
ANALYSIS AND OPTIMIZATION OF A MACHINED STEEL KIT MANUFACTURING PROCESS

CHRISTOPHER ROSE



MAY 3, 2013

Thesis for the degree of MSc in Marine Technology in the specialization of *Ship Design, Production, and Operation*

Analysis and Optimization of a Machined Steel Kit Manufacturing Process

By

Christopher Daniel Rose

Performed at

IHC Metalix

This thesis (SDPO.13.009.m) is classified as confidential in accordance with the general conditions for projects performed by the TUDelft.

May 3rd, 2013

Company supervisors

Responsible supervisor: Drs. ing. H.P.T Jellema

E-mail: h.jellema@ihcmerwede.com

Daily supervisor: Ir. R. Voorend

E-mail: r.voorend@ihcmerwede.com

Thesis exam committee

Chair/Responsible Professor: Prof.Ir. J.J. Hopman

Staff Member: Ir. J.F.J. Pruyn

Staff Member: Dr. W.W.A. Beelaerts van Blokland

Company Member: Drs.ing. H.P.T Jellema

Company Member: Ir. R. Voorend

Author Details

Studynumber: 4205189

Author contact e-mail: tophi.rose@gmail.com

ABSTRACT

IHC Metalix, a producer of machined steel kits for the shipbuilding industry, is currently in the process of improving production efficiency by modifying an existing crane as well as by installing two additional cranes, a pallet conveyor, and a pallet storage rack. The exact effects of these improvements on the production process have not been quantified. Furthermore, the influences of the order properties on the production process not known. The goal of this project is to analyze the effect of the process upgrades and order properties on the production process. This project also aims to generate and test the effect of additional process improvements.

Different order portfolios were created to represent the current order book of IHC Metalix and possible changes in the order book in the next few years. The influences of these order portfolios on the production process were determined using a sub-process capacity calculation and simulation model. The simulation model was also used to implement and test further improvements to the process.

This study found that the process improvements installed in the past year should increase production capacity by approximately 25%. The plate cutting machines were found to be the process bottleneck for all of the order portfolios. Large ship types with simple structures (such as pipelaying vessels and construction projects) have a positive effect on the production capacity. Small vessels with complex structures (such as yachts, tugs, and inland cruise vessels) reduced the total production capacity. Coasters and dredgers were found to have little effect on the total production capacity.

To improve the production process, it is recommended that two large part finishing tables are removed to make space for two additional flatrack positions. The printing algorithm of the vector plotters mounted to the cutting machines should also be improved as much as possible. If additional production capacity is required, a separate plate printer could also be installed. These improvements can increase the production capacity up to 18%.

PREFACE

The following report describes my master's thesis work, which is the final part of my master's study in Maritime Technology at TU Delft. This project was completed in cooperation with IHC Metalix. I would like to thank IHC Metalix for giving me the opportunity to complete my graduation project. The committee supervising this project consisted of the following people:

Ir. J.F.J. Pruyn
Drs. ing. H.P.T. Jellema
Ir. R. Voorend

I would like to thank them for their advice and enthusiasm. I would also like to thank my friends and family for their support while I worked on this project.

Christopher Rose

TABLE OF CONTENTS

1	INTRODUCTION	1
2	BACKGROUND.....	2
2.1	EUROPEAN SHIPBUILDING INDUSTRY	2
2.2	IHC METALIX	2
3	PROBLEM STATEMENT, OBJECTIVES, AND SCOPE	4
3.1	CONTEXT	4
3.2	RESEARCH QUESTION.....	4
3.3	SCOPE	5
4	SYSTEM DESCRIPTION	6
4.1	DESCRIPTION OF PRODUCTION PROCESS.....	6
4.2	DESCRIPTION OF ORDER PROPERTIES	12
4.3	ORDER PORTFOLIOS.....	21
5	PRELIMINARY PROCESS ANALYSIS.....	24
5.1	OVERVIEW	24
5.2	ANALYSIS INPUTS	25
5.3	DESCRIPTION OF ANALYSIS	29
5.4	RESULTS	31
5.5	WEAKNESSES OF THIS ANALYSIS	40
6	SIMULATION MODEL	43
6.1	BACKGROUND.....	43
6.2	SYSTEM MODELLED.....	43
6.3	SOFTWARE USED	44
6.4	DESCRIPTION.....	44
6.5	VERIFICATION AND VALIDATION.....	46
7	RESULTS	55
7.1	SHIP TYPE CHARACTERISTICS	55
7.2	ORDER PORTFOLIOS.....	58
7.3	PROCESS IMPROVEMENTS.....	67
7.4	FACTORS WHICH INFLUENCE PROCESS PERFORMANCE	77
8	CONCLUSIONS.....	82

9	RECOMMENDATIONS.....	85
9.1	ECONOMIC ANALYSIS	85
9.2	MARKET ANALYSIS.....	85
9.3	EXPAND CURRENT SIMULATION	85
10	REFERENCES	86
11	APPENDICES	90
11.1	SUB-PROCESS CHARACTERISTICS	90
11.2	SECTION INDEPENDENT PROPERTIES	94
11.3	CONFIDENCE INTERVALS FOR PRELIMINARY PROCESS CAPACITY	100
11.4	PRELIMINARY PROCESS ANALYSIS RESULTS	101
11.5	DESCRIPTION OF SIMULATION	106
11.6	PROCESS FLOW DIAGRAM USED FOR SIMULATIONS MODEL.....	122
11.7	DATA COLLECTION PROCEDURE	127
11.8	SAMPLE TRACE VERIFICATION OUTPUT	128

LIST OF FIGURES

Figure 4-1: Loaded Flatrack at IHC Metalix	6
Figure 4-2: Overview of Old Process at IHC Metalix	7
Figure 4-3: Process Flow Diagram Old Process at IHC Metalix.....	8
Figure 4-4: Overview of New Process at IHC Metalix	10
Figure 4-5: Process Flow Diagram New Process at IHC Metalix	11
Figure 4-6: Diagram of TSHD Dredging Seafloor [9].....	13
Figure 4-7: Diagram of CSD Dredging Seafloor [9]	14
Figure 4-8: <i>Beaver 50</i> Built by IHC Beaver Dredgers [10]	14
Figure 4-9: Backhoe Dredger <i>Ijzeren Hein</i> [9].....	15
Figure 4-10: Combi Coaster <i>Aldebran</i> [11].....	15
Figure 4-11: OSV <i>Toisa Polaris</i> [12].....	16
Figure 4-12: Pipelaying Vessel <i>Seven Pacific</i> [12].....	17
Figure 4-13: Tugboat Pushing Larger Vessel [15]	17
Figure 4-14: Inland Cruise Vessel <i>S.S. Antoinette</i> [17]	18
Figure 4-15: Superyacht <i>Imagine</i> at Sea [18].....	19
Figure 4-16: Section Type Definitions.....	20
Figure 5-1: Order History by Weight from October 2011 to October 2012	22
Figure 5-2: Base Portfolio	23
Figure 6-1: Relationship of Production Data and PPA	24
Figure 6-2: Overview of Preliminary Process Analysis.....	25
Figure 6-3: Achieved and Calculated Production Capacity (Oct. 2011 – Oct. 2012).....	32
Figure 6-4: Preliminary Production Capacity Distribution, Cutter Suction Dredger, Non-Grinded.....	33
Figure 6-5: Preliminary Bottleneck Location, Large Beaver Dredgers	34
Figure 6-6: Influence of Ship Type on Production Capacity, Old Process, Non-Grinded.....	35
Figure 5-7: Influence of Section Type on Production Capacity, Old Process, Non-Grinded .	36
Figure 6-8: Absolute Production Increase Due to New Process Upgrades, Non-Grinded	37
Figure 6-9: Relative Production Increase Due to New Process Upgrades	38
Figure 6-10: Production Increase Due to New Process Upgrades for Base Portfolio	39
Figure 6-11: Absolute Production Decrease Due to Grinding, Old Process	39
Figure 6-12: Relative Production Decrease Due to Grinding	40
Figure 5-13: Production Capacities for Sample Ship Type.....	42
Figure 6-13: Relationship between Production Data, PPA, and Simulation Model.....	42
Figure 7-1: High Level Operation of Simulation Model.....	45
Figure 7-2: Simplified Version of the Modelling Process [35]	46
Figure 7-3: Results of Mock Uniform Sections.....	49
Figure 7-4: Operational Validation of Profile Cutting Sub-Process.....	50
Figure 6-5: Operational Validation of Ship Types	52
Figure 6-6: Effect of Number of Simulation Runs of Production Capacity of TSHDs	53
Figure 7-7: Summary of Operational Validation.....	54
Figure 8-1: Influence of Ship Type of Production Capacity	56

Figure 7-2: Effect of Number of Simulation Runs on Production Capacity of Base Portfolio	59
Figure 8-2: Effect of Order Portfolio 1, Grinded Sections	60
Figure 8-3: Effect of Order Portfolio 2, Dredging Orders	61
Figure 8-4: Effect of Order Portfolio 3, Offshore Orders	63
Figure 8-5: Effect of Order Portfolio 4, Shipping Vessel Orders	64
Figure 8-6: Effect of Order Portfolio 5, Luxury Vessel Orders	65
Figure 8-7: Effect of Order Portfolio 6, Construction Orders	66
Figure 8-8: Effect of Additional Flatrack Positions	69
Figure 7-10: Effect of Combining Flatracks	70
Figure 7-11: Effect of Increasing Printing Algorithm.....	72
Figure 8-11: Effect of Separate Plate Printers	74
Figure 8-12: Effect of Operating the Plate Process for Three Shifts	75
Figure 8-13: Influence of Part Size on Production Capacity.....	78
Figure 8-14: Influence of Plate Thickness on Production Capacity	79
Figure 8-15: Influence of Percent of Profiles on Production Capacity	79
Figure 8-16: Influence of Bottleneck Utilization on Production Capacity	80
Figure 8-17: Influence of Required Plate 3-D Forming on Production Capacity.....	81

LIST OF TABLES

Table 6-1: Summary of Sub-Process Characteristics.....	26
Table 6-2: Summary of Section Independent Properties	27
Table 6-3: Summary of Sections Types Examined.....	28
Table 6-4: Capacities for Resources, from Calibration.....	30
Table 6-5: Capacities for Resources set to Capacity of 3-D Forming	30
Table 6-6: Achieved and Calculated Production Capacity (Oct. 2011 – Oct. 2012).....	32
Table 7-1: Operational Validation of Ship Types.....	53
Table 8-1: Bottleneck Location of Ship Types.....	57
Table 8-2: Effect of Combining Flatracks on End Sorting Space	71
Table 8-3: Summary of Process Improvements.....	76

ABBREVIATIONS

BHD – Backhoe dredger

BD – Beaver dredger

CSD – Cutter suction dredger

OSV – Offshore support vessel

PPA – Preliminary process analysis

TSHD – Trailing suction hopper dredger

1 INTRODUCTION

The purpose of the following Master's thesis is to investigate the effect of order properties on the production characteristics of IHC Metalix's facilities in Kinderdijk. These facilities produce finished steel plate and profile parts mainly for the shipbuilding industry. This research also aims to generate and test possible improvements which could be implemented in the production process.

The report is composed of the following sections:

1. Background: This section describes the role of the production process of IHC Metalix in the shipbuilding industry.
2. Problem statement, objective, and scope: The main research question of this research project is contained in this section. This section also outlines the main factors limiting the scope of this project.
3. System description: This section describes the characteristics of the production process of IHC Metalix as well as the properties of the orders which are cut and finished by the process.
4. Preliminary process analysis: This section describes the methodology used and results obtained from a Microsoft Excel based capacity analysis of the production process.
5. Simulation model: A description of the simulation model used to analyze the process performance is included in this section. The simulation model section also contains the validation of the simulation.
6. Results: This section contains the characteristics of the production process which were obtained using the simulation model. This section also contains a description of various improvements which could be implemented to the production process. Estimations of the increase in production capacity are also included for each improvement.
7. Conclusions: This section contains a summary and analysis of the results obtained.
8. Recommendations: Suggestions for future work which could be done to expand and enhance the research presented in this report are presented in the recommendations section.

2 BACKGROUND

2.1 EUROPEAN SHIPBUILDING INDUSTRY

The European shipbuilding industry is a key component of the global transportation industry, which has strong economical and social importance. The industry is composed of approximately 150 large shipyards which directly employ around 120,000 people [1]. The European shipbuilding industry supplies vessels for the global shipping industry, which transports over 8 billion tons of cargo annually. This accounts for more than 90 percent of global trade [2].

Dutch and German shipyards are currently striving to improve their production processes by using process simulations. These yards aim to reduce delivery times and production costs while increasing product quality [3].

The shipbuilding process is composed of the following stages [4]:

1. Design and engineering
2. Procurement
3. Pre-fabrication
4. Assembly
5. Outfitting
6. Testing

This paper focuses on the process required to create machined steel kits, which lies within the pre-fabrication stage of the shipbuilding process. These kits are composed of both plate and profile parts and are assembled into vessel sections by shipyards.

2.2 IHC METALIX

IHC Metalix is a business unit of IHC Merwede, a Dutch shipyard which specializes in building dredging, mining, and pipelaying vessels. As a result of the company's strong focus on innovation, IHC Merwede is a global market leader in the production of efficient vessel designs [5].

IHC Metalix produces machined steel kits that are used to build ship sections. IHC Metalix not only produces steel kits for the dredging and offshore divisions of IHC Merwede, but also for various other shipyards and construction companies located in the Netherlands, Belgium, and northern Germany [6].

Like its parent company, IHC Metalix places a strong emphasis on innovation and process efficiency. As a result, the company is continuously searching for ways to improve its production process. Since 2006, IHC Metalix has been working towards rearranging its production process to increase production capacity, improve efficiency, and better serve the needs of its clients. This effort included creating a simulation model of the production process and implementing a new production philosophy [7][8].

Starting in 2012, IHC Metalix has also worked to improve its production process with a series of investments. These investments include additional cranes, transporters, and a pallet storage rack. These improvements allow the company to improve its sorting process. The

research presented in this report began prior to the installation of these improvements. Although the majority of the improvements were operational by the conclusion of this project, the research was ended before the production process of IHC Metalix was fully operational with these new investments. The final system studied in this report is the production process of IHC Metalix after these improvements have been installed.

Since the beginning of 2013, IHC Metalix has also obtained approval for an additional series of process improvements. These improvements include constructing an enclosed plate storage hall, an investigation into the profile process, and a designated expedition area. The effects of these upgrades on the production process of IHC Metalix were not considered in this report.

The production capacities and bottleneck locations which have been recorded by IHC Metalix in the past are no longer valid due to the changes implemented to the production process. Furthermore, the simulation model which was created of the production process in 2006 no longer accurately represents the production process. As a result, this project is part of an effort to understand the characteristics of the newly improved production process without needing to collect several years' worth of production data.

3 PROBLEM STATEMENT, OBJECTIVES, AND SCOPE

3.1 CONTEXT

This Master's thesis project was conducted with IHC Metalix, a company which cuts and finishes steel plates and profiles. These parts are shipped to customers in the form of machined steel kits. The amount of time required to complete a given order depends on the order's properties, such as the total weight, number of parts, ship type, section type, and required finishing work.

IHC Metalix is currently in the process of installing improvements to their production facilities with the goal of increasing the facility's throughput. These improvements include the installation of several new cranes, a pallet storage rack, and a conveyor belt system for moving pallets.

The precise relationship between the properties of a given order and the time it takes to complete an order is not known for the new production layout. Furthermore, the production planning department of IHC Metalix only has a general feeling about the effect of changes in the order portfolio have on the production process.

The order portfolio describes what types of orders are being processed by the facility. The order portfolio changes as the properties of the orders being processed change. For example, if the order portfolio shifts in a direction of customers building more complex vessels, the production process will need to produce parts and profiles with more complex curvature and bends. If the order portfolio shifts in the direction of customers who want to outsource more of the required finishing work, the production process will need to complete more grinding and bevelling tasks.

3.2 RESEARCH QUESTION

The purpose of this Master's thesis is to investigate the following research question:

What effect do changes in the order portfolio have on the throughput and bottleneck location of the newly implemented production process of IHC Metalix?

To answer the research question, the following sub-questions must be examined.

1. What are the throughput characteristics and possible bottleneck locations of the old production process at IHC Metalix?
2. What is the expected time required to complete each process step?
3. What are the expected increases in throughput that will occur when the new production process is implemented?
4. What is the expected throughput time distribution of a given type of order for the new production process?
5. What is the effect of the order portfolio on the location of the process bottleneck?
6. What are possible solutions to alleviate the bottlenecks found in the process, and how effective will these solutions be?

3.3 SCOPE

The scope of this research project was limited by the following factors:

1. Only the IHC Metalix facilities in Kinderdijk were considered for this analysis. The IHC Metalix cutting machine in Hardinxveld and outsourcing to subcontractors was not considered. Furthermore, the extremely thick plate parts cut in Kinderdijk using the oxy-fuel cutting machine were also excluded from the analysis.
2. Process improvements were required to be confined to the existing IHC Metalix facilities in Kinderdijk. It was not realistically possible to expand the size of these facilities.
3. All future upgrades to the IHC Metalix production process approved after the onset of this research project were not considered.
4. Only ship types for which sufficient data was available using IHC Metalix's resource planning and nesting software (Nestix) were considered in this analysis. Nestix contains detailed information regarding the part characteristics and required production work of all orders cut at IHC Metalix for the past five years.
5. No economic factors were quantitatively considered in this analysis. Economic calculations were not performed to compare the various ship types produced at IHC Metalix. Furthermore, no economic analysis was done to determine the financial effectiveness of the examined process improvements.
6. This project was limited to a period of approximately nine months.

4 SYSTEM DESCRIPTION

In order to examine the effects of the order portfolio on the production process of IHC Metalix, the system being studied must be defined. The following chapter describes the production process of IHC Metalix as it was considered for this project.

4.1 DESCRIPTION OF PRODUCTION PROCESS

4.1.1 Overview

IHC Metalix is a steel cutting and finishing company which produces machined steel kits. These steel kits, which are mainly used in shipbuilding, are composed of parts cut from both plates and profiles. IHC Metalix also completes the necessary finishing tasks for the parts. These finishing tasks include:

1. Beveling
2. Grinding
3. Pressbrake
4. 3-D forming

The un-cut plates and profiles are delivered to a plate park just outside of the production hall on trucks from raw material suppliers. A crane in the plate park unloads the trucks, sorts the uncut plates and profiles in the plate park, and feeds the production process.

The finished parts are delivered to the customer on a flatrack. Large plate parts are placed directly on the flatracks. At a customer's request, these plate parts can be sorted in a specific order. Smaller parts are placed either onto pallets or into boxes. Profiles are typically bundled together. The pallets, boxes, and profile bundles are placed on top of the large plate parts on the flatrack. Figure 4-1 shows a picture of a loaded flatrack before being delivered to a customer.



Figure 4-1: Loaded Flatrack at IHC Metalix

4.1.2 Old Process

During the course of this project, the production process at IHC Metalix underwent a series of upgrades. The old process refers to the production process at the beginning of this research project (September 15, 2012). Much of the available data about the production process was collected prior to the start of the thesis, and therefore this data was recorded from the old process. Figure 4-2 contains an overview diagram of the old process at IHC Metalix.

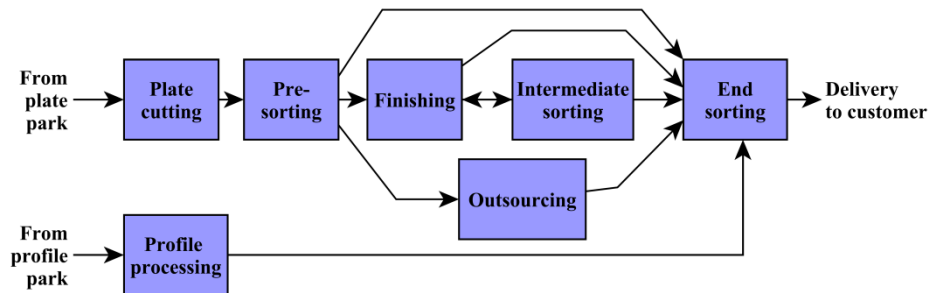


Figure 4-2: Overview of Old Process at IHC Metalix

In the old process, plates are first cut by the plasma cutting machines after being picked from the plate park. Once the plates are cut, they are sorted from the sorting table. Parts can either be sent to be finished on-site, to an off-site sub-contractor, or directly to a pallet or flatrack. Intermediate sorting is done in order to move parts between the on-site finishing locations. Small and medium parts are collected on pallets or in boxes once they are cut and finished. Once a pallet is full or if all of the small and medium sized parts for a given flatrack are collected, the pallet is wrapped.

The profiles can either be cut by the profile cutting machine or by hand using a bandsaw and acetylene torch. Once the profiles are cut they are moved to the bending machine or grinding tables, if required. After all of the profiles for a given flatrack are cut and finished, they are bundled together.

Once all of the large parts are placed on a flatrack, the bundled profiles and wrapped pallets are loaded onto the flatrack, and the flatrack is sent off to the customer.

Figure 4-3 contains a detailed process flow diagram of the old process at IHC Metalix. This diagram contains greater details about the sub-processes which occur within each of the process steps shown in Figure 4-2.

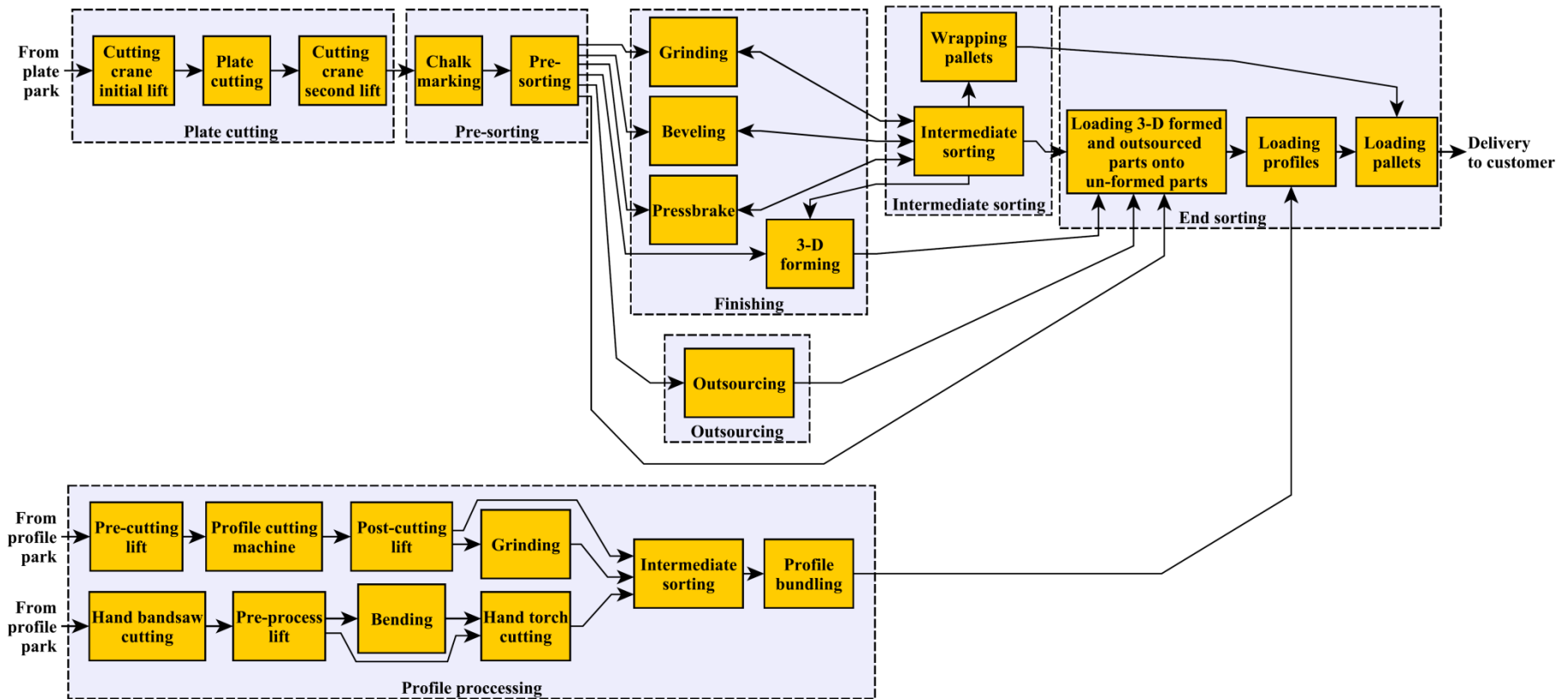


Figure 4-3: Process Flow Diagram Old Process at IHC Metalix

4.1.3 New Process

The production facilities at IHC Metalix underwent a series of major upgrades starting in September 2012. The new process refers to the production process after these upgrades were installed. The goal of this thesis is to determine the influence of the order portfolio on the throughput and bottleneck location of the new process. However, because the new process was not fully commissioned until after the conclusion of this project, it was not always possible to directly take measurements from the new process. For most measurements, including sub-process times and section input characteristics, the changes to the process had no influence on the gathered data.

