2. Finally the comparison of the resource utilisation diagrams is provided.

11.2.1. Part and annual throughput

In Figure 11.2 the improvement ratios of the average process time per part (KPI$_5$) and maximum annual throughput (KPI$_6$) are included. First KPI$_5$ is described followed by KPI$_6$.

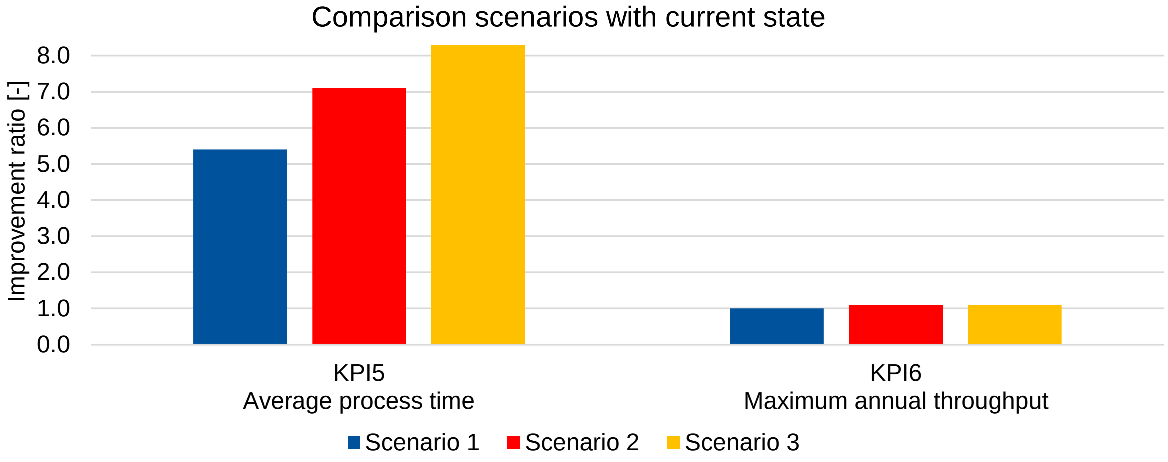


Figure 11.2: Improvement ratios of KPI$_5$ and KPI$_6$ of scenarios versus current state

The part throughput increased significantly to a factor 5 to 8 compared to the current state. The development of scenario 2, compared to scenario 1, enabled the dependency reduction on specific subsequent processes. As a consequence possible bottlenecks in those processes are more localised. Such the other flows are improved as for those the bottleneck is mitigated. Hence the overall part throughput increases. The assessment of the design freedom in scenario 3 enables improvement on bottleneck of scenario 2 and allows further part throughput increase.

In Section 5.1 KPI$_5$ is defined for the strictly value adding activities, which equals 1.25 hrs. For scenario 3 KPI$_5$ equals 17 hrs. About 45% of the part duration is spend in the end buffer waiting until the entire customer demand batch is collected (pre-processing JIT aspect). This could be improved by implementing the nesting constraint 'cut the parts for a customer demand instantly', as shown in the previous Chapters. Hence there is still room for improvement to enable a highly value adding flow.

The increase of part throughput does not directly result in a large improvement of KPI$_6$, because of the bottlenecks and required balance of parts (e.g. fixed ratio between sub panel and main panel parts). Finally a improvement in throughput of 10% is enabled. Such the annual throughput improves from 9275 to 10350 tons.

11.2.2. Station throughput

Here the station throughput KPI's are considered in detail, namely the station occupancy rate (KPI_7) and the active occupancy variability (KPI_8). Difficulty concerning the definition of improvement ratios for KPI_7 and KPI_8 exist, because of the different definition of work stations. Presenting them in bar charts as well does not result in a transparent overview. Therefore for each work station the KPI results are presented in Table 11.1. The tapering-bevelling-grinding-flanging cells, as defined in Chapter 8, are abbreviated as TBGF stations. Related work stations are coloured similarly. As described in Section 2.3.4 the purpose of these KPI's is to capture whether the work station have levelled operations. Therefore KPI_7 and KPI_8 should be 1 and 0 respectively.

Table 11.1: Improvement ratios of scenarios versus current state of KPI_7 and KPI_8

		KPI results				
Item	Unit	CS - S1	CS - S1a	Sc. 1	Sc. 2	Sc. 3
$KPI_{7,cutting}$	[-]	1	1	1	-	-
$KPI_{7,cutting,1\&2}$	[-]	-	-	-	0.88	0.9
$KPI_{7,cutting,3\&4}$	[-]	-	-	-	1	1
$KPI_{7,forming}$	[-]	0.52	1	0.95	0.97	1
$KPI_{7,grinding}$	[-]	0.89	1	-	-	-
$KPI_{7,flanging}$	[-]	0.4	0.89	-	-	-
$KPI_{7,TBGF}$	[-]	-	-	1	1	1
$KPI_{8,cutting}$	[-]	0.84	0.68	0.28	-	-
$KPI_{8,cutting,1\&2}$	[-]	-	-	-	0.78	0.6
$KPI_{8,cutting,3\&4}$	[-]	-	-	-	0.25	0.3
$KPI_{8,forming}$	[-]	0.6	0.57	0.69	0.67	0.6
$KPI_{8,grinding}$	[-]	0.66	0.62	-	-	-
$KPI_{8,flanging}$	[-]	0.56	0.74	-	-	-
$KPI_{8,TBGF}$	[-]	-	-	0.85	0.5	0.7

The results for KPI_7 show improved behaviour compared to the current state, which is conform expectation. However the active station occupancy variability (KPI_8) does not show a clear improvement.

Due to the introduction of a more continuous, one-piece flow the active station occupancy of the cutting station is improved significantly. This is clearly found in the result of scenario 1. For scenario 2 and 3, which deploy two cutting stations, station 3&4 shows the same behaviour. The reduced occupancy rate of cutting station 1&2 results in more fluctuation of the daily occupancy and hence the active occupancy variability. Due to the rearranged part allocation per cutting station of scenario 3 compared to scenario 2, this KPI improved slightly. Concerning the allocation of product lines to cutting station room for improvement exists, which obviously depends on the existence of next process' bottlenecks.

The daily occupancy of the forming and TBGF station is related to the number of parts which originate from each plate, which is determined by the plate nestings. Due to the nesting issues it cannot be advocated that the relation between plates and parts is exactly true. This mainly concerns KPI_8.

In Section 2.3.4 these KPI's are defined on the basis of part weight, since that is a well excepted metric in shipbuilding and incorporates the differences in parts. However, a levelled flow on part weight does not necessarily imply that the work station is levelled in terms of work load. Furthermore the collection of customer demand batches is included (Appendix H.4.1). This introduces some variation as well.

Hence for obtaining stringent conclusions on the active station occupancy variability (KPI_8) improved nestings are required. Moreover the measured part attributed might require revision.

11.2.3. Resource utilisation

The resource utilisation diagram (KPI_9) comparisons show a slight improvement of the cutting machine utilisation. Still they are significantly under utilised. Date based utilisation wise three cutting machines would suffice. In Chapters 8 to 10 several causes are determined. First of all the sorting crane portals show a high utilisation, making them susceptible for being bottlenecks. Furthermore the crane which is responsible for offloading the parts from the transverse conveyor is reasonably active. This activity is characterised by a batch to single flow phenomena. Generally speaking the batch to single flow events pose key transport requirements. The three scenarios are still not fully optimised for that.

11.3. Comparison objective related scenarios

Finally the required investments (KPI_{10}) and ratio between throughput and space utilisation (KPI_{11}) are compared. The study's objective is to merge the two DSGa pre-processing facilities into S1a and to meet peers performance. KPI_{11} is therefore the main parameter. Figure 11.3 presents the results.

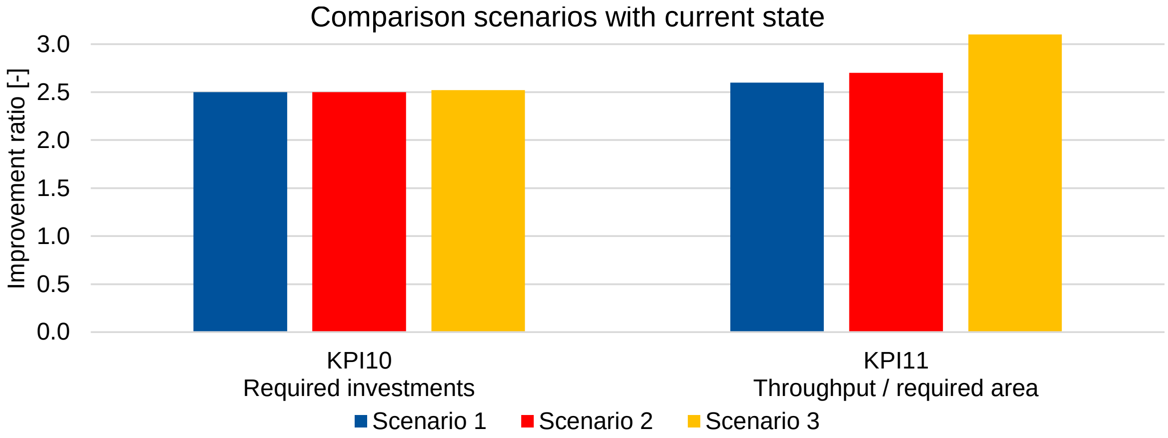


Figure 11.3: Improvement ratios of scenarios versus current state of KPI_{10} and KPI_{11}

Chapter 6 presented preliminary investments figures. Based on those each of the future state scenarios require about €2.5 million for the investments in resources. This amount equals about 2.1% of the annual yard turnover. More detailed definition is required to conduct detailed comparison.
As discussed in Section 3.2.1 the cutting machines reached their economic lifetime. Accounting them entirely in the layout redesign expenses leads to a flawed conclusion. The four cutting machines require an investment of €2 million. Hence €0.5 million is required for the process redesign. Furthermore the number of cutting machines could be reduced to three since they are currently not fully utilised.
With this expenditure the process can be significantly improved as shown in Figures 11.1 to 11.3. KPI_1 shows that the two pre-processing facilities of DSGa can be merged in S1a. This is possible for all three scenarios. Furthermore the throughput is increased, which is highest for the third scenario. Conclusively the ratio between throughput and space utilisation meets the peer industry levels of about 3. Hence finally also the second objective is met. Such the objective of this study is reached and the main research question is answered.

11.4. Summary

Subsequent to the scenario analysis their results are compared and the main research question is answered. **What is the quantitative effect of the proposed improvement strategies in terms of space utilisation and throughput?**

The implementation of nesting constraint 'cutting less sections from a plate' results in a feasible, improvement scenario. The additional implementation of the constraint 'cutting less product lines from a plate' enables further improvement, both when adopting the same layout and when designing a new layout. The improvement scenarios underlined the effectiveness of the implementation of this nesting constraints.
Finally the two objectives of this study are addressed, 1) merging the two pre-processing facilities into facility S1a and 2) improvement of throughput versus space utilisation to industry peer's levels. The first objective is met by all three scenarios as the required space reduced with a factor 2.3-2.5. The second objective is met by the third scenario, as the ratio between throughput and space utilisation is increased with a factor 3.1. Hence the quantitative effect of the improvement strategies is such that both objectives are met.
In all scenarios there is still room for improvement Especially the sorting transport after cutting is critical. This statement is underlined by all three scenarios.

12

Improvement scenario 4 outlook

As shown in Chapter 11 the sorting transport after cutting is critical. Next to that batch to single flow events are unavoidable since the parts are generated in batches and processed individually. Chapter 9 shows that allocating more cranes to improve the sorting transport does not improve throughput significantly. Assigning more cranes increases the likelihood of crane clashes, which reduce their effective utilisation. However during this study other novel alternatives for sorting transport systems are found, which could overcome the issues related to cranes. Since the main research question is already addressed in Chapter 11 this Chapter is a supplement. It provides and discusses insight in the effect of addressing the sorting transport issue.

First the crane deployment analysis is described in Section 12.1. Secondly a promising concept derived from the Parcel Delivery industry is selected. This concept is then further described and analysed in Section 12.3 to Section 12.5. Moreover this concept is compared with the previous analysis in Section 12.6.

12.1. Crane deployment analysis

Within shipbuilding normally more cranes are deployed to mitigate the batch to single flow events [20, 38]. In order to check the effect of this the simulation models are adapted and the following checks are executed:

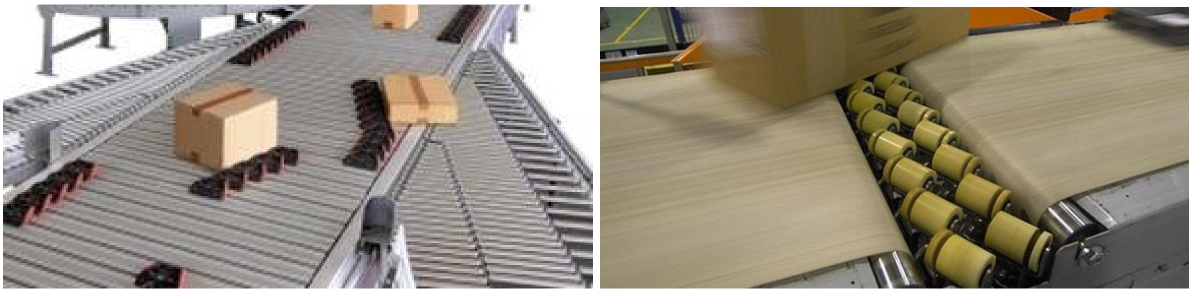
- For scenario 1 and 2 additional cranes are implemented in the simulation models. For the batch to single flow event in lane 1 (sub panel processing station) this approach is successful. Two separate lanes are constructed. Such the part and annual throughput are improved reasonable and approach the scenario 3 result. Particular tuning of the flow separation to the cranes lanes is required.

  The batch to single flow event in lane 2 (sorting after cutting) is not reasonably improved with the introduction of additional cranes. This was already discussed in Chapter 9. As a result the utilisation is spread over several cranes. Conclusively the event in lane 1 shows more potential for further improvement.
- For scenario 3 also more crane portals are included, for the cutting-sorting event, which is the main batch to single flow event in scenario 3. This enabled a slight throughput improvement. However the joint crane utilisations increased more, relative to the improvement. This indicates the existence of waiting and crane clashes when executing the operations.

The results of the simulation model checks show that adding additional cranes only has a marginal effect on the annual throughput.

12.2. Parcel Delivery industry application

To improve the sorting transport bottleneck another industry involved with much sorting transport activities is reviewed, namely the Parcel Delivery (PD) industry. It links to the pre-processing process of DSGa, so far the logistic process is concerned. Both logistic flows are subjected to a reasonable amount of customers and part variability. Characteristic for a PD industry is the deployment of conveyor systems to move parcels, instead of cranes as in shipbuilding [39, 85]. Different conveyor sorting systems exist, namely shoe-, pop-up-, tilt-tray- and Celluveyor sorters, as shown in Figure 12.1 [8, 84, 85].



(a) Shoe sorter (b) Pop-up sorter

(c) Tilt-tray sorter / cross sorter (d) Celluveyor sorter

Figure 12.1: Sorting system illustration, [8, 84, 85]

In shipbuilding pre-processing a batch of parts arrives from cutting. This batch has to be pulled apart and sorted per customer. Furthermore the sorting system has to cope with the significant part size variability and part weights. A compact system is preferred to minimise space requirement. Those parameters are listed in Table 12.1.

Table 12.1: Comparison sorting systems

	Pull batch apart	Sort per customer	Large part sizes	Small part sizes	Part weight	Space requirement
Shoe sorter	x*	v**	v/x	v	v/x	v/x
Pop-up sorter	x	v	v	v/x	v	v/x
Tilt-tray sorter	x	v	x	v	x	x
Celluveyor	v	v	v	v/x	v	v

**Application is most likely not possible, *Application is most likely possible.

For each of the sorting systems it is indicated whether application in pre-processing is possible in Table 12.1. These indications are based machine functionality descriptions [53, 64, 83, 84]. They are indicative only, since currently such systems are not deployed in heavy industries like shipbuilding .
The Celluveyor system seems most appropriate. The shoe, pop-up and tilt-tray systems are line or loop sorters, which implies that positioning parts in series is not included in the mechanism. Contrary, the Celluveyor enables moving and positioning several objects simultaneously and independently. Hence it is also able to pull apart a batch of parts.
Hence for this outlook scenario the Celluveyor technique is adopted for the definition of scenario 4. This scenario is described similar to the previous scenarios in Chapter 8 to Chapter 10.

12.3. Scenario description

Here the layout and crane allocation are explained. Moreover the related KPI's are defined. The investment related KPI is not defined since uncertainty about the expenditures exists. Such the functional potential is underlined only. The layout and crane allocation are described below.

The Celluveyor is a highly flexible modular conveying and positioning system that is based on the approach of cellular conveying technology. It enables a high adaptability of the layout of the conveying system [8]. Such main flow from cutting can be separated in smaller flows to the sorting 'customers'. Scenario 1 is taken as starting point since there the highest number of flows originate from the cutting station and sorting is therefore most complicate. Furthermore only the nesting constraint 'cutting less sections from a plate' is implemented. The constraint 'cutting less product lines from a plate' is less advantageous when using such platform. In Figure 12.2 the updated scenario 1 layout is presented. Specific points of interest are numerically labelled, which are described below.

The Celluveyor sorting system (label 1) is supplied by means of an infeed conveyor. Crane S1a-L2-a is dedicated for loading. Parts can be nested within the open spaces of larger parts. Since the sorting system is not able to separate those a phase difference between different parts sets is required when loading the cut parts on the conveyor. The handling is similar to the scenario 1 operation. Therefore it will not form a bottleneck. The Celluveyor has an area of at least 13x13m for turning large parts.

In Figure 12.2 the main panel parts (930PLS) are directly moved to lane 3 by means of a transverse conveyor (label 2). The Celluveyor is positioned at the upper side of lane 2 such that the main panel parts can be easily transported. This is advantageous since they require much space to turn otherwise and now the transverse conveyor can directly be reached.

The parts for forming are moved to the longitudinal forming infeed conveyor (label 3), which acts as an infeed buffer as well. For proper space utilisation and feasible conveyor transport the conveyor is positioned on the upper side of lane 2. To enable straightforward access to the roller press, the (roller) pressure press is positioned on the upper side of the conveyor (Figure 12.2). The S1a-L2-d crane is fully assigned to the forming station, similar to the scenario 1 design. However also crane S1a-L2-c is partly assigned to level peaks in operation.

The sub panel grinding station in lane 1 is supplied by the conveyor system as well. As generally these parts are smaller turning them is more convenient concerning conveyor space occupancy (label 4). The analysis of scenario 1 and 2 show that the offloading of the lane 1 - lane 2 transverse conveyor revealed a bottleneck, due to the batch to single flow phenomena. Hence the deployment of such platform in lane 1 is preferred as well (label 5). The main strengths of using such platform is the turning of large parts and direct sorting of small parts. Furthermore it enables dedicated grinding lanes for certain part types (e.g. C-G or C-G-FI routines). The deployment of two parallel portals enable a faster offloading of the platform. The platform is able to level the supply of parts over the different lanes.

Table 6.1 shows that about 60% of the parts for section-, block- and hull assembly can require processing as well. All large (>20kg) parts are first moved to a outfeed conveyor to reduce the Celluveyor's occupation. The conveyor is relatively long to enable levelling its in- and outfeed. Subsequently the parts are either directly sorted for end buffers (label 7) or loaded on the grinding work benches (label 6). Crane S1a-L2-b is fully dedicated ad crane S1a-L2-c is partially assigned to this operation. From the grinding work benches the working cranes are able to sort the parts for end buffers. The small parts are moved from the Celluveyor to a small parts grinding station (label 8) using a small conveyor. Then those parts are processed and manually sorted for end buffers. A brake press is positioned in between both stations to allow operation by both processes. These grinding processes qualify for automisation processes, which is not futher considered in this study.

The implementation of a conveyor system requires a proper stable information flow. The flow attributes must specifically be available for the operation of the Celluveyor. Since the position of each part in the nesting is known, the start position of each part is also known. This poses a significant software requirement. Hence this application is actually clearly driven by industry 4.0 techniques [65].
Resuming the implementation of a conveyor system, using Celluveyor sorting platforms enable:

- utilisation reduction of crane S1a-L2-b (scenario 1 sorting portal). This crane does not transport the sub- and main panel and to be formed parts anymore. Furthermore, the sorting for end buffers and loading of parts on the work benches operations are now shared with crane S1a-L2-c.
- utilisation reduction of crane S1a-L2-d, since peak operations are shared with crane S1a-L2-c.

Figure 12.2: Outlook scenario layout, conveyor application.

- equal space requirement. Although the Celluveyor platform requires to be reasonably large less space is required for (lift)truck movement.
- a process which is less susceptible process to human factors, while still being flexible.
- a levelled supply of parts per product lane. This mainly concerns the Celluveyor platform in lane 1. Hence faster offloading of the lane 1 - lane 2 transverse conveyor is enabled.
- less dense section-, block- and hull assembly sorting space. This is positive since now this sorting space can more flexibly act as intermediate buffer as enough space is available.
- a more continuous flow, as crane handling is reduced.

Subsequent to the scenario description the related KPI's are derived. Detailed background information is provided in Appendix H.2. Furthermore the improvement ratios (IR) compared to the current state are present. They are defined positive, meaning that an increased ratio implies an improvement.

$$\text{KPI}_1 = \text{Area}_{\text{total}} = 5500\ [m^2] \qquad \text{IR}_1 = 2.3$$

$$\text{KPI}_2 = \frac{\text{Process space}}{\text{Total space}} = 47\ [\%] \qquad \text{IR}_2 = 2.1$$

$$\text{KPI}_{3,\text{number}} = 143\ [\text{m}] \qquad \text{IR}_{3,\text{number}} = 2.4$$

$$\text{KPI}_{3,\text{weight}} = 136\ [\text{m}] \qquad \text{IR}_{3,\text{weight}} = 3.5$$

$$\text{KPI}_{4,\text{number}} = 5.0\ [\text{-}] \qquad \text{IR}_{4,\text{number}} = 3.9$$

$$\text{KPI}_{4,\text{weight}} = 4.3\ [\text{-}] \qquad \text{IR}_{4,\text{weight}} = 4.8$$

Although the position of some resources changed the total area of the work stations and processes did not reasonably changed. Hence also KPI_1 and KPI_2 did not change. Due to the minor layout changes KPI_3 also is not physically changed. However the implementation of the conveyor system results in less different transports. KPI_4 does improve by about 15% to 20% compared to scenario 1 and 2.

12.4. Model construction

A simulation model is constructed to obtain the defined KPI's for scenario 4. This scenario comprises the implementation of nesting constraint 'cutting less sections of a plate' and the implementation of a conveying and Celluyevor sorting system. The model construction and behavior are discussed.

12.4.1. Model construction

As far as possible the same layout, crane allocation, cutting program, sorting spaces, personnel requests and handling procedures are used. Moreover the same verification procedures are followed. The Celluveyor system is modelled by a single processing unit which transfers the parts from the infeed to the different outfeed conveyors, within a time interval of 5 minutes. The duration is based on consultancy with the Celluveyor company [53]. Furthermore internal conveyor length is introduced to cope with the fact that the software conveyors do not straightforwardly allow parallel transport.

Flexibility in designing the grinding-flanging stations exists, because of the available area shape. By means of simulation iterations multiple configurations are checked. Furthermore different logical crane allocations are checked for the forming and grinding-flanging stations. Out of those the best performing options are selected and implemented.

12.4.2. Model behaviour

The implementation of the conveyor system has an effect on the process variability. Therefore the model behaviour of the fourth scenario is studied. For multiple simulation runs the cumulative mean and standard deviation of the entire process duration and all parts is derived. They are normalised and plotted with a 99% confidence interval in Figure 12.3. In order to limit the computational effort 8 simulation runs are performed. Hereafter a stable cumulative mean is found.

Conclusively in 99% of the runs the entire process duration of all parts is smaller than 1.5%, which is accepted. This uncertainty equals the results of scenario 1 and 2. Hence the results of the 8 runs are used for the determination of the throughput and resource utilisation KPI's.

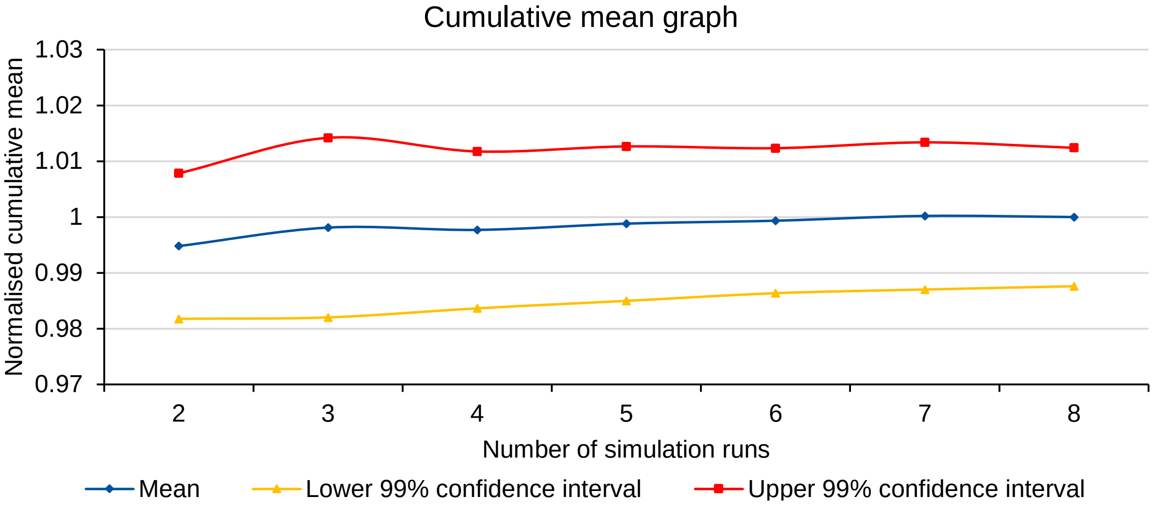


Figure 12.3: Plot of cumulative mean and 99% confidence lower and upper limit, scenario 4

12.5. Throughput analysis

First the part throughput is presented. Then the annual and station related throughput are discussed. Last the resource utilisation is determined.

12.5.1. Part throughput

The entire process duration per part is measured, which spans the time between a raw plate entering on the conveyor and a customer demand batch being entirely finalised and collected. In Figure 12.4 the distribution of parts per specific time 'in the process' is presented. The current state and scenario results are plot in the Figure as well. Compared to the previous scenarios, scenario 4 shows a much wider distribution. This is explained by the conveyor system character. The flows are separated in an early state and are thus processed individually. Such multiple peaks are arising for multiple flows.

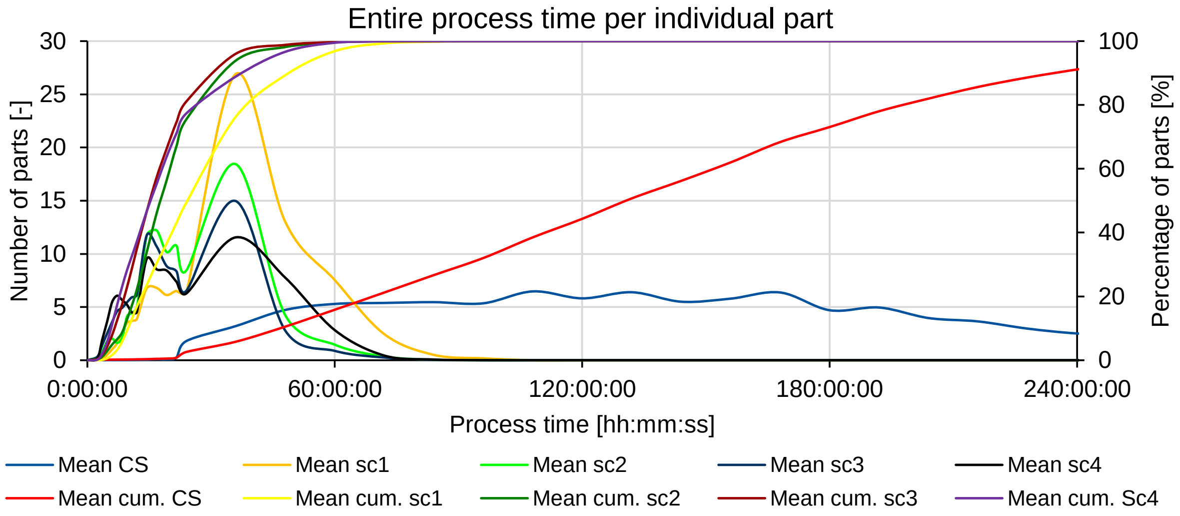


Figure 12.4: Cumulative number of parts per entire process duration, for scenario 1

Based on the distribution of Figure 12.4 KPI_5 is defined. Similar to the previous scenarios the duration in the end buffer is related to the second additional nesting constraint: 'all parts for a customer demand batch need to be cut in a small period of time'. In order to study the effect of this the entire process duration is also determined including a modification for waiting in the end buffer. Hence two KPI's are defined, namely a original and modified one respectively.

$$KPI_5 = \text{time average of process time per individual part distribution} = \bar{x}_{time}$$

$$\text{KPI}_{5,\text{real}} = 18{:}11{:}00 \text{ [hh:mm:ss]} \qquad \text{IR}_{5,\text{real}} = 7.8$$

$$\text{KPI}_{5,\text{modified}} = 8{:}16{:}00 \text{ [hh:mm:ss]} \qquad \text{IR}_{5,\text{modified}} = 17.1$$

KPI_5 is improved with a factor 7.8 compared to the current state. Compared to scenario 1, which applies the same nesting constraints, this is an improvement of 45%. Hence the flow has become much more continuous by the application of the conveying system.

12.5.2. Annual throughput

Here the annual throughput is presented. The cumulative annual throughput is determined in KPI_6. This value shows a reasonable increase compared to the current state (and previous scenarios) of about 30%.

$$\text{KPI}_6 = \text{maximum throughput per year (weight)} = 12200 \text{ [ton]} \qquad \text{IR}_6 = 1.3$$

The station occupancy rate shows that all stations are occupied similarly to the previous scenarios, therefore they are not specifically presented. The active station occupancy variability results are not specifically presented because of the reasons provided in Section 11.2.

12.5.3. Resource utilisation

Finally the utilisation of the resources is considered. The resource utilisation diagrams enable bottleneck identification. The resources are named as indicated in Figure 12.2. When more resources are deployed (cutting machines and crane portals) the labels -a to -b are provided from left to right. The result is provided in Table 12.2. The working cranes are not included in the Table, as their utilisation diagrams do not show bottleneck behaviour and there are a number of them.

$$\text{KPI}_9 = \text{resource utilisation} = \frac{\text{utilised time}}{\text{total time}} \text{ for } \begin{cases} \text{Cutting machines} \\ \text{Presses} \\ \text{Cranes} \end{cases}$$

Table 12.2: Resource utilisation (KPI_9) results

Resource name	Util. [-]	Resource name	Util. [-]	Resource name	Util. [-]
Cutting portal 1	0.49	Cutting bed 1-a	0.98	Crane L1-b	0.38
Cutting portal 2	0.49	Cutting bed 2-a	0.98	Crane L2-a	0.3
Cutting portal 3	0.49	Cutting bed 3-a	0.98	Crane L2-b	0.48
Cutting portal 4	0.49	Cutting bed 4-a	0.98	Crane L2-c	0.23
Brake press L1	0.12	Cutting bed 1-b	0.98	Crane L2-d	0.18
Brake press L2	0.26	Cutting bed 2-b	0.98	Crane L3-a	0.1
Roller press	0.77	Cutting bed 3-b	0.98		
Roller pressure press	0.48	Cutting bed 4-b	0.98		

The cutting portal utilisation's improved compared to the current state and previous scenarios. However still under-utilisation is found. The utilisation results of the cranes show a reduced utilisation, compared to the previous scenarios. This is expected because of the use of the conveying system and the reduced KPI_4. What is most interesting is the high utilisation of the forming presses. Especially the roller press, processing all to be formed parts, is highly occupied. Visual inspection of the simulation model underlines this. Due to the high utilisation of the forming station the forming infeed conveyor is significantly utilised. As a result the Celluveyor platform is not able to operate and the other flows are stopped as well. The high utilisation of the forming station is resulting from the throughput increase of 30%. Hence the bottleneck shifted from sorting to the forming.

12.6. Comparison and bottleneck improvement iteration

Although the Celluveyor system is applicable in terms of part weight range and capacities it is currently not applied on such scale. Therefore investment figures cannot be derived easily and reliable.