The following upgrades were installed to change the production process at IHC Metalix from the old process to the new process:

1. Two small cranes, capable of lifting small and medium parts from the sorting tables to boxes/pallets, were installed in the pre-sorting area.
2. A conveyer belt was installed to transport the boxes/pallets away from the pre-sorting area to a separate small and medium parts finishing area.
3. Three tables were installed in the small and medium parts finishing area for bevelling and grinding.
4. A rack was built for the storage of completed pallets/boxes.
5. The function of the two large part bevelling tables and two large part grinding tables were converted into four multi-skilled bevelling/grinding tables.
6. A new crane with a magnet traverse was installed in the end sorting area to replace an old crane.

These upgrades resulted in the following changes to the production process flow diagram:

1. Small and medium parts are separated from the large parts during the pre-sorting process.
2. Separate finishing processes are established for small/medium parts and large parts.
3. Intermediate sorting of large plates is no longer necessary. This occurs because plates no longer move between the bevelling and grinding station and any reordering of plates can be done in the end sorting area.
4. The pallet wrapping process is no longer part of the intermediate sorting process, but instead part of the pallet completion process.

The changes to the production process diagram can be seen graphically in Figure 4-4. This figure contains an overview of the new process at IHC Metalix. The changes listed above can be seen on this diagram.

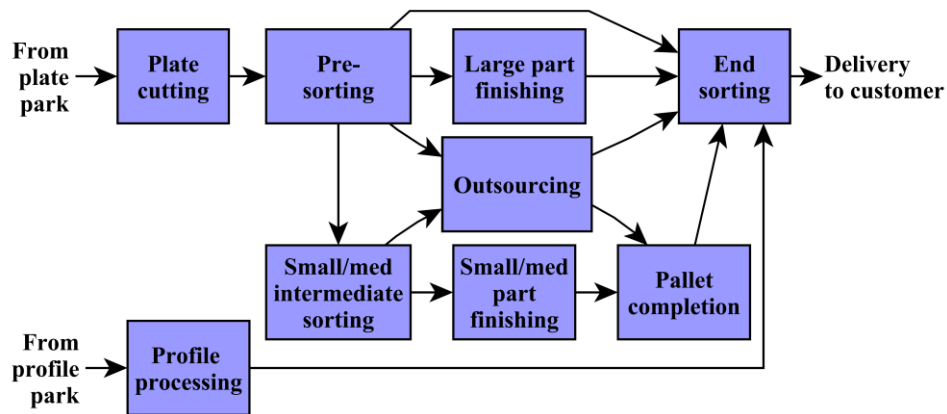


Figure 4-4: Overview of New Process at IHC Metalix

Overall, the changes to the production process increase the number of required lifts to complete the production process. Three new cranes, however, have been installed to take on this additional workload, as well as reduce the required work for the existing cranes. This change should ultimately increase the production capacity of the facility. Other changes, such as combining the bevelling and grinding tables, aim to reduce the required number of crane lifts.

Figure 4-5 shows the detailed process flow diagram of the new process at IHC Metalix. All of the upgrades to the production facility discussed above are incorporated in this diagram. Comparing Figure 4-5 to Figure 4-3 shows that the new production process has significantly more sub-processes than the old production process.

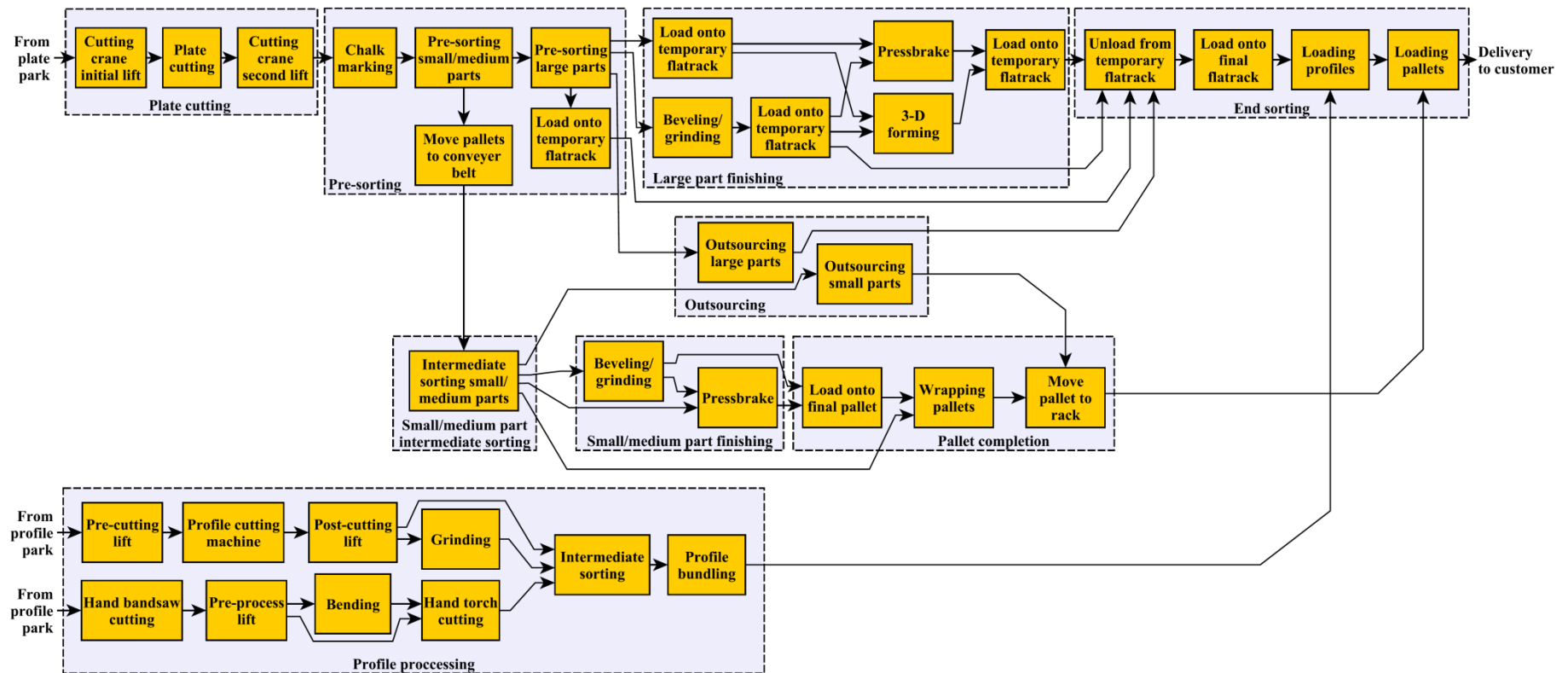


Figure 4-5: Process Flow Diagram New Process at IHC Metalix

4.2 DESCRIPTION OF ORDER PROPERTIES

The objective of this thesis is to examine the effect of different order properties on the production process of IHC Metalix. The following section provides a description of the order properties examined.

4.2.1 Ship Type

The main factor differentiating between the orders processed by IHC Metalix was the ship type of the order. The ship type has a strong influence on the properties of a vessel. These properties include:

1. Vessel size
2. Vessel weight
3. Overall shape
4. Structural complexity
5. Hull curvature
6. Hull strength

Differences in these properties affect the entire shipbuilding process, including the cutting and finishing of the steel parts. Therefore, the ship type of an order influences the production process at IHC Metalix.

IHC Metalix supplies machined steel kits to shipyards across the Netherlands and northern Germany. The range of potential customers is limited to this region by transportation costs. Shipyards in this region mainly produce the following vessel types [5][9][10][11][12][13][14]:

1. Yachts
2. Cruise ships (both inland and ocean going)
3. Coasters
4. Dredgers
5. Offshore (pipelaying and offshore support)
6. Ferries (ro-ro, passenger, and high speed)
7. Military vessels

For this project, only ship types for which part data was available in IHC Metalix's resource planning and nesting software (Nestix) were examined. These ship types were selected because sufficient amounts of production data for these ship types were readily available. This includes all of the above mentioned ship types except for military vessels, ferries, and ocean going cruise ships. The selected ship types also represent the vessel types for which IHC Metalix has produced parts in the past five years. Barring drastic shifts in the shipbuilding market, IHC Metalix will continue to produce mainly these vessel types. This is especially true for the dredging and offshore vessels, which are primary built by the dredging and offshore divisions of IHC Merwede.

In the coming years, IHC Metalix's order portfolio could potentially expand to include sections for ocean going cruise ships, ferries, and military vessels. In the past few years, IHC

Metalix has already cut a few small sections for military projects. At this point, however, the data was not available to include these ship types.

The following sections briefly describe the ship types examined in this thesis.

4.2.1.1 Trailing Suction Hopper Dredger (TSHD)

A trailing suction hopper dredger is a self-propelled vessel which removes sand and other soft material from seafloor by means of suction pipes. The sand is pumped from the seabed into the vessel's hopper using large pumps. The sand settles to the bottom of the hopper and most of the excess water in the hopper can be removed using an overflow system. Once the hopper is full, the vessel sails to a discharge location to release the sand using doors or valves attached to the hopper [15]. Figure 4-6 depicts a diagram of a trailing suction hopper dredger performing its mission.



Figure 4-6: Diagram of TSHD Dredging Seafloor [15]

4.2.1.2 Cutter Suction Dredger (CSD)

Cutter suction dredgers use a cutter head in order to break up soil prior to pumping it onboard using a dredging pump. To complete this operation, the dredger rotates around a spud pole at the stern of the vessel by using winches and anchors located near the vessel's bow. The anchors need to be reset as the vessel slowly advances forward. The soil removed from the seafloor is either unloaded to a pipeline or an adjacent barge [15]. Figure 4-7 illustrates the operations of a cutter suction dredger.



Figure 4-7: Diagram of CSD Dredging Seafloor [15]

4.2.1.3 Beaver Dredger (BD)

A beaver dredger is a small cutter suction dredger. Due to their size, these vessels are usually built in a standard series. In this thesis, beaver dredgers are divided into two categories, large and small. Small beaver dredgers are defined as vessels with a pontoon length less than 20 meters, while large beaver dredgers have pontoon lengths greater than 20 meters. Figure 4-8 shows an example of a small beaver dredger at sea.



Figure 4-8: *Beaver 50* Built by IHC Beaver Dredgers [16]

4.2.1.4 Backhoe Dredger (BHD)

Backhoe dredgers are stationary vessels anchored with spuds. A backhoe operates a bucket which shovels soil from the seafloor onto an adjacent barge. Backhoe dredgers are

usually used when the seafloor is composed of firm soil types and is full of large rocks [15]. A picture of a backhoe dredger in operation can be seen in Figure 4-9.



Figure 4-9: Backhoe Dredger *Ijzeren Hein* [15]

4.2.1.5 Coaster

Coasters are small coastal trading vessels which are characterized by their modest size, short range, and relatively shallow draft. These vessels can carry a variety of cargo including bulk cargo and containers. In general, coasters are fairly simple vessels with large cargo holds.

In the past five years, IHC Metalix has cut parts for a several different coaster designs. Although each design differs in size, power, and features, the general arrangements of these vessels are very similar. Figure 4-10 depicts an example of a coaster built by Damen Shipyards.



Figure 4-10: Combi Coaster *Aldebaran* [17]

4.2.1.6 Offshore Support Vessel (OSV)

Offshore support vessels are used by the offshore industry to perform and assist during offshore related tasks. These tasks include supplying platforms, performing inspections, and carrying out repair and maintenance tasks. These vessels can aid during the construction and decommissioning of offshore facilities and also assist during pipelaying and cablelaying operations [18]. Offshore support vessels are usually fairly complex vessels due to the wide range of missions each vessel must complete.

The offshore support vessels studied in this project were very specialized vessels with an extremely shallow draft, high installed power, and icebreaking capabilities. These vessels have a complex structure composed of thin plates and a high number of parts [19]. The characteristics of the OSVs studied in this research do not represent typical OSVs. Only production data for these specialized OSVs was available at the time of this study. Figure 4-11 shows an offshore support vessel built by the offshore division of IHC Merwede.



Figure 4-11: OSV *Toisa Polaris* [18]

4.2.1.7 Pipelaying Vessel

Pipelaying vessels install pipelines offshore which transport oil and gas from offshore wells to production centers. As the offshore industry continues to drill in deeper waters, the technology of pipelaying vessels must also advance to meet the challenges of installing pipelines at those depths. Therefore, innovative and complex designs for pipelaying vessels continue to emerge [18]. Figure 4-1 shows a pipelaying vessel built by IHC Offshore.



Figure 4-12: Pipelaying Vessel *Seven Pacific* [18]

4.2.1.8 Tugboat

A tugboat is a vessel which is used primarily to help large ships dock safely in harbors. Tugboats accomplish this task by towing and pushing larger vessels. Tugboats are characterized by power dense designs capable of controlling ships many times larger than themselves. As ships become larger and carry more dangerous cargo, such as liquefied natural gas (LNG), tugboat designs must also become larger and more powerful [20]. Figure 4-13 shows a tugboat aiding a much larger vessel in the docking process.



Figure 4-13: Tugboat Pushing Larger Vessel [21]

4.2.1.9 Inland Cruise Vessel

Inland cruise vessels take passengers on luxury trips along inland waterways and are designed with the comfort of the passenger in mind. Such trips allow patrons to visit multiple cities and historical landmarks on a single trip without the hassle of changing accommodation and switching modes of transportation [22]. These vessels are only designed to operate in the inland waterways.

The inland cruise vessel sections used in this study were from a series of three passenger ships designed to sail on the Rhine River. The basic design characteristics of these vessels are similar to most inland cruise vessels. Figure 4-14 shows an inland cruise vessel on the Rhine River.

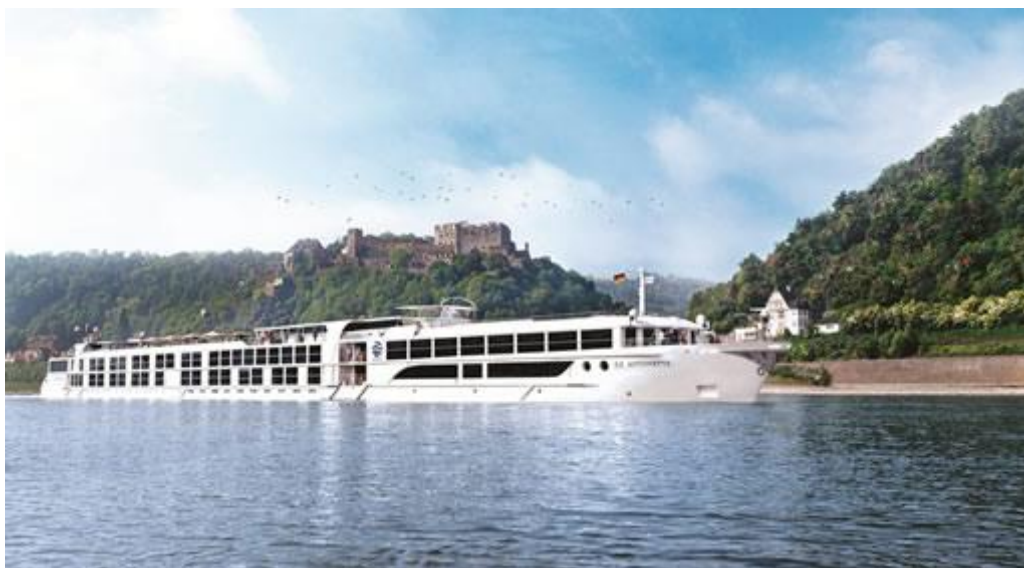


Figure 4-14: Inland Cruise Vessel S.S. *Antoinette* [23]

4.2.1.10 Yacht

Yachts are luxury vessels designed for recreational use by their owner. These vessels are also often made available for charter to help recuperate some of the operational costs for the owner [24]. Yachts are designed to meet the highest standards in aesthetics and passenger comfort. As a result, these vessels often have complex hull shapes full of curvature.

When a customer orders yacht parts cut by IHC Metalix, the customer sometimes only orders the shell plates. Yachts from both this type of order as well as complete orders were used in this project. It is expected that in the future some customers from the yacht market will continue to request only shell plates. Figure 4-15 contains an example of a large yacht.



Figure 4-15: Superyacht *Imagine* at Sea [24]

4.2.1.11 Construction Projects

Not all of the steel cut at IHC Metalix is used to construct marine vessels. Approximately 10% of the company's annual production capacity is used for construction projects. These projects include bridges, towers, offshore structures, and other small construction projects.

4.2.2 Section Type

Sections cut at IHC Metalix can also be classified by what part of the ship they belong to. This type of division was only possible for large vessels, which contain enough sections to make this distinction. Furthermore, data must be obtainable for a sufficient number of sections of each section type to have a robust analysis. Because of these two constraints, the effect of section types was only examined for the following ship types:

1. Trailing suction hopper dredgers
2. Cutter suction dredgers
3. Coasters
4. Pipelaying vessels

Figure 4-16 depicts a diagram of a coaster which illustrates the section type definitions used for this project. A brief description of the section types examined is located below the figure.

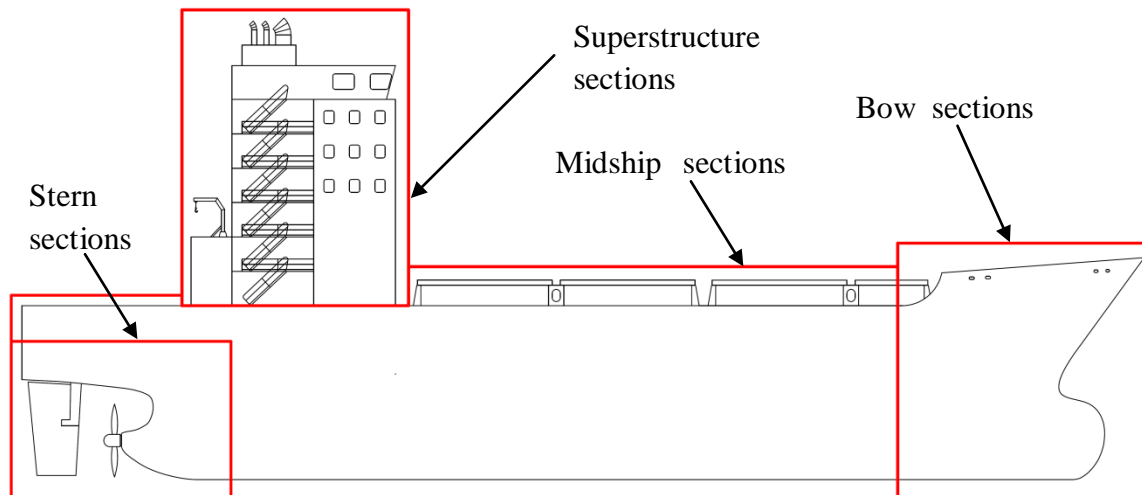


Figure 4-16: Section Type Definitions

4.2.2.1 Bow Sections

Bow sections are situated at the bow of a vessel. These sections have relatively low volume and usually only contain ballast tanks. The ship's hull usually has complex curvature in these sections, especially if the vessel has a bulbous bow. For this analysis, a bow section is defined as any section containing shell plating located forward of the parallel midship sections.

4.2.2.2 Midship Sections

Midship sections are mainly used to hold a vessel's cargo. These sections usually contain wing and double bottom ballast tanks. They are located between the bow and stern sections of a vessel. The hull cross-section does not change between midship sections. Sections at the stern of the vessel with flat-of-side hull plates were also considered to be midship sections.

4.2.2.3 Stern Sections

Stern sections are located at the aft end of a vessel. The vessel's propellers and rudders are mounted to these sections. These sections usually contain machinery spaces and tanks. Like the bow sections, these sections usually have complex curvature. For this analysis, a stern section is defined as any section containing shell plating which is located aft of the parallel midship sections. Sections at the stern of the vessel with no curvature were not considered to be stern sections.

4.2.2.4 Superstructure Sections

Superstructure sections are defined as any section located above the sheerline of a vessel. These sections do not contain any hull plating. In general, these sections are used for the deckhouse and crew accommodation.

4.2.3 Grinding

When a customer places an order with IHC Metalix, that customer can request IHC Metalix to perform finishing tasks. One service IHC Metalix offers is to grind and paint the non-welded edges of each part prior to delivering the parts to the customer [6]. Sharp edges need to be grinded before protective paint can be applied because paint does not adhere properly to sharp edges [25]. Proper grinding and protective coating is also required for a vessel to satisfy the IMO Performance Standard for Protective Coatings (IMO PSPC) [26].

Grinding is a time consuming process which is normally performed by shipyards after the sections are already welded together. This can be inefficient and dangerous since grinders are often working in tight spaces [27]. At IHC Metalix, parts are grinded on open grinding tables which are easily accessible.

Delivering a grinded section requires significantly more work for IHC Metalix than delivering a non-grinded section because between 50% and 90% of the parts in a grinded section typically require grinding. This not only adds the additional man-hours of grinding the parts, but also the associated movement task of lifting the parts on and off of the grinding tables.

4.3 ORDER PORTFOLIOS

The following chapter describes the base portfolio used in this analysis. The effect of the shift of the order portfolio away from the base portfolio on the characteristics of the production process of IHC Metalix was examined by this project.

Using order portfolios allows the production process to be studied when a combination of different ship types are being produced. This provides better insight into the real operations of the production process than examining the effect of ship types individually because the production process usually produces sections from a variety of different ship types.

4.3.1 Base Portfolio

A base order portfolio was established for IHC Metalix before creating scenarios for possible shifts in the order portfolio. In order to determine this, the order history of IHC Metalix was examined from October 2011 to October 2012. The most recent year of production data represented a good estimate of what would be produced next year. Therefore, it was selected to be the base portfolio.

Figure 4-17 shows the distribution of order type by weight produced by IHC Metalix between October 2011 and October 2012. This figure also shows what percent of parts belong to a grinded section.