This scenario builds on scenario 1 as the same nesting constraints are applied. Compared to scenario 1 all KPI's are improved. Compared to scenario 2 and 3 especially the transport and annual throughput related KPI's are improved. The part throughput of scenario 4 approaches the result of scenario 3. Due to the separation of product lines the flows can be locally optimised further resulting in an improved part throughput.
The maximum annual throughput increased with 30%. Such the ratio between throughput and space utilisation further increased. This ratio is well above the results of the previous scenarios.

$$\mathrm{KPI}_{11,\mathrm{scenario}\ 4} = \frac{\text{Throughput}}{\text{Required space}} = 2.2 \qquad \mathrm{IR}_{11} = 3.3$$

The forming station becomes the main bottleneck. As a case problem it can be easily solved by the implementation of additional forming presses. The effect of such adaption is preliminary checked by means of the simulation model. Such the total required area slight increases. However the maximum annual throughput (KPI_6) is significantly improved to 17900 tons, which results in an improvement ratio of 1.9. Based on those figures KPI_{11} can be redetermined as well:

$$\mathrm{KPI}_{11,\mathrm{iteration}} = \frac{\text{Throughput}}{\text{Required space}} = 3.1 \qquad \mathrm{IR}_{11} = 4.6$$

This is a major potential. The entire analysis shows that the required space to execute the pre-processing activities is reduced significantly. As a result the main panel assembly process is entirely re-positioned to the S1a pre-processing facility. Space is freed in the section assembly shed, which provides more space to execute the section- and block assembly processes. Hence the throughput potential of the Celluveyor application and forming station extension can be fully appreciated.

12.7. Summary

The analysis of the three scenarios showed that sorting transport after cutting is critical. Since the main research question is already addressed in Chapter 11 this Chapter is a supplement to provide and additional insight in the effect of addressing the sorting transport issue.

Normally within shipbuilding more crane are deployed to mitigate these issues. Initial simulation attempts show that the results are marginally effective. The Parcel Delivery industry provides a promising solution. The Celluveyor sorting technique is selected because of its required ability to handle 'batch to single flow' events.

A fourth scenario is constructed based on the Celluveyor technique. Scenario 1 is taken as starting point since there the highest number of flows originate from the cutting station and sorting is therefore most complicate. Furthermore only the nesting constraint 'cutting less sections from a plate' is implemented. The constraint 'cutting less product lines from a plate' is less advantageous when using such platform.

The layout and crane allocations are described. Although a re-positioning of stations the layout related KPI's hardly changed. However the transport related KPI's improve by about 15% to 20%, compared to the other scenarios. The part throughput KPI improved by 45% compared to scenario 1. Such it approximates the results of scenario 2 and 3. The annual throughput improved to a factor 1.3. This is significantly more than the previous scenarios. The ratio between throughput and space utilisation is improved to a factor 3.3, which is well above industry peer's performance. This also underlines the advantage of implementing such Celluveyor driven conveying system. The resource utilisation diagrams show that the forming roller press becomes highly occupied. Hence the main bottleneck shifted from 'batch to single flow events' to the forming station being the bottleneck.

The preliminary assessment of this bottleneck shows that the annual throughput can be improved to a factor 1.9 compared to the current state, by implementing additional presses. Such the ratio between throughput and space utilisation is improved to a factor 4.6. The reduction of pre-processing space utilisation provides more process space for the customer processes. Such the significant throughout increase is appreciated.

13

Conclusion and discussion

The objective of this study is to increase DSGa's throughput and decrease space utilisation, such that pre-processing facilities S1 and S1a can be merged in S1a and DSGa meets the industry standard. The Lean Manufacturing framework is implemented for this purpose. Therefore the main research question is formulated as follows.

To what extent can the two pre-processing areas of DSGa (i.e S1 and S1a) be merged into S1a, in order to optimise space utilisation and throughput, by redesigning the process, based on the Lean Manufacturing framework?

First the conclusions are presented in Section 13.1. Second recommendations are presented in Section 13.2. Moreover, in Section 13.3, notions for further research are outlined.

13.1. Conclusion

Four research questions are posed in the introduction of this study. Each of them is answered in order to formulate the answer to the main research question.

Research question 1

How can the performance of the current pre-processing process be described by means of the static Value Stream Mapping approach?

The question is answered by a Lean Manufacturing waste analysis. Moreover layout description and Material Flow Analysis (MFA) are used to obtain the space utilisation related design KPI's.

Much waste is recognised and the performance of the current pre-processing process is subjected to significant inefficiencies. In the current situation all parts of a section are nested in cutting groups of several sections. Significant inventory is being build up as not all parts of a section are required directly. Furthermore an implication on the required space to sort and store all part is found. The batches are repacked and sorted several times which underline the inventory, waiting, transport and movement waste. The large cutting batches and station supply variability are a result of improper nesting, from process efficiency perspective. The over-processing, defects and waiting waste types are found in sub-processes, information availability and lack of dedicated processes. Last, waste is induced by the current layout design, by its size and the positions of workstations. It is strongly related to building up inventories all over the facility. Furthermore it has an effect on transport crane requirement and transverse lane transports.

About 22% of the available space is used for value-adding activities. On average the parts travel more than 400m, which is more than twice the facility length. The statement still persists when excluding this distance between S1 and S1a. Directly related is the number of transports, which is on average 20. This underlines the absence of a clear continuous flow.

Research question 2

What is the quantitative performance of the current pre-processing process obtained by means of dynamic simulation analysis?

A dynamic simulation model is constructed to quantify the time-related waste in the DSGa pre-processing process and enable comparison between current and future states by obtaining KPI results. The conclusions of the first research question are confirmed.

The distribution of the entire process duration of all individual parts shows that the parts are on average approximately 140 hours 'in the process', from which on average only 1.25 hours is value-adding. Hence the relation between value add and non value add is clearly quantified. Much of this time is spend on cutting sorting spaces, intermediate buffers and part processing spaces.
The occupancy rate and active occupancy variability, capturing whether the work stations have a levelled throughput, show a fluctuating behaviour typical for batch driven processes. This is underlined by the resource utilisation assessment. The occupancy variability also stresses the effect of different batch sizes. The qualitatively recognised supply and demand variability is clearly underlined by those indicators. The resource utilisation diagrams clearly show the waiting wastes of the cutting beds due to inefficient sorting routines and ratio between portals and supports. Moreover they show the absence of dedicated working space and cranes.

Research question 3

What process improvement strategies can be proposed, for redesigning process, based on the Lean Manufacturing framework?
A transition from a functional driven process organisation to a product line driven organisation is required. Product lines need to be defined to benefit from repeated manufacturing and facilitate continuous, uniform flows. The main drivers are the batch generation and demand, significant part variability and sorting routines reduction. Product lines can be based on routines, customer demands, and part attributes. It is not feasible to implement all of them due to implications like resource duplication and flow contributions. Merging several customer demand flows in a tapering-grinding-flanging routine flow succeeds. Moreover a distinction based on part weight makes sense for grinding and flanging. Product line dedicated logistic resources are required to minimise transfers and enable flow.

Particular emphasis is required for batch size reduction. Batch size reduction poses logistical implications, which effects need to be further analysed, because it enables the approaching of a true continuous flow. For bevelling, tapering, forming, grinding and flanging the batch size can be reduced to one. By the nature of cutting, one-piece flow is not possible. The number of sections and customer demands cut from one plate must be reduced to reduce the required sorting space and enable smooth flows. Hence the implementation of the flow and timing principles, to enable a continuous and value adding flow, is directly related to the parts generation. That makes part generation the start point for global effective flow improvements.
The implementation of these principles results in additional constraints on the nestings. The following constraints are found: nest a smaller number of sections per plate sequence, cut an entire customer demand batch in a short period of time, nest per levelled customer demand, nest per specific product line and nest flat bar from profiles.

Research question 4

What is the quantitative effect of the proposed improvement strategies in terms of space utilisation and throughput?
For two feasible, global effective nesting constraints the quantitative effect is studied on two different layouts. The current state (CS) KPI results, except for the occupancy and resource utilisation KPI's, are presented in Table 13.1. Furthermore the improvement ratios (IR) of the scenarios are provided. First the 'nest less section per plate sequence' constraint is implemented. As a consequence a single cutting station is defined. By positioning the customers close by and enabling a shorter, more continuous flow the total required area is reduced by a factor 2.3. The annual throughput still equals the current state throughput. Resource utilisation shows that the sorting action is the flow bottleneck due to the high sorting crane and transverse conveyor off-loading crane utilisation. Hence additional room for improvement exists. The ratio between throughput and space utilisation can be improved by 2.6 times at the expense of €2.5 million.

Secondly the ‘nest per specific product line’ constraint is additionally implemented, adopting the scenario 1 layout. The implementation of this constraint localises apparent bottlenecks. Hence the part throughput is further improved to a factor 7. The annual throughput increases as well, resulting in a ratio between throughput and space utilisation of 2.7. Particular attention is required for the levelling of the working load over both cutting stations, else waiting and under utilisation are induced.

The adopted design freedom of the ’nest per specific product line’ constraint enables further logistic improvement. The layout related KPI’s do not significantly change compared to scenario 1 and 2, nor do the required investments. However the part throughput is further improved to a factor 8.3. This has a positive effect on the cumulative annual throughput which also reasonably improves, providing a ratio between throughput and space utilisation of 3.1. Resource utilisation assessment shows that the sorting cranes and cutting machines are high and utilised respectively. Hence the third scenario can also be further improved.

Finally the effect of improved nesting and related flow improvements is confirmed. The development of several scenarios show the implication of logistics, which underline the potential of further improvements. All three scenarios show that the sorting transport after cutting is critical for further improvement. Based on the improvements the main research question can be answered.

Table 13.1: KPI comparison table

Name	Description	Units	CS	IR. 1	IR. 2	IR. 3
KPI_1	Available $area_{total}$	[m^2]	12840	2.3	2.3	2.5
KPI_2	Process vs in/outfeed space	[-]	22	2.0	2.0	2.2
$KPI_{3,number}$	Mean transport distance	[m]	344	2.4	2.4	2.1
$KPI_{3,weight}$	Mean transport distance	[m]	482	3.6	3.6	4.3
$KPI_{4,number}$	Mean number of transports	[-]	19.4	3.5	3.5	3.3
$KPI_{4,weight}$	Mean number of transports	[-]	20.7	4.0	4.0	4.4
KPI_5	Part process time average	[hh:mm:ss]	141:13:00	5.4	7.0	8.3
KPI_6	Max. annual throughput	[ton]	9200	1.0	1.1	1.1
KPI_{10}	Required investment	[k€]	-	2500	2500	2520
KPI_{11}	Throughput / required area	[-]	0.7	2.6	2.7	3.1

Supplement model analysis shows that the implementation of additional cranes is marginally effective for mitigating the sorting transport criticality. The implementation of a conveyor system, including a Celluveyor sorting technique, shows much improvements on annual throughput. Such an improvment ratio between throughput and space utilisation of 3.3 is obtained. Further improvement analysis enables an increased ratio of 4.6 by deploying more forming presses. Hence the possibility of further improvements is clearly underlined.

Main research question

Frankly the main research question can be straightforwardly answered. The two pre-processing spaces (i.e. S1 and S1a) can be merged in S1a. The pre-processing processes are redesigned such that this merge is possible to a great extend. Furthermore the ratio between throughput and space utilisation is improved by a factor 3.1. Such it meets the industry standard. Hence the second objective of this study is reached.

Both objectives are met at the expense of approximately € 2.5 million, which is 2.2% of the annual turnover of the DSGa yard. It should be encountered that € 2 million is dedicated to investing in new cutting machines, which already reached their approximate economic lifetime.

13.2. Recommendations

This Section deals with some recommendations to the DSGa yard and Damen Yard Support department. The following notions are listed:

- Improvements in job preparation are required prior to improvements in facility layout. This follows from the part generation being key for further improvements and the fact that improving is a cyclic,

cascading process. As a result batch sizes will reduce and space will be freed. By adding nest file information and using available machine functionalities the risk of defects or over-processing is mitigated.
- Subsequent to the first notion product lines can be defined and customers can be positioned close by. Hence the layout can be redesigned such that a continuous flow is enabled.
- This study showed that no additional investment in facility buildings, but in the proper allocation of proven equipment is required. For this the required information flow needs to be facilitated by job preparation.
- Since a lot of improvements are straightforward and result from logic reasoning a bottom up approach for improvement must be enabled. A culture of continuous improvement should be established.
- Improvement is a cyclic process. Therefore it is advised to continue improving.

13.3. Future research

In this Section several follow-up steps are presented for further research and is therefore from particular interest for the Delft University of Technology or Damen Research Department.

- Since production process improvements start with part generation specific attention is required to the definition of the nestings. Since uncertainty exist about the effect of additional nesting constraints on the scrap rate, additional research into this topic is required.
- The application of Design For Production (DFP) has potential to improve the parts generation process. Hence the feasibility of this topic is to be studied and continuous awareness of design implications should be created.
- This study was not able to study the customer aspect of the Just In Time (JIT) principle. Hence this aspect requires particular additional attention. The result will provide positive feedback on the part generation planning and further reduce buffer space.
- Last the effect of smaller cutting machines is of interest for the increased performance of material handing and sorting. Within this study the traditional plate and profile sizes are considered. Hence this aspect still requires further attention.

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A

Data collection and description

In Section 2.3.1 the product data composition is justified and briefly explained. Here a more detailed description is provided in Appendix A.1. In Appendix A.2 the nesting methodology is explained.

A.1. Data explanation

In Table A.1 an overview of the product data set is provided.

- In the first column the data concerning the projects and ship sections is provided.
- In the second column the part data is included, dealing with the parts size and weight.
- Subsequently the nesting data is available. This data is user specific and is changed for the current state and to be scenarios.
- Fourthly the end buffer data is included. An overview of the end buffer codes is provided in Table A.2.
- Last the routine data is included, dealing with the meters which require bevelling, tapering or grinding and specifications for forming or flanging. An overview is provided in Table A.3. The process times are linked to the routing data. An overview of the defined process times is included in Tables A.4 and A.5. In those Tables the links between times and thicknesses/meters/weight is provided.

Table A.1: Product data format

Project data	Part data	Nesting data	End buffer data	Routing data	
Project, section	Part ID, description, geometry, weight	Nesting numbers	End sorting code, panel names, assembly orders	Type	Time

Table A.2: Explanation End buffer data

Part attribute	explanation
910	Plate-sub-panels assembly
920	T-Beams assembly
930	main panel assembly
940	section assembly
950	block assembly
960	hull assembly
970	small steel workshop
980	mechanical workshop
990	subcontractors

Table A.3: Explanation part data and routing data

Part attribute	explanation
t	plate thickness
length	length of the smallest square around a part (derived from cadmatic)
width	width of the smallest square around a part (derived from cadmatic)
mass	mass of the part
nesting No.	nesting in which the part is nested
part of	where the part is assembled
bevelling type	multiple types are possible: "1" - 1 run type - V,Y (can be done on cutting machines) "2" - 2 run type - K, X "3" - combination of V, X (length of 1 time V pass + 2 time length of X pass) "4" - overlength with bevel, bevel will be done in section building stage "_" - leave blank if no bevel is applicable
bevelling length	length of the bevel in m. - with 2 run type the length has to be cut 2 times, thus double process time
tapering	"x" - indication that the tapering is applicable. "_" - leave blank if no tapering is applicable
tapering length	length of the tapering - process calculation based on this length
forming type	"type of (shell) plate to be formed - following types are: "1" - for corrugated plates "2" - for 2D plates "3" - for 3D plates
forming class	"number indicating for 3D plates the difficulty class "1" - simple "2" - moderate "3" - intensive
grinding type	"the 2 types of grinding are: "c" - contour grinding only (e.g. brackets) "h" - these parts have internal grinding (holes) in combination with contour (if applicable) "br" -nesting bridge (one part has at least one bridge). For parts with no "c" or "h"
grinding length	length of the contour to be grinded. For grinding this means the double length to be grinded (2 edges)
flanging	"the 2 types of flanging which can occur: "b" - buckling of bulkheads (big parts more difficult to handle) "bxx"-"xx" number of buckling "f" - flanging of parts (difficulty in handling of part is depending on the length of the part)
flanging length	length of the flange
milling	"x" - indication of the part should be milled
order no plate	"#" - following number of the plate in a main panel, numbering from one side to the other

Table A.4: Process time determination [25]

Plates	Process time	Unit	Infeed time	Setup time	Change over time	Outfeed time
Cutting/marking plasma	Nesting	min (average)	5 min	5 min	10 min (5-15mm; 15-22mm; 22+)	AS-IS = sort; TO-BE = 5 min
Cutting/marking oxy-gas	Nesting	min (average)	5 min	5 min	10 min (5-15mm; 15-22mm; 22+)	= sort
Remove scrap per piece	2	min/25kg	x	5 min	x	x
Remove scrap uncut (crane)	5	min/plate	x	x	x	x

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Plates	Process time	Unit	Infeed time	Setup time	Change over time	Outfeed time
Cleaning/drying	10	min/plate	x	x	x	x
Signing manual	15	sec/part	x	x	x	x
Signing machine	5	sec/part	x	x	x	x
Remove rest plate(s)	3	min/part	x	x	x	x
Sorting <25 kg by hand	walking	sec/part	10	x	x	10
Sorting <25 kg by crane (TO-BE - 10 parts)	crane	sec/part	10	x	x	10
Sorting 25>w<100 kg by magnet/hook	crane speed	m/s	30 sec	x	yoke - magnet 30 min	30 sec
Sorting >100 kg by yoke	crane speed	m/s	1 min	x	magnet - yoke 30 min	1 min
Tapering	0.07	m/min	3 min	15 min	x	3 min
Forming 2D plate roller	0.05	hr./t.(mm)	3 min	3 min	x	3 min
Forming 3D plate roller	0.05	hr./t.(mm)	3 min	3 min	x	3 min
Forming 3D press class 2	0.08	hr./w.(m)/t.(mm)	3 min	3 min	20 min (class 2 to 3)	3 min
Forming 3D roller press class 2	0.04	hr./w.(m)/t.(mm)	3 min	3 min	20 min (class 2 to 3)	3 min
Forming 3D press class 3	0.12	hr./w.(m)/t.(mm)	3 min	3 min	20 min (class 2 to 3)	3 min
Forming 3D roller press class 3	0.06	hr./w.(m)/t.(mm)	3 min	3 min	20 min (class 2 to 3)	3 min
Forming 3D line heating class 2	0.19	hr./w.(m)/t.(mm)	3 min	5 min	x	3 min
Forming 3D line heating class 3	0.29	hr./w.(m)/t.(mm)	3 min	5 min	x	3 min
Grinding big (per side)	0.3	m/min per side	3 min	2 min	x	3 min
Grinding small <10kg (all sides)	0.5	m/min	1 min	1 min	x	3 min
Grinding small 10>w<25 kg (per side)	0.3	m/min per side	3 min	1 min	x	3 min
Flanging big (per flange)	1	min/part	1 min	1 min	30 min (change angle/ t. range 6-10; 10-14; 14-18; 18-20)	1 min
Flanging/corrugation on plate roller	5	min/part	3 min	3 min	3 hr. (change to flange/ corrugation plate and back)	3 min
Flanging small (per flange)	25	sec/part	15 sec	5 sec	30 min (change angle/ t. range 6-10; 10-14; 14-18; 18-20)	15 sec

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Plates	Process time	Unit	Infeed time	Setup time	Change over time	Outfeed time
Knuckle big (per knuckle)	1	min/part	1 min	1 min	30 min (change angle/ t. range 6-10; 10-14; 14-18; 18-20)	1 min
Knuckle small (per knuckle)	25	sec/part	15 sec (part)	5 sec	30 min (change angle/ t. range 6-10; 10-14; 14-18; 18-20)	15 sec (part)
2D bend by knuckle big (10x knuckle)	10	min/part	1 min	1 min	30 min (change angle/ t. range 6-10; 10-14; 14-18; 18-20)	1 min (part)
2D bend by knuckle small (10x knuckle)	4.17	min/part	15 sec (part)	5 sec	30 min (change angle/ t. range 6-10; 10-14; 14-18; 18-20)	15 sec (part)
Move container	crane speed	m/s	5 min	x	mount/dismount chains and hooks 5 min	5 min

Table A.5: Process time determination continued [25]

Profiles	Process time	Unit	Infeed time	Setup time	Change over time	Oufeed time
Cutting/marking robot	1.64	min/part/w./t.	3 min	3 min	5 min (t range 6-10 and 10-16 mm)	2 min (part)
Flame cutting/beveling pipe (round/square)	6.55	min/part/dia	3 min	3 min/part	x	2 min (part)
Sawing bar (incl. cleaning oil)	6.55	min/part/w.	3 min	3 min/part	x	2 min (part)
Signing manual	15	sec/part	x	x	x	x
Remove scrap	2	min/ piece 25kg	x	x	x	x
Grinding (per side)	0.3	m/min	x	x	x	x
Remove rest profile >6m	3	min/part	x	x	x	x
Sorting	3	min/part	x	x	x	x
Bending simple shape	4.46	min/m/t/B	3 min	5 min	x	3 min
Bending complex shape	8.93	min/m/t/B	3 min	5 min	x	3 min
Cutting bent profiles	0.2	m/min	x	x	x	x
Grinding bent profiles (per side)	0.3	m/min	x	x	x	x
Straightening	5	min/m	3 min	5 min	x	3 min
Knuckle (per knuckle) *(=plate machine)	25	sec/part	15 sec (part)	5 sec	30 min (change angle/ t. range 6-10; 10-14; 14-18; 18-20)	15 sec (part)
2D bend by knuckle (10x knuckle)	4.17	min/part	1 min (part)	1 min	30 min (change angle/ t. range 6-10; 10-14; 14-18; 18-20)	3 min
Move profile bundle	crane speed	m/s	5 min	x	hook/unhook slings 5 min	5 min
Move profile cassette	crane speed	m/s	5 min	x	mount/dismount chains and hooks 5 min	5 min

A.2. Nesting relation structure

As discussed in Section 2.3.1 the product data of the PSV vessel consists of indicative sections, in order to reduce the data collection effort. In Figure A.1 an overview of the division in indicative sections is provided. The indicative character is clearly observed. Hence a reference for all sections to the indicative section is provided. This relation is provided Damen Yard Support [25].

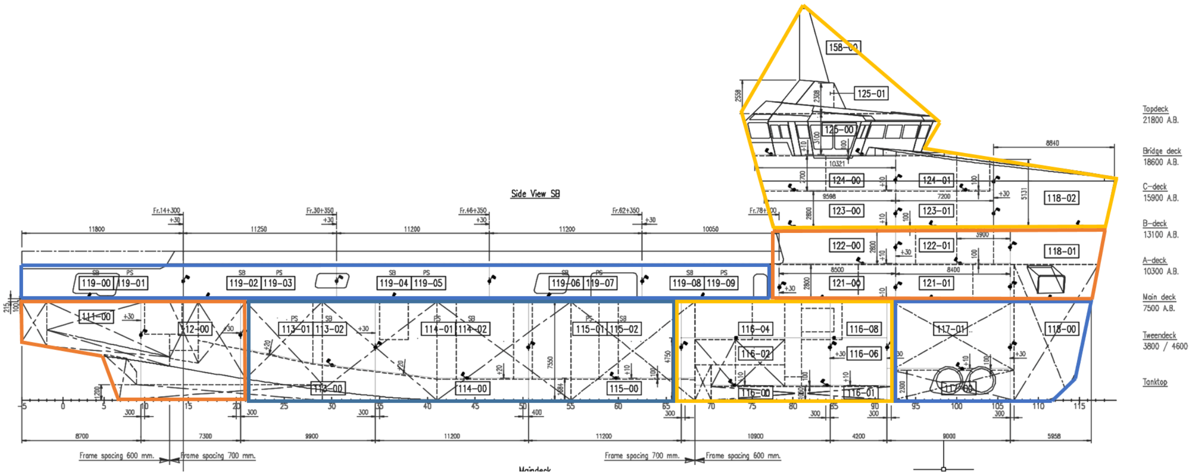


Figure A.1: PSV section plan, indicative sections

In the product data set the data of all plates is available. Furthermore, due to the reference relation, all information about the parts is available. Moreover the relation between the section and cutting group definition exist. Hence it is known which parts are cut from which cutting group. Subsequently those parts are assigned to individual plates based on a average number of parts per plate.

For the analysis of the scenarios the cutting groups are reduced. The cutting groups are reduced such that the relation between the raw plates batch correspond to the parts batch. The latter concerns the the ASD tug nestings as well. As stated in the recommendations of this study this link requires additional investigation (Section 13.3).

B

Process model description S1

In this Appendix the process model description of the DSGa facility S1 is provided. This process model description is written by the author and is validated jointly within Damen, as discussed in Section 4.2. In Appendix C the process model description of the S1a facility is provided.
They are structured as follows. The processes are described based on the layout delineations, likewise in Chapter 3. Per part of the map the processes are described. The following topics are recognised: They are linked to the map presented in Figure B.1.

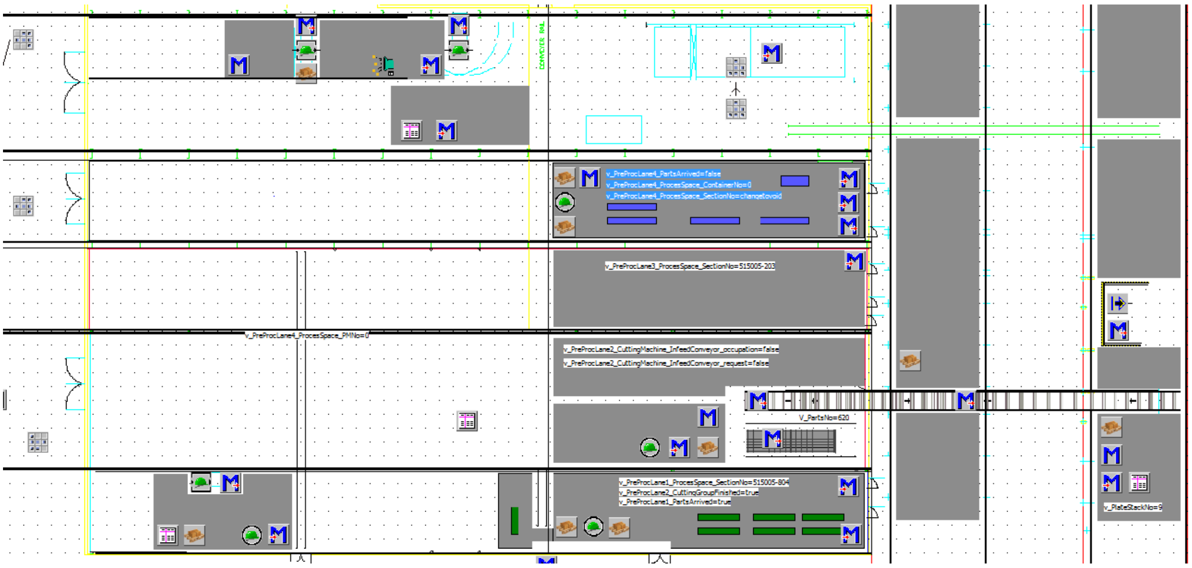


Figure B.1: Overall figure S1 facility

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 B.2.

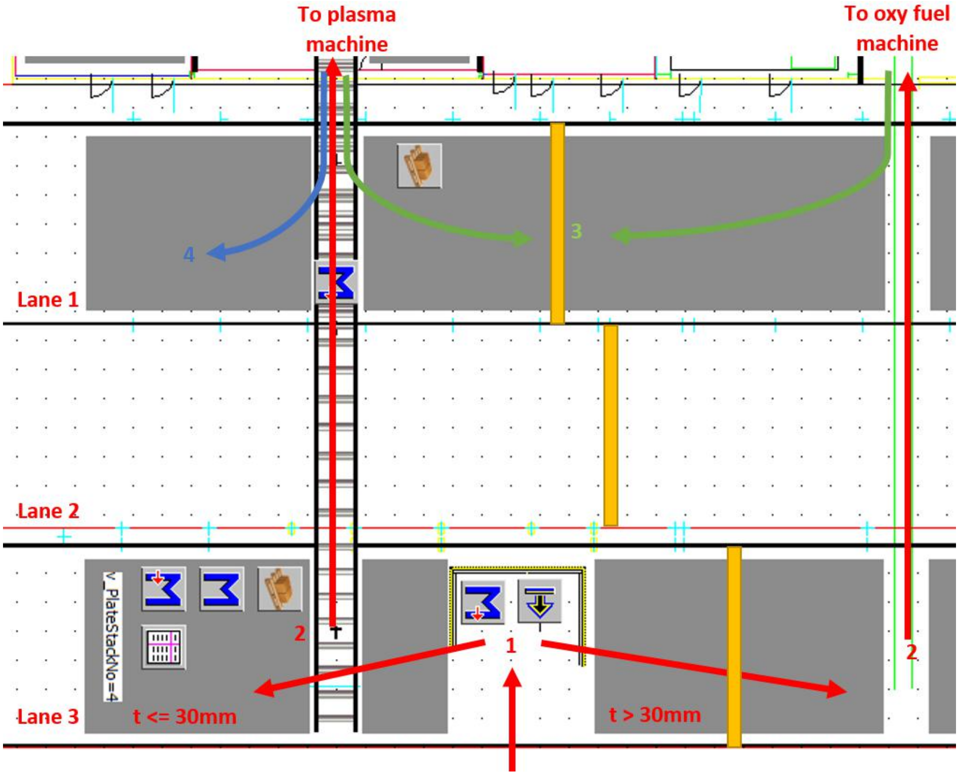


Figure B.2: Overall Figure S1 facility

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.

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 B.3 and department general characteristics are described. Then the following arrows are described: Subsequent general notions are described, followed by notions on logistics and people.

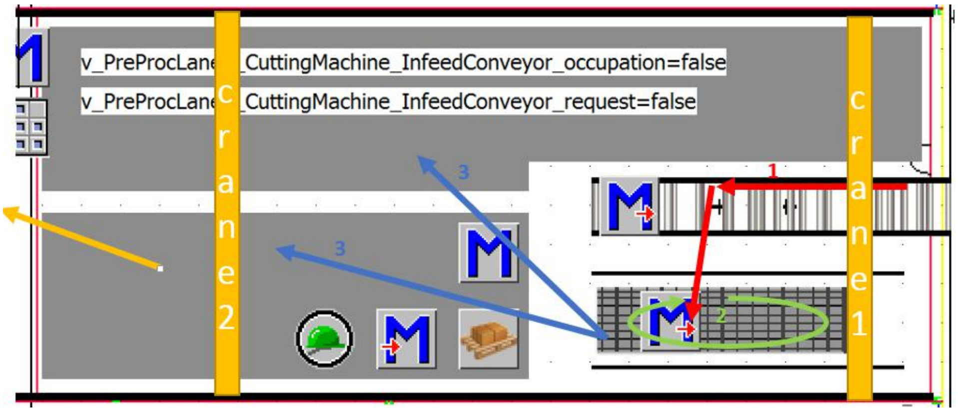


Figure B.3: Overall figure S1 facility

- 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 crane1: 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.

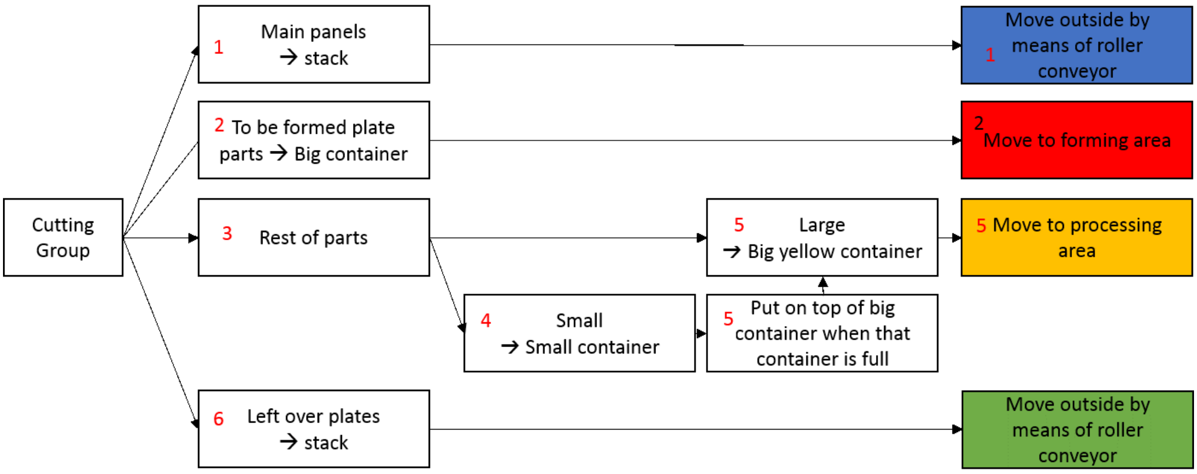


Figure B.4: Cutting sorting process diagram

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.

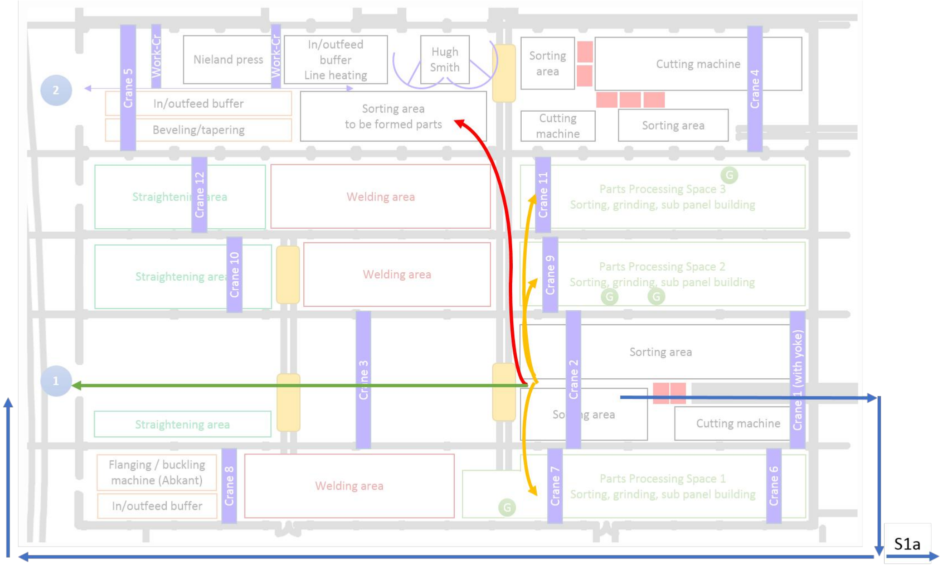


Figure B.5: Cutting transport overview

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)
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.

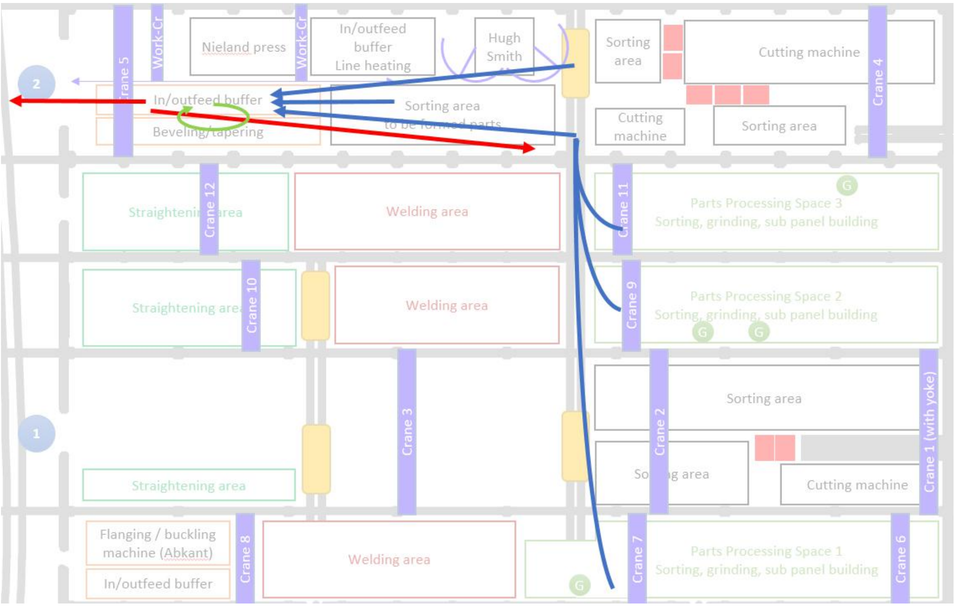


Figure B.6: Tapering station S1

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.

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

3. Output process

The processed parts are stored on containers or stacks and are moved to the next destinations.

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 B.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.

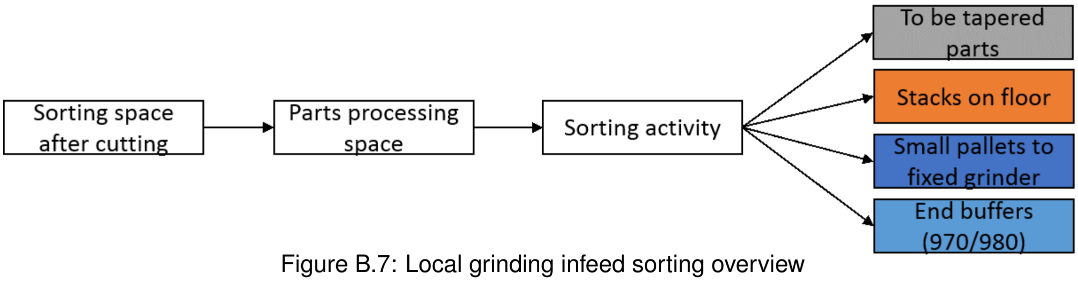


Figure B.7: Local grinding infeed sorting overview

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 B.8, is described in the following steps:

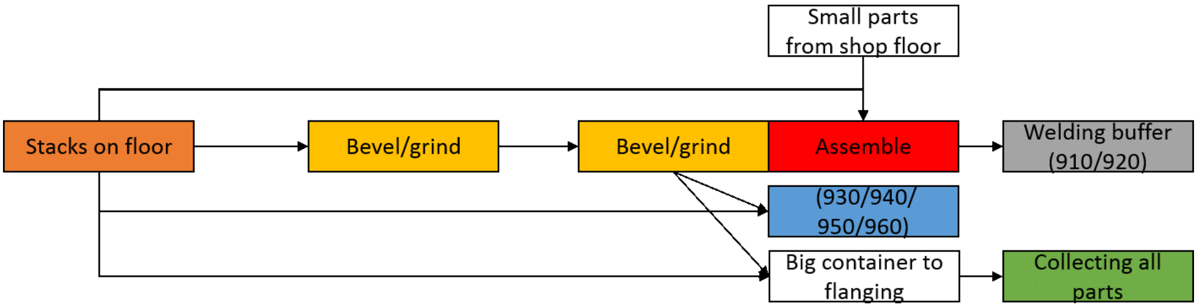


Figure B.8: Processing of large parts

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 B.9, is described in the following steps:

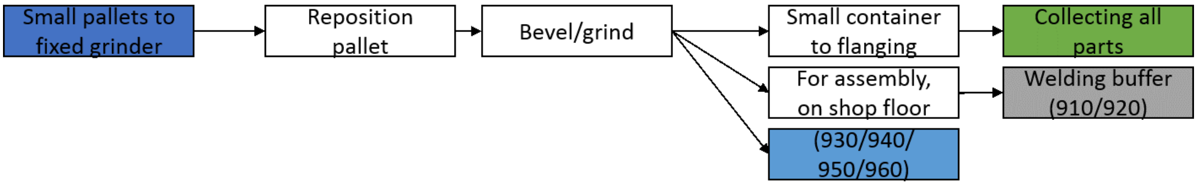


Figure B.9: Processing of small parts

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 B.10. The flows are described below.

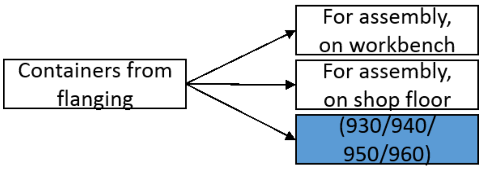


Figure B.10: Collection to be flanged parts

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 B.11.

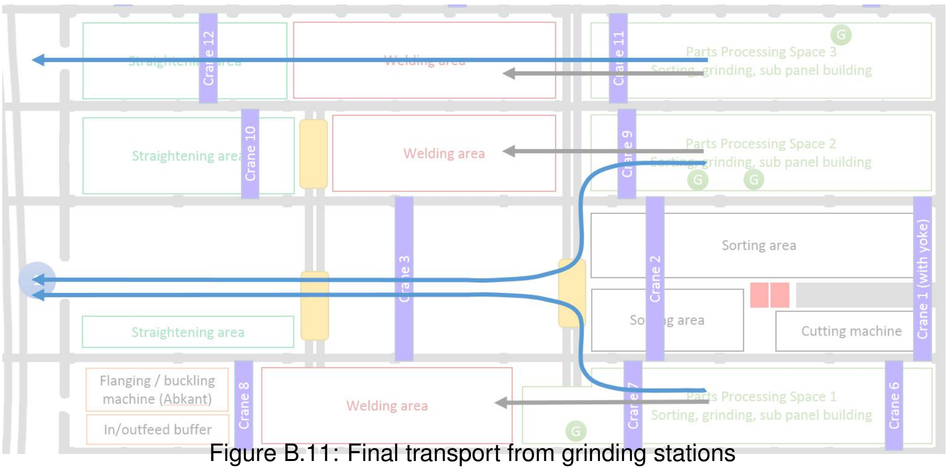


Figure B.11: Final transport from grinding stations

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 B.12. First some general notions are made. Then the flows are described individually.

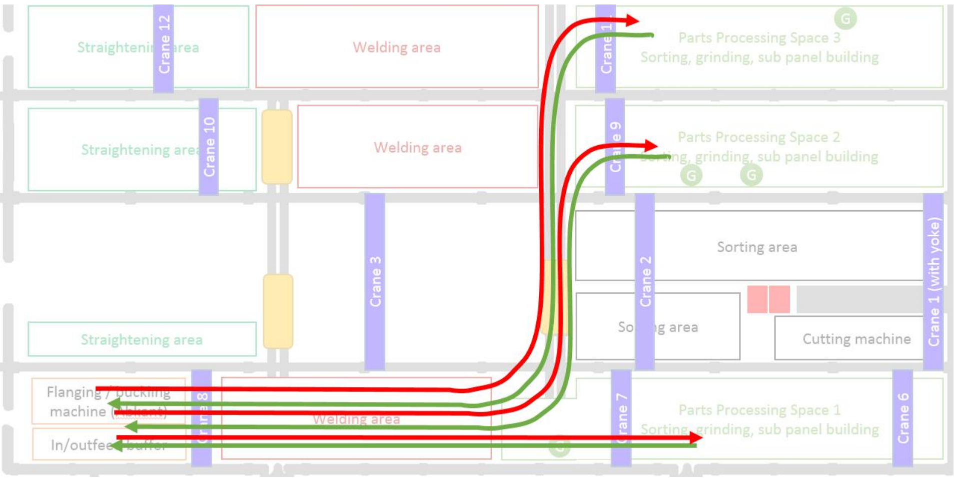


Figure B.12: Transport between grinding-flanging-grinding

General:
- Same handling rules as in parts processing.

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

machines/tooling
- brake press

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 brake press.
  - 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

C

Process model description S1a

This document contains Process-related information on facility S1A. In this document, the modelling is explained more extensively, 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

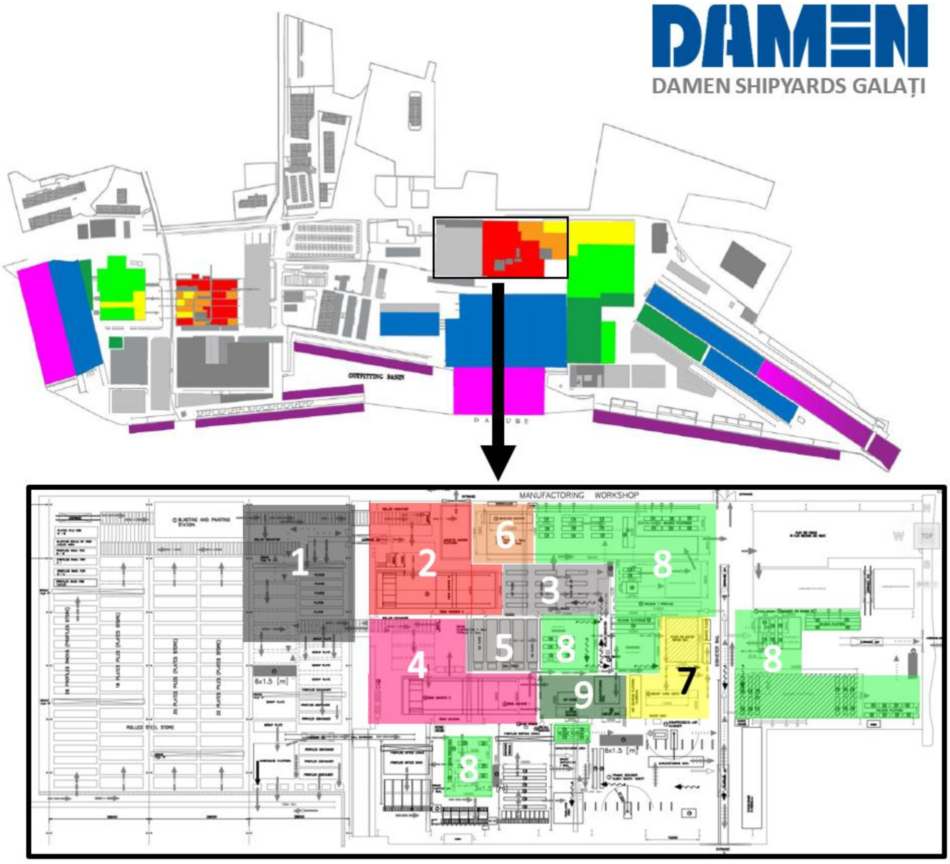


Figure C.1: Overview of various parts of the preprocessing department of section 1A.

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

Chapters 1 to 9 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.

C.1. Plate Storage

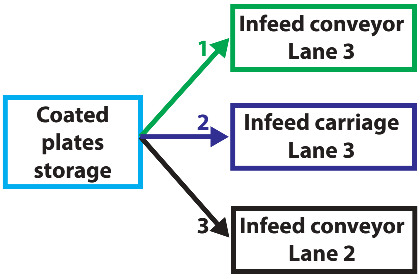


Figure C.2: Possible flows at the plate storage

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 C.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:
  - Pupaza
- The cranes, carriage and conveyors are all operated by the same team.

C.2. Infeed and Cutting of Plates

A. Description of the Cutting Department of Lane 3

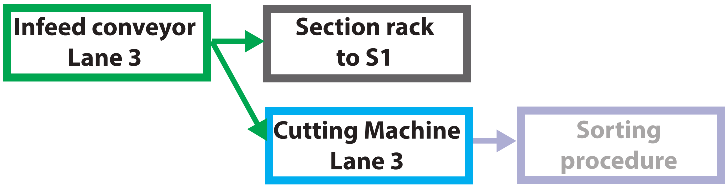


Figure C.3: Possible flows at the infeed of the cutting department of lane 3

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:
  - Pupaza crew
- Skills:
  - Operating ESAB-machine
  - Crane driving

C.3. Sorting after cutting - Lane 3

A. Description of Sorting

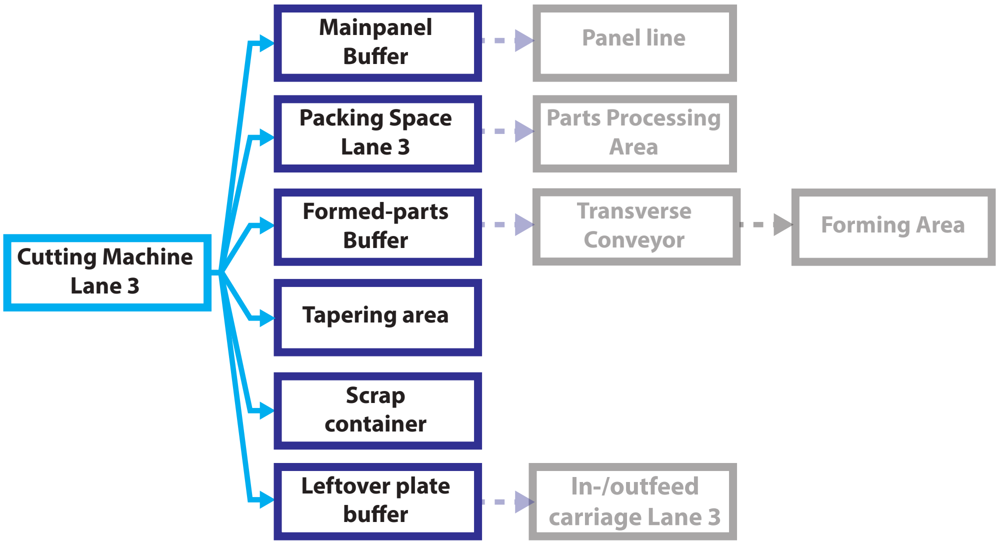


Figure C.4: Possible flows after cutting at the cutting department of lane 3

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 are sorted by hand, into the boxes for small parts on the packing space.
- Main panels 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 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 are removed by crane and brought outside via the carriage.
- All other parts 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.

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

A. Description of the Cutting Department of Lane 2

Figure C.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:
  – Pupaza crew
- Skills:
  – Operating ESAB-machine

C.5. Sorting after cutting - Lane 2

A. Description of Sorting

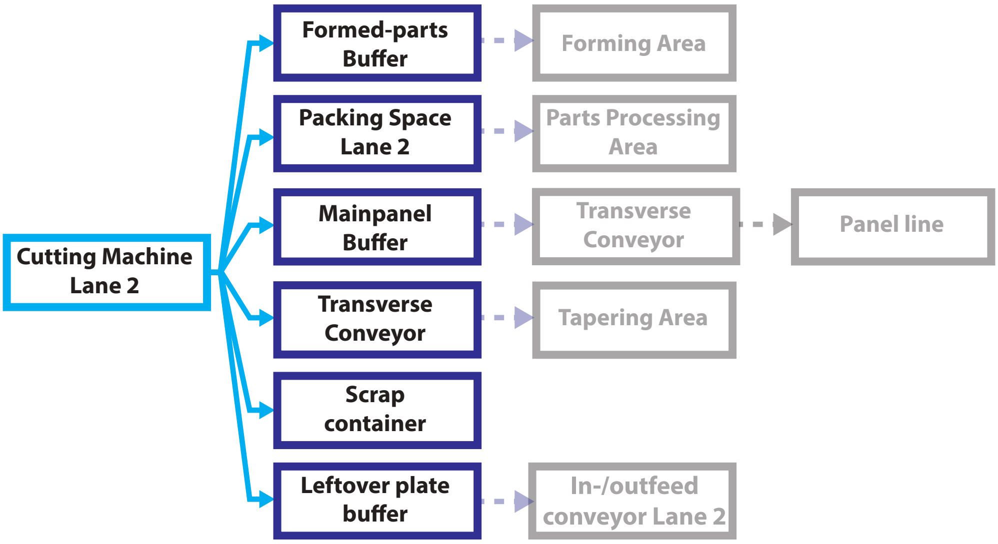


Figure C.6: Possible flows after cutting at the cutting department of lane 2

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.

C.6. Tapering Station

A. Description of Tapering Station

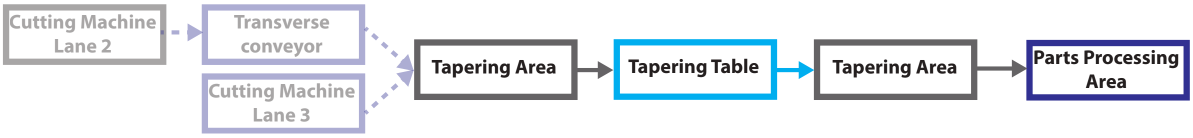


Figure C.7: Flow at the tapering station

- 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 (Slabu) 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:
  - Slabu, Angheluta or Creanga
- Skills:
  - Tapering Semi-automatic

C.7. Forming Area

A. Description of Forming Area

Figure C.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:
  - Poalelungi
- Skills:
  - Forming

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

- Crew:
  - Poalelungi
- Skills:
  - Forming

C.8. Parts Processing Area

A. Description of Parts Processing Area

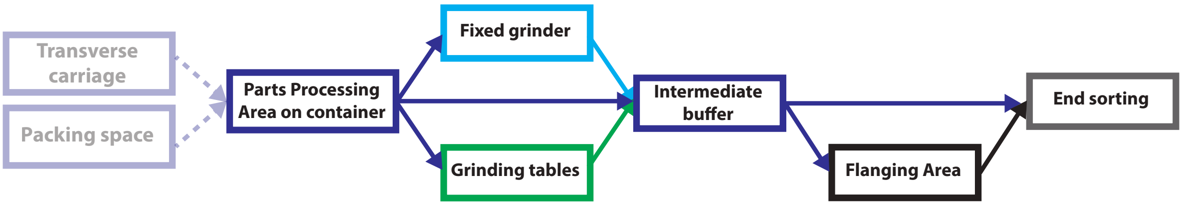


Figure C.9: Flow at the parts processing area

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

C.9. Flanging Area

A. Description of Flanging Area

Figure C.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 Brake Press to sort, pack and flange.

- Crew:
  - Poalelungi
- Skills:
  - Flanging

D

Current State flow and waste definition

This Appendix is dedicated to the construction of the Value Stream Mapping (VSM) and the current state map (CSM).

- In Chapter 2 an attempt is made to delineate the major processes. The detailed results are presented in Appendix D.1.
- In Chapter 3 the flows have been explained by means of Material Flow Analysis (MFA). For that precise definition of indicators is executed. How these indicators are defined is presented in Appendix D.2. The detailed flow diagrams including the transport distances are presented here as well.
- Moreover a detailed machine functionality description is provided in Appendix D.3.
- Furthermore this Appendix provides background information about the waste analysis executed in Chapter 3. A thought experiment was done (Section 3.2.2) for addressing the waste "Nesting of several sections in one cutting group". This experiment is presented in Appendix D.4.
- Furthermore some photos are provided in Appendix D.5, indicating the defined wastes.
- Last the detailed results of the KPI definition are presented in Appendices D.6 and D.7.

D.1. Routing determination

The product data as delivered by DSGa is providing information about the required processing steps for each part. Subsequently the routing for each part can be determined. The different routines are listed in Table D.1. Furthermore the number of each part with that specific routing number is counted. Also the cumulative weight is considered. All figures are included in the table. A distinction between small and large parts is made. For these conditions the same figures are determined and included.

Table D.1: Part routing appearance

	All parts			Parts weight <= 20kg			Parts weight >20kg		
Routing	No.*	Wgt.**	Avg.***	No.	Weight	Avg.	No.	Weight	Avg.
C	26347	2642	42769	17866	114	1663	8481	2529	41105
C-B/T	84	51	184	0	0	0	84	51	184
C-B/T-F	42	27	121	0	0	0	42	27	121
C-B/T-G	119	30	339	0	0	0	119	30	339
C-B/T-G-Fl	0	0	0	0	0	0	0	0	0
C-F	1702	746	10122	56	1	23	1646	745	10099
C-F-G	2744	106	1455	1060	10	145	1684	96	1310
C-G	77104	1743	32880	58675	261	5064	18429	1482	27815
C-G-Fl	2159	68	1453	1416	17	310	743	51	1143
C-Fl	1275	67	1572	826	7	128	449	61	1444
Total	111576	5481	90895	79899	410	7334	31677	5071	83561

* Number of parts per specific routing, ** Cumulative weight of all parts in kilogram, *** Average weight per part.

D.2. Material Flow Analysis

For the definition of the MFA indicators the annual product data set is used. The indicators are based on conditional statements which are described in this Appendix. They are discussed per layout topic, conform the description in Chapter 3.

The naming of the different conveyors and carriages is consistent with the naming of departments. For flow description flow charts are drawn. Some symbols are introduced in Figure D.1. In the flow diagrams the transport distances are presented for each movement, based on Autocad drawings and area centre points estimations. Their exactness is conform the objective of the value stream current state map approach, rounded to a five meter precision [51].

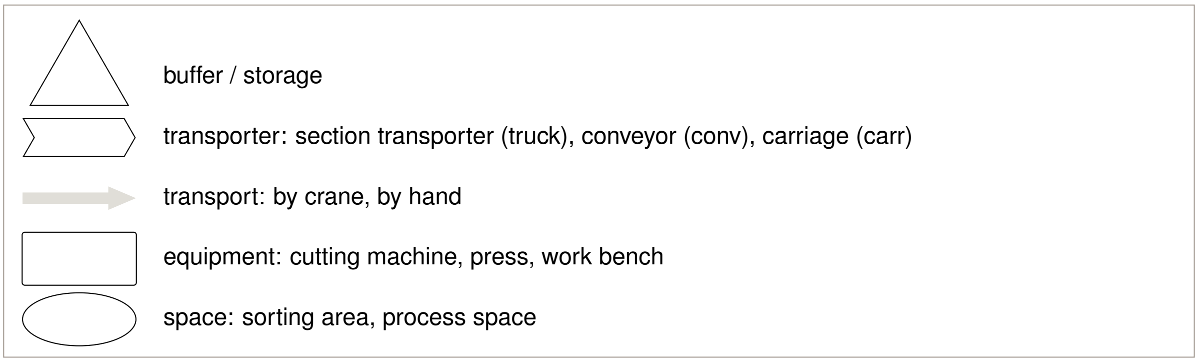
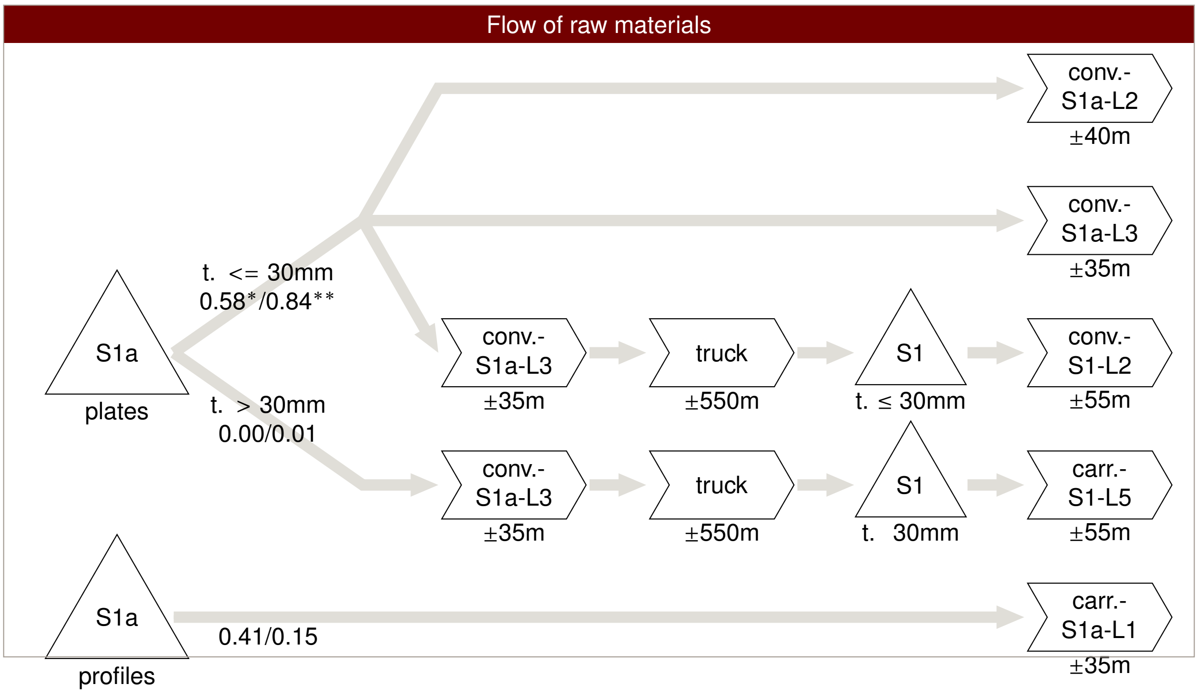


Figure D.1: Legend of flow analysis

Plate storages

The following part attributes are used to establish the material flow analysis indicators for the plate storages. A detailed result is presented in Figure D.2.

PartType:	Based on the PartType attribute the profile flow is separated from the plate flow.
Thickness:	Based on the Thickness attribute the thick plates are separated from the other plates
Weight:	When the part suffices the conditions above the weight is accumulated.



* normalised number of parts, ** normalised cumulative part weight.

Figure D.2: Flow of raw material entrance, in Figure 3.2

Profile cutting station

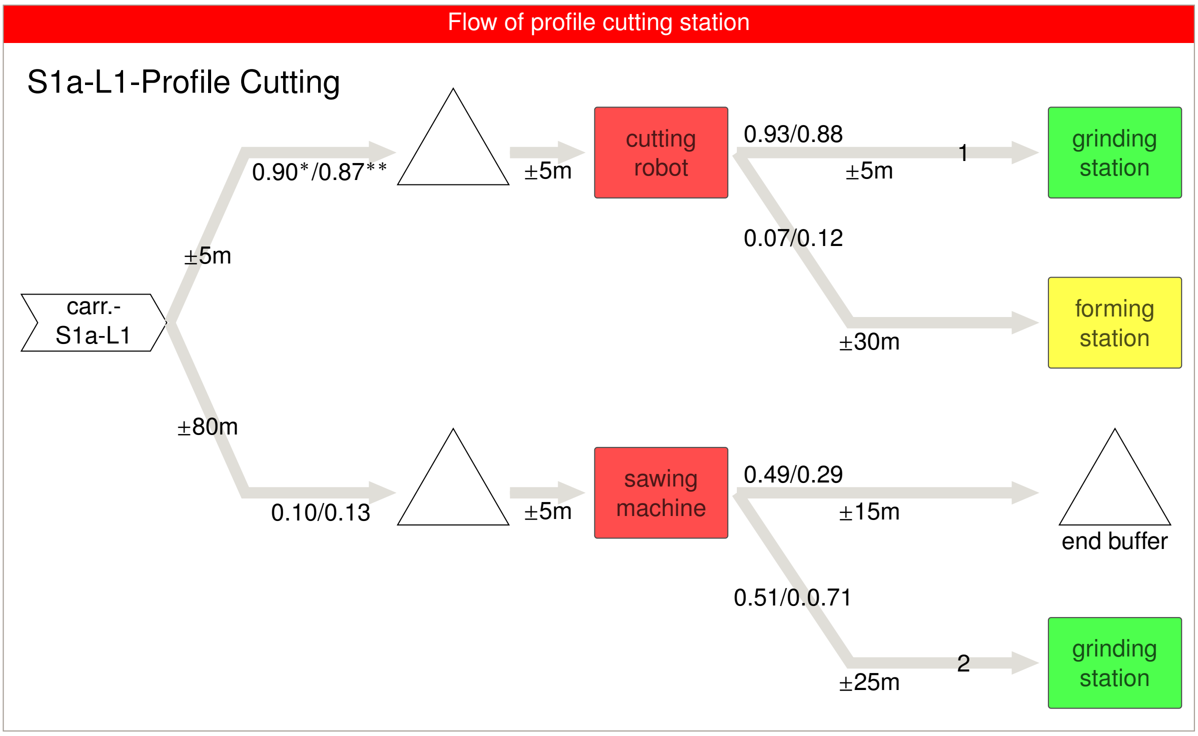
Based on the part data, routing data and end buffer data conditional statements are developed, to outline the different flows. The detailed result is enclosed in Figure D.3:

HP/Rest: Based on the PartType attribute the profile flow is separated from the plate flow. Furthermore the HP flow is be separated from the other profiles

FormingType: Based on the FormingType attribute the to be formed parts can be separated.

GrindingType: Based on the GrindingType attribute the to be ground parts can be separated.

EndBuffer: Analysis showed that the rest of the part create a flow directly to the end buffers.



* normalised number of parts, ** normalised cumulative part weight.

Figure D.3: Flow of profile cutting station, in Figure 3.2

Plasma cutting stations

Within each station the flows can be separated. The flows are separated following the conditions below. The result is enclosed in Figure D.4. Moreover some output flow explanation is given.