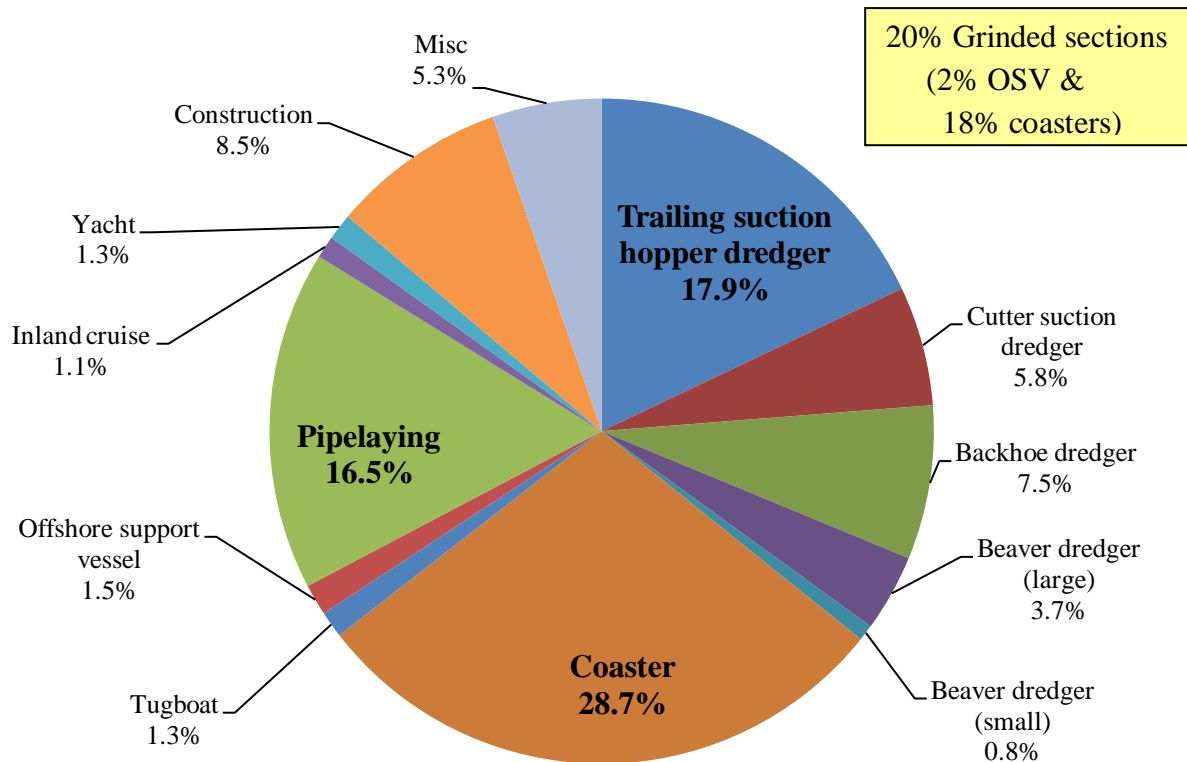


Figure 4-17: Order History by Weight from October 2011 to October 2012

The construction category includes any order for a large construction project which cannot be considered as another category. Although this category does include on-land projects such as bridges, the bulk of the weight of this category is composed of orders related to offshore construction projects, such as legs and crane foundations for offshore platforms.

The miscellaneous (misc) category shown in the order history is composed of replacement parts, wear stripes, internal improvement orders, small orders, parts for naval vessels, and various other one-of items. This category also includes sections for ship types which IHC Metalix does not normally produce parts for, such as tankers. Due to the high variability and lack of consistency between the items of this category, the miscellaneous category was removed from the order history prior to establishing the base portfolio.

It was assumed that the properties of the miscellaneous orders roughly represented the average order properties. Therefore, when establishing the base portfolio, all other order types were proportionally increased by weight to compensate for the removal of the miscellaneous category. This assumption was made because it was not possible to determine the production characteristics of the miscellaneous orders due to the small size and unique nature of each order. The total production capacity of the process could be slightly affected by this assumption, but the relative effects of the shifts in order portfolios would be unaffected. Furthermore, the effect of this assumption is limited by the small size of the miscellaneous orders.

Figure 4-18 shows the base portfolio used in this analysis. This figure shows the distribution of order types produced by weight at IHC Metalix. All subsequent order portfolios consist of variations of this base portfolio.

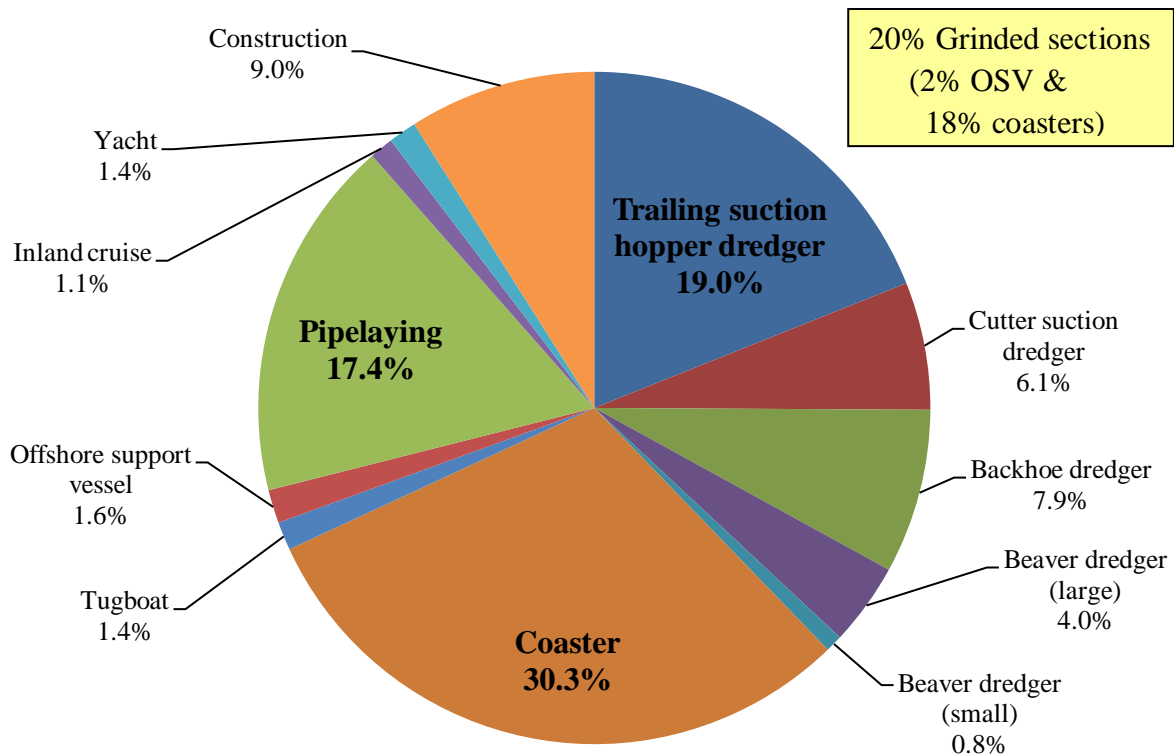


Figure 4-18: Base Portfolio

4.3.2 Examined Portfolios

The following portfolios were examined to determine the effect of shifts in the order book of IHC Metalix on its production process:

1. Increase in the number of grinded sections
2. Increase in the number of dredging vessel orders
3. Increase in the number of offshore vessel orders
4. Increase in the number of shipping vessel orders
5. Increase in the number of luxury vessel orders
6. Increase in the number of construction orders

The extreme cases where only vessels of one type are produced were also examined for each of the ship types. A detailed description of each of the portfolios can be found in section 7.2 *Order Portfolios*.

5 PRELIMINARY PROCESS ANALYSIS

Initially, a preliminary process analysis (PPA) was performed to determine the production characteristics of IHC Metalix's Kinderdijk facilities. The following chapter describes this analysis. This analysis was based on the available production data, which existed only for the old process. Therefore, the PPA was first completed for the old process. The analysis was then adapted to determine the production characteristic of the new process. Figure 5-1 outlines the relationship between the production data and the PPA.

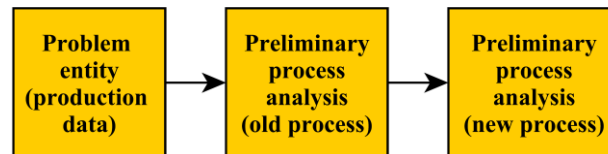


Figure 5-1: Relationship of Production Data and PPA

The PPA analysis was performed for the following purposes:

1. Gather detailed data about the characteristics of each process step of the steel cutting and finishing process at IHC Metalix.
2. Collect a database of section parts. This database should contain a sufficient number of entries for each combination of section properties.
3. Predict the process throughput increase and change in bottleneck location as a result of the upgrades to the process.

5.1 OVERVIEW

Figure 5-2 shows an overview of the PPA. The PPA relies on three sets of input data: sub-process characteristics, section independent properties, and section dependent properties. Both the sub-process characteristics and section independent properties are independent of the section being analyzed. Whether the examined section is a grinded or non-grinded section is also input into the PPA. For each of the examined ship sections, the PPA calculation is performed for both the old and new process to determine the production capacity and bottleneck location of both processes when producing that section. These production characteristics are then compared.

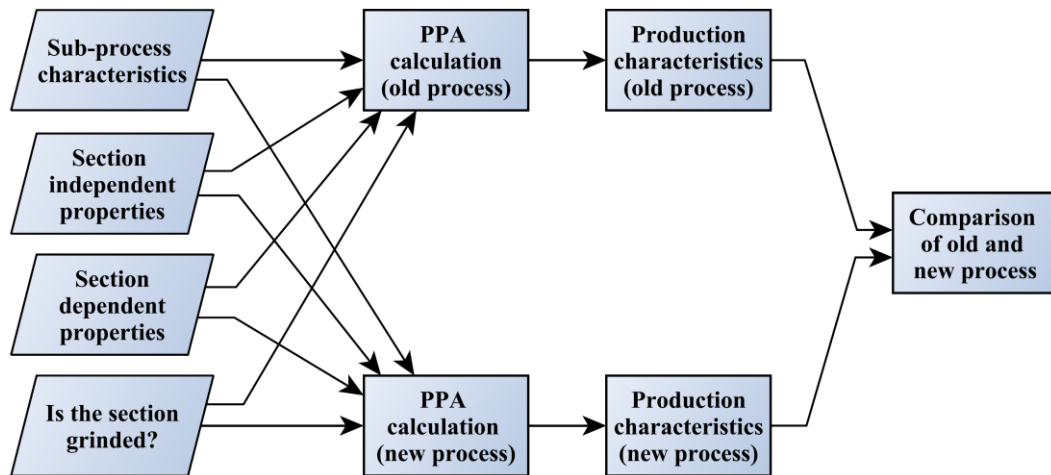


Figure 5-2: Overview of Preliminary Process Analysis

5.2 ANALYSIS INPUTS

In order to complete the PPA, it was necessary to first collect detailed information about the process at IHC Metalix and the sections being cut and finished. The following three sections describe the type of information required and how it was collected.

5.2.1 Sub-Process Characteristics

The first set of input values required for the PPA was the characteristics of each sub-process at IHC Metalix. A detailed description of both the old and new production process can be found in section 4.1 *Description of Production Process*. The section also contains flowcharts outlining both the old and new production process.

Table 5-1 contains a summary of the sub-process characteristics for which data was collected. Only the average values of these processes were input into the PPA. However, distributions were constructed if necessary and possible to have as robust of a data set as possible.

This table contains three main types of characteristics. The first was very repeatable in nature, and therefore had a relatively small range of possible values. It was not necessary to construct distributions for these characteristics because of the low variance within the process.

The other two types of characteristics required distributions to fully describe the characteristics. For some of the characteristics, however, insufficient data existed to construct a distribution. For example, at the onset of the study, no data had been recorded regarding the time required to bend a profile. This process was only performed a few times a day and took approximately 45 minutes to complete. To construct a distribution for this processing time, weeks of data collection would be required. This level of data collection to construct a single process time distribution was considered outside of the scope of this project.

Having a distribution is not required to perform the PPA since only average values for the production times of sub-processes were input into the PPA. Therefore, not creating a distribution does not affect the results of the PPA. Distributions, however, increase the robustness of the data gathered.

In the case of plate 3-D forming, a previous study has been performed to determine the average time. This study did not create a distribution to describe the plate 3-D forming process. The data used by this study, however, has been lost. Collecting new data for this process would also be very time consuming, as this study showed that each plate takes approximately 2.5 hours to form.

Table 5-1: Summary of Sub-Process Characteristics

Sub-process characteristics	Number of measurements	Distribution required	Possible to construct distribution with data	Type of distribution constructed
Crane lifts/sorting tasks	4 – 17	No	-	-
Marking parts	3	No	-	-
Speeds (beveling, grinding, painting)	3	No	-	-
Pallet wrapping/profile bundling	2 – 4	No	-	-
Profile cutting (bandsaw)	5	No	-	-
Plate 3-D Forming	1000+	Yes	No	-
Profile bending	4	Yes	No	-
Profile cutting (acetylene torch)	3	Yes	No	-
Pressbrake	57	Yes	Yes	Exponential
Beveling setup	31	Yes	Yes	Gamma
Profile cutting machine	32	Yes	Yes	Gamma

Appendix 11.1 contains a complete description of the sub-processes examined, the sub-process throughput average times and distributions, and the methodology used to collect the data.

5.2.2 Section Independent Properties

A numerical description of a series of section independent properties was also required to complete the PPA. Like the sub-process characteristics, only the averages of these properties were required for the PPA. Sufficient data was collected to create distributions for these properties, where possible. This was done to have a robust data set.

These properties were assumed to be independent of the ship type and section type. This assumption was made because insufficient data existed for determining the effect of section and ship type on these properties. For example, grinding has only been performed for several

orders in the past five years. The production drawings were only available for some of these orders. Therefore, when determining the average grinded length of a part, it was only possible to measure the grinded length of sections from a few orders. It was necessary to assume that the measured grinded length applied to all vessel types. If more data becomes available in the future, it is strongly suggested to recalculate these characteristics based on vessel type.

In general, distributions were created to describe these properties. However, one of the section independent properties, the required turning of bevelled parts, was binary in nature. For this property, only an average percentage was calculated. Table 5-2 contains a summary of the examined section independent properties.

Table 5-2: Summary of Section Independent Properties

Sub-process characteristics	Number of measurements	Type of distribution constructed
Grinded length (large parts)	49	Lognormal
Grinded length (small parts)	90	Beta
Grinded length (profiles)	52	Gamma
Percent of grinded parts	19	Beta
Percent of grinded profiles	20	Exponential
Bevelled length (large parts)	37	Exponential
Bevelled length (small parts)	20	Gamma
Bevelling turning required (large parts)	15	-
Bevelling turning required (small parts)	14	-

The plate characteristics were also considered to be section independent properties for the PPA. An easily accessible database existed to determine the exact values of any of these properties for a given part. Therefore, it was not necessary to create distributions for these properties. For the PPA, only average values were required for the plate properties.

These characteristics include:

1. Weight
2. Scrap percentage
3. Cutting time

Appendix 11.1 contains a complete description of the process independent characteristics examined, the average values calculated, the distributions created, and the methodology used to collect the data about these characteristics.

5.2.3 Section Dependent Properties

The PPA calculation also requires a set of section properties which are dependent on the ship and section type. The processing times and required capacity are calculated for each

sub-process using the sub-process characteristics, section independent properties, and section dependent properties.

Differences in the section dependent properties result in differences in the total process throughput and bottleneck location between sections. These properties can be directly calculated from the set of parts which belong to a section. These properties include:

1. Ratio of plate parts to profiles
2. Proportion of small, medium, and large plate parts
3. Average weight of small parts, medium parts, large parts, and profiles
4. Percentage of parts which need bevelling
5. Percentage of parts and profiles which need pressed and formed

These properties were collected for each combination of ship type and section type examined in this analysis. Table 5-3 contains a summary of the number of sections of each combination of ship and section type for which the section dependent properties were obtained. The effect of section type was only investigated for the four ship types for which sufficient amounts of data were available. For the remaining ship types, insufficient data existed to examine the effect of section type. A description of the different section types can be found in section 4.2.2 *Section Type*.

Table 5-3: Summary of Sections Types Examined

Ship type	No. of ships	No. of sections	Bow sections	Midship sections	Stern sections	Superstructure sections
Cutter suction dredger	3	291	46	138	12	38
TSH dredger	7	344	76	120	35	52
Coaster	6	371	57	80	35	20
Pipelaying	2	125	21	57	12	22
Offshore support	2	57	-	-	-	-
Inland cruise	3	95	-	-	-	-
Yacht	5	62	-	-	-	-
Tugboat	3	34	-	-	-	-
Beaver dredger (sml)	9	64	-	-	-	-
Beaver dredger (lrg)	13	73	-	-	-	-
Backhoe dredger	3	83	-	-	-	-
Construction	4	45	-	-	-	-

In order to carry out the PPA, a separate calculation was completed for each of the examined sections and its associated section dependent properties. Therefore, it was not necessary to calculate averages or distributions for these properties.

Appendix 11.3 contains the statistical calculations performed to verify that a sufficient data points were collected for each of the section types shown in Table 5-3. The appendix shows that sufficient confidence was obtained for each ship type that the mean of the calculated production capacities represented the real mean.

5.3 DESCRIPTION OF ANALYSIS

5.3.1 Overview of Approach

The following steps outline the approach taken to analyze the production capacity (in tons/week) of the steel cutting and finishing process at IHC Metalix based on the properties of the section being produced.

1. Assume an initial total process throughput (in tons/week) of zero.
2. Determine the throughput of each process step based on the section properties and the total process throughput. For example, if a section contains 85% plates by weight and 10% of the plates in the section require bevelling, then the throughput of the bevelling stations is 8.5% of the total process throughput.
3. Determine the utilization of each resource for each process step.
4. Determine the total utilization of each resource by summing the utilization of that resource for each process step. For example, if a beveller is required to spend 10% of the week setting up parts, 15% of the week bevelling parts, and 5% of the week waiting for the sorting crane to turn parts, the beveller would be occupied 30% of the week.
5. Increase the process throughput until a bottleneck occurs. In general, a bottleneck occurs when the capacity of a resource is reached.

5.3.2 Capacities of Resources

The PPA outlined in section 5.3.1 *Overview of Approach* relies on knowing when the capacity of each resource is reached. Due to complex interactions between sub-processes, machine downtime, worker mistakes, and various other factors, the achieved capacity of a resource is less than 100%. For example, if a large batch of beveled parts enters the system, the sorting crane may need to wait on the beveling process for part of the day even though the sorting crane is the overall bottleneck on that day.

In order to estimate these capacities, a calibration was performed. For this calibration, 22 days of production data were taken. The general consensus of the production department of IHC Metalix was that the selected days were representative of normal production days. Furthermore, the order book was full on these days.

All of the parts produced on each day were joined together to form a virtual section. The PPA calculation was performed on each virtual section with the total process throughput set equal to the achieved throughput during that day's production. Using this methodology, the utilization of each resource was calculated for each of the virtual sections.

The utilization of each resource was recorded when that resource was the process bottleneck. The average of each resource's utilization as the process bottleneck was taken to be the capacity of that resource.

The utilization of each resource was calculated separately for each process due to the differences between how the resource interacted with the process. Some resources, like the plate 3-D forming stations and the pressbrake, operated independently. A buffer is located

before these processes to manage the inconsistent influx of parts. These processes do not directly rely on any of the other sub-process. If the independent sub-processes were idle on a given day, not enough parts were processed that day to fill that processes capacity.

Other processes, like the sorting crane and profile crane, rely heavily on other processes for their workload. For example, the sorting crane's workload is a function of the plate cutting machines, beveling tables, and grinding tables. When the sorting crane is the bottleneck, it still may spend a significant portion of time waiting on other processes.

Table 5-4 contains the maximum capacities for each resource calculated using this methodology. This table also shows the number of days that resource was found to be the process bottleneck out of the 22 days examined.

Table 5-4: Utilization Capacity for Resources, from Calibration

Resource	Days resource was bottleneck	Utilization Capacity
Sorting crane	8	87%
Profile crane	8	93%
Profile cutting machine	8	92%
3-D forming	13	95%
Profile hand process	4	90%

Some resources were never the bottleneck on any of the calibration days. For these resources, the maximum capacity was assumed to be the maximum capacity of the most similar resource. All of the resources were part of almost completely independent sub-processes. Therefore, it was assumed that these resources operate in a similar manner as to 3-D forming, which is also an almost completely independent process. The capacity of these resources was set to be equal to the capacity of 3-D forming. Table 5-5 contains these resources and their assumed capacities.

Table 5-5: Utilization Capacities for Resources set to Capacity of 3-D Forming

Resource	Utilization Capacity
Cutting crane	95%
Plate cutting machine	95%
Pressbrake	95%
Plate grinding	95%
Profile grinding	95%
Beveling	95%

5.3.3 Process Analysis Calculation

A process analysis calculation was constructed to complete the PPA. This calculation followed the steps outlined in section 5.3.1 *Overview of Approach*. This calculation determined the production capacity (in tons/week) and bottleneck location from the sub-process characteristics, section independent properties, and section dependent properties.

Initially, a process analysis calculation was constructed for the old process at IHC Metalix. This calculation was performed for each of the sections for which data on the individual parts was collected. A summary of the section types examined can be found in section 5.2.3 *Section Dependent Properties*. From the results of this series of calculations, a process throughput distribution for the old process was constructed.

The process analysis calculation was also modified to reflect the changes between the old and new process at IHC Metalix. A detailed description of these changes can be found in section 4.1.3 *Description of Production Process: New Process*. The modified calculation was performed again for each section in order to construct the process throughput distribution for the new process.

5.4 RESULTS

5.4.1 Validation of Calculation

Figure 5-3 shows a comparison of the achieved production capacity of IHC Metalix and the production capacity calculated using the PPA. The achieved production capacity was measured by determining the tons of material which were cut at IHC Metalix in a given week. Due to variations in the required amount and type of finishing, this does not necessarily represent the total weight of parts which were delivered to customers in a given week. However, the average annual production capacity achieved by IHC Metalix can be determined by averaging these weekly values. The annual production capacity calculated for the base portfolio using the PPA is also shown on Figure 5-3.

The annual average production capacity calculated by the PPA does not represent the maximum production capacity of IHC Metalix. Depending on the types of sections being cut and the frequency of outgoing delivery units, it is possible for the production process to temporarily have a higher production capacity than this number. This number represents the expected production capacity of the production process of IHC Metalix over an extended period of time, assuming that the company has a full order book representing the base portfolio.

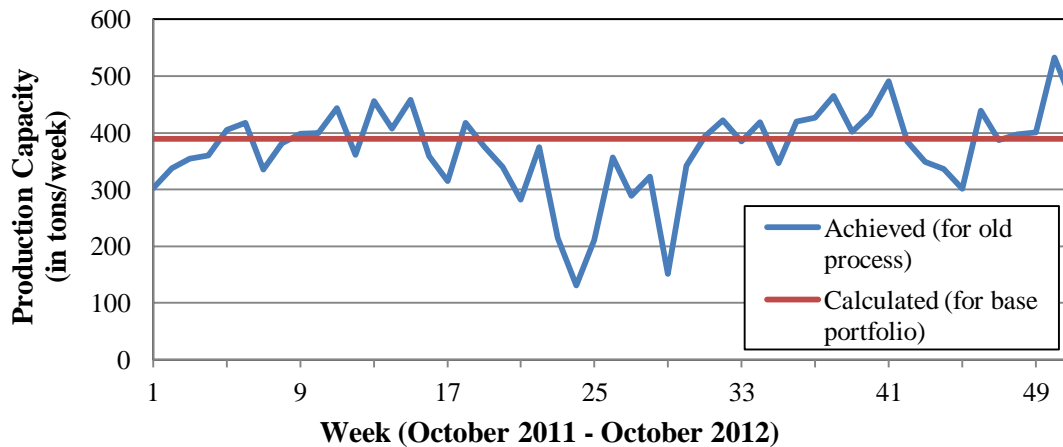


Figure 5-3: Achieved and Calculated Production Capacity (Oct. 2011 – Oct. 2012)

Figure 5-3 shows that the achieved production capacity at IHC Metalix was fairly variable, ranging between 300 and 500 tons per week. The reasons for the high variance in the weekly production capacity are the differences in the complexity and thickness of the parts being cut, the required finishing tasks, and the frequency of delivery units. This figure also shows that production dipped below 200 tons per week twice between October 2011 and October 2012. Both of these temporary production drops at IHC Metalix occurred because the company's order book was not filled for these weeks [28]. These slow weeks in production were disregarded when calculating the average achieved capacity of IHC Metalix.

Table 5-6 shows a comparison of the annual averages for calculated and achieved production capacity at IHC Metalix. This table shows that the calculated production capacity of IHC Metalix was slightly higher than the achieved production capacity, differing by approximately 0.7%.

Table 5-6: Achieved and Calculated Production Capacity
(Oct. 2011 – Oct. 2012)

Average achieved capacity	387 tons/week
Calculated average capacity	389 tons/week
Percent difference	0.7%

5.4.2 Preliminary Production Capacity

Preliminary production capacity distributions were constructed for each ship type using the methodology outlines in section 5.3 *Description of Analysis*. Figure 5-4 shows an example of one of the constructed preliminary production capacity distributions.

Appendix 11.4 contains the complete set of production capacity distributions constructed from the PPA. This includes each examined ship types for both grinded and non-grinded sections.