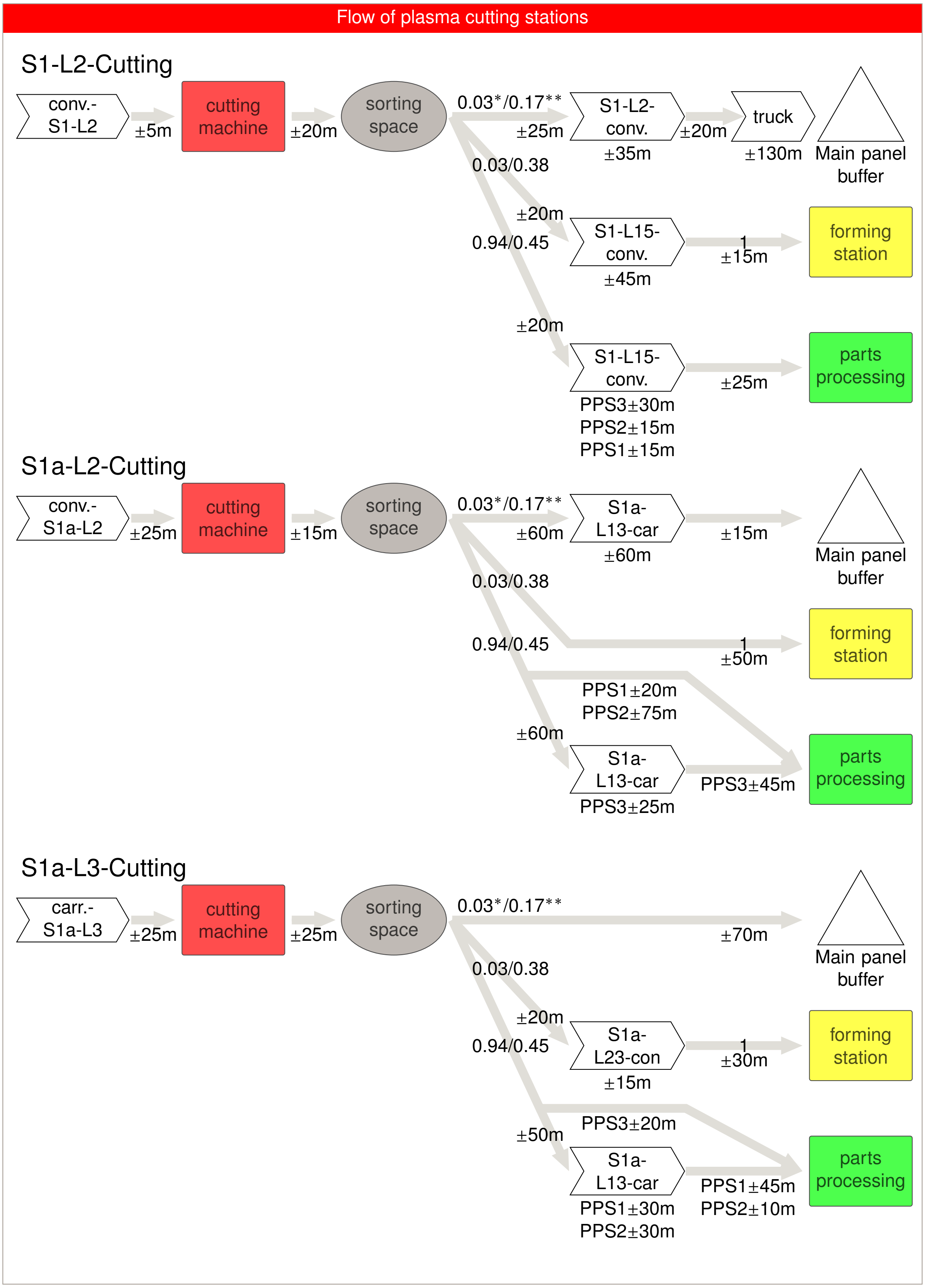
Thickness: The thickness attribute is used for identifying all parts with a thickness smaller than 30mm.

FormingType: Based on the FormingType attribute the to be formed parts can be separated.

EndBuffer: The EndBuffer part attribute is used to identify all parts which need to go to the main panel line. Furthermore the PartType attribute is used.

PartType: The PartType attribute distinguishes the panels from profiles which have the same EndBuffer attribute.

Rest: The parts which should go to the parts processing spaces are identified by taking the reciprocal of the other two flows.



* normalised number of parts, ** normalised cumulative part weight.

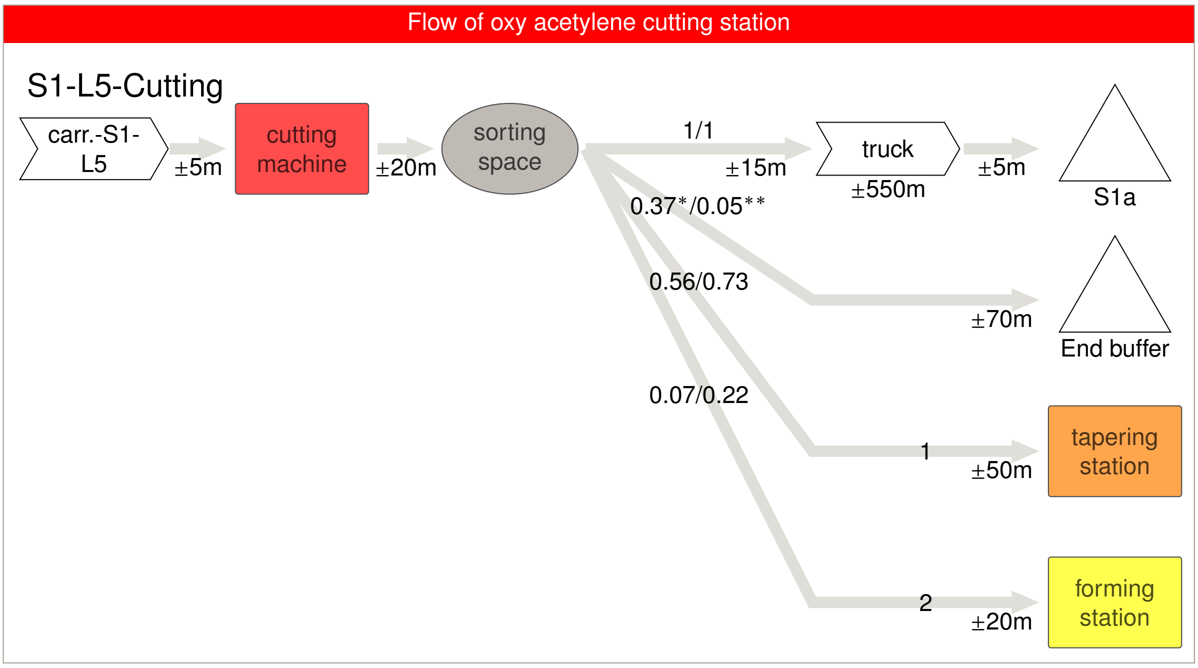
Figure D.4: Flow of plasma cutting stations, in Figure 3.2

1. The to be formed parts are moved to the forming stations. In S1 they are first batched on a container. In S1a they are moved one by one (by means of the transverse conveyor S1a-L23).
2. S1 and S1a both have several part processing spaces (PPS). Subsequently Figure 3.6 shows different flows. Some part processing spaces can be reached by cranes directly whilst for others a conveyor or carriage is required. For short notation they are noted as 1, 2 and 3, numbered down to top.
   Parts processing space S1a-L12 is located in two crane lanes. For simplicity reasons the space in lane two is considered. As noted in Section 3.5 the areas are also used for sub panel building. This is mainly done in the lane 1 part of the pre-processing space S1a-L12.
3. In S1 the main panels are moved outside again by the conveyor. Then they are loaded onto a section rack and moved to the end buffer location at the right side of the facility or at the main panel line in S1a. In S1a they are moved one by one to the entrance of the main panel line.

Oxy fuel cutting stations

The MFA units are based on conditional statements. The following part attributes are used: The results are presented in Figure D.5.

Thickness:	The thickness attribute is used to identify all parts thicker than 30mm.
FormingType:	Based on the FormingType attribute the to be formed parts can be separated.
TaperingType/ BevellingType:	The part is sent to the Tapering station when it either has a bevelling or tapering indication (or both).
Rest:	The parts for the outside buffer are identified by the reciprocal of the other flows.



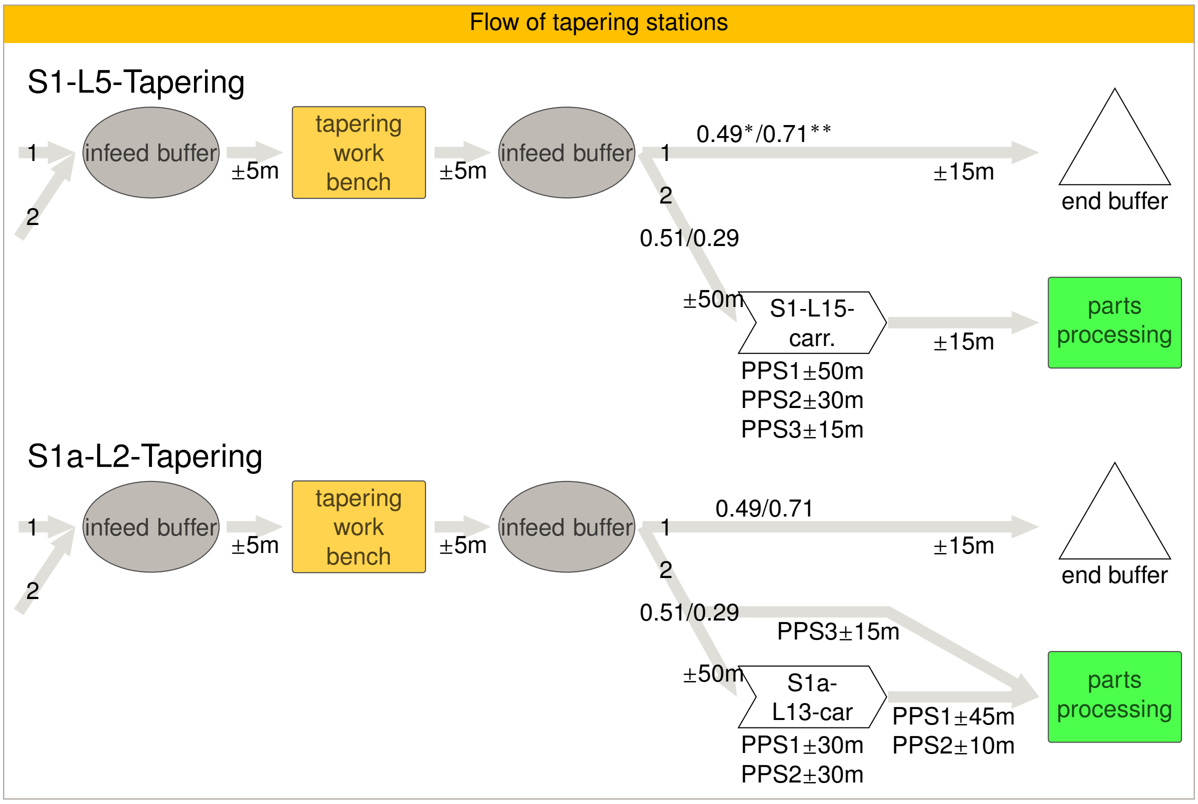
* normalised number of parts, ** normalised cumulative part weight.

Figure D.5: Flow of oxy fuel cutting station, in Figure 3.2

Tapering stations

The MFA units are based on conditional statements. The following part attributes are used. The results are presented in Figure D.6.

Thickness:	The thickness attribute is used to identify all parts thicker than 30mm.
BevellingType:	The bevelling type attribute is used to incorporate the parts which have a X/V (or combination) bevel. Due to the cutting machine bevel functionality for part thinner than 30 mm. the V/Y bevel is excluded for that flow.
TaperingType:	The tapering type attribute is used to identify all parts which require a taper.



* normalised number of parts, ** normalised cumulative part weight.

Figure D.6: Flow of tapering stations, in Figure 3.2

Forming stations

Due to the direct input-output flow of the forming stations (as indicated in Figure D.7) no MFA indicators are required for this flow.

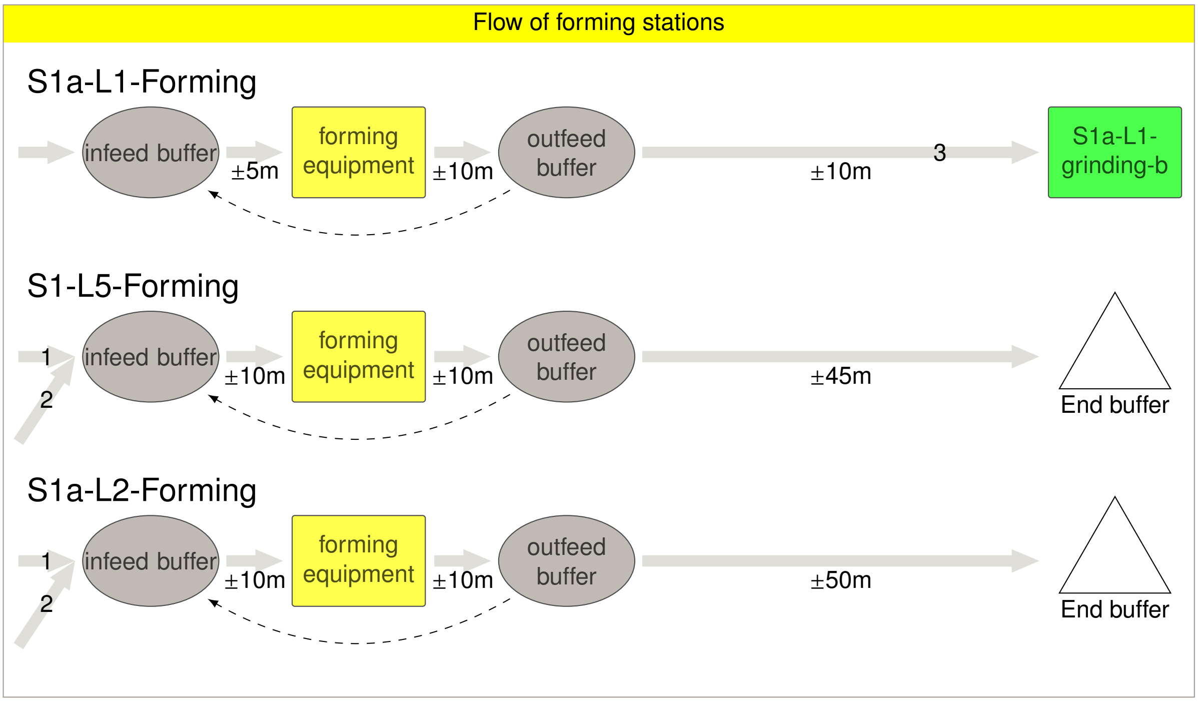


Figure D.7: Flow of forming stations, in Figure 3.2

Grinding stations

The profile grinding stations show a direct input-output relation. Therefore no MFA indicators are defined for that. In Figure D.8 only the transport to the intermediate end buffer is given. Actually this transport is extended to the locations of the customers. These mainly are the sub and main panel assembly.

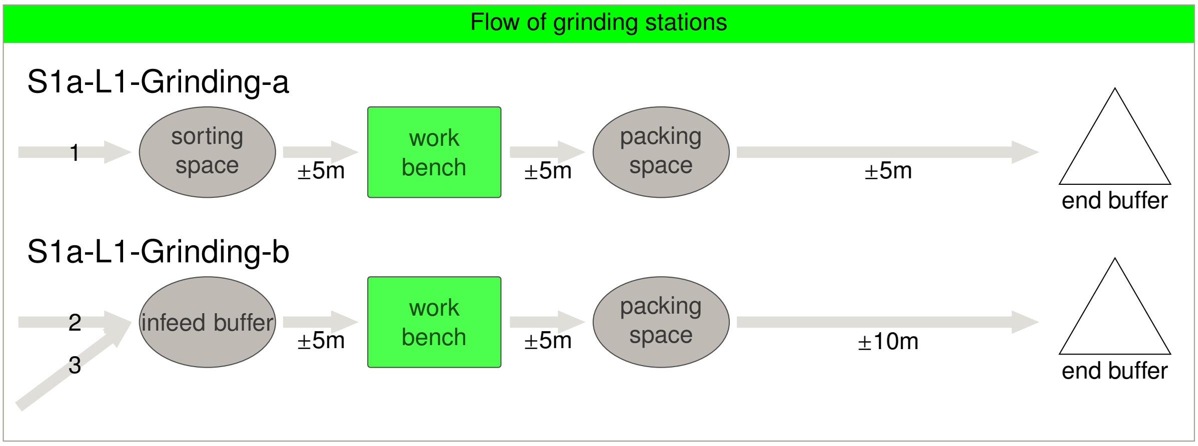


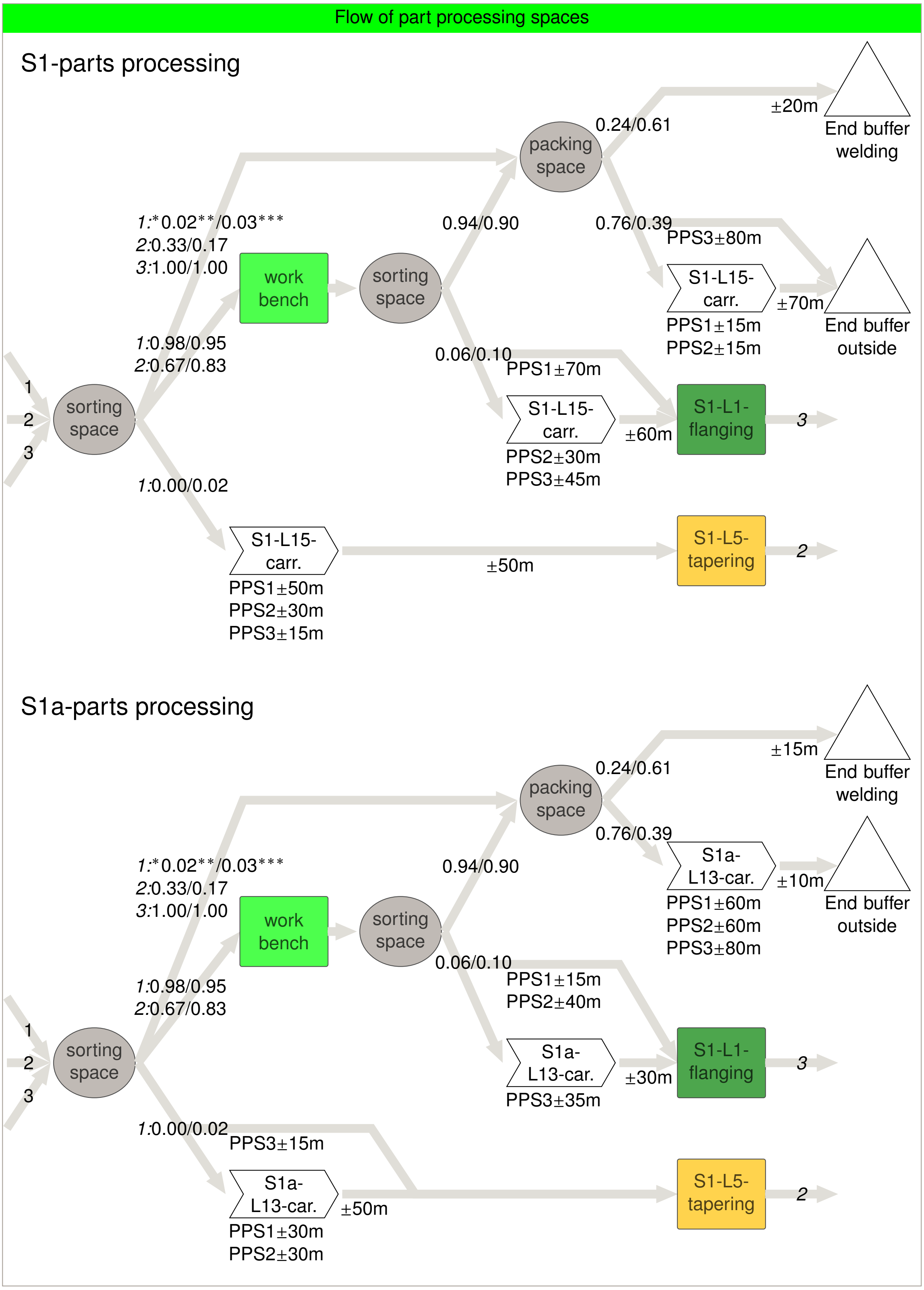
Figure D.8: Flow of grinding stations, in Figure 3.2

For the plate grinding stations MFA indicators are to be defined. This is done below. The results for facility S1 and S1a are presented in Figure D.9.

EndBuffer:	This attribute is used first to identify all 970/980/990 parts, being the parts which do not require pre-processing and can be directly sorted for end buffers.
TaperingType:	The tapering type attribute is used to identify all parts which need to be tapered and sent jointly to the tapering station. The bevelling type attribute is not included because parts are bevelled at the part processing stations.
GrindingType/ bevellingType:	This attribute is used to define which parts need to be processed and which parts can be sorted for end buffers
FlangingType:	The parts which need to go to flanging are identified by the flanging type attribute.
Weight:	The part weight attribute is used to identify which containers are required. However this does not have a significant implication on the MFA indicators.
Rest:	Reciprocals of flows are used to delineate other flows.

The sorting and packing spaces are physically the same space. Because the size of the spaces make the definition of transport distances very part specific no transport distances are presented in Figure 3.20 for those operations. If so, they would have been in the order of 5-20 meters.

The number of flow diagram is limited by jointly presentation per facility (S1/S1a). Actually in S1a there are different end buffers having different locations. For simplicity reasons the main location is presented. In Appendix B all details are presented.



* entrance flow number, ** normalised number of parts, *** normalised cumulative part weight.

Figure D.9: Flow of part processing spaces, in Figure 3.2

Flanging stations

Since all parts which are flanged are sorted for end buffers on the part processing spaces this flow has straightforward MFA indicators again.

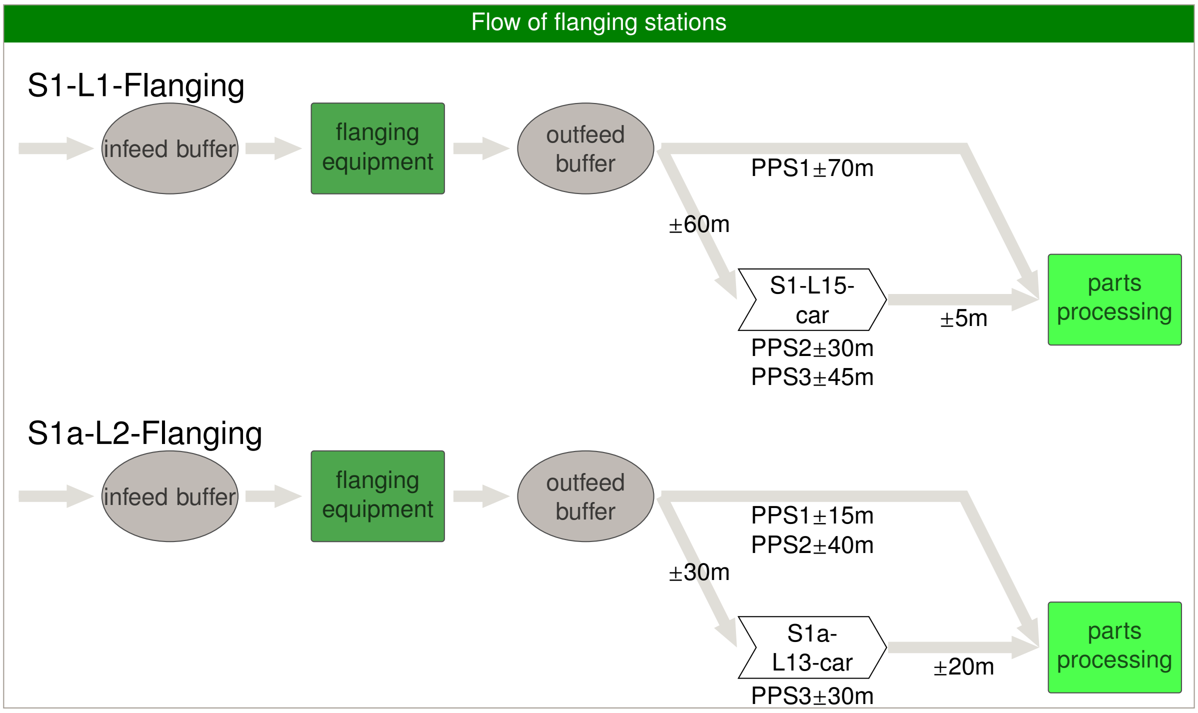


Figure D.10: Flow of flanging stations, in Figure 3.2

D.3. Machine functionality description

In this Section detailed machine functionalities are discussed. Especially the time relate aspects are dealt with. For forming also the micro routines between the different presses are provided.

D.3.1. Process times cutting

The cutting, marking and automatic signing speeds are incorporated in the nesting program. This total time is a plate attribute. The total time depends on the number of parts cut from a plate and is in the order of 40 minutes to 2.5 hours.

Plate cutting machines S1a-L2 and S1-L2 have an automatic signing functionality. However currently this is still done by hand in 50% of the cases, because the data file does not contain all information to be printed. This takes on average about 15 seconds per part. (Appendix B).

When using cutting machines S1a-L2 and S1a-L3 the plates need to be cleaned and dried afterwards. This takes on average about 10 minutes. (Appendix B).

Currently the scrap is cut manually, because the nesting files to not contain information for automatic grid cutting. As manual labour is involved no precise changeover time can be displayed. It takes about 15 minutes per plate (Appendix B).
After cutting the parts are sorted for processing (grey areas in Figure 3.2). Sorting small (≤20kg) parts by hand takes on average 30 seconds per part [7]. The duration of sorting larger parts by crane depends on the crane availability and speeds. They are offloaded from the cutting bed one by one. When the crane has to change between a magnet (max. carry capacity of 100kg) and yoke a changeover time of 5 minutes is required. This is only the case of the crane dedicated to S1-L5.
The cutting machine settings are related to plate thickness categories (t.≤ 15mm/t.>15mm). On average a change overtime of 10 minutes is required for all cutting machines. (Appendix B).

D.3.2. Process times tapering

The tapering stations mainly consist out of a in- and out-feed buffer and dedicated work bench with a semi automatic tractor. The semi automatic tractor has one flame torch. Once a part is loaded onto the table the semi automatic tractor has to be setup. This takes about 15 minutes per part.

D.3.3. Process times forming

For each forming/straightening execution the press needs to be setup again, because of different part shapes and the connection to the cranes and machine. This takes on average about 5 minutes.
2D plates are bent as follows:

- S1 - pressure press with bending tool (Hugh Smith 1000t).
- S1 - brake press, only thin and small plates.
- S1a - roller press (Hugh Smith 1000t).
- S1a - brake press, only thin and small plates.

3D plates are bent as follows:

- S1 - pressure roller press (Nieland 100t), maximum plate thickness is 20mm.
- S1 - line heating, all plates, much slower therefore using pressure roller press is preferred.
- S1 - pressure press with spot stretch tool (Hugh Smith 1000t)
- S1a - line heating

All forming equipment have a setup time. In this setup time the set up of the parts and the arrival of the moulds is included. The setup times are included in the process model descriptions (Appendix B). Once finished the parts are moved to the end buffers. Detailed information about the internal logistics and flows is available in Appendix B. In S1 this end buffer is located at the right side of the facility. In S1a this buffer is located at the entrance of the section assembly facility.

D.3.4. Process times grinding

The setup time of the grinding process would entail the picking up of the angle grind tools. On the duration of the actual grinding this is negligible small.

D.3.5. Process times flanging

For flanging no clear specific sequence of part thicknesses is followed. For corrugated and other parts the setup time is about 3 and 1 minute respectively (Appendix B). Only one section is processed at the time. However there is space to temporarily store parts from different sections.

D.4. Section assignment thought experiments

When determining the possible assignments of sections to part processing spaces in a thought experiment in Section 3.2.2, the following surfaces.
In Figure D.11 and Figure D.12 the possible assignments are determined. The possible cutting group generations and part processing spaces (PPS) demand are randomly varied. The number of sections waiting before being assigned is counted.
Only when (1) the cutting groups are processed twice as fast as supplied, (2) the supply cascades equally in time and (3) the processing always has the same duration, no waiting or building up inventory occurs. In all other cases the part processing space will be waiting or the cut parts will be building up inventory.

c1	c2	c3	sections ready	pps1	pps2	pps3	pps4	pps5	pps6	sections finished	sections waiting
4	4	4	12	1	1	1	1	1	1	6	6
			12	1	1	1	1	1	1	12	0
4	4	4	24	1	1	1	1	1	1	18	6
			24	1	1	1	1	1	1	24	0
4	4	4	36	1	1	1	1	1	1	30	6
			36	1	1	1	1	1	1	36	0
4	4	4	48	1	1	1	1	1	1	42	6
			48	1	1	1	1	1	1	48	0

c1	c2	c3	sections ready	pps1	pps2	pps3	pps4	pps5	pps6	sections finished	sections waiting
4	4		8	1	1	1	1	1	1	6	2
		4	12	1	1	1	1	1	1	12	0
4	4		20	1	1	1	1	1	1	18	2
		4	24	1	1	1	1	1	1	24	0
4	4		32	1	1	1	1	1	1	30	2
		4	36	1	1	1	1	1	1	36	0
4	4		44	1	1	1	1	1	1	42	2
		4	48	1	1	1	1	1	1	48	0

c1	c2	c3	sections ready	pps1	pps2	pps3	pps4	pps5	pps6	sections finished	sections waiting
4	4		8	1	1	1	1			4	4
			8		1	1	1	1		8	0
		4	12			1	1	1	1	12	0
4	4		20	1	1	1	1			16	4
			20		1	1	1	1		20	0
		4	24			1	1	1	1	24	0
4	4		32	1	1	1	1			28	4
			32		1	1	1	1		32	0
		4	36			1	1	1	1	36	0
4	4		44	1	1	1	1			40	4
		4	48		1	1	1	1		44	4
			48			1	1	1	1	48	0

c1	c2	c3	sections ready	pps1	pps2	pps3	pps4	pps5	pps6	sections finished	sections waiting
4			4	1	1	1	1			4	0
	4		8			1	1	1	1	8	0
		4	12	1	1			1	1	12	0
4			16	1	1	1	1			16	0
	4		20			1	1	1	1	20	0
		4	24	1	1			1	1	24	0
4			28	1	1	1	1			28	0
	4		32			1	1	1	1	32	0
		4	36	1	1			1	1	36	0
4			40	1	1	1	1			40	0
	4		44			1	1	1	1	44	0
		4	48	1	1			1	1	48	0

Figure D.11: Thought experiment, interaction between parts supply after cutting and part processing spaces demand.

c1	c2	c3	sections ready	pps1	pps2	pps3	pps4	pps5	pps6	sections finished	sections waiting
4	4		8	1	1	1				3	5
			8		1	1	1			6	2
			8			1	1	1		9	-1
		4	12				1	1	1	12	0
4	4		20	1	1	1				15	5
			20		1	1	1			18	2
			20			1	1	1		21	-1
		4	24				1	1	1	24	0
4	4		32	1	1	1				27	5
			32		1	1	1			30	2
			32			1	1	1		33	-1
		4	36				1	1	1	36	0
4	4		44	1	1	1				39	5
			44		1	1	1			42	2
			44			1	1	1		45	-1
		4	48				1	1	1	48	0

c1	c2	c3	sections ready	pps1	pps2	pps3	pps4	pps5	pps6	sections finished	sections waiting
4			4	1	1	1				3	1
	4		8		1	1	1			6	2
			8			1	1	1		9	-1
		4	12				1	1	1	12	0
4			16	1	1	1				15	1
	4		20		1	1	1			18	2
			20			1	1	1		21	-1
		4	24				1	1	1	24	0
4			28	1	1	1				27	1
	4		32		1	1	1			30	2
			32			1	1	1		33	-1
		4	36				1	1	1	36	0
4			40	1	1	1				39	1
	4		44		1	1	1			42	2
			44			1	1	1		45	-1
		4	48				1	1	1	48	0

Figure D.12: Thought experiment, interaction between parts supply after cutting and part processing spaces demand. continued.

D.5. Inventory waste impression

In this Section some impressions of the inventory waste are given. First in Figure D.13 and Figure D.14 the inventory at the sorting spaces is highlighted.

In Figure D.15 the inventory piles at the outside steel storage are shown. In Figures D.15 and D.17 impressions of the inventory loaded onto containers is given. The risk of loosing parts is apparent here. Figure D.18 underlines the required space and building up of inventory during the sorting step when the parts arrive from cutting at the part processing spaces. In Figures D.19 and D.20 the sorting for end buffers at the part processing spaces is underlined. Moreover some impressions of the inventory and space occupation at the forming stations are presented in Figures D.21 and D.22. The repacking and piling and the extensive space can be observed. Last the inventory at the profile cutting line infeed and outfeed is presented in Figures D.23 and D.24. The bundling of profiles can be clearly observed.