Figure 5-4 shows the preliminary production capacity distribution for cutter section dredger sections for both the old process and the new process. This figure shows the probability of a given process capacity being achieved if a cutter suction dredger section is produced. The figure shows that the production capacity of the process at IHC Metalix is on average higher for the new process for this section type because the production capacity curve for the new process is located further to the right. This trend was found for all of the vessel types. A detailed analysis of the degree of this shift can be found in section 5.4.7 *Influence of the New Process*.

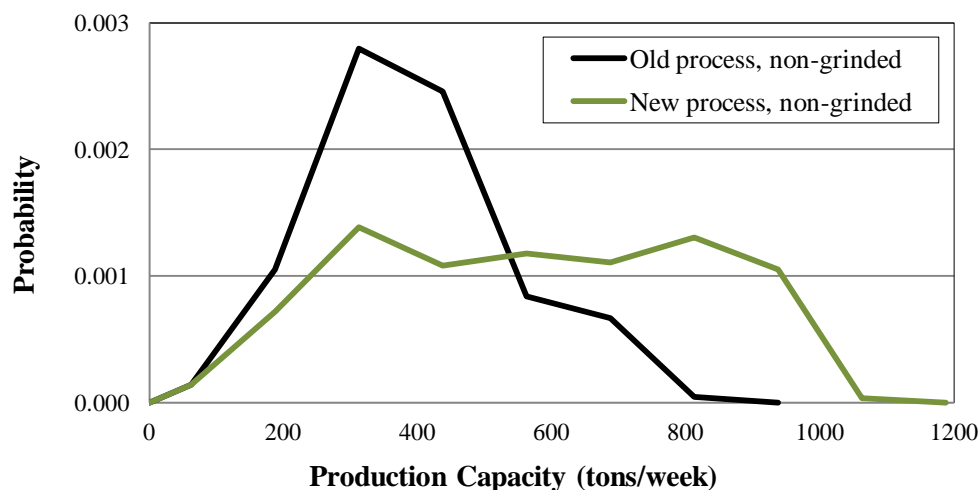


Figure 5-4: Preliminary Production Capacity Distribution, Cutter Suction Dredger, Non-Grinded

5.4.3 Preliminary Bottleneck Location

The process bottleneck is the component in the process which limits the total production capacity of a process. A process will always have a bottleneck when operating at full capacity. If no bottleneck exists in a process, then the process is not operating at full capacity. It is preferable to have the process bottleneck at the front of the production process because it is less effort to remove items from the production process downstream of the process bottleneck than to prevent a large build-up of parts prior to the bottleneck.

Charts were also constructed for each ship type to graphically illustrate the bottleneck location of the process. Figure 5-5 shows an example of one of these charts.

These figures show the distribution of bottleneck locations for the sections examined for each ship type. For example, consider a ship type where the bottleneck location was the bevelling tables 50% of the time and the plate 3-D forming process 50% of the time. This means that for half of the sections, if the production process at IHC Metalix was only producing that specific section, the bevelling tables would be the bottleneck locations. For the other half of the sections, the plate 3-D forming sub-process would be the bottleneck if the production process was only producing any one of those sections.

These bottleneck location figures do not necessarily indicate what bottleneck location would occur in the production process of IHC Metalix if a variety of sections were being produced. Consider the example section of the previous paragraph. All parts which are being bevelled and 3-D formed need to be sorted by the sorting crane and cut by the plate cutting machines. Therefore, it is impossible to tell the bottleneck location of the production process of IHC Metalix when a variety of sections are being produced from these figures.

Appendix 11.4 contains the complete set of preliminary bottleneck location charts constructed from the PPA. This includes each of the examined ship types for both grinded and non-grinded sections and both the old and new process.

Figure 5-5 shows the preliminary bottleneck location for large beaver dredgers. This figure shows that for large beaver dredgers, the bottleneck was usually the profile cutting machine for non-grinded sections and the profile crane for grinded sections. The sorting crane was also the bottleneck for about 28% of the examined sections for the old process. After the new process was implemented, however, the number of sections for which the sorting crane was the process bottleneck was greatly reduced.

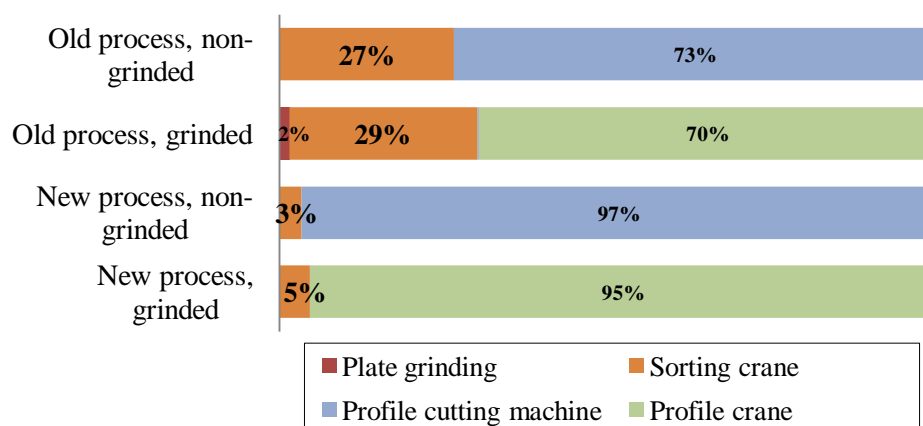


Figure 5-5: Preliminary Bottleneck Location, Large Beaver Dredgers

5.4.4 Significance of Production Capacities

Due to the large variety in section characteristics within a ship type, the standard deviation of production capacities calculated within a ship type is rather high. Therefore, error bars were not included on any of the figures in sections 5.4.5 to 5.4.8. Instead, a confidence analysis was performed to show that the difference between the real mean and calculated mean was within an acceptable confidence interval. Appendix 11.3 contains this calculation.

5.4.5 Influence of Ship Type

The influence of ship type on production capacity of the steel cutting and finishing process at IHC Metalix can be seen by comparing the averages of the preliminary production capacity distributions created in using the PPA. Figure 5-6 shows the influence of ship type on the production capacity for the old process for non-grinded sections.

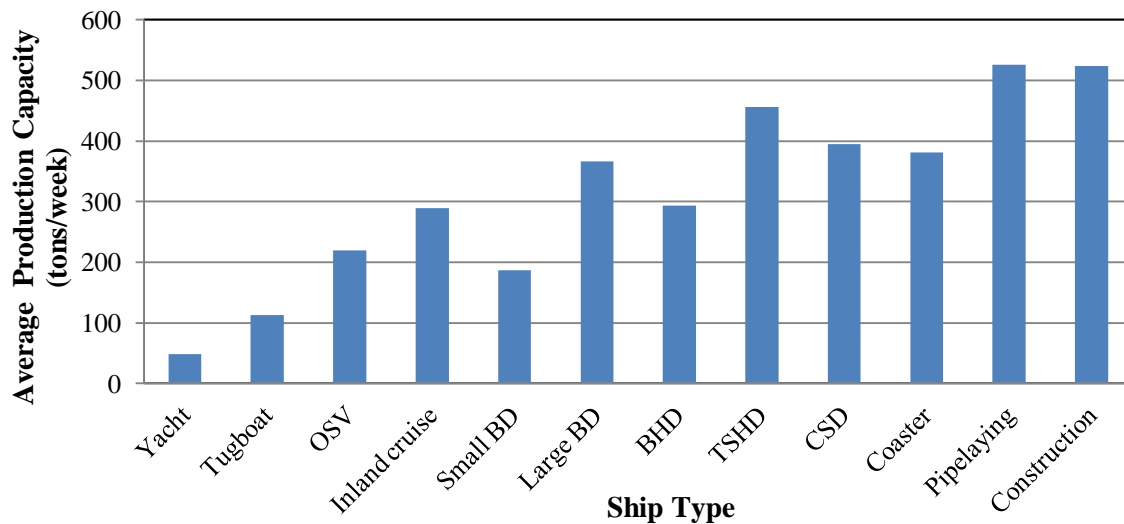


Figure 5-6: Influence of Ship Type on Production Capacity, Old Process, Non-Grinded

Figure 5-6 shows that the larger, simpler vessels have a higher average production capacity than the smaller, more complex vessels. The highest production capacities are realized by trailing suction hopper dredgers, pipelaying vessels, and construction projects. Sections for yachts and tugboats have the lowest production capacities.

5.4.6 Influence of Section Type

The average values of the preliminary throughput distributions constructed using the PPA can also be used to show the effect of section type on the total process throughput. Figure 5-7 contains the production capacity of each section type for non-grinded cutter suction dredger, trailing suction hopper dredger, pipelaying vessel, and coaster sections for the old process. This figure illustrates the influence of section type on production capacity for each of these ship types.

Figure 5-7 shows the production capacity of each vessel's section types as a percentage of the average production capacity of all sections of that vessel type. For example, Figure 5-7 shows that bow sections of trailing suction hopper dredgers take approximately 40% longer to produce than the average trailing suction hopper dredger section.

The production percentages of each ship type do not add up to 100%. This occurs because these vessels have significantly more midship sections than bow, stern, and superstructure sections.

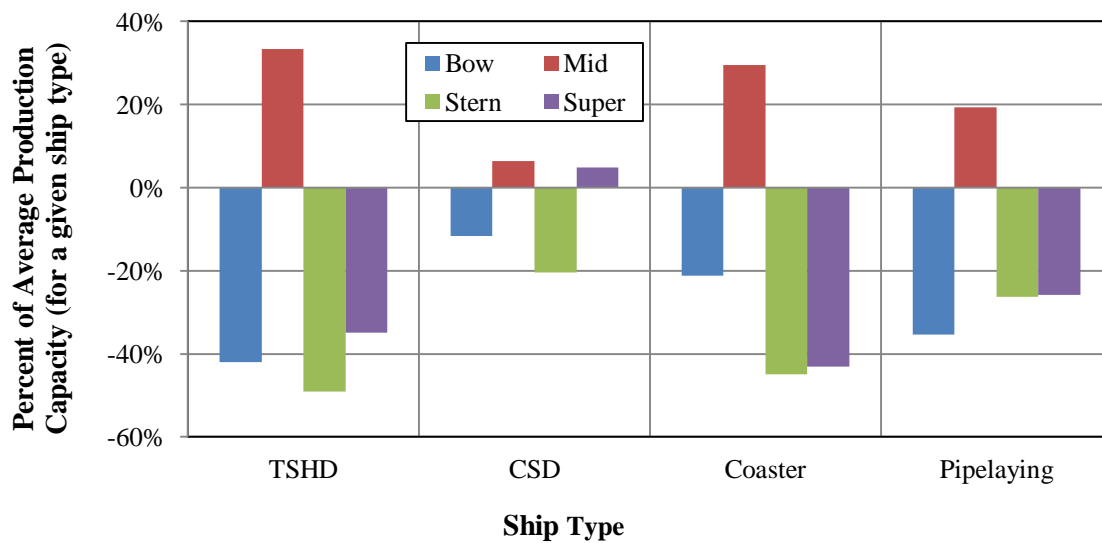


Figure 5-7: Influence of Section Type on Production Capacity, Old Process, Non-Grinded

Figure 5-7 shows that for trailing suction hopper dredgers, coasters, and pipelaying vessels, significant gains in production capacity are realized when producing midship sections. This occurs because these sections are generally the simplest sections with the least amounts of curvature.

For these three ship types, the production capacity of IHC Metalix is below average when producing the bow, stern, and super structure sections. The magnitude of this decrease varies between vessel types. This decrease in production capacity occurs because of the increased complexity of those sections.

Bow and stern sections require strong curvature to create the complex, energy-efficient hull forms found on modern vessels. These hull forms often feature bulbous bows and strongly tapered sterns designed to reduce the wave-making resistance of a vessel and optimize the inlet flow to the propellers. This curvature not only increases the requirement for 3-D formed parts, but also results in complicated structures composed of many small, unique parts. The stern sections also contain complex structures required to house and support the propeller shafts.

Superstructure sections are made of thinner material than hull sections. This means that more parts need to be cut to achieve a given capacity (in tons/week). These sections can also become complex, depending on the mission required of the machinery fixed to the superstructure. For example, pipelaying vessels are usually outfit with multiple towers, cranes, and spools above main deck which are needed to install pipelines.

This trend does not hold true for cutter suction dredgers. Although midship sections are still the fastest to produce for these vessels, the increase is small compared to the other three vessel types (only about 5%). This occurs because the midship section of these dredgers are

generally more complicated than those of the other vessels types since the midship sections of cutter suction dredgers must be designed to supply and manoeuver the cutter head.

Furthermore, the bow and stern sections of cutter suction vessels are relatively simple. Cutter section dredgers do not have the complicated bulbous bows found on the other vessels. Instead, these vessels have two barge shaped pontoons at the bow of the vessel supporting the cutter head. The sterns of these dredgers are also flatter to support the spud poles.

The superstructures of cutter suction dredgers cut at IHC Metalix are also fairly small and simple in construction. However, the increase in the production capacity of cutter suction dredger superstructure sections relative to midship sections shown in Figure 5-7 is mainly a function of the decrease in the production capacity of midship sections.

5.4.7 Influence of the New Process

By examining the average of the preliminary throughput distributions constructed for each ship type, it is possible to estimate the production capacity increase which will occur at IHC Metalix when the facilities are upgraded from the old process the new process. Figure 5-8 shows the average production capacity for each ship type for both the old and new process of IHC Metalix when only non-grinded sections are being produced.

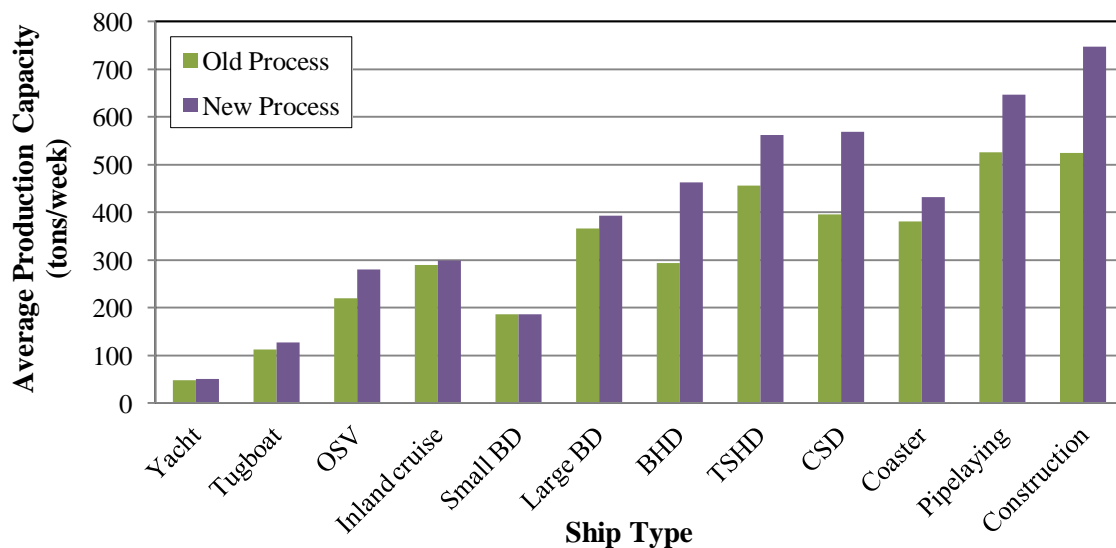


Figure 5-8: Absolute Production Increase Due to New Process Upgrades, Non-Grinded

Although Figure 5-8 indicates that the process improvements will increase the production capacity for most ship types, it is easier to visualize the production increases when examining the relative production capacities of the old process and the new process. Figure 5-9 shows the estimated percent production increase in terms of the average weekly output for each ship type, for both grinded and non-grinded sections. For example, Figure 5-9 shows that for grinded OSV sections, the relative production increase due to the process upgrades was approximately 30%. This means that when producing only grinded OSV sections, the new production process would produce 30% more tons per week than the old production process.

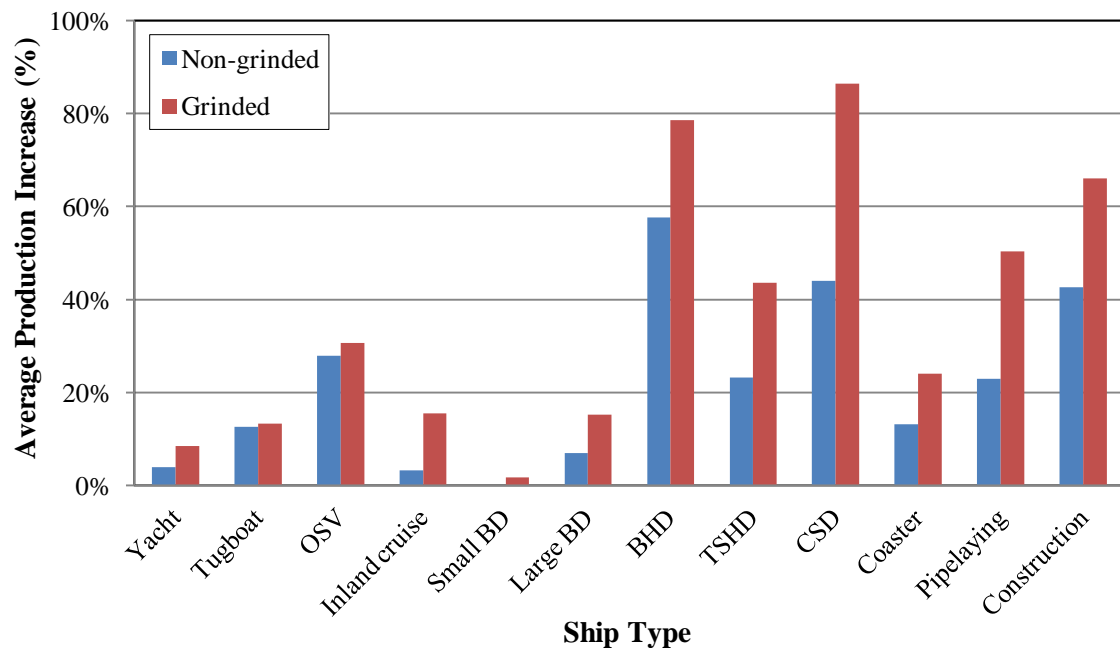


Figure 5-9: Relative Production Increase Due to New Process Upgrades

Figure 5-9 shows that production increases that result from upgrading the facilities at IHC Metalix range from 0% percent to 84% percent, depending on the ship type and grinding requirements. This figure also shows that larger, simpler ship types benefit more for the facility upgrades than smaller, more-complex vessels. This occurred because the bottleneck of the more complex vessels is usually the 3-D forming or profile production. None of the facility upgrades were targeted to improve productivity of these sub-processes.

Instead, the production upgrades were mainly focused on alleviating the load of the sorting crane and improving the grinding process. The bottleneck of the larger, simpler ship types was often the sorting crane, which explains why these ship types experienced a greater production increase. Furthermore, this explains why larger productivity gains are generally realized for grinded sections.

To illustrate the net effect of the process upgrades to the production process of IHC Metalix, the production increases shown in Figure 5-9 can be applied to the base portfolio. The base portfolio contains a distribution of ship types which represent the sections cut at IHC Metalix in the past year (between October 2011 and October 2012). Figure 5-10 shows the estimated net production increase when the production process of IHC Metalix produces sections distributed according to the base portfolio.

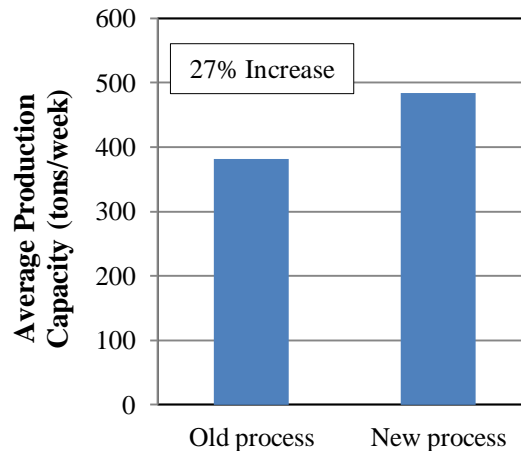


Figure 5-10: Production Increase Due to New Process Upgrades for Base Portfolio

5.4.8 Influence of Grinding

By examining the average of the production capacity distributions for both grinded and non-grinded sections, the decrease in production capacity can be estimated for each ship type when the sections must be grinded. Figure 5-11 shows the production capacity of the old process of IHC Metalix when both grinded and non-grinded sections of each ship type are being produced.

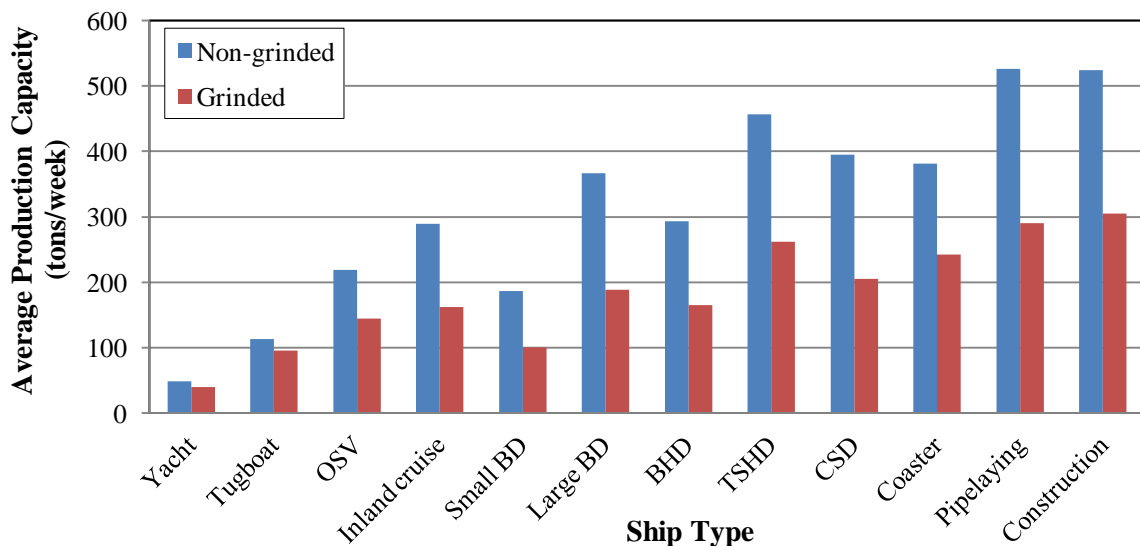


Figure 5-11: Absolute Production Decrease Due to Grinding, Old Process

Although comparing the absolute production capacities of non-grinded and grinded sections provides some insight into the effect of grinding on the production process, comparing the relative production capacities of each ship better illustrates this effect. Figure 5-12 shows the estimated production decrease due to grinding as a percentage of the non-grinded production time experienced by each of the examined ship types for both the old and

new process. On Figure 5-12, if a ship type has a 30% production decrease due to grinding, grinded sections of that ship type take 30% more time to produce than non-grinded sections.

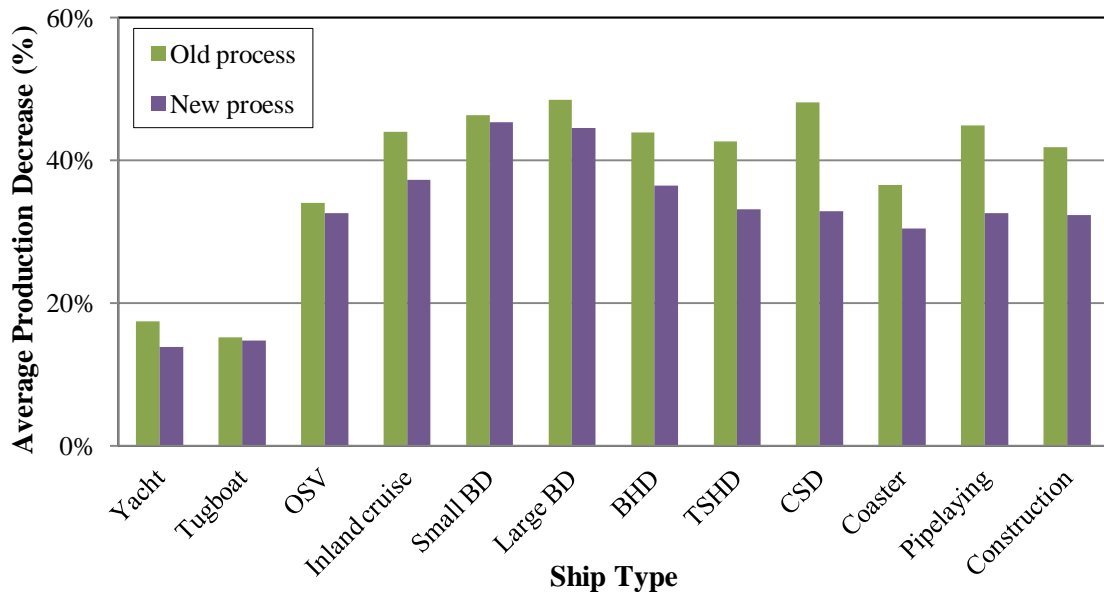


Figure 5-12: Relative Production Decrease Due to Grinding

The above figure shows that grinded sections take between 15% and 50% longer to produce than non-grinded sections. For every ship type, the production decrease due to grinding was greater for the old process than for the new process. This occurred because most of the process improvements implemented to create the new process focused on improving the execution of finishing tasks.

5.5 WEAKNESSES OF THIS ANALYSIS

Although the results obtained by performing the PPA provide valuable insight into the performance of the production process at IHC Metalix, the methodology used greatly oversimplifies the production process. As a result, the PPA cannot account for many important factors which influence the IHC Metalix production process. These factors include the following:

1. Does not account for batching. It only calculates the average work required over a given section and assumes this work is distributed evenly. Batches of a given type of product can greatly slow down production depending on which resources those products require.
2. Complex interactions between different processes and the cranes are not calculated. Instead, a calibration with uncertain effectiveness is used. This assumption could skew the calculated production capacity in either direction, depending on the direction of the error.

3. Does not determine utilization and influence of forklifts and MAFI (vehicle which moves flatracks). This would not affect the results unless these resources limited production during any stage of the production process.
4. Does not account for the interaction between different section types within an order portfolio. If the bottlenecks of the section types are different, then the actual production capacity may be higher than the production capacity calculated by the PPA.

The PPA also makes it very difficult and sometimes impossible to determine the effect of changes to the process on the total process throughput. Such changes include:

1. Varying the number of workers assigned to a given task, especially the multi-skilled grinding and bevelling tables in the new process.
2. Modifying sequence of sections produced or sequence of plates cut within a section.
3. Changing the speed at which plates are fed into the process in order to regulate the size of buffers.
4. Major process changes, such as the addition of a new crane or new production station.

Lastly, the PPA cannot indicate the bottleneck location of the production process of IHC Metalix when a variety of different sections are being produced. Instead, this analysis only determines the bottleneck location for each section individually assuming that only sections of that type are being produced.

To illustrate the potential effect of this assumption on the production capacity, consider a ship type which is composed of two sections, one composed of only plate parts (weighing 400 tons), the other of only profile parts (weighing 50 tons). Each section takes one week to produce.

The PPA would determine the production capacity of each of the sections individually, meaning that the production capacity of the sections composed of only plate parts would be dictated by the capacity of the plate cutting machines while the production capacity of the sections composed of only profile parts would be independently dictated by the capacity of the profile cutting machine. The production capacities are then averaged to determine the average production capacity of the ship type.

In reality, however, both of these machines would be running simultaneously. Buffers before the cutting machines allow the simulation to cope with temporary fluctuations in the number of uncut plates and profiles entering the process.

Figure 5-13 shows the production capacities for the sample ship type described above. In the real situation, both of these processes can run simultaneously, outputting a production capacity of 450 tons/week. The PPA, however, would average these two values, resulting in a production capacity of 225 tons/week. Although this example is extreme, it illustrates the major weakness of the PPA.

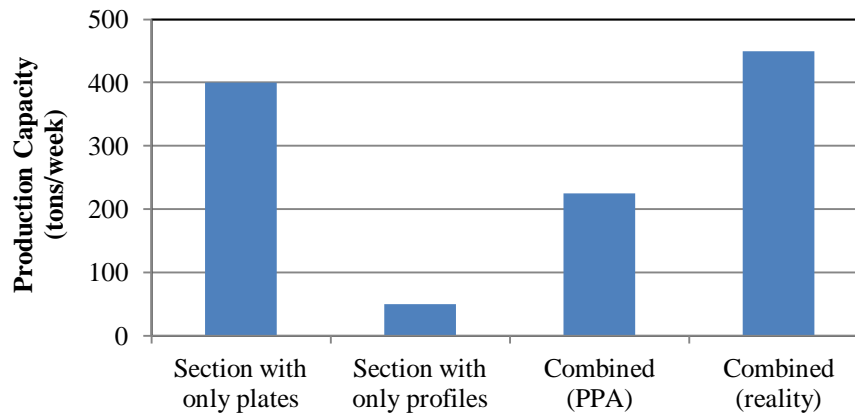


Figure 5-13: Production Capacities for Sample Ship Type

Although the PPA is helpful for gaining insights into the production characteristics of each section type, it is inadequate for analysing the total performance of the production process of IHC Metalix.

A simulation model does not rely on the simplifications used by the PPA. Therefore, using a simulation model can help mitigate or eliminate the errors introduced into the PPA by these simplifications. It is also much easier to quantitatively determine the effects of changes to the production process using a simulation model. As a result, a simulation model was used to complete a better analysis of the production process at IHC Metalix. A detailed description of the simulation model created can be found in section 6 *Simulation Model*.

All of the input information used to perform the PPA can still be used as input information into the simulation model. Furthermore, the results from the PPA will be used as a comparative tool to assess the validity of the simulation model.

Figure 5-14 shows the relationship between the production data, PPA, and the simulation model. This figure shows that the simulation model is based on the PPA of the new process, which was a modification of the PPA of the old process. The PPA of the old process was based on the available production data.

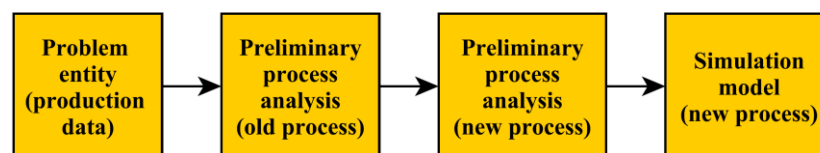


Figure 5-14: Relationship between Production Data, PPA, and Simulation Model

6 SIMULATION MODEL

6.1 BACKGROUND

In recent years, the use of computer simulation has greatly increased in the ship production industry. Using simulations alongside ship production can offer the following advantages [29]:

1. Quality improvement
2. Shortening of lead times
3. Reduction of production costs

In the case of the production process at IHC Metalix, a simulation model can be created to better understand the production process. The PPA outlined in the previous section gives valuable insight into the characteristics of the production process of IHC Metalix. However, this analysis relies on several key assumptions which simplify the production process. These assumptions are outlined in section 5.5 *Weaknesses of this Analysis*.

A simulation model is able to more accurately represent the complex interactions of the different elements of the production process. Therefore, the results of the simulation model rely on fewer assumptions than the results of the PPA. A simulation model can also be used to quickly test the impact of changes to the production process.

6.2 SYSTEM MODELLED

During the PPA, two situations of the production process at IHC Metalix were examined, the old process and new process. A detailed description of both of these systems and the differences between them can be found in section 4.1 *Description of Production Process*.

Although the characteristics of the sub-processes in these two processes are nearly identical, the movement of parts and sorting logic are very different. This means that separate simulation models would need to be constructed to model each of the systems. It is not possible to use the approach used for the PPA of making one model for the old process and then modifying that model to represent the new process.

A simulation model was only created for the new production process of IHC Metalix because the research question aimed to analyse the characteristics of this process. The PPA was used to bridge the gap between the available production data and the simulation model.

Unfortunately, the new situation was not fully installed at the conclusion of this research project. Therefore, it was not possible to directly validate the simulation model of the new situation against real production data. Instead, data taken directly from the production was validated against the PPA for the old situation. The simulation model of the new situation was then validated against the PPA of the new situation. Creating a separate simulation model of the old situation would not help validate the simulation model of the new situation since the two simulation models rely on vastly different sorting and flow logic. A detailed description of the simulation validation approach and results can be found in section 6.5 *Verification and Validation*.

6.3 SOFTWARE USED

The simulation model created for this project was created using FlexSim, an object-oriented simulation environment for modelling discrete-event flow processes [30]. Advantages of FlexSim over other simulation software include the following [3]:

1. Easy to learn
2. Strong statistical analysis
3. Good 3-D model visualization
4. Microsoft Excel integration
5. Compatible with CAD software
6. Strong technical capacity
7. Strong community support

FlexSim does have several disadvantages when compared to other similar simulation software such as Arena, ProModel, Plant Simulation, and Quest. These include [3]:

1. Relatively high application price
2. Poor implementation of custom extensions
3. Poor pre- and post-processing of data

Due to the lack of pre- and post-processing capabilities of FlexSim, Microsoft Excel was used to perform these tasks for this project.

6.4 DESCRIPTION

The simulation model is composed of two main elements: pre-processing and simulation. The purpose of pre-processing is to extract raw plate and part data from a database and prepare that data to be input into the simulation model. For this project, a Microsoft Excel worksheet was used for pre-processing. This worksheet allows the user to select which ship sections should be used in a simulation model run.

The simulation model itself takes the output from the pre-processing worksheet and calculates the production characteristics for those sections. The simulation model was based upon the flowcharts of the production process shown in section 4.1.3 *New Process*.

Appendix 11.5 contains a detailed description of the simulation model used to determine the production characteristics of the production process of IHC Metalix's Kinderdijk facilities.

Figure 6-1 contains a diagram showing the high level operation of the simulation model. This figure shows how the user interacts with the simulation model, what inputs are required, and what output is generated by the simulation model.

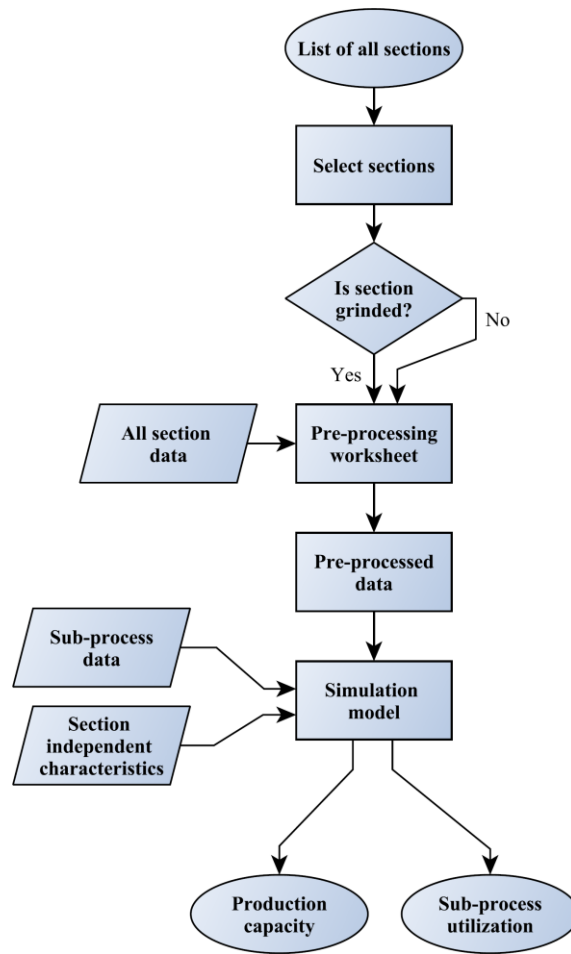


Figure 6-1: High Level Operation of Simulation Model

6.5 VERIFICATION AND VALIDATION

6.5.1 Description of Approach

The approach for verifying and validating simulation models proposed by Robert G. Sargent was used for this project. This validation methodology is based on a simplified version of the model development process [31]. Figure 6-2 contains a diagram of the model development process used by the Sargent simulation model verification and validation method.

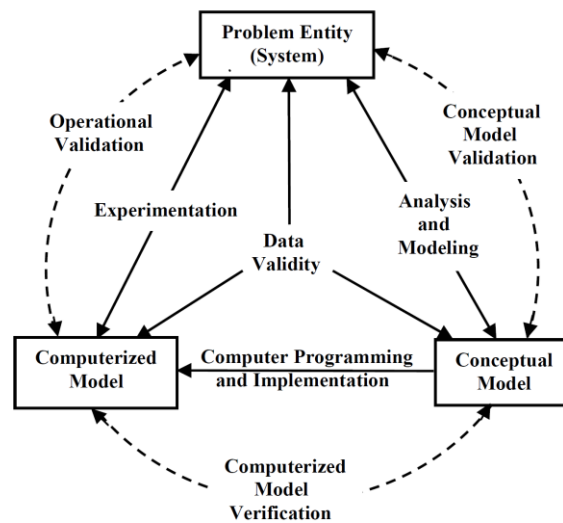


Figure 6-2: Simplified Version of the Modelling Process [31]

Figure 6-2 shows that the modelling process is composed of three main elements, which are connected by steps which must be taken to successfully develop a model. At the top of the diagram is the problem entity, which is the system whose behaviour is being studied. A conceptual model is developed to represent the problem entity using analysis and modelling techniques. The computerized model is created when the conceptual model is implemented on a computer through computer programming. The problem entity is studied using the computerized model through experimentation with the aim of better understanding the behaviour of the problem entity [31].

A validation or verification must be performed for each of these connections as well as for the data being used in the study to ensure that the simulation model is valid. The data validation is used to determine the validity of the data used in the computerized model. The purpose of the conceptual model validation is to ensure that underlying theories and assumptions of the conceptual model are acceptable and applicable. The computerized model verification is used to determine if the computerized model has been programmed to accurately represent the conceptual model, and the operational validation is used to ensure that the output produced by the computerized model accurately represents the behaviour of the problem entity [31].

6.5.2 Verification and Validation

6.5.2.1 Data Validation

The first stage of the validation process was to determine the validity of the data used in the model. The input data used by this project includes:

1. Process characteristics of sub-processes, such as process times, speeds, and capacities.
2. Section characteristics, such as part characteristics, finishing requirements, sorting requirements, and delivery method.

During the data collection phase of this project, the following steps were taken in an effort to ensure the data used in this project was valid:

1. Consistent procedures were used when directly measuring process times and characteristics directly from the production process. These procedures can be seen in appendix 11.7.
2. Measurements taken directly from the production process were checked against previously recorded data, where possible.
3. Data were filtered for error and data points containing errors were removed from the data set.
4. Trends in the collected data were presented to experienced personnel of IHC Metalix for feedback. For example, the order history of the past year presented in Figure 4-17 was checked with the marketing and production planning departments.

6.5.2.2 Conceptual Model Validation

After determining that the input data used in the simulation model was valid, the next step in the verification and validation process was to validate the conceptual model created for the production process of IHC Metalix. A conceptual model was created for both the old situation and new situation of the production process.

The conceptual model for the process was developed closely with personnel at IHC Metalix who have expert knowledge of the production system. The personnel regularly consulted while developing the conceptual model include:

1. Hylco Jellema: Servicedesk Manager in charge of managing process performance and KPIs
2. Robin Voorend: Innovation Engineer in charge of implementing upgrades to the production process (including those installed during the duration of this project)
3. Mathijs Bestebreur: Project Manager

Employees in the nesting, work preparation, material management, and production departments were also consulted as necessary while developing the model.

The conceptual model was visualized in the form of a flowchart. The flowcharts created to represent the conceptual model as well as an accompanying description can be found in section 4.1 *Description of Production Process*.

Once the conceptual models were completed, the detailed flowcharts outlining the behaviour of the model were discussed with Mr. Jellema and Mr. Voorend to ensure that the behaviour of the conceptual model adequately represented the production system at IHC Metalix.

A flow diagram was also created for the new process. This diagram was used as a basis for the simulation model of the new process. Appendix 11.6 contains this flow diagram.

A flow diagram was not created for the old process because no simulation model was created for this process. Section 6.2 *System Modelled* contains an explanation of why a simulation model was only built for the new process.

6.5.2.3 Computerized Model Verification

After the conceptual model upon which the simulation model of the new process was based was validated, a computerized model verification was performed on the simulation model of the new process. The purpose of this verification was to ensure that the simulation model programmed for the new process behaved according to the process flow diagram created for that situation.

Dynamic testing was used in order to ensure that the computerized model accurately represented the conceptual model. Dynamic testing involves running the computerized model under a variety of conditions to determine if the model behaves correctly [31].

The model behaviour was measured using animation and traces. FlexSim can generate a 3-D representation of the model as the model is running which shows the dynamic movements of items as the model runs. The animation was observed to ensure that items followed the correct path and that no items became stuck in the model. As an item in the simulation completed certain stages of the production process, a global table in the model was updated to indicate this movement. This table was used to trace the status of all items in the process. At the completion of a simulation run, this table could be checked to ensure that all items had been successfully processed.

Dynamic testing of the computerized model was conducted for the following conditions:

1. More than one hundred randomly selected sections were tested in the model in groups of one, five, ten, and twenty.
2. Mock sections were created to test extreme cases. The cases include:
 - a. Sections of all grinded, bevelled, pressed, and/or formed parts.
 - b. Sections of only large parts, small parts, or profiles.
 - c. Extremely large and extremely small sections.

In all of the examined cases, results of the dynamic testing showed that each part was routed to the correct sub-processes and exited the production process on the correct delivery unit.

Appendix 11.8 contains a sample of the output of a trace verification performed on the simulation model.

The results from the simulation model when processing the mock sections were also compared against the expected results using capacity calculations. The production capacities for these mock situations can easily be calculated because they represent an oversimplification of the production process.

Figure 6-3 shows the expected and realized results from running the mock uniform sections through the simulation model. This figure shows that for all examined cases, the production capacity calculated by the simulation model closely matches the expected production capacity.

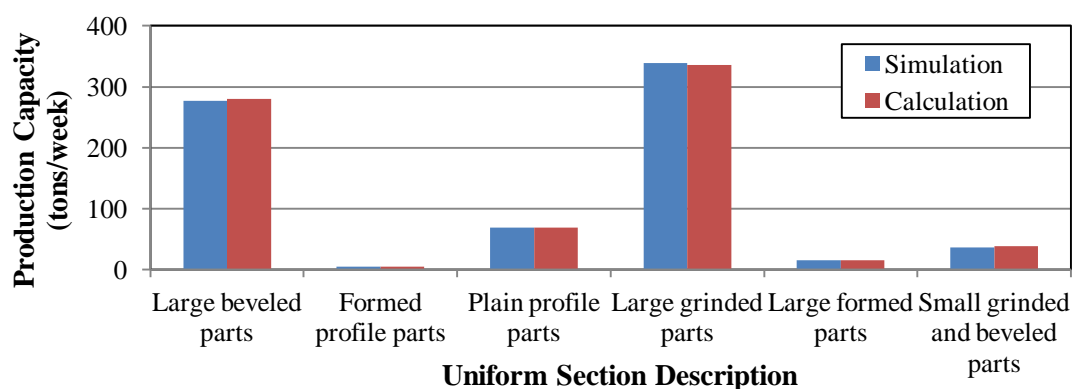


Figure 6-3: Results of Mock Uniform Sections

6.5.2.4 *Operational Validation: Validation of Sub-Processes*

The first step of the operation validation was to validate that the characteristics of the sub-processes being modelled matched those of the production process. All of the data used by the PPA and the simulation model was collected at one level deeper than used by the models. This data was measured directly from production, and was input directly into the model. For example, instead of determining the required time for the sorting sub-process, the time of a crane lift and the number of crane lifts required was measured. These values were used in the simulation model to calculate the required time of the sorting process.

Therefore, it is not necessary to validate the characteristics of each sub-process against production data. Such a validation would only show that the simulation was performing the required calculation correctly. This type of analysis is part of the computerized model verification. A detailed description of this verification can be found in section 6.5.2.3 *Computerized Model Verification*.

To demonstrate that the sub-process characteristics rely directly on the data measured from process, an operational validation was performed for the profile cutting sub-process. Figure 6-4 contains the result of this validation. This figure shows that the distribution of the

profile cutting sub-process times measured from the production process matches those sub-process times generated by the simulation model.

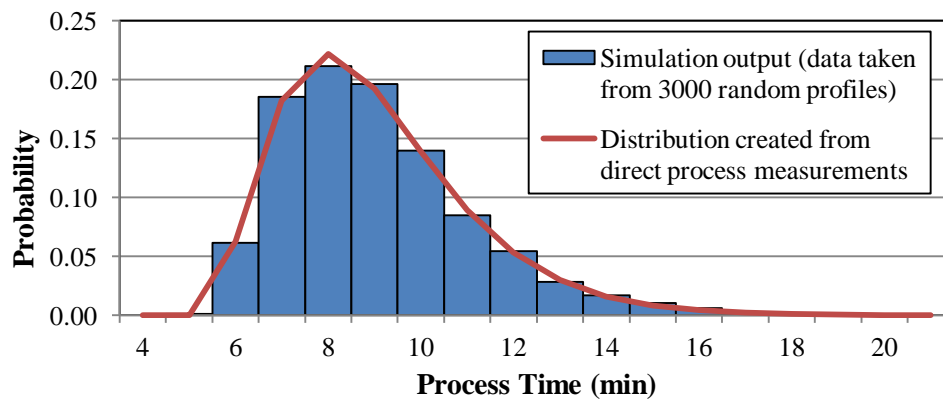


Figure 6-4: Operational Validation of Profile Cutting Machine Sub-Process

Because the sub-process characteristics were measured from the production process at one level deeper than modelled in the simulation, the sub-processes are inherently operationally valid. Therefore, these sub-processes will remain valid regardless of how the parts flow through the system. This means that the sub-process times for the new situation will remain valid, even though the sub-process times were measured when the production process of IHC Metalix was operating as the old situation.

6.5.2.5 *Operational Validation: Production Data to PPA (Old Process)*

The next step of the operational validation is to validate the production data against the PPA of the old process. The production data represents the problem entity because this data was taken directly from the performance of the production process of IHC Metalix. A comparison of the production capacities determined using these two methods is shown in section 5.4.1 *Validation of Calculation*.

This section contains Figure 5-3, which shows that the average production capacity calculated for the parts produced between October 2011 and October 2012 roughly matches the achieved production capacity of that period. Therefore, the PPA of the old process was operationally valid to the production data.

6.5.2.6 *Operational Validation: PPA (Old Process) to PPA (New Process)*

After the PPA of the old process was validated directly against the production data, it was necessary to validate the PPA of the old process against the PPA of the new process. It was not possible to validate the PPA of the new process directly against the production data because the process upgrades were not yet fully operational at the time of the conclusion of this research.

As long as the sub-processes remain valid for the PPA of both the old and the new process, the PPA of the new process is operationally valid with the PPA of the old process.

Section 6.5.2.4 *Operational Validation: Validation of Sub-Processes* contains a detailed explanation of validation of the sub-processes.

6.5.2.7 Operational Validation: PPA (New Process) to Simulation Model (New Process)

The final step of the operational validation is to validate the PPA of the new process against the simulation model of the new process. The simulation model could not be directly validated against production data since such data did not yet exist at the time this report was written. No production data existed because the improvements to the production process at IHC Metalix which were modelled in the computerized model had not yet been fully implemented.

To perform this validation, each of the twelve ship types examined by this project was individually validated. This validation was performed based on the different ship types because the production characteristics of the different ship types directly influenced the research question. The computerized model was considered to be operationally valid if each of the ship types examined was found to be valid.

To perform this validation, the following procedure was used:

1. A selection of sections were taken from a given ship type. Usually, between 20 and 30 sections were taken to try to maximize the variety of sections without slowing down the run time of the model. Data availability and time restrictions both prevented significantly larger data sets from being used. The sections were selected with the following objectives:
 - a. As diverse a selection of sections as possible should be made with respect to size, section type, order number, and predicted production capacity.
 - b. The selected sections should have close to the same average predicted production capacity as the examined ship type. The purpose of this requirement was to ensure that on average the selected sections had similar production capacities to the examined ship type.
2. The selected sections were run through the simulation model and the production capacity calculated by the simulation model was recorded.
3. The previous step was repeated while randomly varying the order the sections were input into the simulation model. This was done to ensure that different sections would be used to warm up the simulation model since production capacity is not measured during this stage.
4. The average of the production capacities calculated by the simulation model was compared to the predicted production capacity of the PPA.