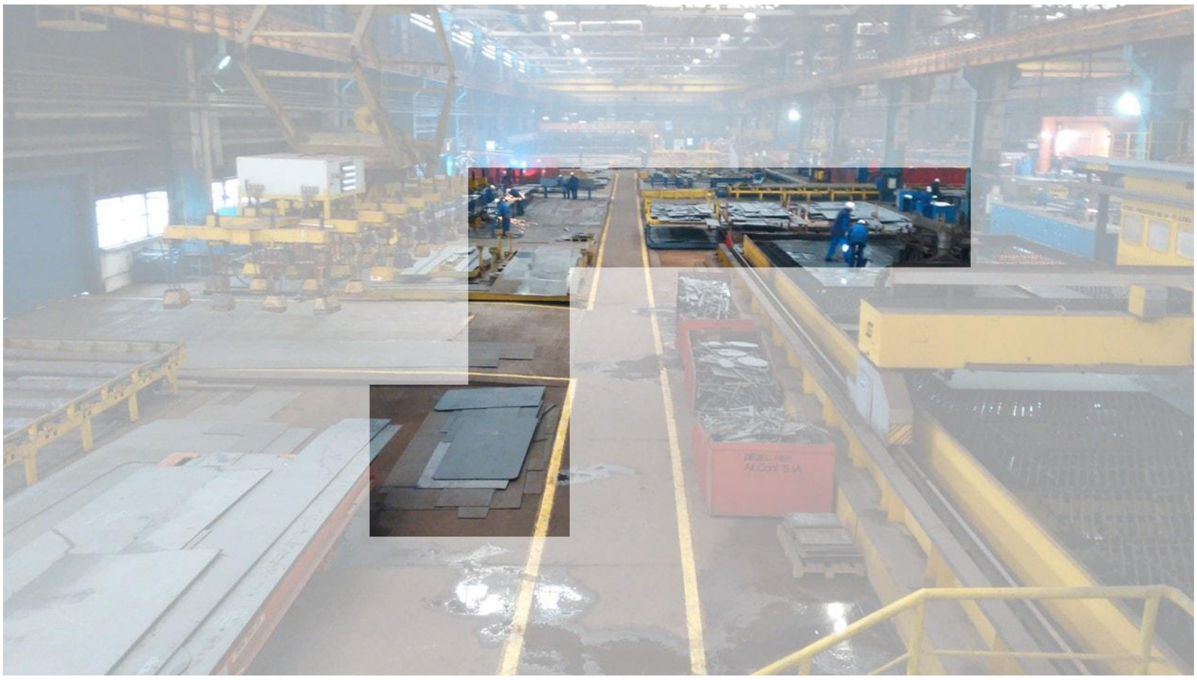


Figure D.13: Sorting space after cutting - utilisation

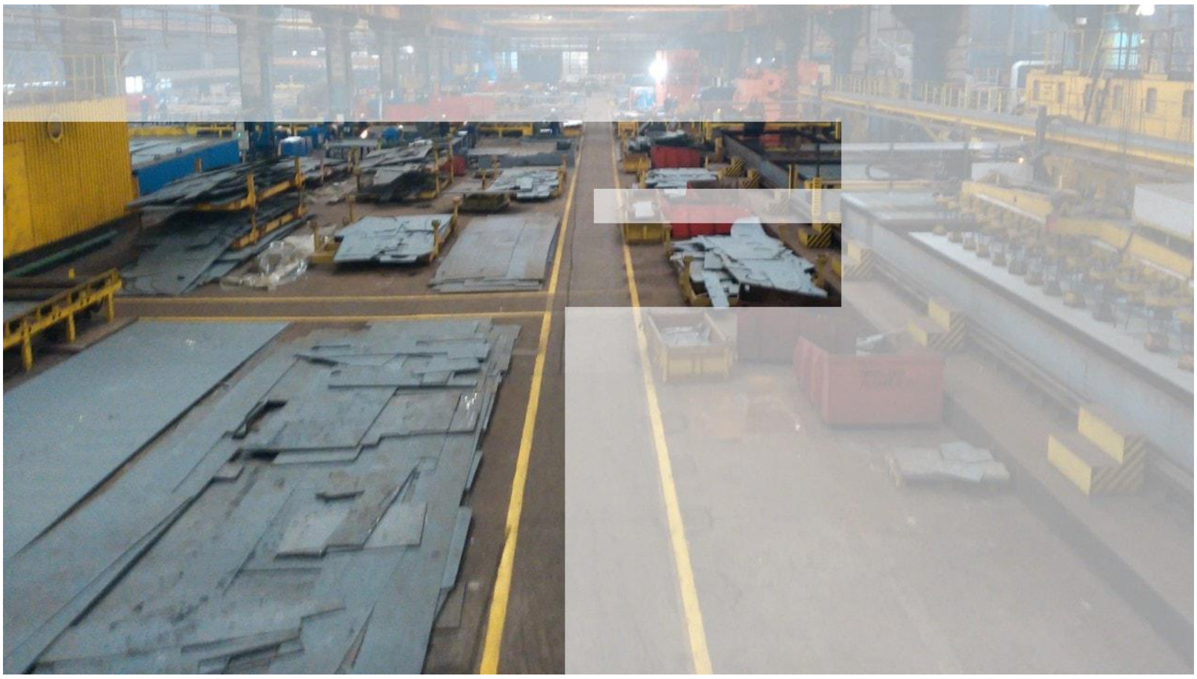


Figure D.14: Sorting space after cutting - utilisation

Figure D.15: Waste impression, raw plate storage

Figure D.16: Waste impression, container inventory

Figure D.17: Waste impression, container inventory, losing parts risk

Figure D.18: Waste impression, PPS sorting for processing

Figure D.19: Waste impression, PPS sorting for end buffers

Figure D.20: Waste impression, PPS sorting sorting for end buffers

Figure D.21: Waste impression, forming sorting buffer

Figure D.22: Waste impression, forming in/outfeed

Figure D.23: Waste impression, profile line infeed

Figure D.24: Waste impression, profile line outfeed

D.6. Space utilisation detailed results

This Section presents the detailed result of the analysis performed in Section 3.9. First the detailed space utilisation per work station is provided. Then the division in in/outfeed buffers and process space is presented.

D.6.1. Analysis of space requirement

Table D.2 presents the used area per station/work step, based on the layout description. In S1 both the plasma and the oxy acetylene cutting station are included in the name ‘cutting station’. Also in S1a the plate cutting stations are jointly presented. Also the part processing spaces areas are taken together, because the same work steps are executed. Only half of the area is included since sub panel assembly takes place as well. For process spaces the area consists out of work bench area and the area for worker movement (3 times workbench). The detailed results are the basis for the KPI developed in Section 3.9.1.

Table D.2: Overview space utilisation per work step

Name S1 - plates	Area [m^2]	Name S1a - plates	Area [m^2]	Name S1a - profiles	Area [m^2]	Total [m^2]
Cutting station	614	Cutting station	904	Cutting robot	612	-
Cutting sorting spaces	1360	Cutting sorting spaces	1545	Sawing machine	115	-
Tapering station	256	Tapering station	208	-		-
Forming station	707	Forming station	557	Forming station	554	-
Part processing spaces	1907	Part processing spaces	2170	Grinding station	304	-
Flanging station	387	Flanging station	363	Sorting spaces	276	-
Total	5231	Total	5747	Total	1861	12839

D.6.2. Analysis of in/outfeed buffer space

In Table D.3 a detailed overview of the in/outfeed buffer and process space is presented, supporting the analysis discussed in Section 3.9.1.

The result is obtained by determining the area in which value added processes are executed. For cutting this mainly equals the cutting bed sizes. For tapering and grinding this is equal to the workbench area, including some movement space (factor 2.5). For forming and flanging it equals the press work spaces mainly. No specific separation between infeed and outfeed buffers is made. Because only the cutting work stations would have a dictated infeed/outfeed buffer separation.

Table D.3: Overview space utilisation per work step

	S1		S1a			S1a	
Plates	Process [m^2]	In/out [m^2]	Process [m^2]	In/out [m^2]	Profiles	Process [m^2]	In/out [m^2]
Cutting station	280	1694	440	2009	Cutting robot	350	262
Tapering station	100	156	50	158	Sawing machine	40	75
Forming station	200	507	100	457	Forming station	150	404
Grinding station	420	1487	420	1750	Grinding station	210	370
Flanging station	50	337	50	313	-	-	-
Total	1050	4181	1060	4687	Total	750	1111

D.7. Transport analysis detailed results

In Section 3.9.2 the transport distance and number of transports per flow is discussed. There transport distance versus flow contributions based on part numbers is plot. Here in the Appendix the result is plot versus the flow contributions on weight as well. The results is presented in Figure D.25 and Figure D.26 for the transport distance and number of transport respectively.

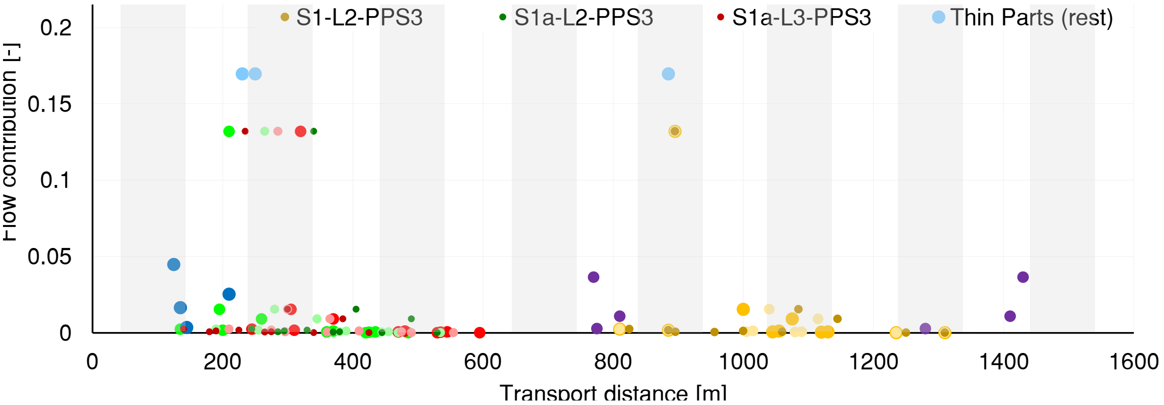


Figure D.25: Flow contribution per distance transported based on normalised cumulative weight

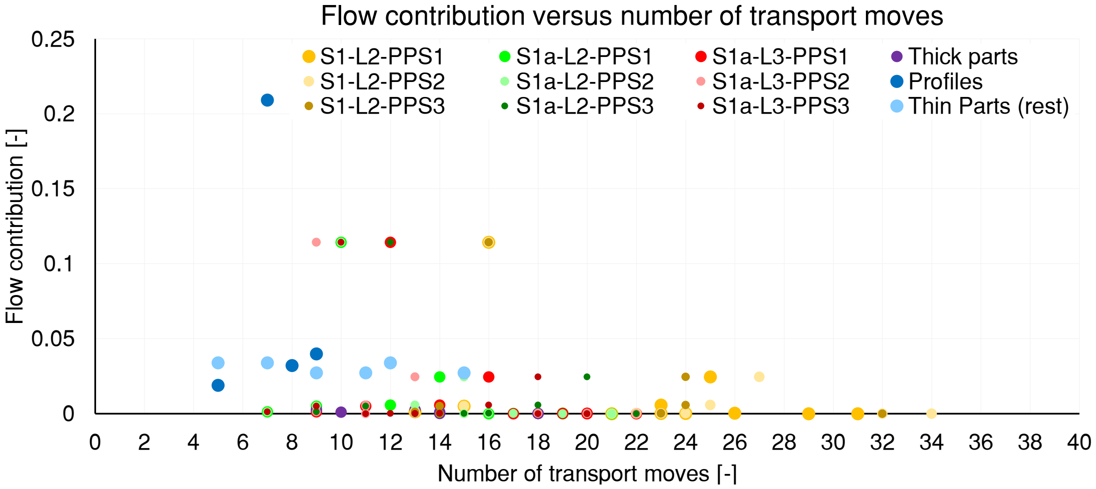


Figure D.26: Flow contribution per number of transports, based on normalised number of parts

E

Simulation model verification and validation

This Appendix provides the verification test plan and validation detailed results in respectively Appendix E.1 and Appendix E.2. Hence it is supportive to Chapter 4 which deals with the construction of the simulation model.

E.1. Simulation model verification test plan

In Section 4.3 the current state simulation model verification is introduced. There the process of executing proper verification is described. Furthermore several model aspects which require specific emphasis due to their case specifics and programming assumptions are outlined. They are listed in a test plan, which is incorporated in Table E.1.

The following test procedures are used; from which a short description is given below.

1. Sample test: checks a random number of parts and is used for verifying sorting criteria and batch definitions.
2. Cumulative number test: checks the total numbers and compares it with the input data. It is used to support the sample tests.
3. Track and trace test: follows individual parts to check whether the flow is conform requirements.
4. New call chain analysis: checks the sequence of executing rules and processes and is mainly used for follow up processes.
5. Visual inspection: verifies the expected behaviour by assessing the graphics. This test is appropriate for checking the transportation means.
6. Block settings and trace functionality test: verifies the dependency on resources and settings. It is useful for checking the programming of worker, carriage and crane requirements.

The completion of the test plan test provides a proper model verification since the reflection of the process model description and simulation model is found.

Table E.1: Simulation model verification tests

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	track and trace	V

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No.	Verification test	Verification method	Check
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
10	Worker dependency for cranes, conveyor, and carriage	block settings and trace functionality	V
11	Crane speeds/capacity	block settings and trace functionality	V
	Cutting stations		
12	LIFO stack unloading	track and trace	V
13	Cutting machine change over time	track and trace of several plates with different thicknesses	V
14	Cutting program duration	timing process by means of break points.	V
15	Hand signing and scrap cutting execution	timing process by means of break points.	V
16	FIFO crane requests for sorting	track and trace / settings	V
17	Forming plate destination	track and trace / cumulative number test	V
18	Main panel destination	track and trace / cumulative number test	V
19	Main panels are moved to S1a	track and trace / cumulative number test	V
20	Tapering destination	track and trace / cumulative number test	V
21	Big parts by crane	track and trace / visual inspection	V
22	Small parts by hand	track and trace	V
23	Container full criterion	new call chain analysis	V
24	Container stacking when full	new call chain analysis	V
25	Loading small on large container when large container is full	new call chain analysis	V
26	Container fastening to crane changeover time	track and trace, sample tests	V
27	Container transport to PPS or buffer	new call chain analysis	V
28	Transporter/sorting worker dependency	block settings and trace functionality	V
29	Cutting machine operator dependency	block settings and trace functionality	V
30	Crane dependency (portals, speeds, capacity)	block settings and trace functionality	V
31	Changeover times between yoke and magnet	sample test	V
32	Carriage operator request	block settings and trace functionality / track and trace	V
33	Part enters infeed buffer and wait until section number is processed (S1a)	new call chain analysis	V
34	Part enters infeed buffer and is LIFO unstacked on space (S1)	track and trace	V

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No.	Verification test	Verification method	Check
35	FIFO processing and loading on container	track and trace	V
36	Transport container when all parts are processed	new call chain analysis	V
37	Different processes for thick and thin parts	new call chain analysis	V
38	Worker request for process and crane use	block settings and trace functionality / track and trace	V
39	Crane dependency (portals, speeds, capacity)	block settings and trace functionality	V
	Forming stations		
40	Part enters infeed buffer starts directly (S1a)	track and trace	V
41	Containers (FIFO) are unstacked on space (LIFO) (S1)	track and trace	V
42	Priority for unpacking above processing	new call chain analysis	V
43	All parts are processed on S1a Plate roller or S1 Pressure Press	track and trace	V
44	Parts are rotated to correctly enter the presses	visual inspection	V
45	3D plates are also processed on Line Heating (S1a) or Roller Pressure Press (S1)	track and trace	V
46	Sorting and packing per section	sample test and cumulative plate number test	V
47	Crane requests are executed FIFO apart from parts which have priority	new call chain analysis	V
48	Maximum loading capacity containers	new call chain analysis	V
49	End buffer transport	visual inspection	V
50	Crane dependency (portals, speeds, capacity)	block settings and trace functionality	V
51	Worker requests (operator/assistant)	block settings	V
	Part processing spaces		
52	Parts are sorted for processing or end buffers (LIFO)	track and trace	V
53	Priority for unpacking above processing	new call chain analysis	V
54	Different transport equipment are used	track and trace	V
55	Small parts to belt grinder	track and trace	V
56	Big parts are processed on work bench	track and trace	V
57	Big parts are rotated before other side is grinded	track and trace	V
58	Parts are also bevelled, before grinding	track and trace	V
59	Small parts for flanging on pallet	track and trace	V
60	Pallet is moved by fork lift (S1a)	visual inspection	V
61	Large parts move to flanging one by one (S1a)	track and trace	V
62	Large parts for flanging on container (S1)	track and trace	V
63	Pallet is loaded on container and sent to flanging jointly (S1)	new call chain analysis	V
64	Sorting and packing for end buffers	track and trace	V
65	Maximum loading capacity	new call chain analysis	V
66	Crane dependency (portals, speeds, capacity)	block settings and trace functionality	V
67	Worker requests (different skills)	block settings	V
	Flanging process		
68	Pallets and containers are unpacked (LIFO)	track and trace	V
69	Priority for unpacking above processing	new call chain analysis	V
70	Smaller parts do not require cranes	track and trace	V

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No.	Verification test	Verification method	Check
71	Big parts require cranes to be processed	track and trace	V
72	Crane requests are executed FIFO	new call chain analysis	V
73	Parts are rotated to correctly enter the presses	visual inspection	V
74	Parts are moved back to PPS same way as the entered	track and trace	V
75	Crane dependency (portals, speeds, capacity)	block settings and trace functionality	V
76	Worker requests (operator/assistant)	block settings	V
77	Transport process		
78	Transport of section rack	track and trace / visual inspection	V
79	Transport of single parts by truck/forklift	track and trace / visual inspection	V

E.2. Simulation model validation results

In this Section the detailed results of the model validation process is presented. First the man hour is presented. Secondly some results concerning the throughput validation are presented.

E.2.1. Man hour validation

In Section 4.4.3 the simulation model validation based on man hours is determined. There the overall results per ship type are presented. Here the detailed results per pre-processing facility are presented. In Figure E.1 the results of an ASD processed in facility S1 is presented. In Figure E.1 the results of an ASD processed in facility S1a is shown. The thick plates of a vessel are cut in facility S1 anyhow. Hence on the S1a result the S1 oxy fuel cutting hours are included. Minor differences between the two facilities occur. The results of the PSV are not yet available, therefore the correct results are not yet implemented.

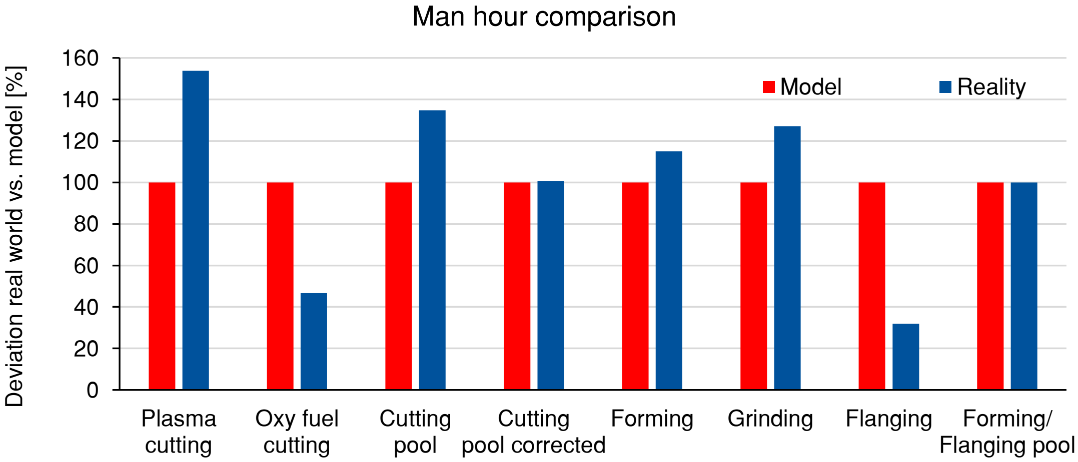


Figure E.1: Man hour determination difference model and real world - ASD - S1

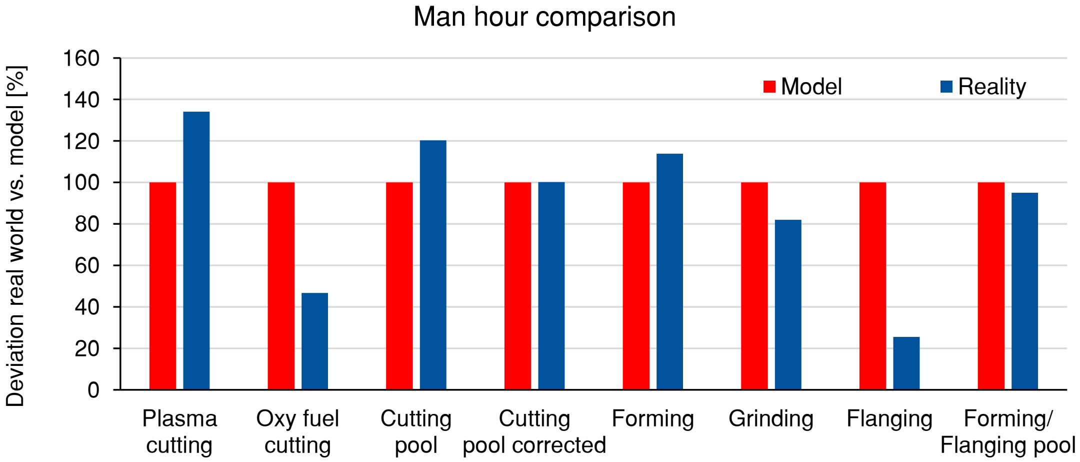


Figure E.2: Man hour determination difference model and real world - ASD - S1a

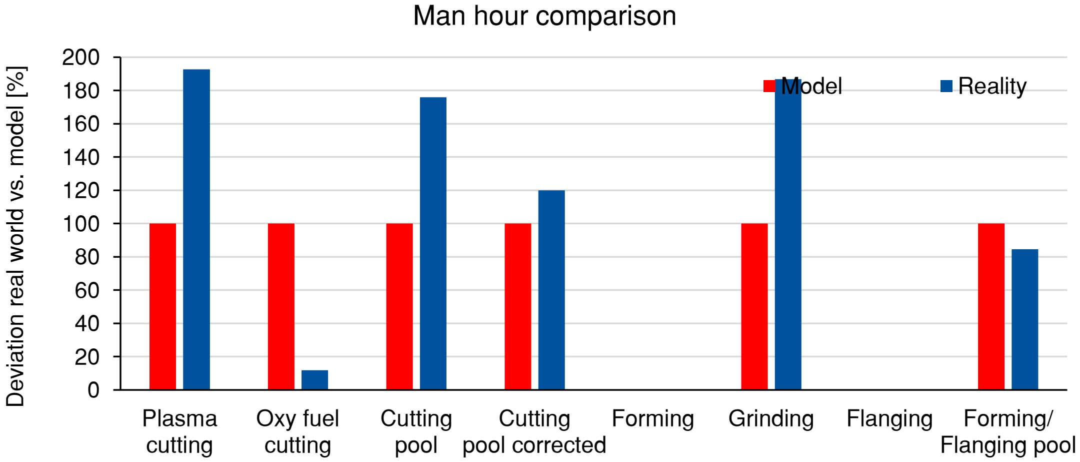


Figure E.3: Man hour determination difference model and real world - PSV - S1

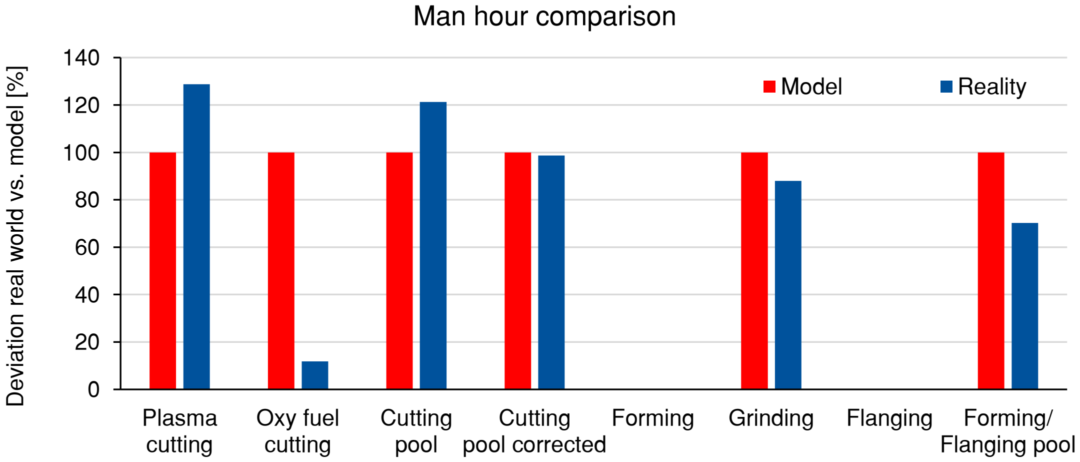


Figure E.4: Man hour determination difference model and real world - PSV - S1a

E.2.2. Annual throughput validation

In Section 4.4.4 the validation of the simulation model with the reality is discussed. It is state that the real world throughput is determined on the annual portfolio and product data. Here this determination is presented. The result is presented in the grey cell.

Table E.2: Annual throughput based on product data

	Raw material mass			Parts mass		
	ASD [ton]	PSV [ton]	Total [ton]	ASD [ton]	PSV [ton]	Total [ton]
Plates (incl. flat bars)	311	1455	1766	-	-	-
Plates (excl. flat bars)	-	-	-	221	1043	229
Flat bars	-	-	-	8	45	53
Profiles	36	163	199	24	149	194
Total per ship	347	1618	1965	253	1237	1490
No. ships	12	6	18	12	6	18
Total plates (incl. flat bars)	3732	8730	12462	-	-	-
Total plates (excl. flat bars)	-	-	-	2652	6258	8910
Total flat bars	-	-	-	96	270	366
Total profiles	432	978	1410	288	894	1182
Total	4164	9708	13872	3036	7422	10458
Total plates	3732	8730	12462	2748	6528	9276

F

Current state performance analysis detailed results

This Appendix is dedicated to Chapter 5. First the break points are defined for the definition of sub processes. Second the part throughput analysis results are presented. In Appendix F.3 the date based annual throughput is presented. Finally the detailed resource utilisation results are provided.

F.1. Break point definition

In order to study the individual work step contribution the process is cut in different pieces. A description is given below. The tapering work step has not been specifically paid attention to because it contribution is minor and takes place at the start of the grinding work step. The phase durations are measured by the following time breakpoints:

	Process	Start time definition	End time definition
1.	Cutting	Plates enter facility on conveyor	Parts are ready for sorting, still on cutting bed.
2.	Sorting	End of cutting process	(S1) Parts leave the sorting space.
2.	Sorting	End of cutting process	(S1a) End of cutting group
3.	Transport to PPS	Parts leave the sorting space	Parts enter the PPS
4.	PPS process	Parts enter the PPS	Parts leave the PPS to flanging/end buffers
5.	Transport to flanging	Parts leave the PPS for flanging	Parts enter flanging infeed buffer
6.	Flanging process	Parts enter flanging infeed buffer	Parts leave flanging outfeed buffer
7.	Transport to PPS	Parts leave the flanging outfeed buffer	Parts enter PPS (second time)
8.	Transport to End buffers	Parts leave PPS for end buffers	Parts enter in end buffers
9.	Transport to forming	Parts leave the sorting space	Parts enter forming sorting space
10.	Forming sorting process	Parts enter forming sorting space	Parts leave to forming infeed buffer
11.	Forming process	Parts enter forming infeed buffer	Parts leave forming outfeed buffer
12.	Forming sorting process	Parts leave forming outfeed buffer	Parts leave to forming sorting space
13.	Transport to End buffers	Parts leave forming sorting space for end buffers	parts enter in end buffers

F.2. Part throughput results

In Figure F.1 and Figure F.2 the results of a single simulation run are presented. Furthermore the value added time is included in these graphs. The processing work steps enable a physical transformation of the parts, being value added steps. The accumulative durations are included. This implies that when a part requires tapering and grinding both durations are included. The parts are presented in the order in which they are cut.

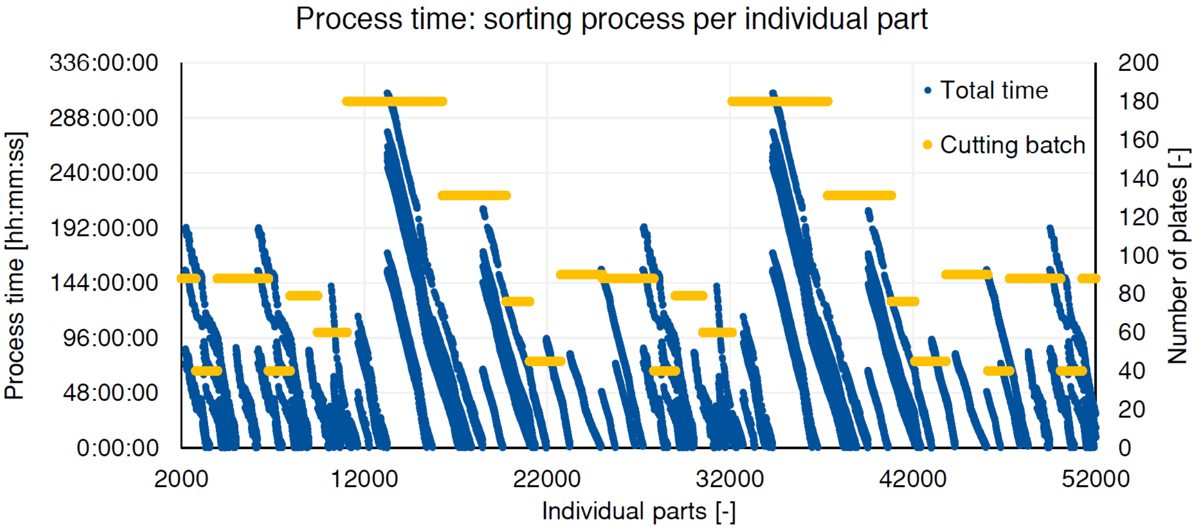


Figure F.1: Process time: sorting process per individual parts (parts are ordered in sequence of cutting)

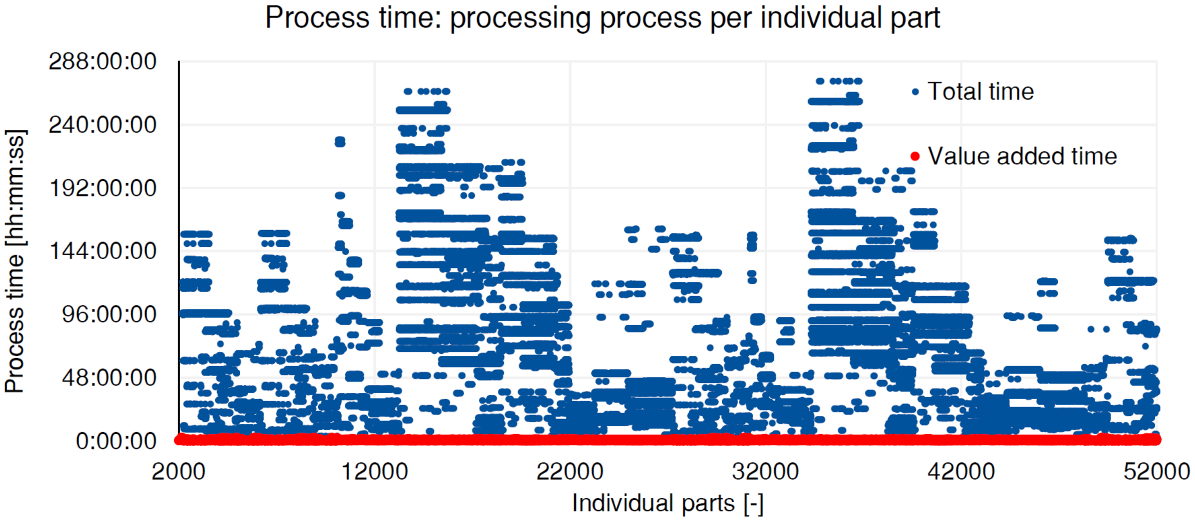


Figure F.2: Process time: processing process per individual parts (parts are ordered in sequence of cutting)

F.3. Station annual throughput results

In Section 5.2 the annual throughput of the pre-processing stations is dealt with. The S1 cutting station throughput distribution is presented there. Here the Figures for forming, part processing and flanging of the S1 and S1a facility are presented in Figure F.3 to Figure F.5 respectively.