It was expected that the simulation model would generally calculate average production capacities that were higher than those calculated using the PPA. This difference was expected due to one of the main assumptions made while performing the PPA. During this analysis, the production capacity was calculated for each section individually, and then the production capacities of all of the sections within a ship type were averaged in order to determine the production capacity of that ship type.

This approach, however, excludes any gains in production capacity which result from shifts in the bottleneck location. When a ship type is composed of sections with different bottleneck locations, the actual production capacity would be higher than that calculated by the PPA due to this assumption. The simulation model, however, does not rely on this assumption, and therefore this increase in production capacity is reflected in the simulation model results. A detailed example showing the potential effects of the shifts in the bottleneck location of the PPA results can be found in section 5.5 *Weaknesses of this Analysis*.

Figure 6-5 shows a comparison of the production capacities calculated using the PPA and the simulation model for each ship type. Only non-grinded sections were considered in this figure because most sections produced at IHC Metalix are currently not grinded. The comparison of ship types would be distorted if some ship types were grinded which others were not.

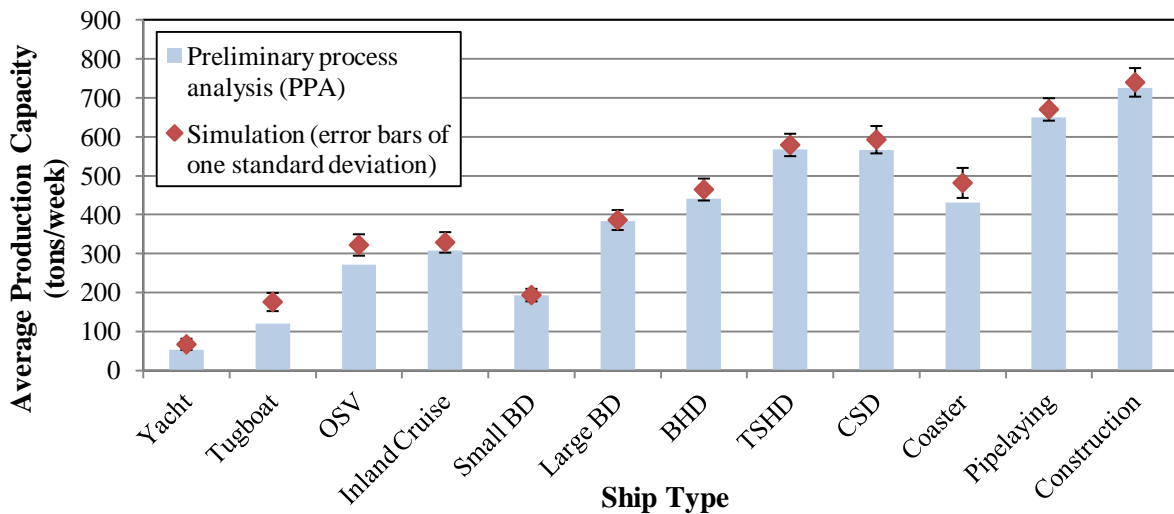


Figure 6-5: Operational Validation of Ship Types

Although Figure 6-5 shows that the same general trends exist between the production capacities determined using the simulation model and the PPA, the figure also indicates the production capacities calculated by the simulation model were higher than those calculated by the PPA. The degree of the difference varied between ship types, ranging from no significant increase to an increase of up to 30%.

In order to determine the production capacities using the simulation model, 15 simulation runs were performed per ship type. This was determined to be a sufficient number of simulation runs so that the calculated average became stable. Figure 6-6 shows the average production capacity of trailing suction hopper dredgers as a function of the number of simulation runs.

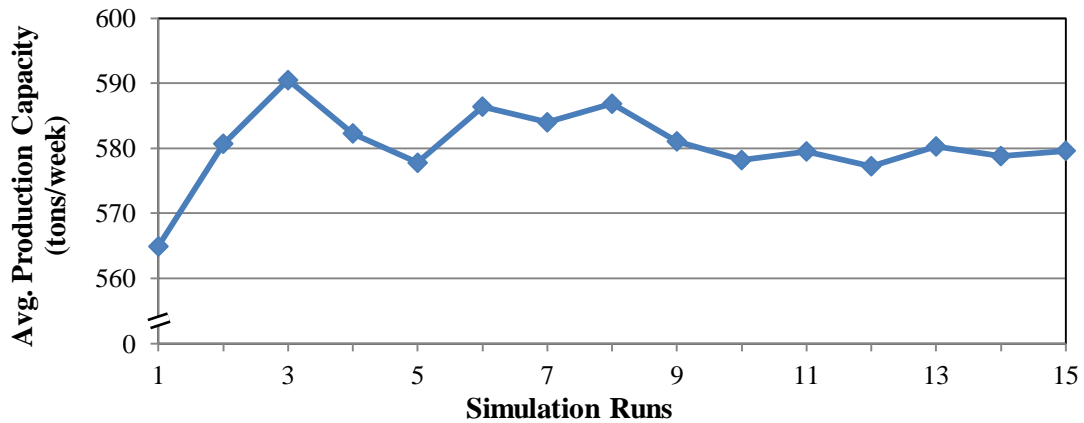


Figure 6-6: Effect of Number of Simulation Runs of Production Capacity of TSHDs

Table 6-1 shows the differences in production capacity between the PPA and the simulation model and the number of bottleneck locations calculated using the PPA. No difference in the production capacities of the two methods was expected for ship types that had the same bottleneck for most of its sections. An increase production capacity was expected for ship types with a significant number of sections having different bottlenecks. If a disagreement occurred between what was expected and what occurred, the simulation model was determined to be invalid for that ship type. If all ship types were determined to be valid, the simulation model was considered to be valid.

Table 6-1: Operational Validation of Ship Types

Ship type	Number of bottlenecks	Realized difference in production capacity
Yacht	2	13 tons/week
Tugboat	2-3	54 tons/week
OSV	3-4	50 tons/week
Inland cruise	2	21 tons/week
Beaver dredger (sml)	1	0.4 tons/week
Beaver dredger (lrg)	1	1.5 tons/week
Backhoe dredger	2	22 tons/week
TSH dredger	2-3	11 tons/week
Cutter suction dredger	2-3	25 tons/week
Coaster	3-4	49 tons/week
Pipelaying	2-3	19 tons/week
Construction	2	13 tons/week

Table 6-1 shows that the realized increase in production capacity is approximately proportional to the number of different bottlenecks found using the PPA. Tugboats are the only exception to this trend. These vessels have a significantly higher increase in production capacity relative to the number of bottlenecks than the other ship types. This occurred because about 60% of the tugboat sections contained a high percentage of parts which

required the profile hand process while the other 40% of the sections had no profiles which needed to be formed. The simulation model was able to spread the profile forming work out over all of the sections while the PPA merely averaged the production capacities of the different sections. Because tugboat sections had either no formed profile parts or a high percentage of formed profile parts, the increase due to the alternating bottleneck was exaggerated for this ship type.

The simulation model of the new process was determined to be operationally valid against the PPA of the new process. Although both methods produced slightly different results, these differences were expected.

6.5.2.8 Operational Validation: Summary and Conclusion

The simulation model of the new process was found to be operationally valid against problem entity. Figure 6-7 contains a summary of the steps taken to arrive at this conclusion. A detailed explanation of each step in the operational validation can be found in sections 6.5.2.4 to 6.5.2.7.

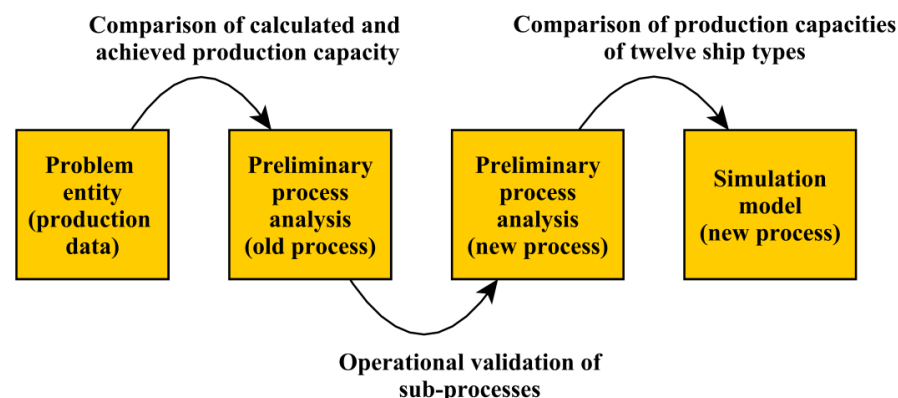


Figure 6-7: Summary of Operational Validation

The reason such a complex operation validation was performed for the simulation model was that no production data existed for the new process at the time this research presented in this report was concluded. It is strongly suggested that once such data become available, the simulation model of the new process be operationally validated directly against production data taken from the production process of IHC Metalix.

6.5.3 Conclusion

The modelling process used in this research project was found to be valid according to the model validation and verification structure outlined by Robert G. Sargent. The conceptual model created to represent the problem entity and the computerized implementation of the conceptual model both were determined to accurately reflect reality. Furthermore, the data used by these models was also deemed valid.

7 RESULTS

The following chapter contains insights into the production process of IHC Metalix found using the simulation model. Although it would be possible to gain similar insights regarding the production capacity of the process using the PPA, the simulation model was used because it relies on fewer assumptions. Therefore, the results of the simulation model should be more accurate than those of the PPA.

This chapter contains results of the following analyses:

1. Analysis of the production characteristics of different ship types. The purpose of this analysis is to determine the driving production characteristics of each ship type produced at IHC Metalix.
2. Order portfolio analysis examining the effect of adding and removing sections of a certain ship type of a base portfolio constructed to represent the average production state of IHC Metalix. The goal of this analysis is to be able to predict the changes in the production process at IHC Metalix as a result of shifts in the order portfolio.
3. An examination of several process improvements which could be implemented to the production process. The influence of these improvements on the production process is determined using the simulation model.
4. Analysis of the factors which could potentially have an influence on the production process. The aim of this analysis is to develop rules of thumb which can be used to help predict the production performance of new sections. This analysis was not part of the research question and was performed using only the available data.

7.1 SHIP TYPE CHARACTERISTICS

The simulation model was used to determine the production characteristics of each of the examined ship types. Section 6.5.2.4 *Operational Validation* contains a detailed explanation of the methodology used to determine the production characteristics of each ship type. These characteristics include:

1. The expected production capacity of the IHC Metalix facilities in Kinderdijk if only sections of a given ship type were produced.
2. The expected bottleneck location for this scenario and the percent utilization of that bottleneck.

7.1.1 Production Capacity

Figure 7-1 shows the average production capacity calculated for non-grinded sections of each ship type using the simulation model. This figure also contains error bars indicating the standard deviation of the results produced by the simulation model. These deviations were caused by random elements in the model, such as process times and differences between the characteristics of the sections used during the model run. A discussion about the methodology used to calculate these production capacities can be found in section 6.5.2.7 *Operational Validation: PPA (New Process) to Simulation Model (New Process)*.

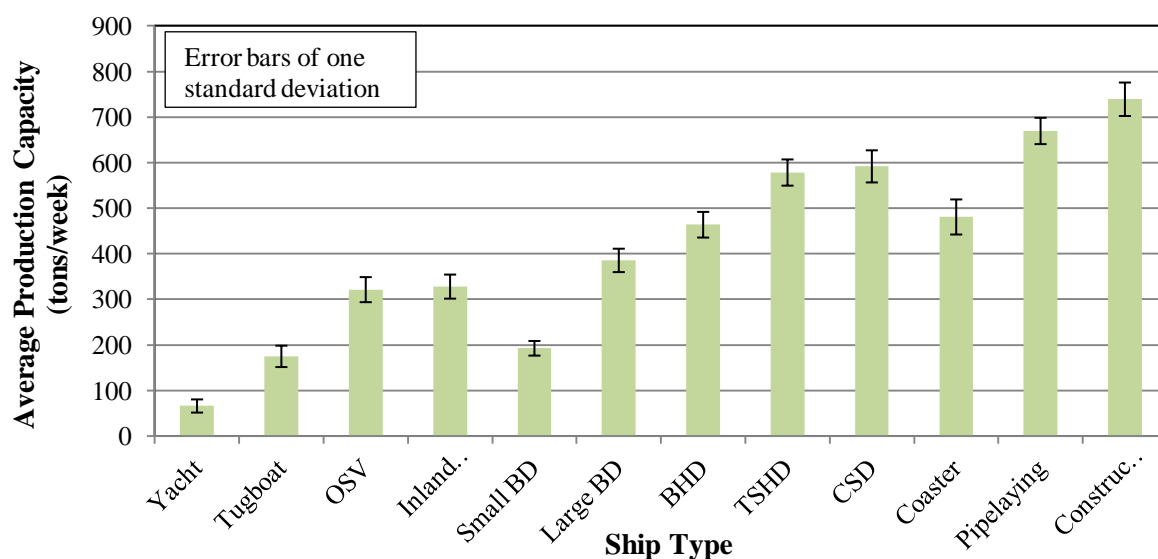


Figure 7-1: Influence of Ship Type of Production Capacity

This figure shows that ship type has a strong influence on the production capacity of the Kinderdijk facilities of IHC Metalix. Figure 7-1 indicates that smaller vessels with extremely formed hull shapes take more time per ton to produce than large vessels with relatively simple hull shapes. Therefore, the IHC Metalix production facilities have less production capacity when producing luxury vessels or small workboats than when large dredgers, pipelaying vessels, or construction projects are being produced. This information can be used by the sales, marketing, and production departments of IHC Metalix when making quick decisions about order pricing and process management when little other information is available.

The production capacities calculated for each ship type using the simulation model are very similar to those determined using the PPA. A detailed comparison of the production capacities calculated for each ship type using both of these two methods can be found in section 6.5.2.7 *Operational Validation: PPA (New Process) to Simulation Model (New Process)*.

7.1.2 **Bottleneck Location**

From a process management perspective, it is preferred that the bottleneck is located at the beginning of a process. This helps prevent a pile up of material in the production process. In the case of IHC Metalix, the plate and profile cutting machines are the initial sub-processes.

Table 7-1 contains the bottleneck location and utilization of that bottleneck that resulted when a group of sections of each of the examined ship types were run through the simulation model. This table shows that 3-D forming was the bottleneck for yachts and tugboats, the ship types with the lowest production capacities. Having the plate 3-D forming process as the bottleneck would result in additional process management effort.

For the remaining ship types, either the plate or profile cutting machines were the process bottleneck. This is ideal from the perspective of managing the process because the rest of the process should be able to smoothly handle whatever parts are cut by these machines.

This table also shows that the bottleneck utilization does not directly correlate with production capacity. For example, small beaver dredgers have a higher utilization of the profile cutting machines than construction projects, yet the production capacity of construction projects is almost four times greater than that of small beaver dredger sections. This occurs because the production capacity is a complex function of many factors. A description of these factors can be found in section 7.4 *Factors which Influence Process Performance*.

Table 7-1: Bottleneck Location of Ship Types

Ship type	Bottleneck location	Utilization
Yacht	Plate 3-D forming	87%
Tugboat	Plate 3-D forming	91%
OSV	Plate cutting machines	79%
Inland cruise	Profile cutting machine	87%
Beaver dredger (sml)	Profile cutting machine	98%
Beaver dredger (lrg)	Profile cutting machine	96%
Backhoe dredger	Plate cutting machines	80%
TSH dredger	Plate cutting machines	87%
Cutter suction dredger	Profile cutting machine	89%
Coaster	Plate cutting machines	90%
Pipelaying	Plate cutting machines	90%
Construction	Profile cutting machine	97%

The methodology for calculating the bottleneck location was fundamentally different for the simulation model and the PPA. When the bottleneck location was calculated for a ship type using the simulation model (shown in Table 7-1), a group of sections of that ship type were input into the simulation model, and the sub-process with the highest utilization was determined to be the bottleneck. The utilization of that bottleneck was taken to be the utilization of that sub-process from the simulation model run.

However, when the bottleneck location was calculated using the PPA (shown in Appendix 11.4), the bottleneck location was calculated for each individual section of a ship type assuming that only sections of that ship type would be produced. The percentages corresponding to each bottleneck location in Appendix 11.4 do not correspond to the utilization of those bottlenecks. Instead, these percentages correspond to the percentage of sections of a given ship type for which each process was the bottleneck.

Although the methodology for determining the bottleneck location used in the PPA provides some insight into the bottleneck location for each ship type, the simulation model calculates the bottleneck location to a much more realistic manner.

7.2 ORDER PORTFOLIOS

Although running the simulation model with a set of sections comprised of only one specific ship type gives valuable insight into the production characteristics of the ship types, this type of analysis does not directly provide results regarding the actual performance of the IHC Metalix facilities in Kinderdijk. To accomplish this, a series of order portfolios were created, and variations of these portfolios were run through the simulation model. Each examined portfolio was a deviation away from a base portfolio, which was designed to represent the sections cut in the past year (from October 2011 to October 2012).

The purpose of examining order portfolios is to be able determine the effect of changes in IHC Metalix's order book on its production process. This section was designed to answer the main research question.

7.2.1 Methodology

To perform this analysis, a representation of the base portfolio was created from 109 sections. These sections were selected with the goal of accurately representing the base portfolio in terms of the distribution of ship type and grinding. The size of the base portfolio was limited by the time required to run the simulation model. The base portfolio contains approximately 6 weeks of recordable production data (in addition to the time required to warm up and cool down the model).

To examine each order portfolio, sections of the highlighted ship type were added to the sections of the base portfolio. These modified base portfolios were then run through the simulation model. For example, to examine the effect of an increase in the number of coaster orders, additional coaster sections were added to the base portfolio. In order to get a more complete idea of the effect of each of the examined portfolios, the effects of removing sections of the highlighted ship types were also examined. For each portfolio, the effect of varying the percentage sections of the highlighted ship by 10% in either direction was examined. A shift of 10% was considered to be a large shift in terms of annual orders, since most orders are less than 5% of the annual order book of IHC Metalix.

The one exception to this methodology was the investigation into the effect of grinding. For this portfolio, the composition of the sections within base portfolio was unchanged. Instead, the grinding requirements of those sections were altered. The percentage of grinded sections was increased up to 70%. It is very unlikely that this level of grinding would ever be desired by the customers, since currently only 20% of sections are grinded.

Ten simulation runs were performed per data point. This was determined to be an adequate number of runs for the calculated production capacity to reach a stable level. Figure 7-2 shows the average production capacity calculated for the base portfolio as a function of the number of simulation runs.

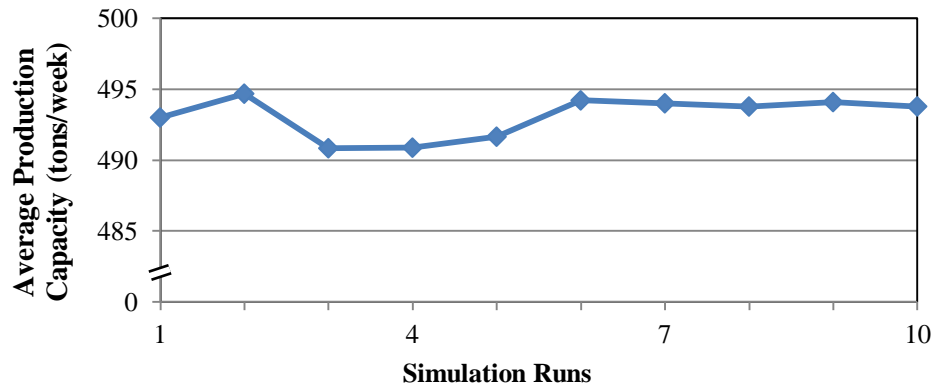


Figure 7-2: Effect of Number of Simulation Runs on Production Capacity of Base Portfolio

7.2.2 Portfolio 1: Grinded Sections

The first order portfolio examined how changing the number of grinded sections within the base portfolio influences the performance of the production process. Grinding is an important part of the shipbuilding process because the paint used to protect a vessel's steel structure does not adequately adhere to sharp edges. Therefore, all exposed sharp edges of a vessel need to be grinded [25]. In general, shipyards perform the required grinding prior to painting a compartment. However, it is also possible to perform some of the required grinding before the plates are welded together in sections. Grinding plates immediately after cutting offers the following advantages [27]:

1. Increased efficiency since grinders work in an open space, free of awkward positioning, cramped working conditions, and vibrational interactions.
2. Increased worker safety for the above mentioned reasons.

A vessel is also required to have properly grinded and painted steel according to the IMO Performance Standard for Protective Coatings (IMO PSPC). This standard is an amendment to the SOLAS convention, which ensures safe vessel construction and operation [26].

IHC Metalix offers clients the service of grinding steel parts before delivering cut plates and profiles to the customer [6]. The grinding at IHC Metalix takes place on open grinding tables where grinders can work safely and efficiently.

Due to the reasons mentioned above, customers can potentially benefit greatly by outsourcing some of the required grinding to IHC Metalix.

In the base portfolio, 20% of the sections were grinded, exclusively belonging to coasters and offshore support vessels. Figure 7-3 shows the effect the percentage of grinded sections has on the production process at IHC Metalix.

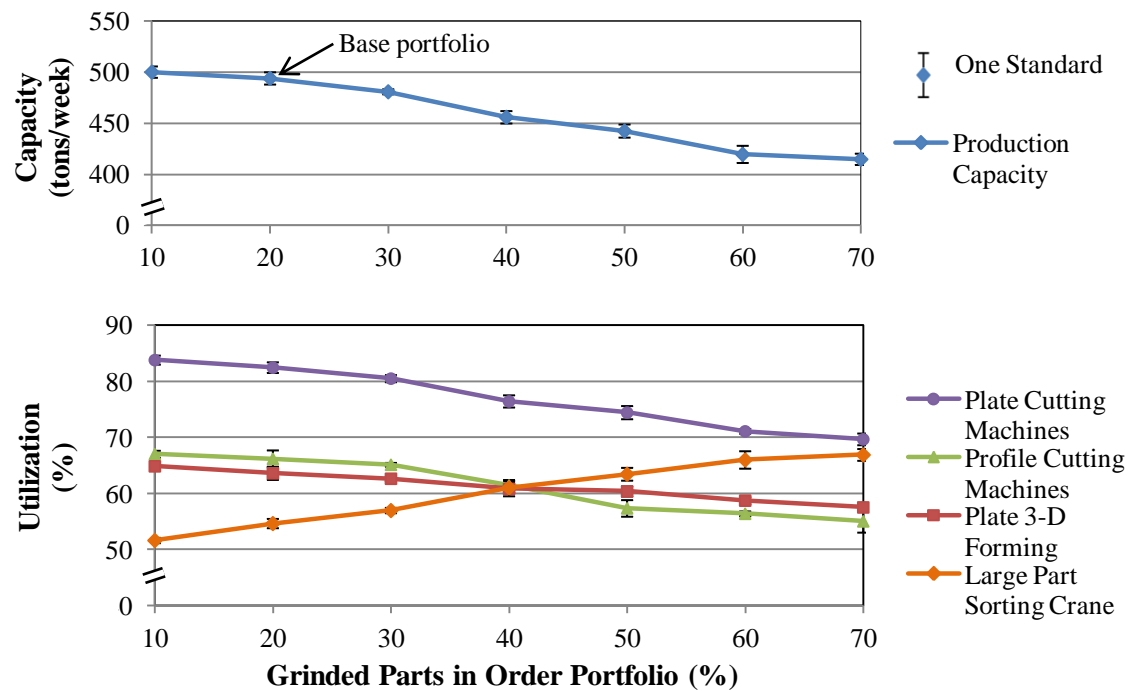


Figure 7-3: Effect of Order Portfolio 1, Grinded Sections

Figure 7-3 shows the production capacity of the process is slightly reduced as the number of grinded sections is increased from 10% to 30%. Between 30% and 40%, however, a steep drop in production capacity occurs.

Figure 7-3 also provides valuable insight into the effect of grinding on the process bottleneck location. At low levels of grinding, the plate cutting machines are the process bottleneck, with a utilization around 85%. As the amount of grinding is increased and the production capacity of the process decreases, so does the utilization of the plate cutting machines. The utilization of the profile cutting machines and plate 3-D forming also decrease, but the usage of the sorting crane increases.

Furthermore, none of the finishing tables are shown on the graph. The reason for this is that none of the grinding sub-processes ever achieve utilization above 35% for any of the examined cases. Instead, it is the large part sorting crane that ultimately slows down the process as the amount of grinding is increased.

The reason the sorting crane usage is strongly correlated with the number of grinded sections is that the sorting crane must move each grinded large part to and from the grinding tables. If there is no buffer before the grinding tables this results in one additional lift per large grinded part. However, if the grinding tables are temporarily backed up, two additional lifts by the large part sorting crane are required per large grinded part.

7.2.3 Portfolio 2: Dredging Orders

The second order portfolio was designed to examine the effect of changes in the number of dredging vessels on the production process of IHC Metalix. The dredging industry has continued to perform well in recent years despite the global economic recession which has

affected almost all industrial activity. Reasons for the continued success of the dredging industry include [32]:

1. Continued growth of industries which depend on dredging such as waterborne trade, urbanisation, and offshore energy.
2. Investment in new port infrastructure, especially in South America and Australia.
3. Continued harbour maintenance.

Predictions of the dredging industry created by International Association of Dredging Companies (IADC) show that the demand for dredging vessels will increase over the next decade [32].

IHC Merwede is the market leader in the design and construction of dredging equipment, offering dredging vessels ranging from 12 meter beaver dredgers to the world's largest self propelled dredgers [33] [34]. The potential growth in the dredging industry coupled with IHC Merwede's position within that industry could result in an increase in the amount of dredging projects completed by IHC Metalix in the upcoming years.

Dredging vessels include trailing suction hopper dredgers, cutter suction dredgers, beaver dredgers, and backhoe dredgers. In the base portfolio, dredging vessels comprise approximately 37.5% of all orders. To examine this portfolio, dredging orders were added to and removed from the base portfolio. Effort was taken to proportionally add and remove orders based on the individual ship type. Figure 7-4 shows the influence of the percentage of dredging orders on the production process of IHC Metalix.

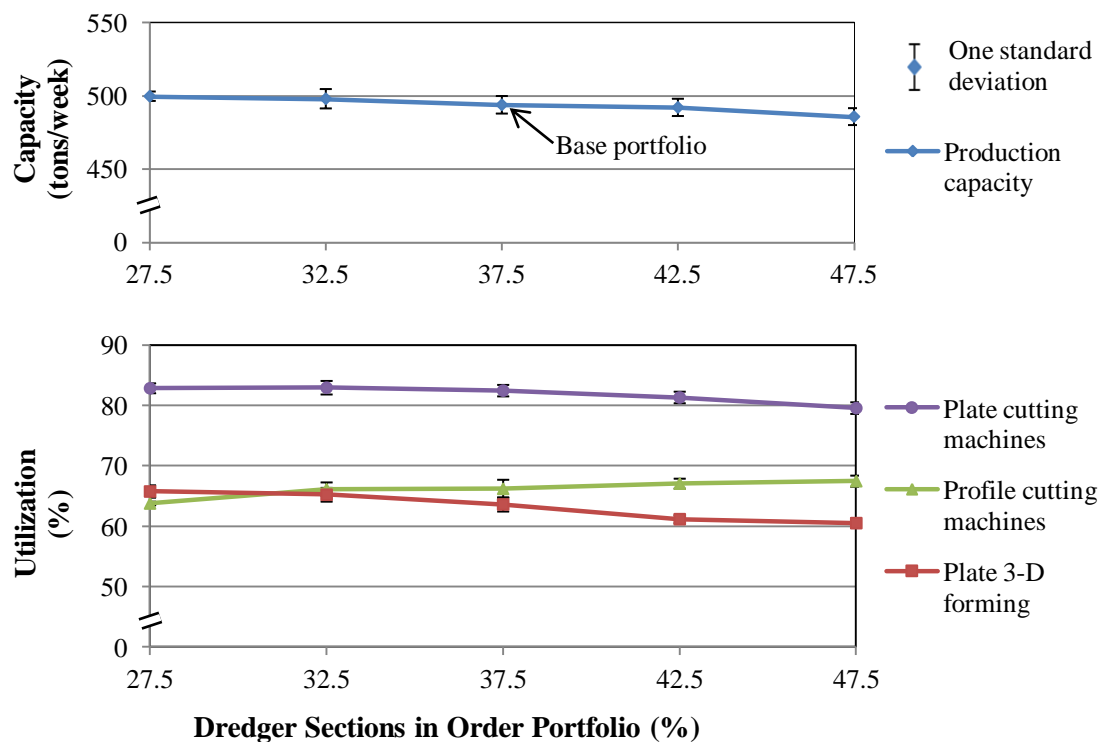


Figure 7-4: Effect of Order Portfolio 2, Dredging Orders

The above figure shows that adding additional dredging vessels to the order portfolio only slightly reduces the production capacity of the process. Reducing the number of dredging orders slightly increases the capacity of the production process. The reason this shift is so slight is that cutter suction dredgers and trailing suction hopper dredgers have slightly above-average production capacity while backhoe dredgers and beaver dredgers have below-average production capacities.

Figure 7-4 also shows that the plate cutting machines were the bottleneck over the entire examined range. This figure also shows that the utilization of the profile cutting machines is proportional to the number of dredgers and the utilization of the plate 3-D forming stations is inversely proportional to the percentage of dredgers in the base portfolio. This means that on average, dredging vessels have less 3-D formed parts and more profile parts than the other vessel types.

7.2.4 Portfolio 3: Offshore Orders

This order portfolio examines the effect of variations in the number of offshore vessel orders. The global demand for energy continues to increase, and offshore oil and gas production is one of the fastest growing industries poised to help meet this demand. In the next 10 years, this trend will continue as traditional on-land oil reserves diminish further and offshore oil companies drill in deeper waters [35].

IHC Merwede has designed and built a wide range of vessels which supply the offshore oil and gas industry including pipelaying, cablelaying, well intervention, offshore support, and diving support vessels. In the past year, the majority of the offshore tonnage build by IHC Merwede has been pipelaying vessels [18]. IHC Metalix has also cut the steel for a pair of ice breaking multipurpose offshore support vessels built by Royal Niestern Sander Shipyard [36].

Approximately 20% of the parts cut at IHC Metalix belong to offshore vessels, the bulk of which belong to pipelaying vessels. To analyze this portfolio, sections from offshore orders were added to and taken from the base portfolio. Figure 7-5 contains the results of the analysis made for this order portfolio using the simulation model.

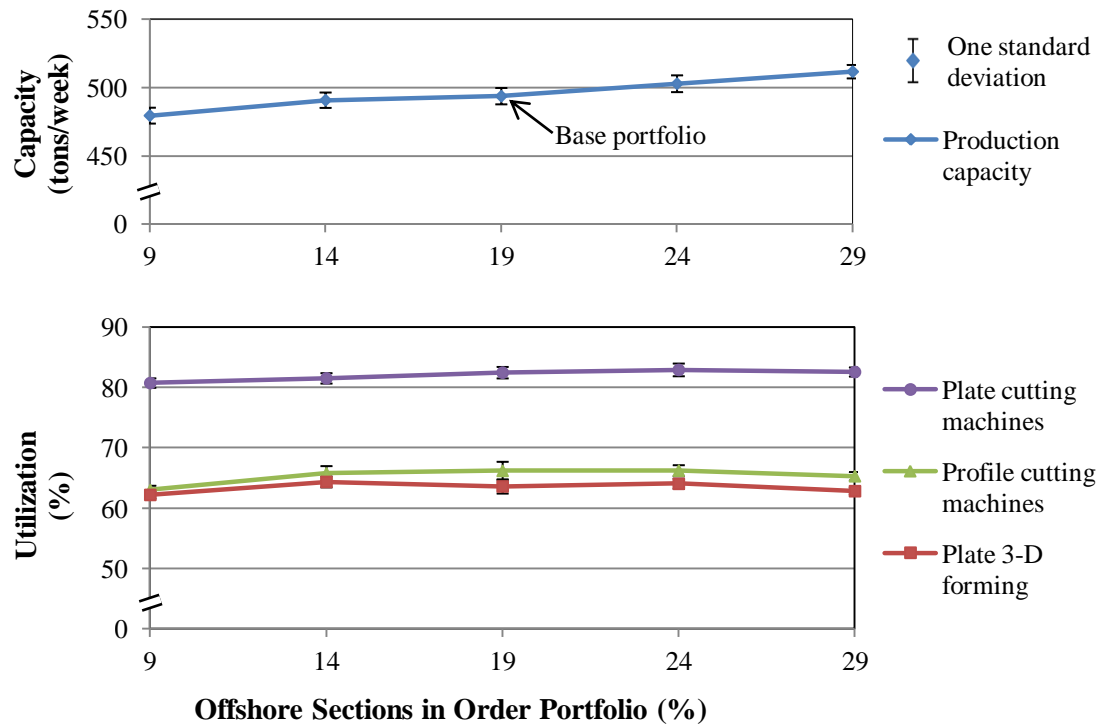


Figure 7-5: Effect of Order Portfolio 3, Offshore Orders

A fairly strong positive correlation between offshore orders and overall production capacity is shown on Figure 7-5. This occurs because pipelaying vessels have the second highest production capacity of the examined ship types (after construction projects).

Figure 7-5 also shows that the plate cutting machines were the bottleneck over the entire examined range, with a utilization between 80% and 85%. The utilization of the profile cutting machines and plate 3-D forming remained relatively constant as offshore sections were added to and removed from the base portfolio. This indicates that offshore sections have roughly average amounts of 3-D formed and profile parts compared to the rest of the base portfolio.

7.2.5 Portfolio 4: Shipping Vessel Orders

The shipping vessel order portfolio was designed in order to examine the effects of shifts in the number of coaster orders on the production process of IHC Metalix. The shipping industry is vital to the success of the global economy because this industry is necessary to transport goods and resources between producers and consumers. As the world population continues to increase, so will its needs for cheap and efficient transportation [37]. Coasters are an integral part of the global shipping industry, moving cargo relatively short distances (compared to deep water vessels) between coastal ports.

Approximately 30% of the steel cut at IHC Metalix in the past year was part of a coaster. Also, nearly 90% of the grinded sections cut in the last year belonged to coasters. The effect of adding and removing coaster sections from the base portfolio can be seen in Figure 7-6.

While adding and removing coaster sections, care was taken to maintain the same proportion of grinded to non-grinded sections as existed in the base portfolio.

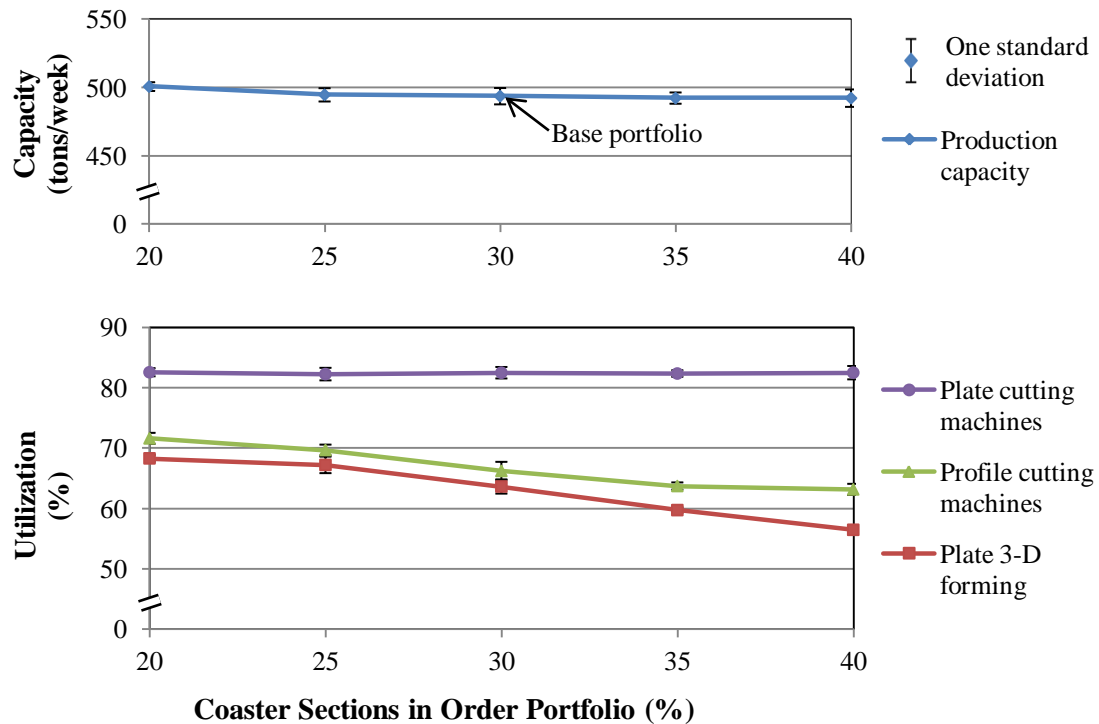


Figure 7-6: Effect of Order Portfolio 4, Shipping Vessel Orders

Figure 7-6 shows that the production capacity calculated by the simulation model is fairly independent to the addition and removal of coaster sections. The graph only shows a very minor decrease in production capacity. This occurs because the calculated production capacity of only coaster sections is only slightly less than the production capacity of the base portfolio.

The above figure also indicates the cutting machines are the bottleneck over the entire examined range. The utilization of these machines does not significantly change as the number of coaster sections in the base portfolio is varied. The utilization of both the profile cutting machines and the plate 3-D forming sub-process decrease as the number of coaster sections increase. This indicates that in general coaster sections have less profiles and formed parts than the average section in the base portfolio.

7.2.6 Portfolio 5: Luxury Vessel Orders

The fifth order portfolio examined the effect of luxury vessels orders on the production process at IHC Metalix. The number of annual deliveries of superyachts has been decreasing over the past few years, mainly due to the current economic downturn [38][39]. Similar trends have been observed for inland cruise vessels. However, it is possible for certain luxury markets to grow even during times of reduced economic activity [40]. Furthermore, if the global market begins to recover, the demand for luxury ships could also increase.

Luxury vessels include yachts and inland cruise ships. In the past year, these vessels only comprised a small portion of the total orders, roughly 2.5%. The effect of adding additional luxury vessel sections to the production process at IHC Metalix can be seen in Figure 7-7.

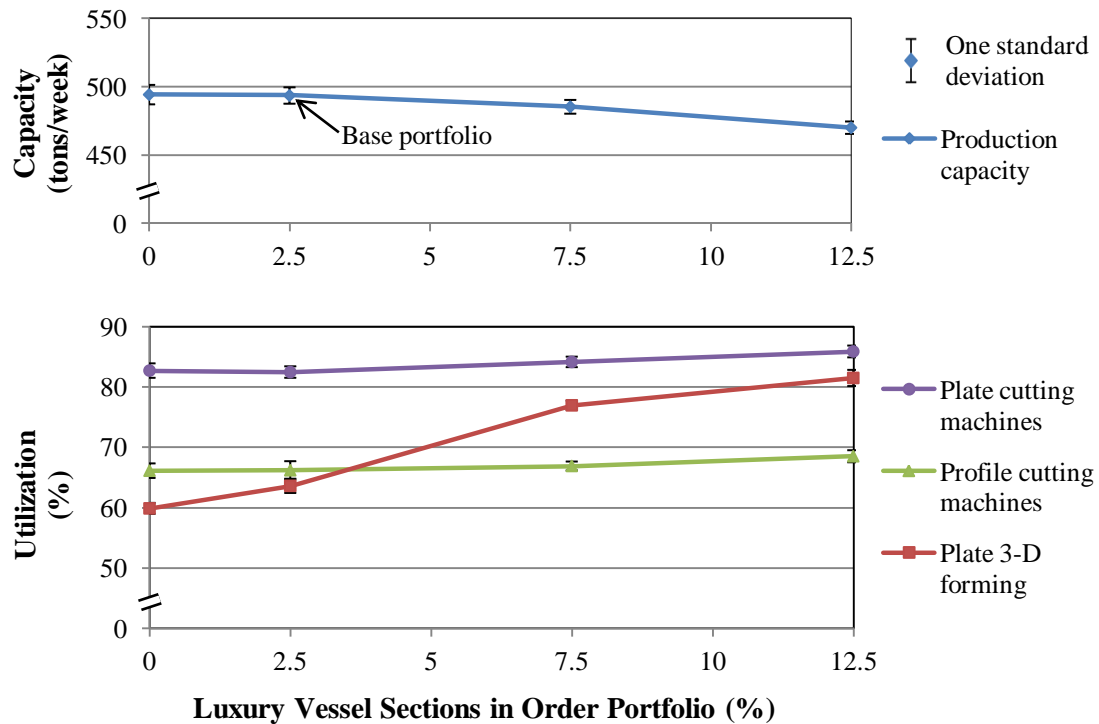


Figure 7-7: Effect of Order Portfolio 5, Luxury Vessel Orders

This figure shows that adding sections of luxury vessels to the base portfolio decreases the production capacity of the steel cutting and finishing process at IHC Metalix. Only a slight drop in production capacity occurs as the number of luxury vessel sections is increased from 2.5% of the total orders to 7.5%. As the number of luxury vessel sections is increased to 12.5%, however, a much larger drop in production capacity occurs.

This behaviour is explained by the utilization of the plate 3-D forming sub-process. Luxury vessels have a very high number of formed parts due to their complex hull shapes. Figure 7-7 indicates that as the number of luxury vessels is increased, the utilization of the 3-D forming sub-process increases rapidly. As the number of luxury vessel sections is increased up to 12.5%, the utilization of the 3-D forming sub-process approaches the utilization of the plate cutting machines, the bottleneck of the system. At this point, the system starts having two alternating bottlenecks, which reduces the overall production capacity.

7.2.7 Portfolio 6: Construction Orders

This order portfolio investigates the effect of varying the number of construction project sections in the production process at IHC Metalix. The success of the shipbuilding industry is strongly linked to the shipping industry, which has been struggling since the economic

downturn in 2008. As a result, the total number of new vessel orders has been decreasing over the past few years [41]. This general industry trend could potentially affect IHC Metalix, shifting the company's order portfolio in the direction of non-shipbuilding projects.

Approximately 9% of the base portfolio is comprised of orders belonging to construction projects. Figure 7-8 shows the effect of varying the number of construction orders on the performance of the production process at IHC Metalix.

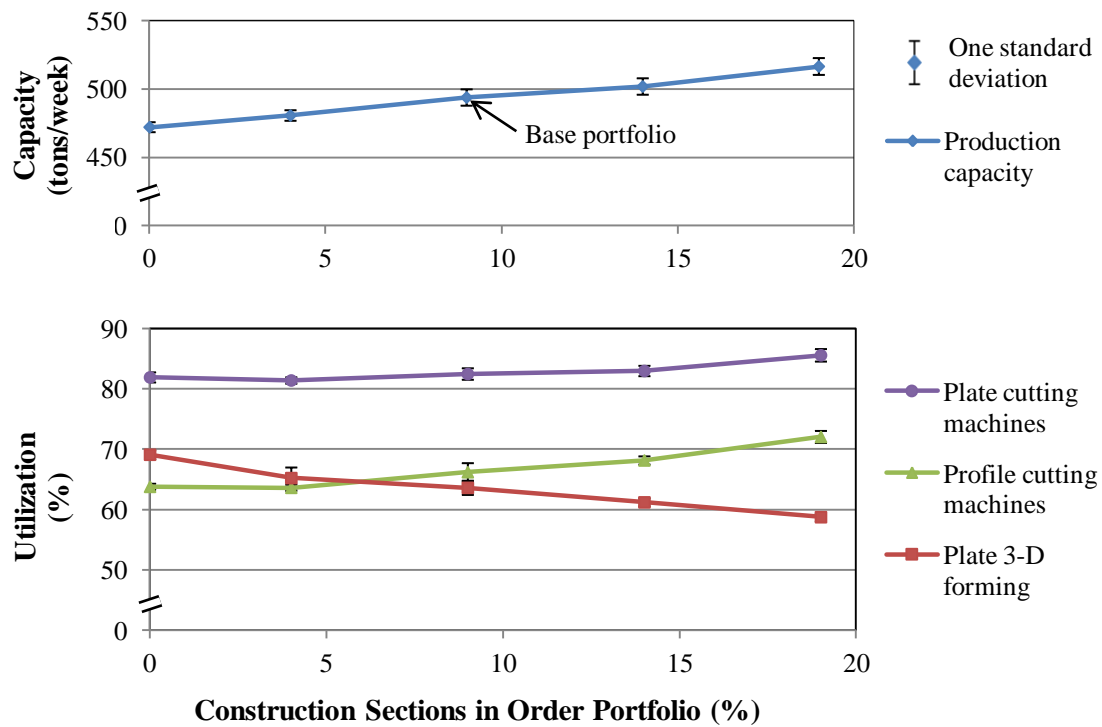


Figure 7-8: Effect of Order Portfolio 6, Construction Orders

Figure 7-8 shows that adding construction sections to the base portfolio increases the production capacity. Similarly, reducing the number of construction sections reduces the production capacity. This occurs because construction sections take the least effort per ton to produce of all of the examined ship types (as seen in Figure 7-1).

Figure 7-8 also indicates that the utilization of plate cutting machines increased slightly as the number of construction sections was increased. The plate cutting machines were the bottleneck over the entire examined range.

This figure also shows the utilization of the profile cutting machines increased as the percentage of construction sections was increased. This indicates that sections of construction projects contain more profile parts than the average section in the base portfolio.

Furthermore, Figure 7-8 indicates that the utilization of the plate 3-D forming sub-process decreased as the construction sections were added to the base portfolio. This means that construction projects have a below-average number of formed parts.

7.3 PROCESS IMPROVEMENTS

The following section examines the potential benefits to the production process of IHC Metalix of several process improvements. The goal of these improvements was to increase the production capacity of the process. This was done by alleviating the load of the process bottleneck.

The portfolio analysis performed in section 7.2 *Order Portfolios* determined that the plate cutting machines were the process bottleneck for all of the examined order portfolios. Therefore, the process improvements focused on increasing the productivity of the plate cutting machines.

One way to improve the production capacity of the process is to increase the utilization of the plate cutting machines. Usually when the cutting machines were idle, they were waiting on flatracks to be cleared out of the large part sorting area. Improvements can be implemented to the large part sorting area to reduce the amount of time this area is slowing down the plate cutting machines. These improvements include:

1. Including additional flatrack positions
2. Combining flatracks in the large part sorting area

The production capacity of the entire process can also be improved by reducing the processing time of the plate cutting machines, the process bottleneck. Currently, the plate cutting machine sub-process includes printing lines and text onto the uncut plates as well as cutting the plates. Although it is not realistic to reduce the processing time of the cutting process itself, the processing time of the plate cutting machines can be reduced in the following ways:

1. The efficiency printing algorithm of the integrated plate printer can be improved to reduce printing time
2. A separate plate printer can be installed to eliminate the printing portion of the cutting machine processing time

The weekly production capacity of the production process can also be increased by increasing the number of hours during which the plate cutting machine is operated. This can be accomplished by operating the plate cutting, finishing, and sorting process for three shifts.

Lastly, the load on the plate cutting machines could be reduced by installing an additional cutting machine to work in parallel to the four existing cutting machines. No space is available in the IHC Metalix Kinderdijk facilities, however, to incorporate an additional cutting machine in the existing process. Expanding the size of the production facilities was outside of the scope of this project. Therefore, the effect of installing an additional cutting machine was not examined.

The simulation model was used to implement and test the effectiveness of these process improvements. Each of these improvements was tested on the base portfolio. Examining these process improvements answers the last sub-question of the research question.

7.3.1 Additional Flatrack Positions

7.3.1.1 Description

The layout of the large part sorting area of IHC Metalix could be altered in order to accommodate up to two additional flatrack positions. Each flatrack position is composed of the floor space required to store large parts of that flatrack which require finishing, as well as the space required for the flatrack itself. Additional flatrack positions offer the following advantages:

1. More flatrack positions allow the large part sorting area to accommodate more unique flatracks at any given time. This increases the chance that the large part sorting area will be able to accept a plate waiting to be cut. As a result, fewer plates will wait outside of the cutting hall, increasing productivity.
2. Relatively little investment is required to implement this improvement.