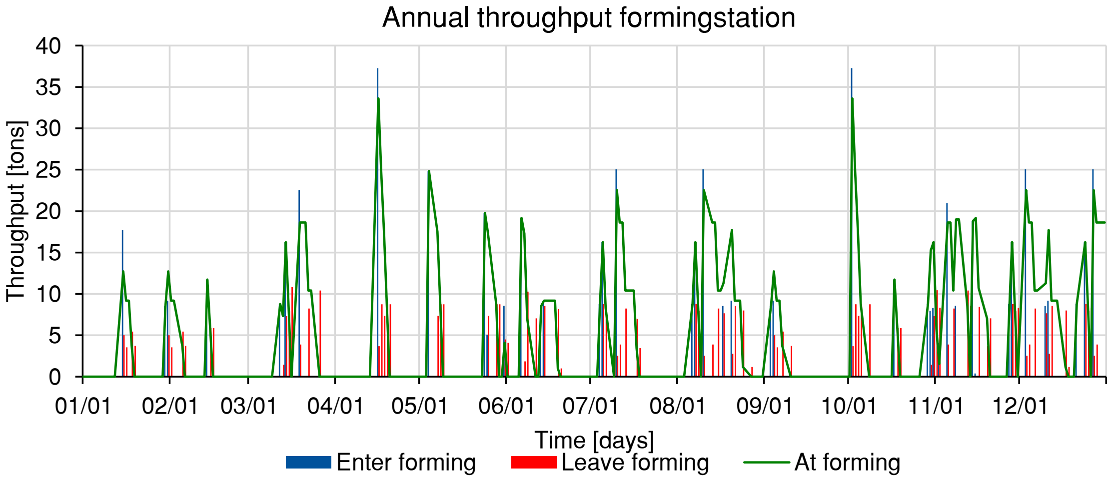


Figure F.3: Throughput S1 forming station per year

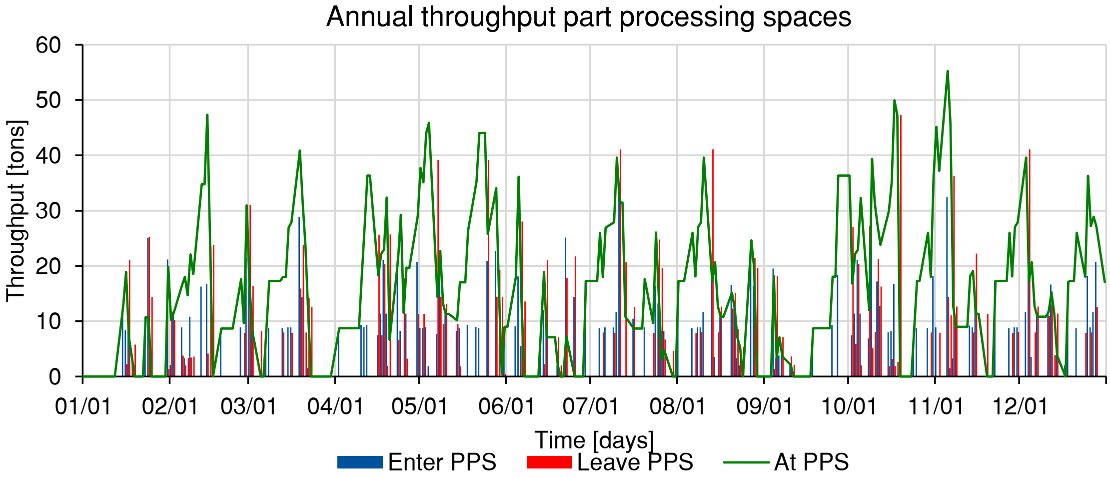


Figure F.4: Throughput S1 part processing spaces

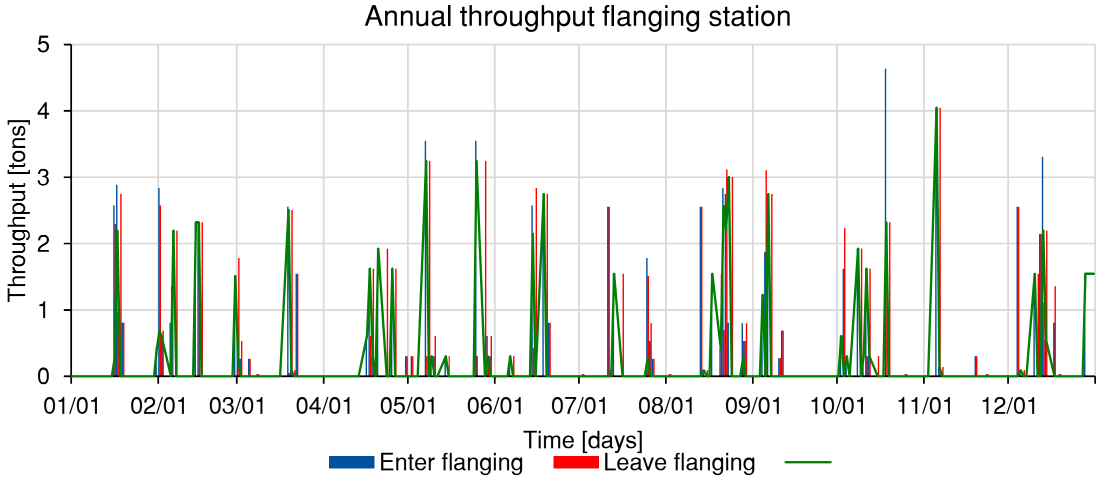


Figure F.5: Throughput S1 flanging station

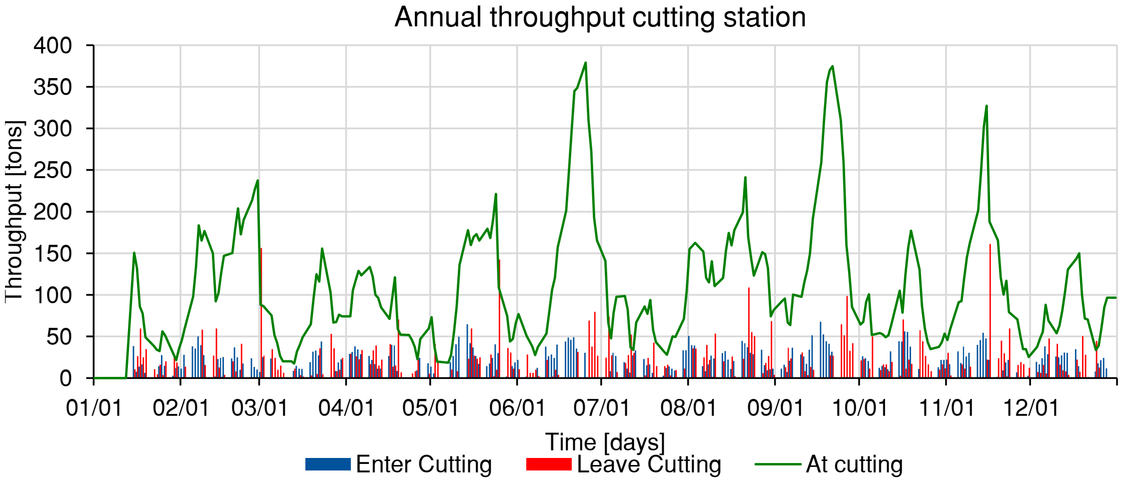


Figure F.6: Throughput S1a cutting stations per year

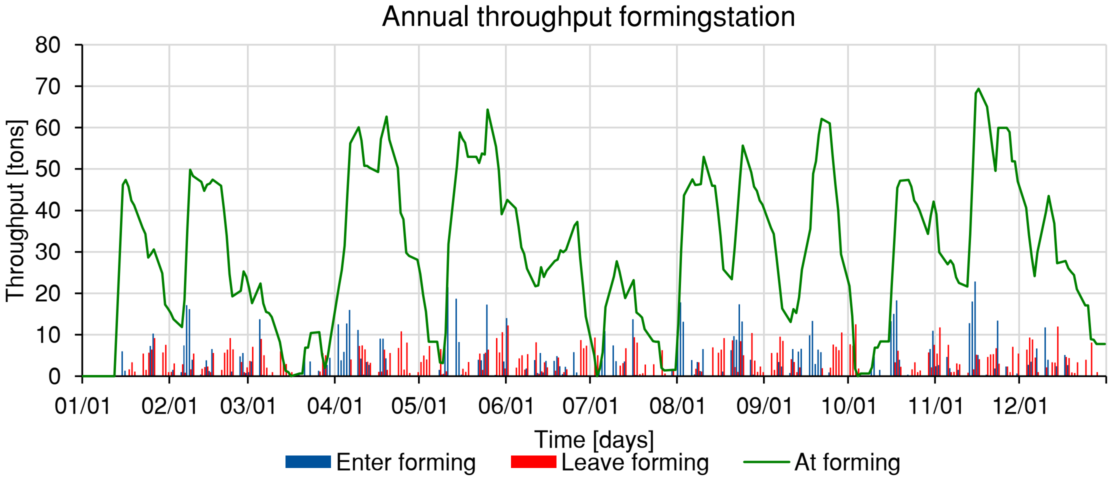


Figure F.7: Throughput S1a forming station per year

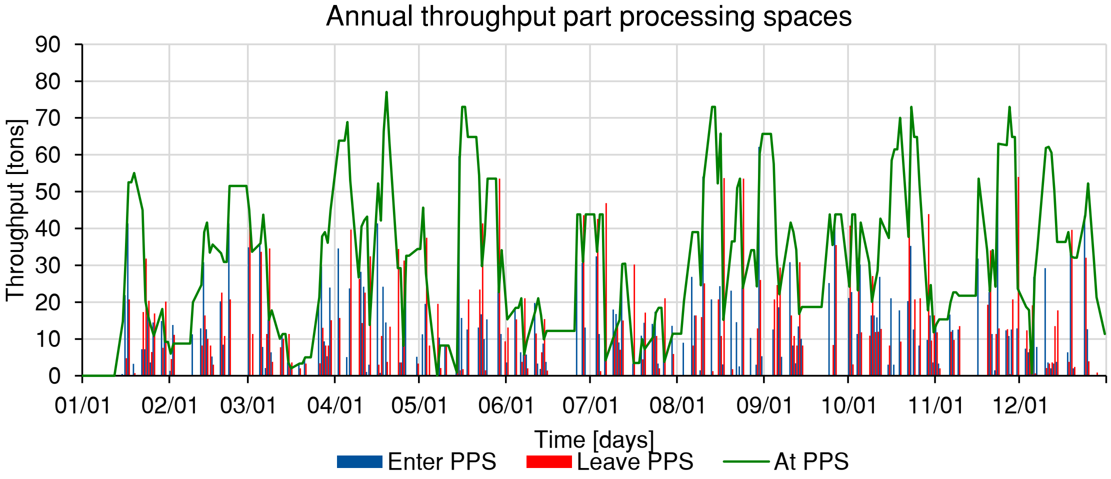


Figure F.8: Throughput S1a part processing spaces

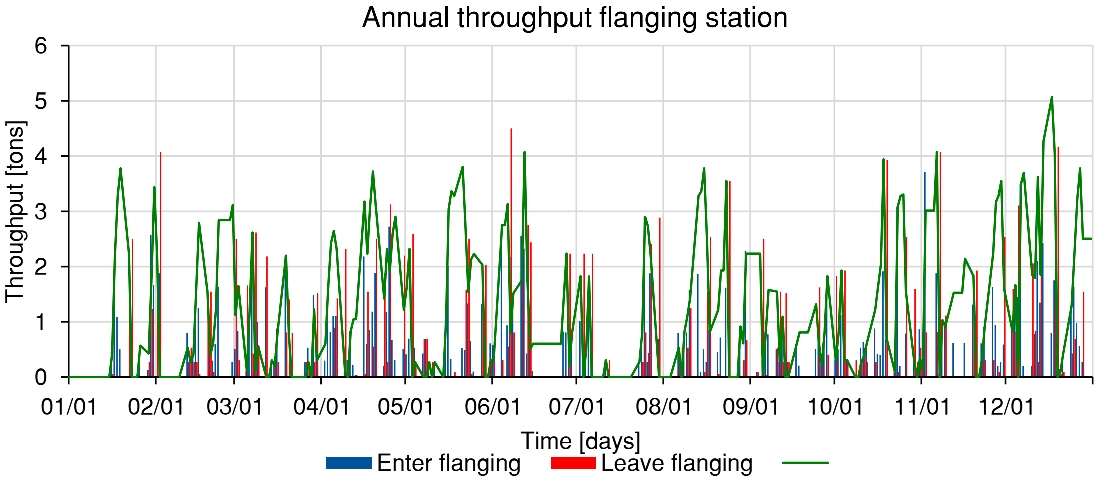
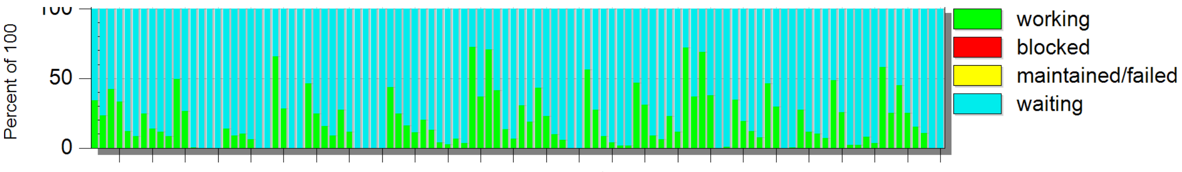


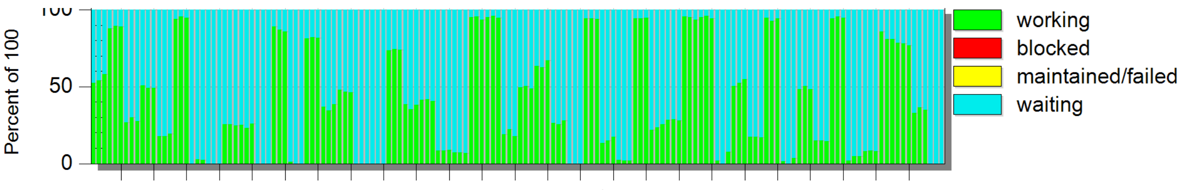
Figure F.9: Throughput S1a flanging station

F.4. Resource utilisation diagrams

Here the resource utilisation diagrams of the resources which are not shown in Section 5.3 are presented.

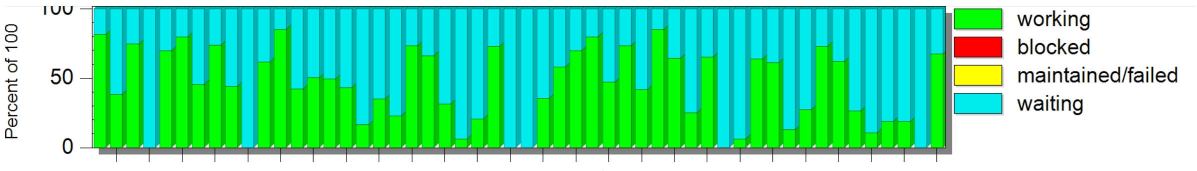


(a) S1a-L2 cutting portals (from left to right)

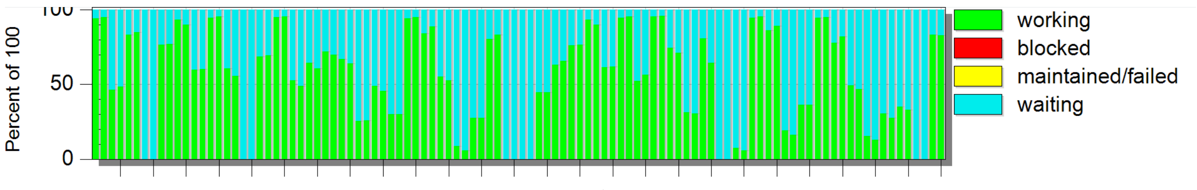


(b) S1-L2 cutting supports, (from left to right)

Figure F.10: Date based utilisation diagrams S1a-L2 cutting station

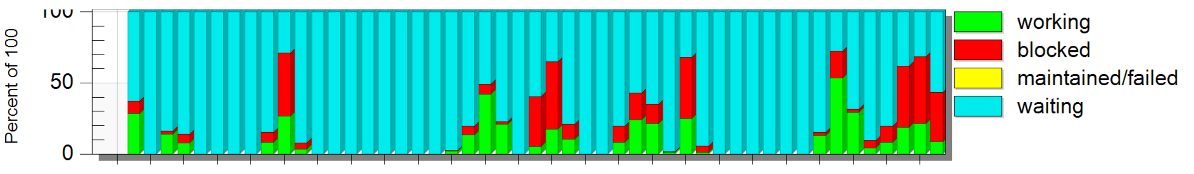


(a) S1a-L3 cutting portals (from left to right)

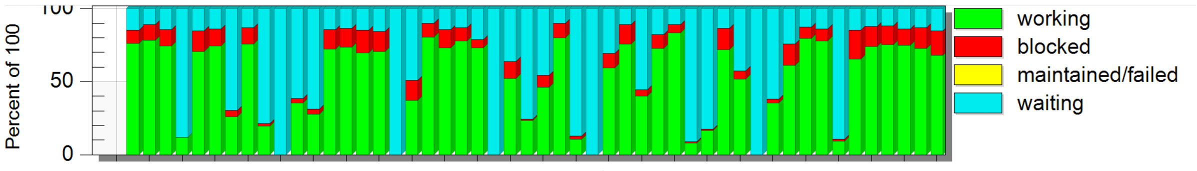


(b) S1-L3 cutting supports, (from left to right)

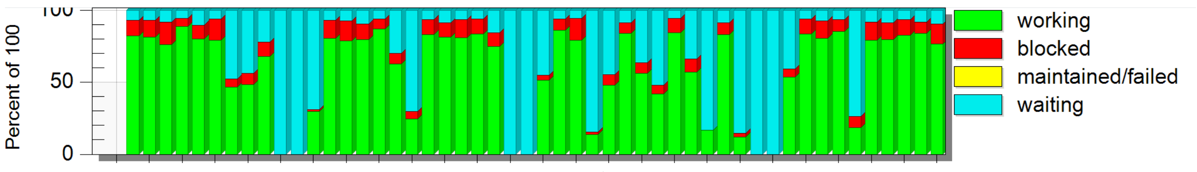
Figure F.11: Date based utilisation diagrams S1a-L3 cutting station



(a) Forming roller pressure press



(b) Forming roller press



(c) Forming line heating

Figure F.12: Utilisation diagrams forming presses

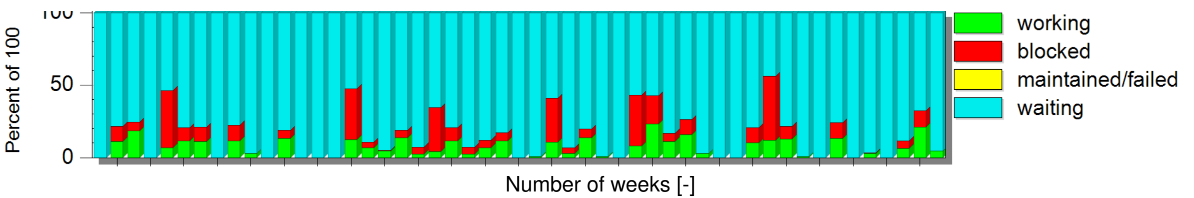
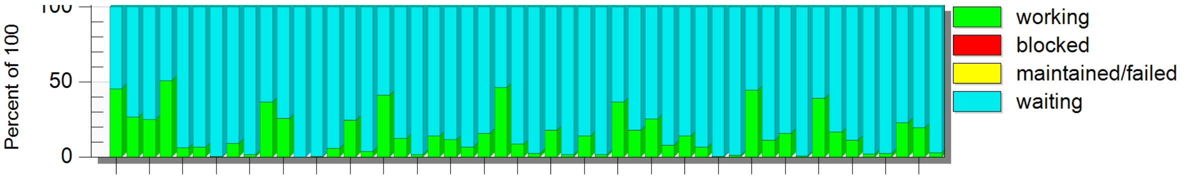
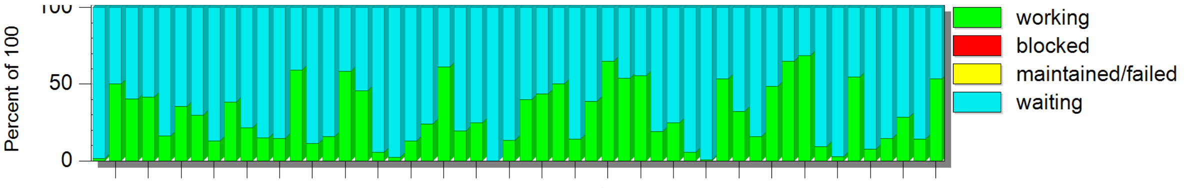


Figure F.13: Date based utilisation diagram flanging brake press S1

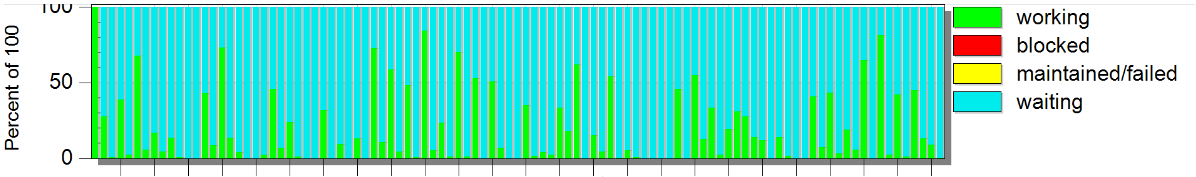


(a) S1 carriage

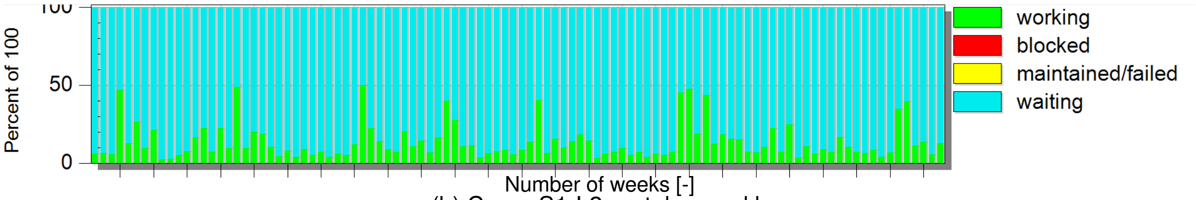


(b) S1a carriage

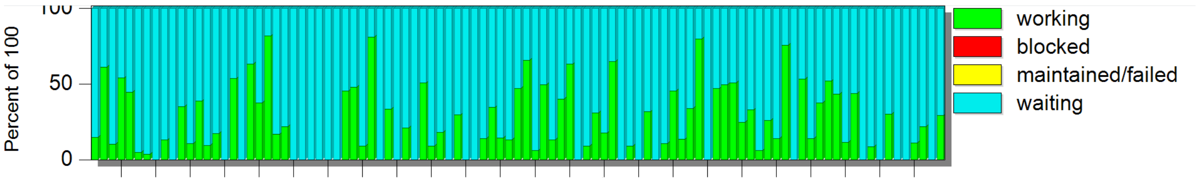
Figure F.14: Date based utilisation diagrams carriages



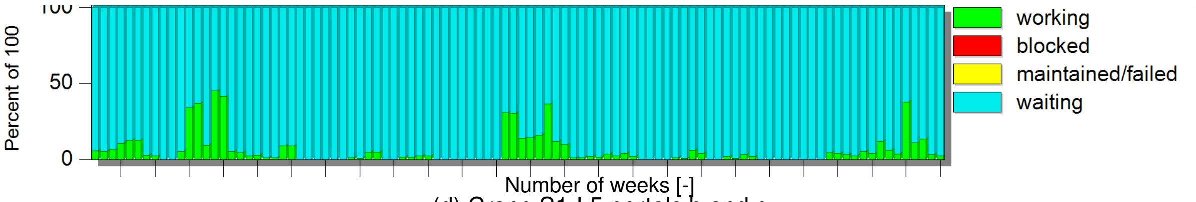
(a) Crane S1-L1 portals a and c



(b) Crane S1-L2 portals a and b

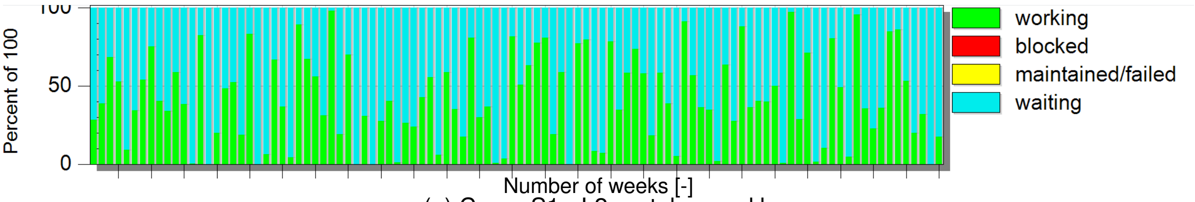


(c) Cranes S1-L3-a and S1-L4-a

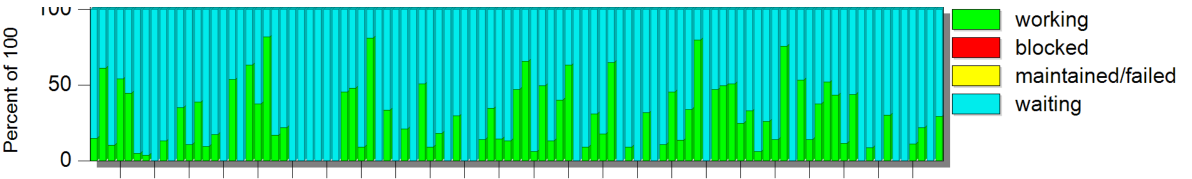


(d) Crane S1-L5 portals b and c

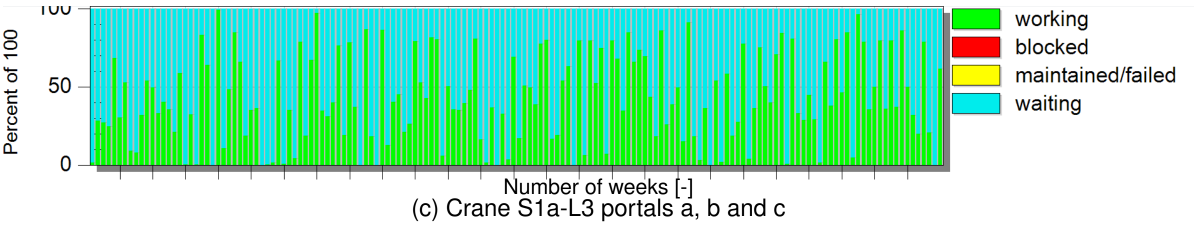
Figure F.15: Date based utilisation diagrams S1 cranes



(a) Crane S1a-L2 portals a and b



(b) Cranes S1a-L2 portals c and d



(c) Crane S1a-L3 portals a, b and c

Figure F.16: Date based utilisation diagrams S1a cranes

G

Improvement strategy development detailed analysis

This Appendix is supportive to Chapter 6. Detailed results and background analysis are presented. The following subjects are dealt with:.

1. In Appendix G.1 the number of cutting machines is determined. In presents the detailed analysis as discussed in Section 6.2.1.
2. In Appendix G.2 the quantification of the product lines based on routines and customer demand are further outlined. The measurement procedures are discussed.
3. In Appendix G.3 it is explained that cutting flat bars on the profile cutting line is feasible.
4. In Appendix G.4 detailed results about the customer demand batch size concerning weight is presented.

G.1. Resource determination

In Section 6.2.1 the number of cutting machines required for the future states is predicted. The detailed calculation is presented below, in Table G.1.

Based on the available product data the total time for cutting can be determined, consisting of the cutting program duration and on/off loading time. The time for marking and cutting is not changed as the cutting machine performance cannot be changed [28, 55]. However as raised in the Section 6.4, automatic signing is included instead of manual signing.

The time for on-off loading the material depends on the improved logistic flows. As the value depends on the sorting improvements initially a multiplication factor is taken. In the determination of this factor the effect of using double cutting beds is considered. Hence the factor is initially estimated to be 20%, to also include change and setup times. It is strived to locate the resources such that this factor is decreased as much as possible.

Hence the total cycle time for cutting one plate can be determined. In order to relate the 'total cycle time' to 'tons per year' the average of the entire product data set is taken. For the determination of the expected 'tons per year' the discussion of Section 2.3.1 plays a role.

The maximum available machine up time is 100%, resulting in 4000hours per year. Consequently the number of required cutting machines can be determined. Following the ship delivery driven throughput determination three cutting machines suffices. A detailed calculation is provided in Appendix G.1.

In the objective of this study it was hypothesised that the throughput can be increased to obtain a ratio between throughput and required gross area. Therefore the number of cutting machines is slightly over estimated to four cutting machines.

The drawback of this approach is that it is based on averages only. An average cutting cycle time of ±1.5tons per hour is found. Two kinds of averages are observed, namely, based on plate thickness and based on nesting files.

Still the analysis provides a well educated guess on the number of cutting machines. Final analysis has to provide feedback on the feasibility and utilisation of the provided predictions. Conclusively four cutting machines are to be deployed.

Table G.1: Determination number of cutting machines

	ASD	PSV	Total
total cutting program per ship	146	580	
total tons per ship	310	1455	
factor for on/of loading	0.2	0.2	
total cycle time per ship	175	696	
time per ton	0.75	0.7	
number of ships	12	6	
total tons per year	3720	8730	12450
total time per year	2790	6111	8901
total time per cutting machine			4000
number of cutting machines			3

G.2. Product line quantification

This Section deals with the development of the product line quantification tables. In Section 6.2.1 and Section 6.2.2 different product lines on routines and customer demand are described. Their contribution is quantified.

This is done as follows. It is explained that the data set contains three types of part specific data, namely part data, end buffer data and routing data. In order to identify the parts which follow a delineated product line four levels of distinctions are made.

9xx/9yy	Based on the end buffer data the different customer processes are distinguished.
PL/PR	Based on the part type/kind the profile can be separated from the plate parts.
S/C	The routine attribute “Forming Type” is used to separate straight and to be curved parts.
M	Small parts are parts which are not classified as S or C, or when no classification is required.

Implementing these conditional statements resulted in the number of parts which are to be processed in the specific product line. By coupling the part data attribute weight also the cumulative weight of the parts per product line are identified. This is done since the accepted productivity metric with in shipbuilding is in tons [24, 49]. Furthermore the separation between small (≤20kg) and large parts is made.

For each product line it is determined what routines the parts have. This finally resulted in a matrix in which the product lines on customer demand are stated horizontally and product lines based on routines vertically.

In Table G.2 the results for a half year are presented. This data set entails takes the DSGa portfolio into account, as defined in Section 2.3.1.

In this Section the results are presented per distinction (≤20kg and >20kg) in Tables G.3 and G.4 respectively.

G.3. Flat bar from profiles analysis

This section presents the detailed result of the analysis performed in Section 6.2.3, concerning the question whether flat bars can be cut from profiles. In Figure G.1 the same type of information is plot as in Figure 6.7, but now the assumption that flat bars are cut from profile is incorporated.

Table G.2: Product line quantification, all parts

	ALL PARTS NUMBER																
Routing/Endbuffer	910PL	910PR	920PL	920PR	930PLS	930PLC	930PRS	930PRC	940PLC	940PRC	940M	950M	960M	9++PL	9++PR	9++SM	Total
C	1539	11759	1258	2624	2198		533				2892	315	882	122		2225	26347
C-B/T	14				42						7			21			84
C-B/T-F						35			7								42
C-B/T-G	84		7											28			119
C-B/T-G-Fl																	
C-F	30					712			946					14			1702
C-F-G								1791	35	918							2744
C-G	6698	9983	1510				11099				38624	410	7888	696		196	77104
C-G-Fl	355										1336		468				2159
C-Fl	183	301		112			28				616	14	14	7			1275
Total	8903	22043	2775	2736	2240	747	11660	1791	988	918	43475	739	9252	888		2421	111576

	ALL PARTS WEIGHT in tons																
Routing/Endbuffer	910PL	910PR	920PL	920PR	930PLS	930PLC	930PRS	930PRC	940PLC	940PRC	940M	950M	960M	9++PL	9++PR	9++SM	Total
C	317.42	112.68	65.83	54.41	1732.43		4.37				302.38	0.72	14.40	8.29		29.51	2642.44
C-B/T	1.79				45.90						0.82			2.93			51.44
C-B/T-F						25.65			1.19								26.84
C-B/T-G	17.02		6.16											6.50			29.68
C-B/T-G-Fl																	
C-F	14.82					458.41			271.83					1.13			746.19
C-F-G								66.14	23.64	16.10							105.89
C-G	754.56	124.84	73.74				291.90				456.02	1.77	19.22	14.56		6.29	1742.91
C-G-Fl	39.92										19.44		8.89				68.26
C-Fl	48.21	2.55		0.92			0.07				14.59	0.19	0.22	0.47			67.20
Total	1193.75	240.07	145.73	55.33	1778.33	484.07	296.33	66.14	296.66	16.10	793.25	2.68	42.73	33.88		35.80	5480.86

Table G.3: Product line quantification, parts ≤20kg

ALL PARTS NUMBER <= 20kg																	
Routing/Endbuffer	910PL	910PR	920PL	920PR	930PLS	930PLC	930PRS	930PRC	940PLC	940PRC	940M	950M	960M	9++PL	9++PR	9++SM	Total
C	207	10510	263	1768	84		526				1463	308	568	66		2103	17866
C-B/T																	
C-B/T-F																	
C-B/T-G																	
C-B/T-G-Fl																	
C-F									56								56
C-F-G								410		650							1060
C-G	1452	8121	319				6430				33486	380	7780	602		105	58675
C-G-Fl											1182		234				1416
C-Fl	14	280		105			28				385	7	7				826
Total	1673	18911	582	1873	84		6984	410	56	650	36516	695	8589	668		2208	79899

ALL PARTS WEIGHT <= 20kg in tons																	
Routing/Endbuffer	910PL	910PR	920PL	920PR	930PLS	930PLC	930PRS	930PRC	940PLC	940PRC	940M	950M	960M	9++PL	9++PR	9++SM	Total
C	1.95	72.28	2.93	12.74	0.73		3.47				9.20	0.56	3.42	0.40		6.14	113.82
C-B/T																	
C-B/T-F																	
C-B/T-G																	
C-B/T-G-Fl																	
C-F									0.72								0.72
C-F-G								5.73		4.28							10.01
C-G	12.77	53.85	3.16				57.94				112.41	1.02	15.50	3.96		0.80	261.41
C-G-Fl											14.22		3.04				17.27
C-Fl	0.02	1.21		0.64			0.07				4.63	0.02	0.07				6.65
Total	14.73	127.34	6.09	13.38	0.73		61.48	5.73	0.72	4.28	140.46	1.60	22.03	4.35		6.94	409.88

Table G.4: Product line quantification, parts >20kg

	ALL PARTS NUMBER > 20kg																
Routing/Endbuffer	910PL	910PR	920PL	920PR	930PLS	930PLC	930PRS	930PRC	940PLC	940PRC	940M	950M	960M	9++PL	9++PR	9++SM	Total
C	1332	1249	995	856	2114		7				1429	7	314	56		122	8481
C-B/T	14				42						7			21			84
C-B/T-F						35			7								42
C-B/T-G	84		7											28			119
C-B/T-G-Fl																	
C-F	30					712			890					14			1646
C-F-G								1381	35	268							1684
C-G	5246	1862	1191				4669				5138	30	108	94		91	18429
C-G-Fl	355										154		234				743
C-Fl	169	21		7							231	7	7	7			449
Total	7230	3132	2193	863	2156	747	4676	1381	932	268	6959	44	663	220		213	31677

	ALL PARTS WEIGHT > 20kg in tons																
Routing/Endbuffer	910PL	910PR	920PL	920PR	930PLS	930PLC	930PRS	930PRC	940PLC	940PRC	940M	950M	960M	970.00	980.00	990.00	Total
C	315.48	40.40	62.89	41.67	1731.70		0.89				293.19	0.17	10.99	7.89		23.37	2528.62
C-B/T	1.79				45.90						0.82			2.93			51.44
C-B/T-F						25.65			1.19								26.84
C-B/T-G	17.02		6.16											6.50			29.68
C-B/T-G-Fl																	
C-F	14.82					458.41			271.10					1.13			745.47
C-F-G								60.41	23.64	11.82							95.88
C-G	741.80	70.99	70.59				233.95				343.61	0.75	3.71	10.61		5.49	1481.50
C-G-Fl	39.92										5.22		5.85				50.99
C-Fl	48.20	1.34		0.28							9.96	0.17	0.15	0.47			60.56
Total	1179.02	112.73	139.64	41.95	1777.60	484.07	234.85	60.41	295.94	11.82	652.79	1.08	20.70	29.53		28.86	5070.98

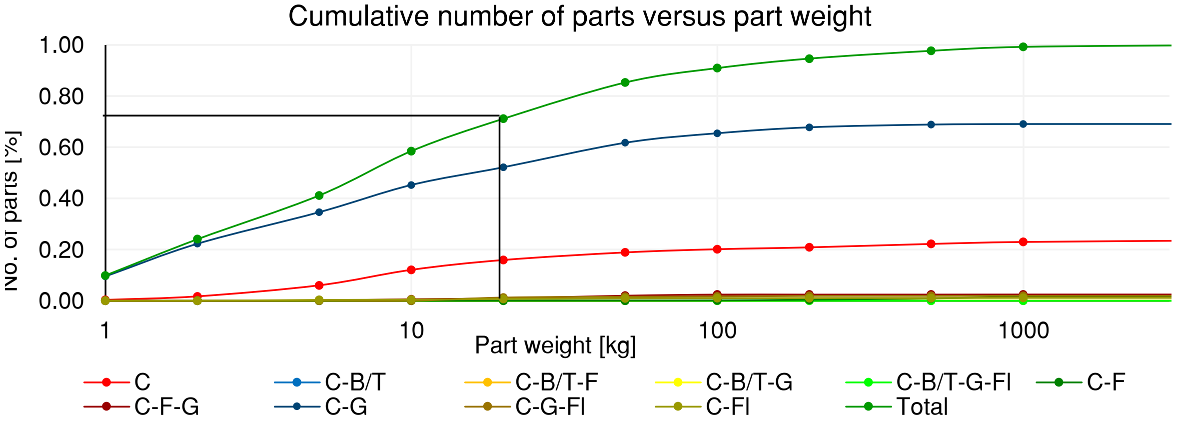


Figure G.1: Cumulative parts mass distribution - Flat bars cut from profile

The question whether flat bars can also be cut on the profile cutting line is discussed. In Table G.5 the cumulative number of profile lengths is presented. The division of the total cumulative length by the pace of the robot cutting line is observed that 740 hours of profile cutting is required. For this the current robot cutting line speed is used. Conclusively the profile robot cutting line is able to cut the flat bars as well, when operation 2 shifts a day. Working 2 shifts a day is common practise.

Table G.5: Flat bar cumulative length calculation

Ship	Profile type	Cumulative length per ship [m]	Cumulative length per year [m]
ASD	FB	911	10931
	HP	2266	27195
PSV	FB	903	5417
	HP	1649	9893
Total			53437

G.4. Customer demand batch definition

In Section 6.3.2 the ability to enable a one piece flow is discussed. There the customer demand batch definition is introduced. Here for each customer demand the amount of tons is presented. The colours of the data point related to different customer demand group, being in order: plate-sub-panels, t-beams, main panels, section-, block-, hull assembly and external outfitting demands.

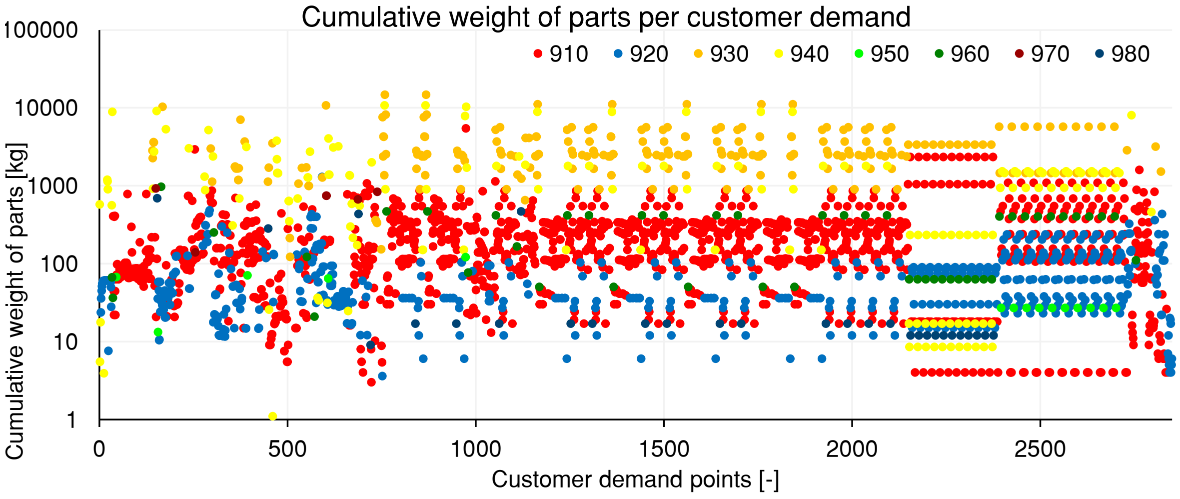


Figure G.2: Plot of cumulative weight of parts per customer demand

H

Scenario analysis results

Within this Appendix the detailed results of the future state scenario development, discussed in Chapter 7 to Chapter 10, are included. An overview of the structure is given.

- First, in Appendix H.1 the detailed results of the experiment performed in Section 7.1 are presented.
- In Appendix H.2 the detailed results concerning space utilisation and transport distances/moves are presented, per scenario.
- Besides, in Appendix H.3 the detailed investment build ups are enclosed, per scenario.
- In Appendix H.4 detailed throughput measures are included, concerning the annual station throughput, per scenario.
- Last some resource utilisation diagrams are included in Appendix H.5, of the different deployed resources, per scenario.

H.1. Cutting group batch size experiment results

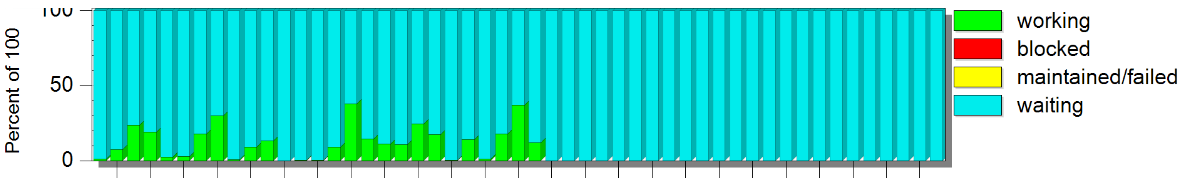
In Section 7.1 a cutting group batch size reduction experiment is performed. More containers are to be moved, resulting in more utilisation of the transport resources, which is most stringent for the transverse carriage because is required for all movements between the sorting space and part processing space and forming infeed buffer. This is underlined by the utilisation diagrams of the carriage presented in Figure H.1.

H.2. Space utilisation detailed results

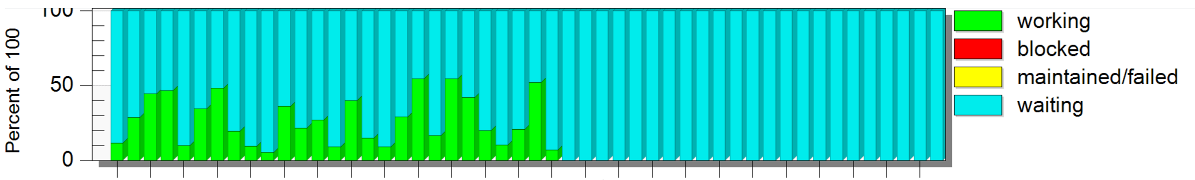
First some detailed results of the space requirement analysis are presented. Then the detailed results concerning transport distances are given.

H.2.1. Analysis of space requirement

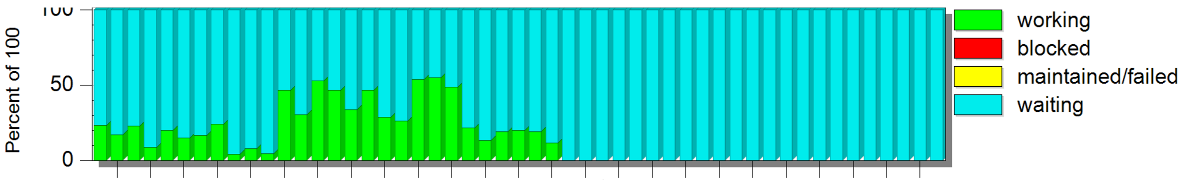
This Section presents the detailed relation between infeed, process and outfeed space. First the detailed results for first two scenarios is given, followed by the results of the third scenario.



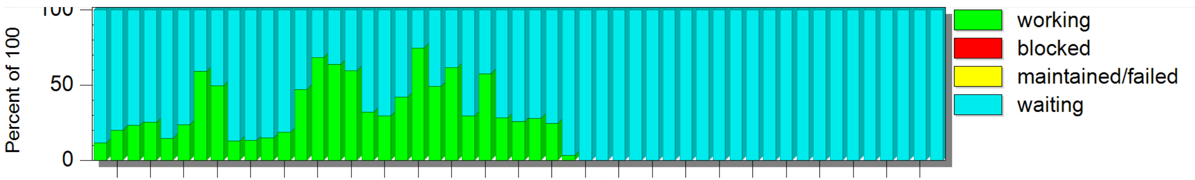
(a) Experiment cutting group batch size all plates



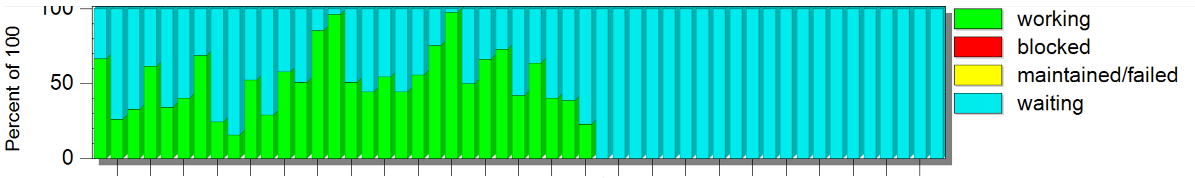
(b) Experiment cutting group batch size 40 plates



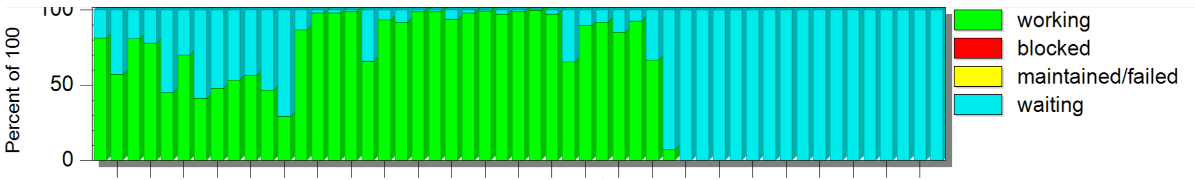
(c) Experiment cutting group batch size 30 plates



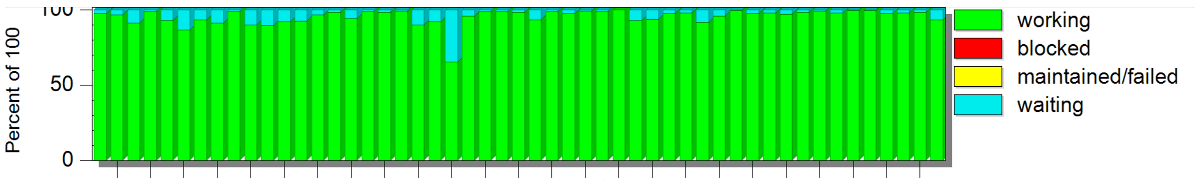
(d) Experiment cutting group batch size 20 plates



(e) Experiment cutting group batch size 10 plates



(f) Experiment cutting group batch size 5 plates



(g) Experiment cutting group batch size 2 plates

Figure H.1: Date based utilisation diagrams carriage

Scenario 1 & 2

In Section 8.1.1 the layout of scenario 1 (and 2) is described. Furthermore the area related KPI's are determined. In Table H.1 the detailed background figures are presented.
Particular attention is paid to the assignment of vacated space, which is presented as well. Between pre-processing and assembly workstations out/infeed buffers are presented. In the Table they are included as pre-processing outfeed buffers. Besides they are presented between brackets as assembly infeed buffers.

Table H.1: Overview space utilisation per work step scenario 1&2

Pre processing work stations	Infeed [m^2]	Process [m^2]	Outfeed [m^2]	Total [m^2]
Cutting station (plasma)	120	700	580	1780
Cutting station (oxy acetylene)	60	120	160	340
Cutting station (profiles)	-	200	220	420
Forming (plates)	120	390	320	830
Forming (profiles)	50	150	200	400
Grinding/flanging (profiles)		150		150
Grinding/flanging/tapering L2		400		400
Grinding/flanging/tapering L1	130	380	700	1210
Total	480	2490	2180	5530
Customer work stations				
Main panel assembly (line/classical)	(390)	4000		4000
Sub panel assembly (panels)	(100)	850		850
Sub panel assembly (t-beams)	(600)	300		300
Total	0	5150		5150
Total (cumulative)	480	7640	2180	10300

Scenario 3

Section 10.1.1 deals with the cascading layout design of the third scenario. Here the detailed area approximations are presented (Table H.2).

Table H.2: Overview space utilisation per work step scenario 3

Pre processing work stations	Infeed [m^2]	Process [m^2]	Outfeed [m^2]	Total [m^2]
Cutting station (plasma)	120	720	520	1550
Cutting station (oxy acetylene)	60	120	160	340
Cutting station (profiles)	-	200	220	420
Forming (plates)	110	350	350	810
Forming (profiles)	50	200	90	340
Grinding/flanging (profiles)		150		150
Grinding/flanging/tapering L3		350	100	450
Grinding/flanging/tapering L1		380	600	980
Total	340	2470	2040	5040
Customer work stations				0
Main panel assembly (line/classical)	(300)	4200		4200
Sub panel assembly (panels)	(100)	950		950
Sub panel assembly (t-beams)	(600)	300		300
Total	0	5450	0	5450
Total (cumulative)	340	7920	2040	10300

H.2.2. Analysis of transport distance

In this Section the detailed measures of the transport distances is given. The distances are based on product line level. The routine related differences are incorporated. A distinction in infeed, cut/sort intermediate transport, processing and outfeed process is made. The distinction between the intermediate transport and processing transport cannot always be clearly made. This is incorporated when assessing the data.

Scenario 1 & 2

Table H.3 provides a detailed overview of the transport distances per product line for scenario 1 (and 2), which are described in Section 8.1.2.

Table H.3: Overview transport distance per product line, scenario 1

Product line	Routine	Number [-]	Weight [-]	Infeed [m]	Cut. & Sort. [m]	Inter trans. [m]	Process. [m]	End trans. [m]	Total [m]
910PL	C	0.014	0.058	30	45	10	20	10	115
	C-G	0.061	0.141	30	45	10	25	10	120
	C-G-Fl	0.003	0.007	30	45	10	30	15	130
	C-FL	0.002	0.009	30	45	10	25	15	125
910PR	C-G	0.198	0.044	25	30	5	5	20	85
920PL	C	0.011	0.012	30	45	10	20	15	120
	C-G	0.014	0.015	30	45	10	25	15	125
920PR	C-G	0.025	0.01	25	30	5	5	50	115
930PLS	C	0.02	0.324	30	45	10	-	35	120
930PLC	C-F	0.007	0.088	30	45	30	25	5	135
930PRS	C	0.005	0.001	25	30	5	5	110	175
	C-G	0.1	0.053	25	30	5	5	110	175
930PRC	C-F-G	0.016	0.012	25	30	15	10	85	165
940PLC	C-F	0.009	0.054	30	45	30	25	50	180
940PRC	C-F-G	0.008	0.003	25	30	15	10	140	220
940M	C	0.026	0.055	30	45	10	-	50	135
	C-G	0.346	0.083	30	45	25	15	50	165
	C-G-Fl	0.012	0.004	30	45	30	15	50	170
	C-Fl	0.006	0.003	30	45	25	15	50	165
950M	C	0.003	0	30	45	10	-	50	135
	C-G	0.004	0	30	45	25	15	50	165
	C-Fl	0	0	30	45	25	15	50	165
960M	C	0.008	0.003	30	45	10	-	50	135
	C-G	0.071	0.004	30	45	25	15	50	165
	C-G-Fl	0.004	0.002	30	45	30	15	50	170
	C-Fl	0	0	30	45	25	15	50	165
970-990-980	C	0.03	0.013	30	45	-	-	90	165

Scenario 3

In Section 10.1.2 the KPI related to transport distances is discussed. Here the detailed results are presented per product line.

Table H.4: Overview transport distance per product line, scenario 3

Product line	Routine	Number [-]	Weight [-]	Infeed [m]	Cut. & Sort. [m]	Inter trans. [m]	Process. [m]	End trans. [m]	Total [m]
910PL	C	0.014	0.058	30	15	-	20	10	75
	C-G	0.061	0.141	30	15	-	25	10	85
	C-G-FI	0.003	0.007	30	15	-	35	10	85
	C-FL	0.002	0.009	30	15	-	30	10	85
910PR	C-G	0.198	0.044	25	30	5	5	40	105
920PL	C	0.011	0.012	30	20	-	20	15	85
	C-G	0.014	0.015	30	20	-	25	15	90
920PR	C-G	0.025	0.01	25	30	5	5	50	115
930PLS	C	0.02	0.324	30	20	-	-	20	70
930PLC	C-F	0.007	0.088	30	15	15	25	20	105
930PRS	C	0.005	0.001	25	30	5	5	60	125
	C-G	0.1	0.053	25	30	5	5	60	125
930PRC	C-F-G	0.016	0.012	25	30	15	30	30	130
940PLC	C-F	0.009	0.054	30	15	15	25	80	165
940PRC	C-F-G	0.008	0.003	25	30	15	30	100	200
940M	C	0.026	0.055	30	20	10	-	150	210
	C-G	0.346	0.083	30	20	10	20	150	230
	C-G-FI	0.012	0.004	30	20	10	35	150	245
	C-FI	0.006	0.003	30	20	10	25	150	235
950M	C	0.003	0	30	20	10	-	150	210
	C-G	0.004	0	30	20	10	20	150	230
	C-FI	0	0	30	20	10	25	150	235
960M	C	0.008	0.003	30	20	10	-	150	210
	C-G	0.071	0.004	30	20	10	20	150	230
	C-G-FI	0.004	0.002	30	20	10	35	150	245
	C-FI	0	0	30	20	10	25	150	235
970-990-980	C	0.03	0.013	30	20	-	-	120	170

Scenario outlook

In Section 12.3 the KPI related to transport distances is discussed. Here the detailed results are presented per product line.

Table H.5: Overview transport distance per product line, scenario outlook

Product line	Routine	Number [-]	Weight [-]	Infeed [m]	Cut. & Sort. [m]	Inter trans. [m]	Process. [m]	End trans. [m]	Total [m]
910PL	C	0.014	0.058	30	40	25	-	20	115
	C-G	0.061	0.141	30	40	25	20	10	125
	C-G-FI	0.003	0.007	30	40	25	30	15	140
	C-FL	0.002	0.009	30	40	25	25	15	135
910PR	C-G	0.198	0.044	25	30	5	5	20	85
920PL	C	0.011	0.012	30	40	25	-	30	125
	C-G	0.014	0.015	30	40	10	25	10	115
920PR	C-G	0.025	0.01	25	30	5	5	50	115
930PLS	C	0.02	0.324	30	45	-	10	30	115
930PLC	C-F	0.007	0.088	30	45	60	25	5	165
930PRS	C	0.005	0.001	25	30	5	5	110	175
	C-G	0.1	0.053	25	30	5	5	110	175
930PRC	C-F-G	0.016	0.012	25	30	15	10	85	165
940PLC	C-F	0.009	0.054	30	45	60	25	50	210
940PRC	C-F-G	0.008	0.003	25	30	15	10	140	220
940M	C	0.026	0.055	30	45	-	25	40	140
	C-G	0.346	0.083	30	45	25	25	40	165
	C-G-FI	0.012	0.004	30	45	25	30	40	170
	C-FI	0.006	0.003	30	45	25	25	40	165
950M	C	0.003	0	30	45	-	10	40	125
	C-G	0.004	0	30	45	25	25	40	165
	C-FI	0	0	30	45	25	25	40	165
960M	C	0.008	0.003	30	45	-	-	40	115
	C-G	0.071	0.004	30	45	25	25	40	165
	C-G-FI	0.004	0.002	30	45	25	30	40	170
	C-FI	0	0	30	45	25	25	40	165
970-990-980	C	0.03	0.013	30	45	25	-	40	140

H.2.3. Analysis of number of transports

In this Section the detailed measures of the number of transports is given. They are determined per product line and per routine. A distinction in infeed, cut/sort intermediate transport, processing and outfeed process is made.

Scenario 1 & 2

Table H.6 provides a detailed overview of the number of transports transport distances per product line for scenario 1 (and 2), which are described in Section 8.1.2.

Table H.6: Overview transport distance per product line, scenario 1

Product line	Routine	Number [-]	Weight [-]	Infeed [m]	Cut. & Sort. [m]	Inter trans. [m]	Process. [m]	End trans. [m]	Total [m]
910PL	C	0.014	0.06	1	1	1	1	1	5
	C-G	0.061	0.14	1	1	1	2	1	6
	C-G-FI	0.003	0.01	1	1	1	3	1	7
	C-FL	0.002	0.01	1	1	1	2	1	6
910PR	C-G	0.198	0.04	1	1	1	1	1	5
920PL	C	0.011	0.01	1	1	1	1	1	5
	C-G	0.014	0.01	1	1	1	2	1	6
920PR	C-G	0.025	0.01	1	1	1	1	1	5
930PLS	C	0.02	0.32	1	1	1	-	1	4
930PLC	C-F	0.007	0.09	1	1	1	2	1	6
930PRS	C	0.005	0	1	1	1	1	1	5
	C-G	0.1	0.05	1	1	1	1	1	5
930PRC	C-F-G	0.016	0.01	1	1	1	3	1	7
940PLC	C-F	0.009	0.05	1	1	1	2	2	7
940PRC	C-F-G	0.008	0	1	1	1	3	1	7
940M	C	0.026	0.06	1	1	-	1	2	5
	C-G	0.346	0.08	1	1	1	1	2	6
	C-G-FI	0.012	0	1	1	1	2	2	7
	C-FI	0.006	0	1	1	1	1	2	6
950M	C	0.003	0	1	1	-	1	2	5
	C-G	0.004	0	1	1	1	1	2	6
	C-FI	0	0	1	1	1	1	2	6
960M	C	0.008	0	1	1	-	-	2	4
	C-G	0.071	0	1	1	1	1	2	6
	C-G-FI	0.004	0	1	1	1	2	2	7
	C-FI	0	0	1	1	1	1	2	6
970-990-980	C	0.03	0.01	1	1	-	-	2	4

Scenario 3

In Section 10.1.2 the KPI related to the number of transports is discussed. Here the detailed results are presented per product line and routine.

Table H.7: Overview transport distance per product line, scenario 3

Product line	Routine	Number [-]	Weight [-]	Infeed [m]	Cut. & Sort. [m]	Inter trans. [m]	Process. [m]	End trans. [m]	Total [m]
910PL	C	0.014	0.06	1	1	-	1	1	4
	C-G	0.061	0.14	1	1	-	2	1	5
	C-G-FI	0.003	0.01	1	1	-	3	1	6
	C-FL	0.002	0.01	1	1	-	2	1	5
910PR	C-G	0.198	0.04	1	1	1	1	1	5
920PL	C	0.011	0.01	1	1	-	1	1	4
	C-G	0.014	0.01	1	1	-	2	1	5
920PR	C-G	0.025	0.01	1	1	1	1	1	5
930PLS	C	0.02	0.32	1	1	-	-	1	3
930PLC	C-F	0.007	0.09	1	1	1	2	1	6
930PRS	C	0.005	0	1	1	1	1	1	5
	C-G	0.1	0.05	1	1	1	1	1	5
930PRC	C-F-G	0.016	0.01	1	1	1	3	1	7
940PLC	C-F	0.009	0.05	1	1	1	2	2	7
940PRC	C-F-G	0.008	0	1	1	1	2	2	7
940M	C	0.026	0.06	1	1	1	-	1	4
	C-G	0.346	0.08	1	1	1	3	1	7
	C-G-FI	0.012	0	1	1	1	5	1	9
	C-FI	0.006	0	1	1	1	4	1	8
950M	C	0.003	0	1	1	1	-	2	5
	C-G	0.004	0	1	1	1	1	2	6
	C-FI	0	0	1	1	1	1	2	6
960M	C	0.008	0	1	1	1	-	2	5
	C-G	0.071	0	1	1	1	1	2	6
	C-G-FI	0.004	0	1	1	1	2	2	7
	C-FI	0	0	1	1	1	1	2	6
970-990-980	C	0.03	0.01	1	1	-	-	1	3

Scenario outlook

In Section 12.3 the KPI related to the number of transports is discussed. Here the detailed results are presented per product line and routine.

Table H.8: Overview transport distance per product line, scenario outlook

Product line	Routine	Number [-]	Weight [-]	Infeed [m]	Cut. & Sort. [m]	Inter trans. [m]	Process. [m]	End trans. [m]	Total [m]
910PL	C	0.014	0.06	1	1	-	-	1	3
	C-G	0.061	0.14	1	1	-	2	1	5
	C-G-FI	0.003	0.01	1	1	-	3	1	6
	C-FL	0.002	0.01	1	1	-	2	1	5
910PR	C-G	0.198	0.04	1	1	1	1	1	5
920PL	C	0.011	0.01	1	1	-	-	1	3
	C-G	0.014	0.01	1	1	1	2	1	6
920PR	C-G	0.025	0.01	1	1	1	1	1	5
930PLS	C	0.02	0.32	1	1	-	-	1	3
930PLC	C-F	0.007	0.09	1	1	-	2	1	5
930PRS	C	0.005	0	1	1	1	1	1	5
	C-G	0.1	0.05	1	1	1	1	1	5
930PRC	C-F-G	0.016	0.01	1	1	1	3	1	7
940PLC	C-F	0.009	0.05	1	1	-	2	2	6
940PRC	C-F-G	0.008	0	1	1	1	3	1	7
940M	C	0.026	0.06	1	1	-	-	2	4
	C-G	0.346	0.08	1	1	-	1	2	5
	C-G-FI	0.012	0	1	1	-	2	2	6
	C-FI	0.006	0	1	1	-	1	2	5
950M	C	0.003	0	1	1	-	1	2	5
	C-G	0.004	0	1	1	-	1	2	5
	C-FI	0	0	1	1	-	1	2	5
960M	C	0.008	0	1	1	-	-	2	4
	C-G	0.071	0	1	1	-	1	2	5
	C-G-FI	0.004	0	1	1	-	2	2	6
	C-FI	0	0	1	1	-	1	2	5
970-990-980	C	0.03	0.01	1	1	-	-	2	4

H.3. Investment figures

In Section 6.4 investment figures are discussed. In Table 6.2 the investments in resources is listed. Only indicative measures are presented, based on educated approximations originating from contact will resource suppliers. In the Paragraphs below the scenario specific overviews are provided, which are discussed in Section 8.1.3, Section 9.1.3 and Section 10.1.1.

Scenario 1

Table H.9: Overview investment figures scenario 1

Item	Number [-]	Investment [k€]	Total [k€]
Cutting machine	4	≈ 500 [54]	2000
Working crane	2	≈ 200 [43]	400
Transverse conveyors	2	≈ 20 [74]	40
Longitudinal conveyors	3	≈ 20 [74]	60
Hand tool equipment / Workbenches	-	-	-
Total			2500

Scenario 2

Table H.10: Overview investment figures scenario 2

Item	Number [-]	Investment [k€]	Total [k€]
Cutting machine	4	≈ 500	2000
Transverse transport crane	1	≈ 500	500
Working crane	2	≈ 200	400
Transverse conveyors	2	≈ 20	40
Longitudinal conveyors	3	≈ 20	60
Hand tool equipment / Workbenches	-	-	-
Total			2500

Scenario 3

Table H.11: Overview investment figures scenario 3

Item	Number [-]	Investment [k€]	Total [k€]
Cutting machine	4	≈ 500	2000
Working crane	2	≈ 200	400
Transverse conveyors	1	≈ 20	20
Forming roller press replacement	1	≈ 100	100
Hand tool equipment / Workbenches	-	-	-
Total			2520

H.4. Throughput detailed results

In the Sections below the annual throughput per station is presented for the three scenarios in subsequent order.

H.4.1. Annual throughput break point definition

In order to study the performance of the individual work stations their inputs and outputs are defined. A description is given below. The phase durations are measured by the following time breakpoints: For clarity the processes are linked to the layout in Section 8.1 (Figure 8.2).

	Process	Layout	Start time definition	End time definition
1.	Cutting sorting	Red area in lane 2 and lane 3	Plates enter facility on conveyor	• Parts for sub panel assembly: parts enter transverse conveyor. • Parts for forming: parts enter longitudinal conveyor. • Main panel parts: customer batch is collected and ready for assembly. • Other parts: customer batch is collected and left sorting space.
2.	Forming	Yellow area in lane 2	Parts enter on longitudinal conveyor	Customer demand batch is collected (and left sorting space)
3.	Grinding/ tapering/ bevelling/ flanging cell L1	Green area in lane 1	Parts enter on transverse conveyor	Customer demand batch is collected (and left outfeed buffer)
4.	Grinding/ tapering/ bevelling/ flanging cell L2	Green area in lane 2	Parts enter work benches	Parts enter end buffer containers on the cutting sorting space.

H.4.2. Annual throughput results

The station throughput is presented for all work stations and scenarios.

Scenario 1

Section 8.3.2 describes the annual throughput measures of the first scenario. In Figure H.2 to Figure H.4 the annual throughput of different stations is plot. Those Figures provide background of the developed KPI's.

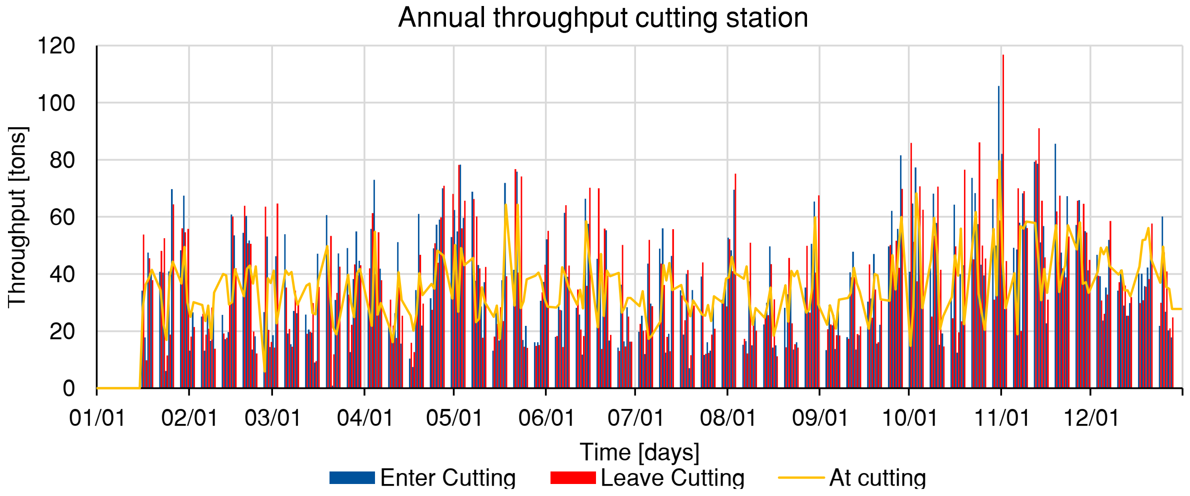


Figure H.2: Annual throughput cutting station, scenario 1

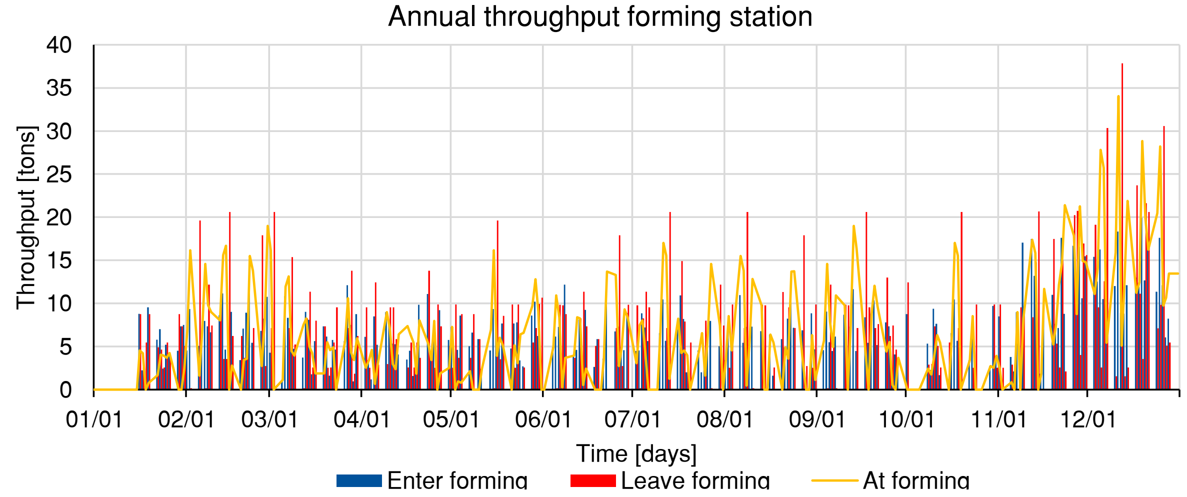


Figure H.3: Annual throughput forming station, scenario 1

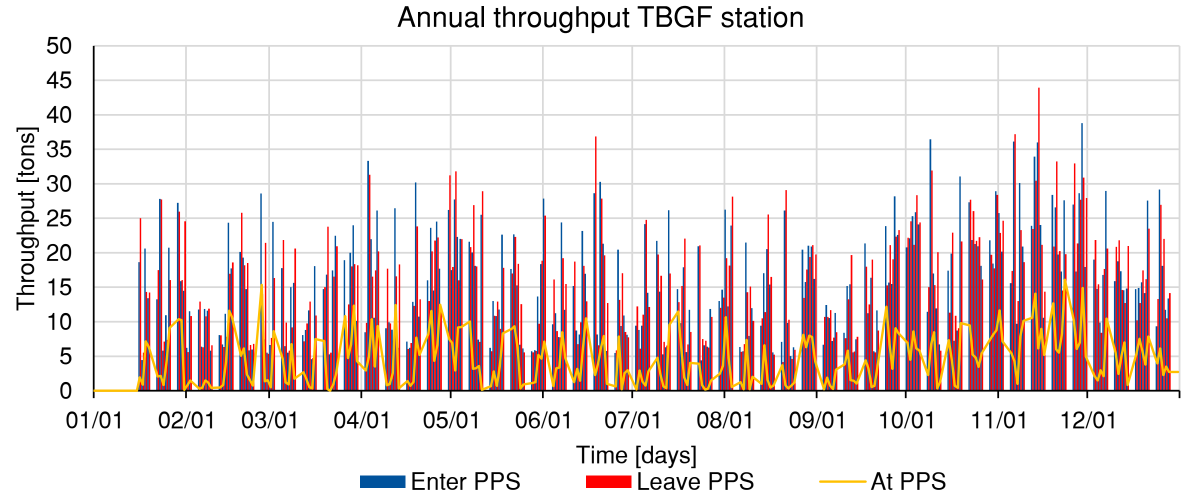


Figure H.4: Annual throughput TBGF station, scenario 1

Scenario 2

In Section 9.3.2 the annual throughput results of scenario 2 are described. Furthermore occupancy rate and variability KPI's are defined. In Figure H.5 to Figure H.8 the throughput is plot per station.

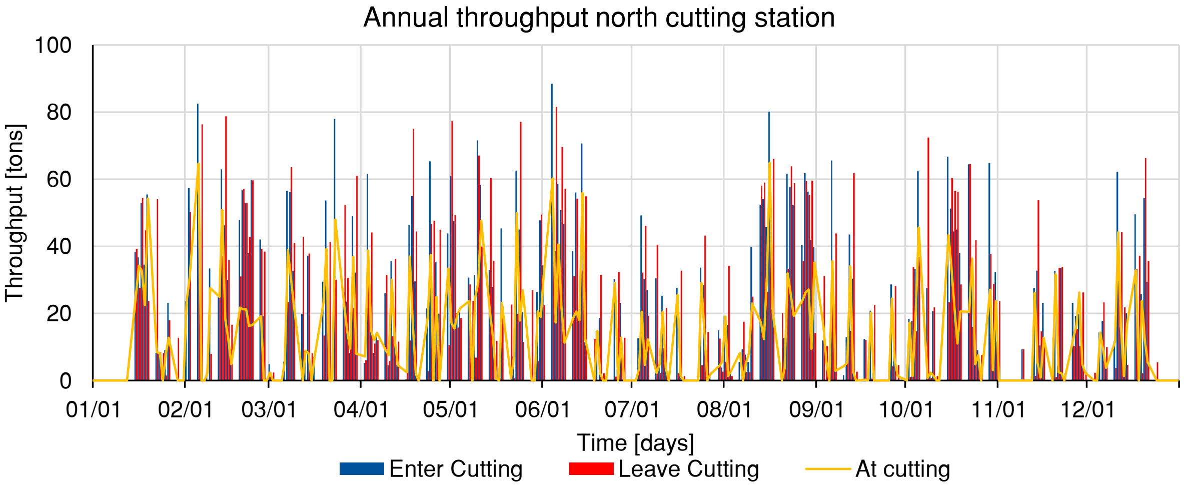


Figure H.5: Annual throughput north cutting station, scenario 2

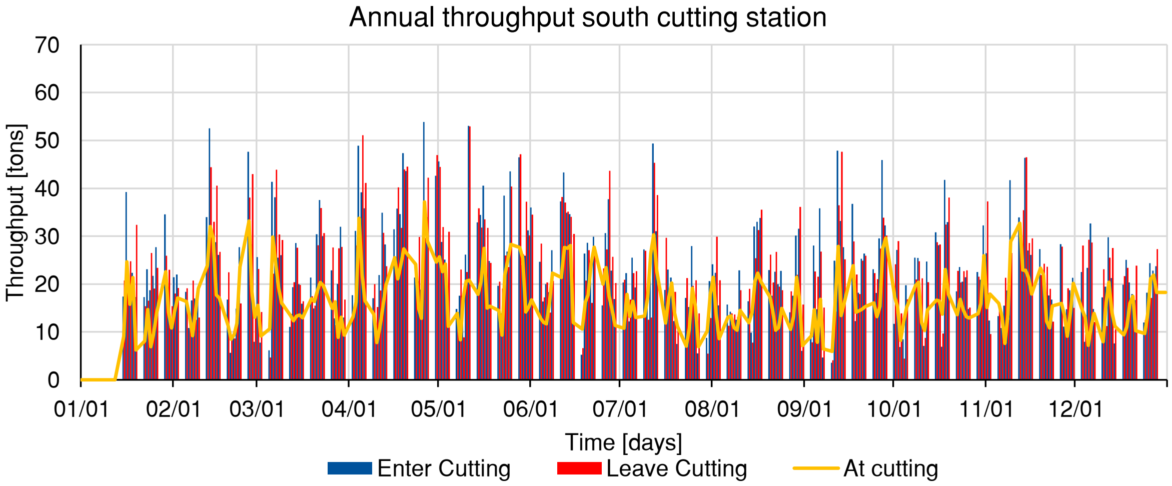


Figure H.6: Annual throughput south cutting station, scenario 2

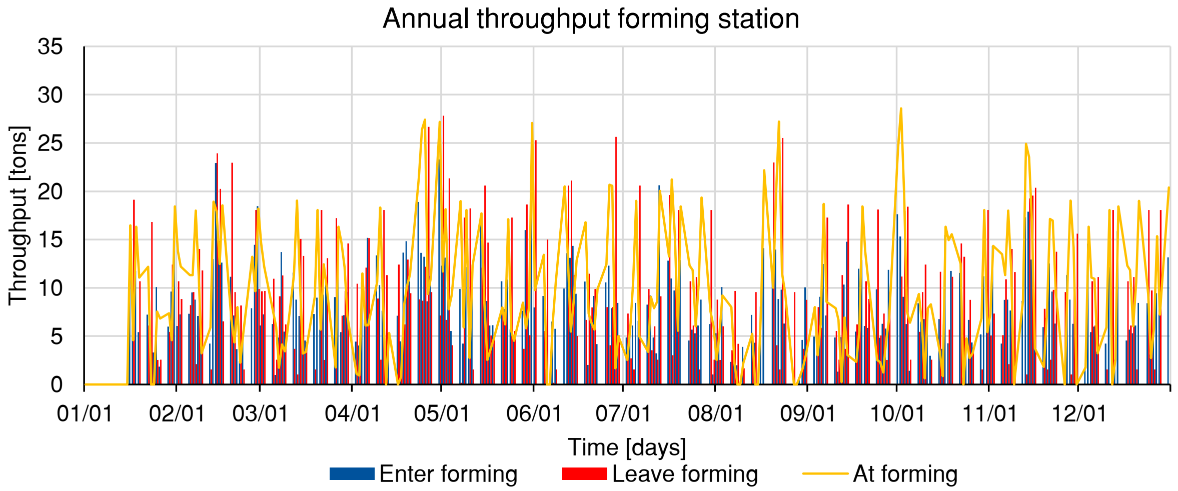


Figure H.7: Annual throughput forming station, scenario 2

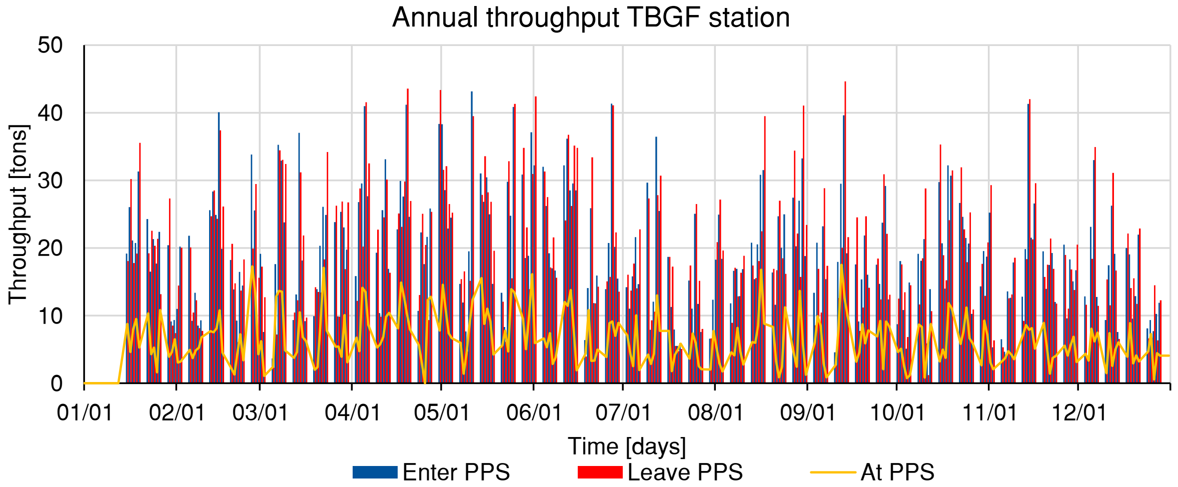


Figure H.8: Annual throughput TBGF station, scenario 2

Scenario 3

Section 10.3.2 deals with the annual throughput measures of scenario 3. In Figure H.9 to Figure H.12 the background plots of the occupancy KPI's are included.

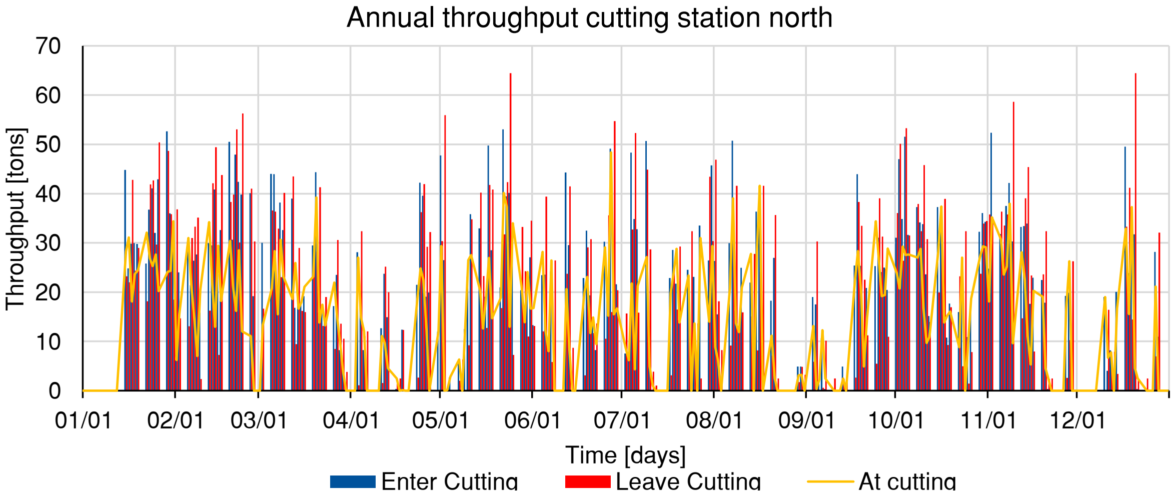


Figure H.9: Annual throughput cutting station north, scenario 3

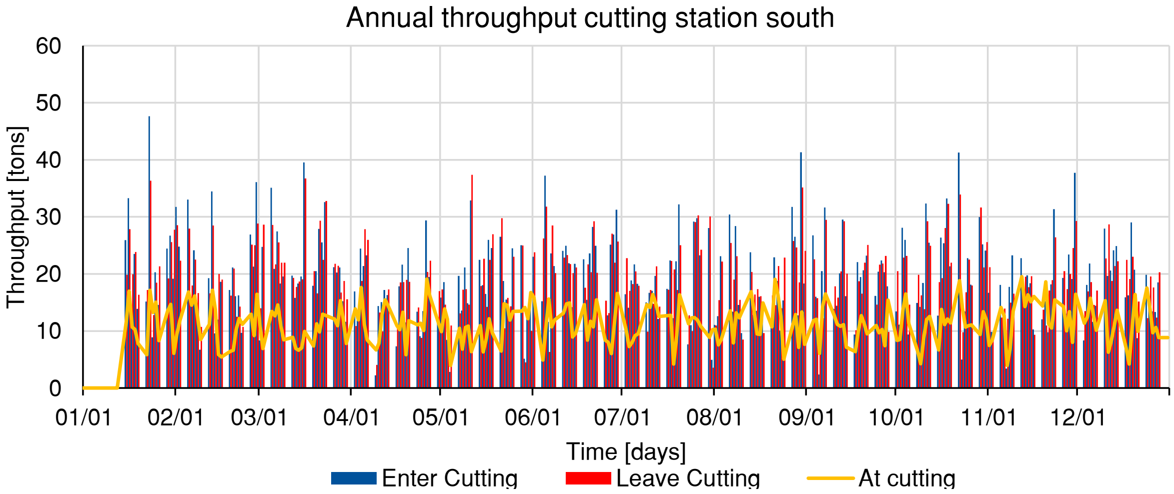


Figure H.10: Annual throughput cutting station south, scenario 3

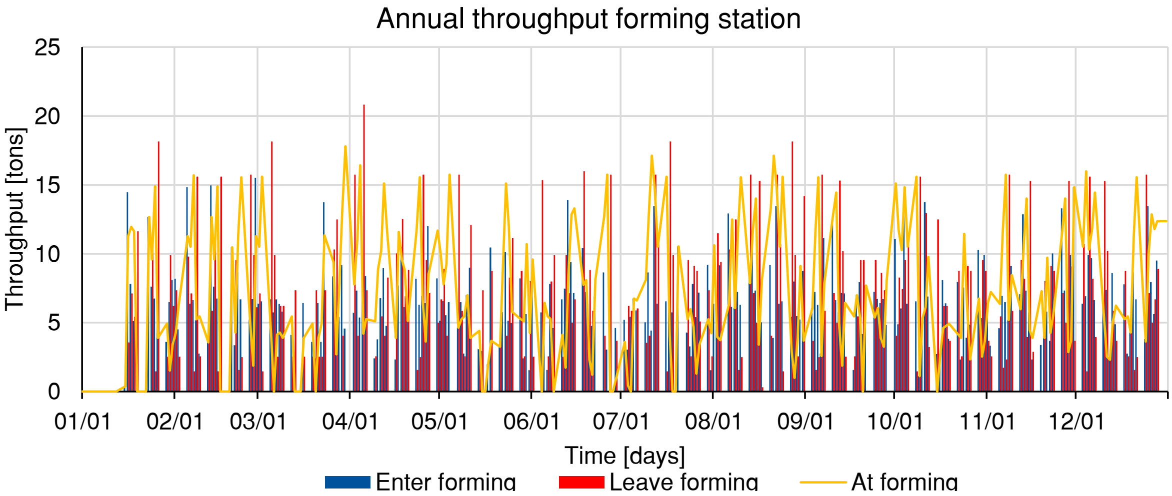


Figure H.11: Annual throughput forming station, scenario 3

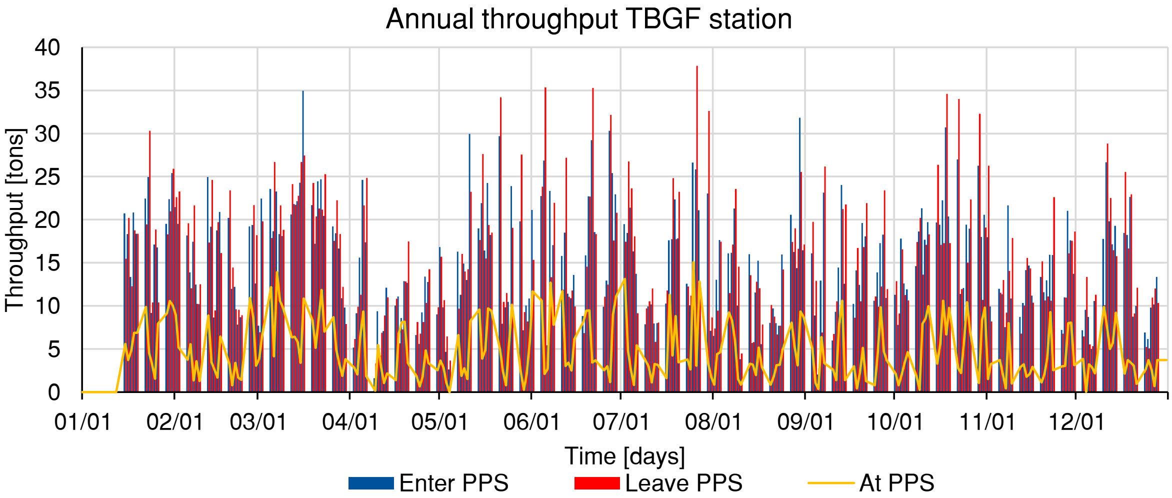
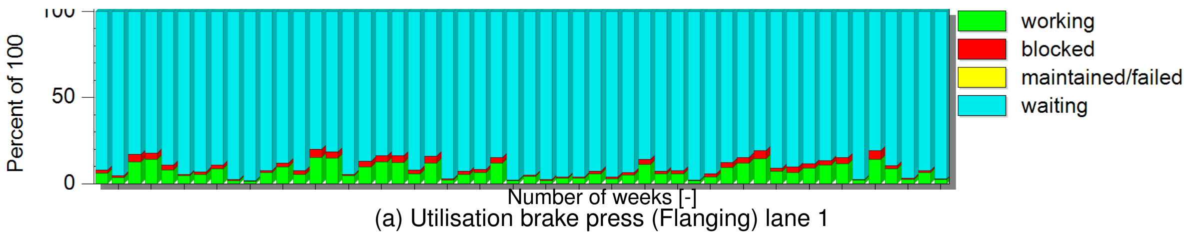


Figure H.12: Annual throughput TBGF station, scenario 3

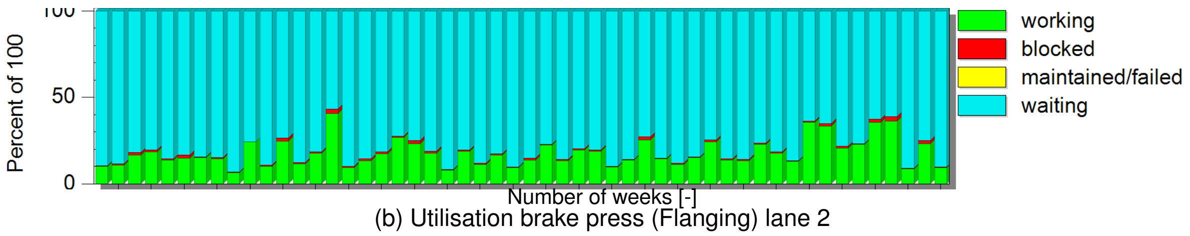
H.5. Resource utilisation diagrams

Scenario 1

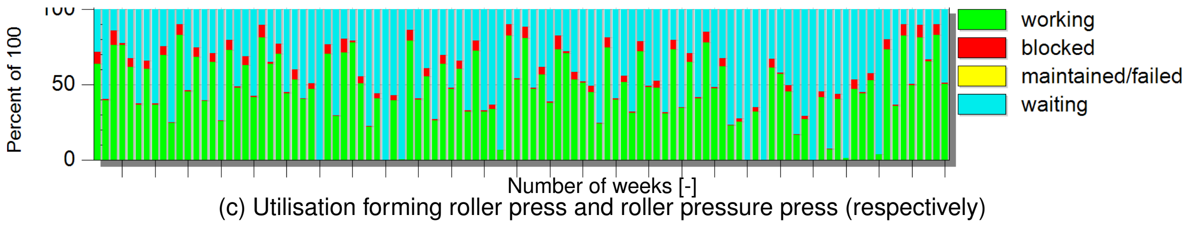
In Section 8.3.3 the utilisation diagrams of the resources in scenario 1 are assessed. In this Appendix the utilisation diagrams of the flanging and forming resources are presented.



(a) Utilisation brake press (Flanging) lane 1



(b) Utilisation brake press (Flanging) lane 2

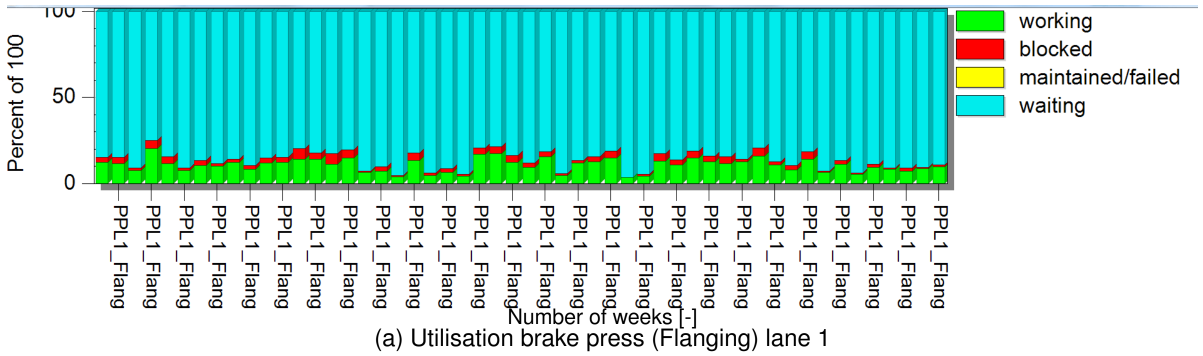


(c) Utilisation forming roller press and roller pressure press (respectively)

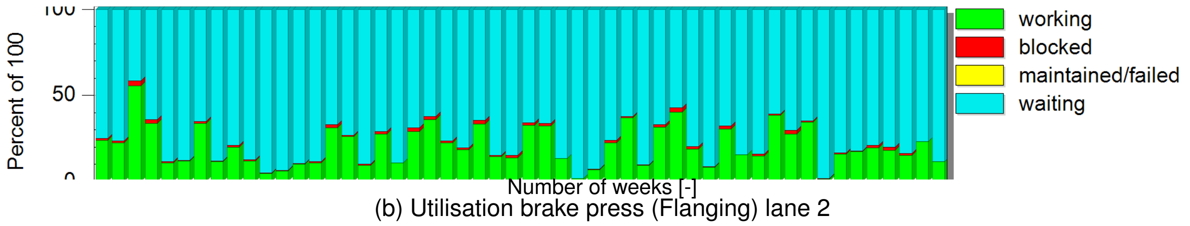
Figure H.13: Date based utilisation diagrams scenario 1

Scenario 2

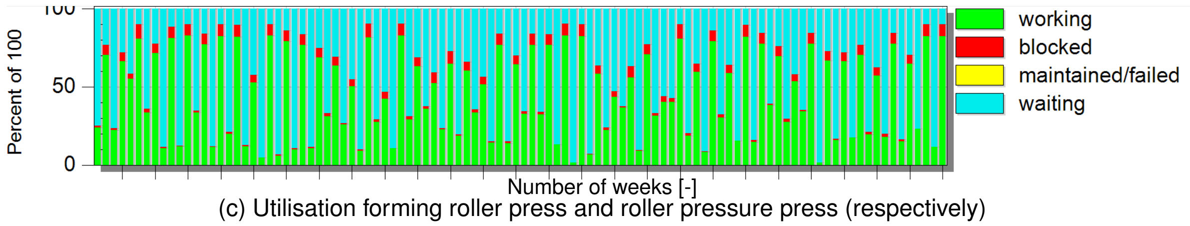
In Section 9.3.3 the resource utilisation diagrams of scenario 2 are introduced. Here the results of the flanging and forming resources are plot.



(a) Utilisation brake press (Flanging) lane 1



(b) Utilisation brake press (Flanging) lane 2

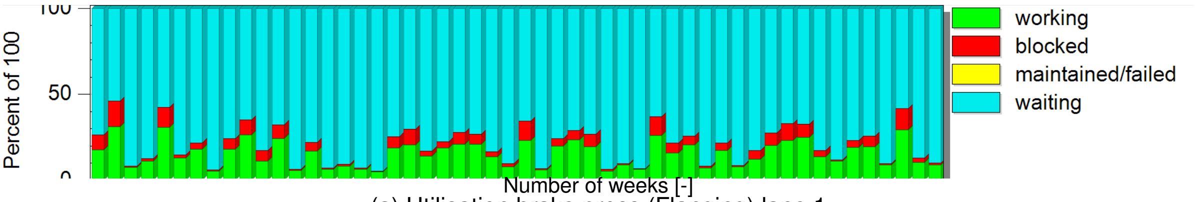


(c) Utilisation forming roller press and roller pressure press (respectively)

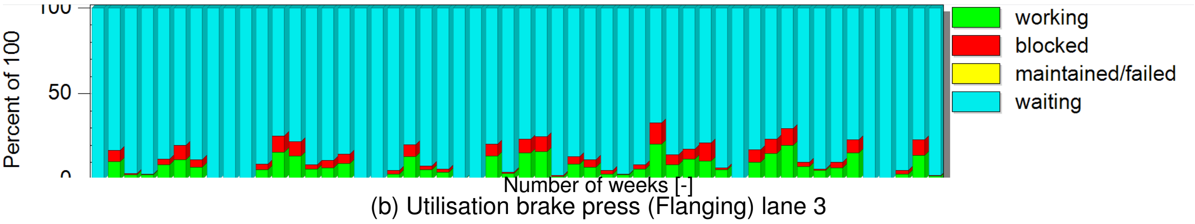
Figure H.14: Date based utilisation diagrams scenario 2

Scenario 3

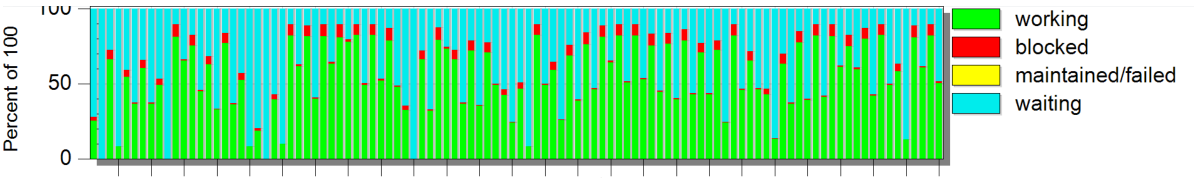
Section 10.3.3 deals with the resource utilisation diagrams. In Figure H.15 the diagrams of the flanging and forming resources are included.



(a) Utilisation brake press (Flanging) lane 1



(b) Utilisation brake press (Flanging) lane 3



(c) Utilisation forming roller press and roller pressure press (respectively)

Figure H.15: Date based utilisation diagrams scenario 3