In order to create space for additional flatracks, however, a large part finishing table would need to be removed per additional flatrack position. In the base portfolio, the average utilization of the large part finishing tables is less than 15%. Removing large part finishing tables would reduce the number of large parts which could be bevelled and grinded at a given time. Furthermore, the stay time of large bevelled and grinded parts would increase in the large part finishing queues.

However, in the event of a large influx of grinded parts to the large part sorting area, sawhorses could be temporarily setup in the additional flatrack positions. This would allow the additional flatrack positions to temporarily serve as grinding tables, increasing the capacity of the large part finishing sub-process. In this way, the main disadvantage of removing large part finishing tables to create additional flatrack positions is mostly mitigated. Using sawhorses as temporary grinding tables was not included in the simulation model of this process improvement.

7.3.1.2 Results

Figure 7-9 shows the effect of additional flatrack positions on the production process of IHC Metalix. The percent of grinded sections in the order portfolio was varied from 10% to 70% to fully understand the implications of removing large part finishing tables.

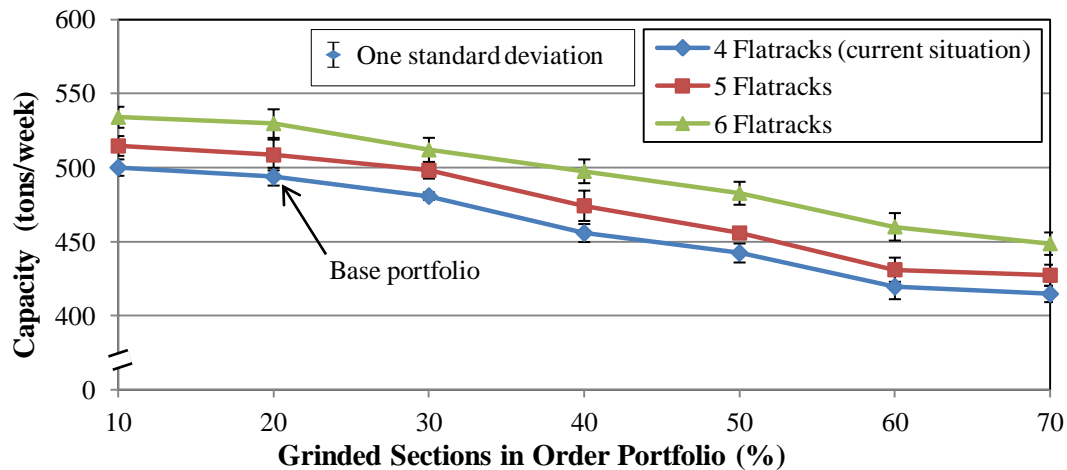


Figure 7-9: Effect of Additional Flatrack Positions

Figure 7-9 indicates that adding two additional flatrack positions results in the highest production capacity regardless of the number of grinded parts. The increase in production capacity was found to be approximately 3% per additional flatrack for each of the examined data points. This indicates that the advantages of having additional flatrack positions outweigh the drawbacks of having less large part finishing capacity.

It is recommended that IHC Metalix remove both grinding tables to make room for additional flatrack positions. The process has a large amount of excess large part finishing capacity, and therefore removing the tables does not hinder the production process. Increasing the number of flatrack position, however, reduces the idle time of the plate cutting machine, the process bottleneck. This improvement also requires almost no investment to implement.

7.3.2 Combining Flatracks

7.3.2.1 Description

In the large part sorting area, two flatracks could be combined to form one temporary flatrack. This would only be done with flatracks belonging to the same section. The flatracks would then be separated in the end sorting area. This process improvement offers the following advantages:

1. The number of flatracks which the large part sorting area could process at any given time increases. Having additional flatrack positions increases the production capacity of the process, as seen in section 7.3.1 *Additional Flatrack Positions*.
2. Relatively little investment is required to implement this improvement.

Combining two flatracks in the large part sorting area and separating those flatracks in the end sorting area also has the following disadvantages:

1. Additional end sorting lifts are required to sort out the different flatracks, increasing the load on the end sorting crane
2. Additional complication would be introduced into the end sorting process
3. More floor space is required in the end sorting area
4. Delivery times of two flatracks are tied together
5. Stay time of flatracks is increased in the large part sorting area

This process improvement could be further expanded by combining three flatracks of the same section in the large part sorting area. Although this would not increase the number of lifts required by the end sorting process, the complication of the end sorting area, floor space requirements of the end sorting area, and stay time of the flatracks in the large part sorting area would all further increase. Moreover, the delivery time of three flatracks would now be tied together.

7.3.2.2 *Results*

The effect of combining multiple flatracks in the large part sorting area is shown in Figure 7-10. This figure shows the effect combining two and three flatracks has on production capacity, the end sorting crane utilization, and the plate cutting machine utilization of the steel cutting and finishing process of IHC Metalix.

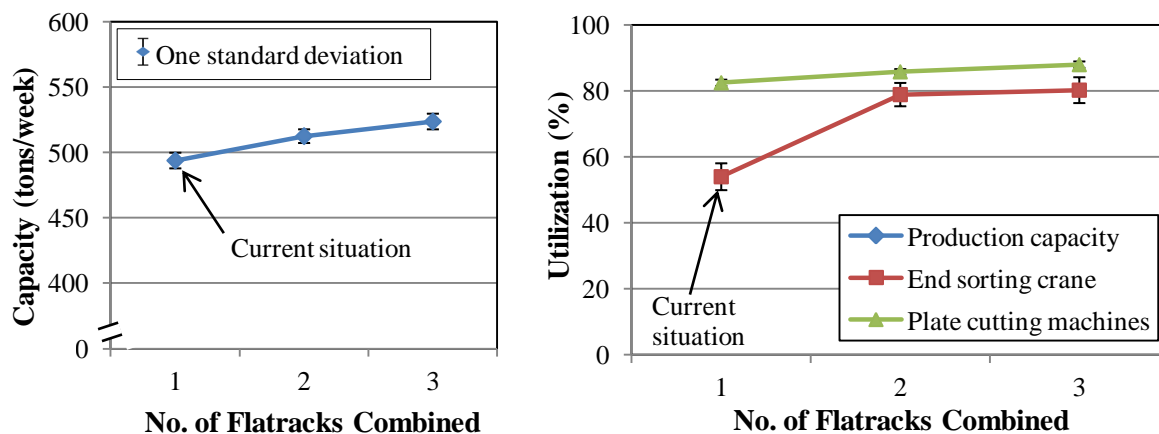


Figure 7-10: Effect of Combining Flatracks

The above figure shows that the production capacity increases by approximately 4% if two flatracks are combined in the large part sorting area and 6% if three flatracks are combined. This indicates that diminishing returns exist when combining flatracks. This mainly occurs due to the increase of flatrack stay time in the large parts sorting area that results from combining flatracks.

Figure 7-10 shows that the plate cutting machines remain the process bottleneck when flatracks are combined. When this process improvement is implemented, the utilization of

the end sorting crane increases from approximately 55% to 80%. Increasing the number of flatracks combined does not significantly increase the utilization of the end sorting crane. However, Figure 7-10 does not show the lost flexibility in the production process that results from making the delivery times of multiples flatracks dependent upon each other.

Furthermore, as the number of combined flatracks increases, the complication and required floor space of the end sorting operation increases. The effect of the increased floor space requirements and sorting complication were not included in the simulation. Table 7-2 shows the effect of combining flatracks on the available space for additional flatracks in the end sorting area.

Table 7-2: Effect of Combining Flatracks on End Sorting Space

No. of Flatracks Combined	Flatrack positions in end sorting area	Flatrack positions required for end sorting	Open spaces for additional flatracks
1	14	8-10	4-6
2	14	9-10	3-5
3	14	10-12	2-4

It is not recommended that IHC Metalix combine flatracks of the same section in the large part sorting area unless the production planning and management departments are confident that the increased load on the end sorting crane, the lost floor space, the increased end sorting complexity, and the tying of flatrack delivery times together will not hinder the production process.

7.3.3 Increasing the Efficiency of the Plate Cutting Machine Printers

7.3.3.1 Description

Currently, the plate cutting machines of IHC Metalix print the required lines and text onto the steel plates before cutting plates. This task is done with a vector plotter attached to the cutting head of the cutting machines. On average, the printing time of a plate takes approximately 40% of the total plate cutting sub-process time.

The vector plotter is not fully optimized to reduce the printing process time. At this point, little effort has been done to optimize the order the plotter prints the lines and text on the plate to reduce the travel time of the plotter while not printing. The exact reduction of printing time due to such an optimization is not known, but it is estimated to be between 10% and 50%.

Installing this improvement would only require the investment to create and implement the optimized printing algorithm. This improvement has no negative effects on the production process.

7.3.3.2 Results

The effect of improving the integrated printers on the plate cutting machines is shown in Figure 7-11. This figure shows the effect of reducing the printing time by up to 50% on the production capacity of the process at IHC Metalix. The utilizations of the most utilized sub-process are also shown on this figure.

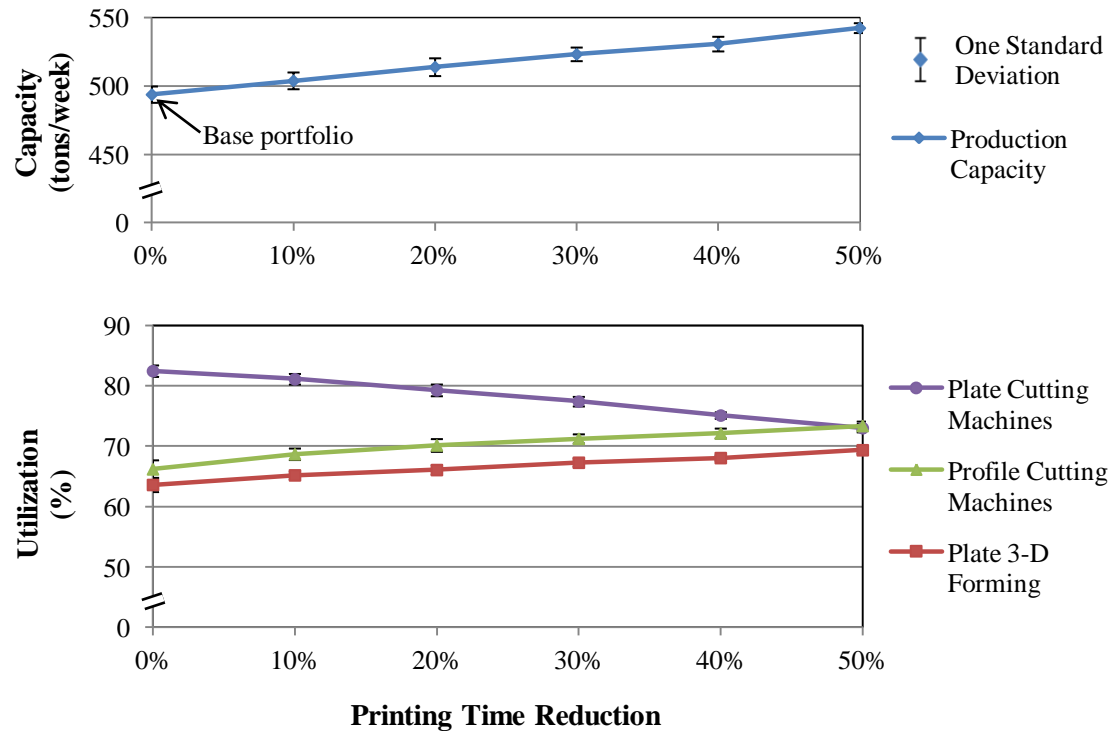


Figure 7-11: Effect of Increasing Printing Algorithm

The above figure shows that the production capacity of the process is increased by approximately 2% for every 10% of reduction in printing time. Figure 7-11 also shows that as the printing time reduction reaches 50%, the utilization of the plate cutting machines approaches that of the profile cutting machines. This means that an alternating bottleneck begins to form between these two sub-processes. This does not pose a large process management problem as both types of cutting machines are located at the beginning of the process.

It is recommended that this process improvement is installed as long the cost of creating an algorithm to optimize the plate printer is relatively inexpensive.

7.3.4 Separate Plate Printer

7.3.4.1 Description

The task of plate printing could also be performed by an independent printer installed before the plate cutting machines. This would reduce the process time of the plate cutting machines (the bottleneck in the current situation) by 40%.

To perform the plate printing task, an independent printer could be installed. For this analysis, it was assumed that an independent printer would have the same printing speed as the printers attached to the cutting head of the cutting machines. The effect on the production process of installing both one and two independent printers was examined using the simulation model.

The printers attached to the cutting heads of the plate cutting machines, however, are not optimized for plate printing. In the future it may be possible to purchase separate plate printers with much faster printer times than those integrated with the plate cutting machines of IHC Metalix. Therefore, the effect of installing an independent printer with twice the production capacity of the current plate printers installed on the cutting machines of IHC Metalix was also examined.

Installing a separate printer in the production process of IHC Metalix has the following advantages:

1. Process time of the plate cutting machines (current process bottleneck) is reduced.
2. Improvement has built in redundancy because original printers can remain installed on cutting machines.

This process improvement also has the following disadvantages:

1. Additional space is required prior to the plate cutting machines to install the separate printers.
2. Separate printers would require a significant investment.

7.3.4.2 Results

Figure 7-12 shows the effect of installing a separate plate printer on the steel cutting, sorting, and finishing process of IHC Metalix. This figure shows the effect of installing one slow printer, two slow printers, and one fast printer on the production capacity and bottleneck utilization of the process.

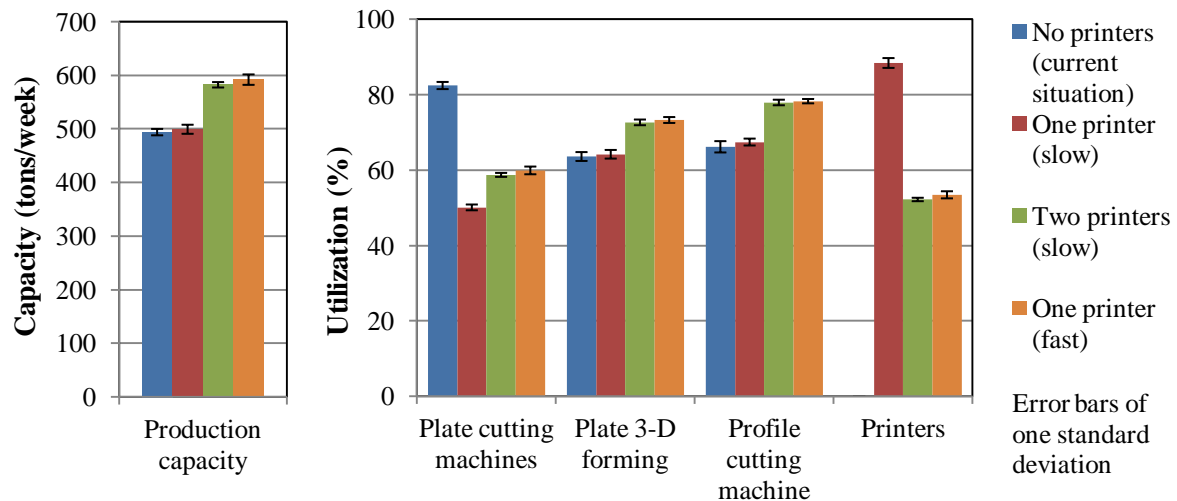


Figure 7-12: Effect of Separate Plate Printers

Figure 7-12 indicates that installing one slow printer does not significantly increase production capacity. This occurs because the one printer becomes the bottleneck, operating at nearly 90% of the time.

The above figure indicates that significant gains in production capacity of nearly 18% are realized when either two slow printers or one fast printer are installed in the production process. Furthermore, this figure also shows that the bottleneck location shifts from the plate cutting machines to an alternating bottleneck between the plate 3-D forming sub-process and the profile cutting machines. This moves the bottleneck partially away from the front of the process (the profile cutting machines are also at the front of the process). This will result in an increased process management effort to ensure that large quantities of parts do not pile up in front of the plate 3-D forming stations.

An economic analysis of the initial investment cost, expected service life, and value added of increased production would need to be conducted to determine which of the two printer options was more economically viable. Such an analysis was outside of the scope of this project. Furthermore, additional floor place would be required to install two slow printers instead of one fast printer.

IHC Metalix should only install a separate plate printer if the increased production capacity is required and an economic analysis shows that installing a printer is a financially sound investment.

7.3.5 Operating Three Shifts

7.3.5.1 Description

In the current situation, the profile process is operated three shifts a day while the plate process operates only two shifts. If additional capacity was required, the plate processing area could also be operated three shifts a day. Running the plate processing area for three shifts a day would have the following disadvantages:

1. An enclosed plate storage area would need to be built because local noise regulations do not allow the plate park crane to operate during the night.
2. Additional wage costs, operating costs, and equipment wear would incur.
3. Less flexibility in the process to temporarily work additional hours.

Both of these factors represent significant costs to IHC Metalix. However, installing an enclosed plate storage area also has additional benefits. These include:

1. Uncut plates would no longer be stored outside. This would eliminate weather damage to these plates.
2. A faster plate park crane would be installed in the enclosed storage area. This would reduce the need to send batches of plates into the cutting area.

7.3.5.2 *Results*

The effect of operating the plate process for three shifts is shown on Figure 7-13. This figure also shows what type of production capacity would be expected if the production capacity of IHC Metalix was proportionally increased based on the number of additional hours of operation of the plate processing area.

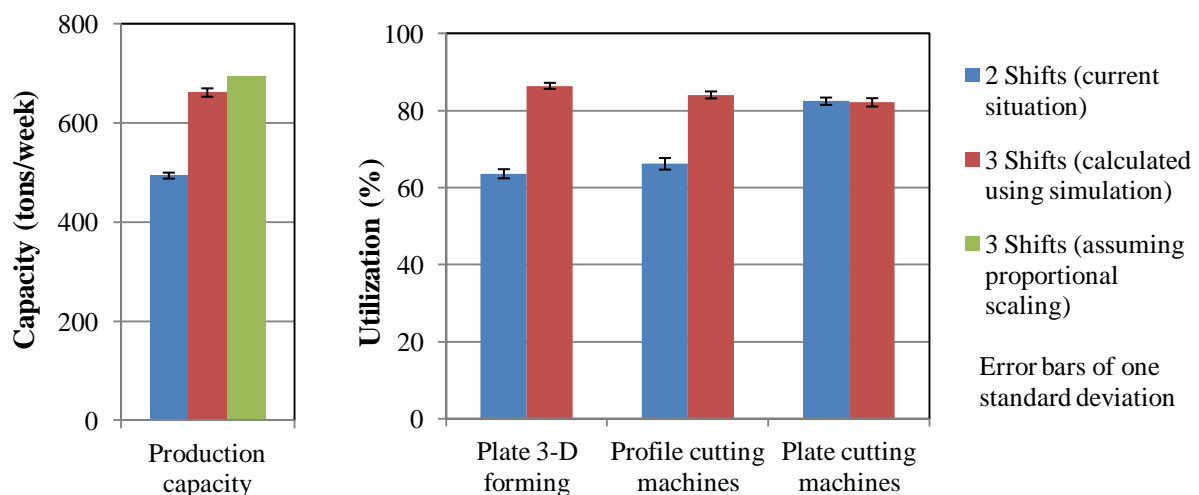


Figure 7-13: Effect of Operating the Plate Process for Three Shifts

Figure 7-13 shows that the estimated increase in production capacity due to operating the plate processing area for three shifts was less than the increase expected due to proportional scaling of hours worked. This occurs because the profile processing and plate 3-D sub-process begin slowing down the total production process. Therefore, the total production capacity per hour worked actually decreases if the plate cutting process is operated for three shifts.

In terms of the production process, operating three shifts is a fairly ideal situation because the utilization of the major three sub-processes is balanced. However, the process with the highest utilization is the plate 3-D forming process, which not located at the beginning of the

process. This could cause increased complication in the process management to ensure that parts do not build up in the system.

It is not recommended that the plate cutting, finishing, and sorting process is operated for three shifts. Implementing this improvement would reduce the production capacity of the process per hour worked and reduce the flexibility of the process to temporarily work additional hours. Furthermore, operating for three shifts would increase the effort required to manage the process.

7.3.6 **Improvement Summary and Recommendations**

Table 7-3 contains a summary of the process improvements evaluated using the simulation model. This table contains the expected capacity increase of each improvement as well as a qualitative comparison of investment costs. The table also summarises any other effects or requirements the improvements have on the production process.

Table 7-3: Summary of Process Improvements

Improvement	Capacity increase	Investment cost	Other requirements	Recommendation
Additional flatrack positions	6%	Very low	Removal of finishing tables	Implement
Combining flatracks	4%-6%	Very low	Increased end sorting complexity	Only implement temporarily if end sorting can handle additional load
Improving printer efficiency	2%-10%	Low	None	Implement only if separate plate printer is not installed
Separate plate printer	18%	Medium	Space for printers	Implement only if additional capacity is required
Operating three shifts	34%	High	Enclosed plate storage area	Only implement temporarily if capacity is required

It is recommended that IHC Metalix remove two large part finishing tables to make space for two additional flatrack positions. This requires very little investment and will improve the capacity of the production process. Furthermore, sawhorses could be set up in these flatrack positions to create temporary grinding tables, if necessary.

Although gains in production capacity can also be achieved by combining flatracks, permanently implementing this improvement is not recommended. Currently, the end sorting process is not a bottleneck in the total production process of IHC Metalix. If flatracks were combined in the large part sorting area, however, significant additional sorting and space requirements would be introduced into the end sorting area. These could potentially hinder the smooth flow of the process.

Improving the efficiency of the printing algorithm should only be implemented if a separate plate printer is not installed. This magnitude of benefit of this improvement is directly proportional to the gains in printer efficiency, which are currently not known. However, implementing this improvement should require low investment and would not disrupt the production process.

If additional production capacity is required, it is recommended that IHC Metalix install a separate printer prior to the plate cutting machines. This improvement requires both the investment of installing, operating, and maintaining the printer as well as enclosed floor space to house the printer.

It is not recommended that IHC Metalix operate the plate production process for three shifts. The total production process operates less efficiently when the plate production is run for three shifts. Furthermore, less flexibility would exist in the process to work additional hours. If additional capacity was temporarily required, however, this process improvement would help IHC Metalix achieve that capacity.

7.4 FACTORS WHICH INFLUENCE PROCESS PERFORMANCE

The following analysis was performed as an afterthought at the request of IHC Metalix. This analysis was not part of the research question and was only done with the available data. A much more systemic and rigorous analysis should be performed in order to gain better insight into the influence of various factors on the process performance. This analysis only provides a superficial, first-look into these influences.

The following section examines the influence of some of the characteristics of an order on the production capacity calculated by the simulation model. The examined characteristics include:

1. Part size
2. Plate thickness
3. Ratio of plates to profiles
4. Bottleneck utilization
5. Required plate 3-D forming

The production capacity is an extremely complex function, which is why a simulation model was built to calculate the production capacity. Thus, the purpose of this section is not to create a mathematical equation to calculate the effect of these factors on the production capacity. Instead, it is to examine the general trends that exist between these characteristics and the production capacity. These trends can be used as rules of thumb to aid the decision making process of the production planning, sales, and marketing departments of IHC Metalix. In order to generate the trends presented in this section, the results of the simulation model were used.

7.4.1 Part Size

The effect of average part size on the calculated production capacity using the simulation model is shown on Figure 7-14. This figure shows a weak positive correlation between the average part size of a ship type and that ship type's production capacity.

In the production process at IHC Metalix, many of the transportation tasks, such as crane lifts, need to be completed once per part. Larger part sizes mean that fewer of these tasks must be completed per ton of finished parts. This increases the productivity of those tasks.

Furthermore, the ratio of part area to perimeter increases as the average part size increases. Many of the sub-process processing times are dependent on the part perimeter, such as plasma cutting, beveling, and grinding. The weight of a part, however, is a function of the part area. Therefore, the output of those sub-processes (in tons/week) increases as part size increases.

Having a smaller average part size can also increase the productivity of the entire process. A section with a smaller average part size will have more parts that fit onto a pallet. These parts do not need to be handled by the large part sorting area, a sub-process that can potentially limit the total production.

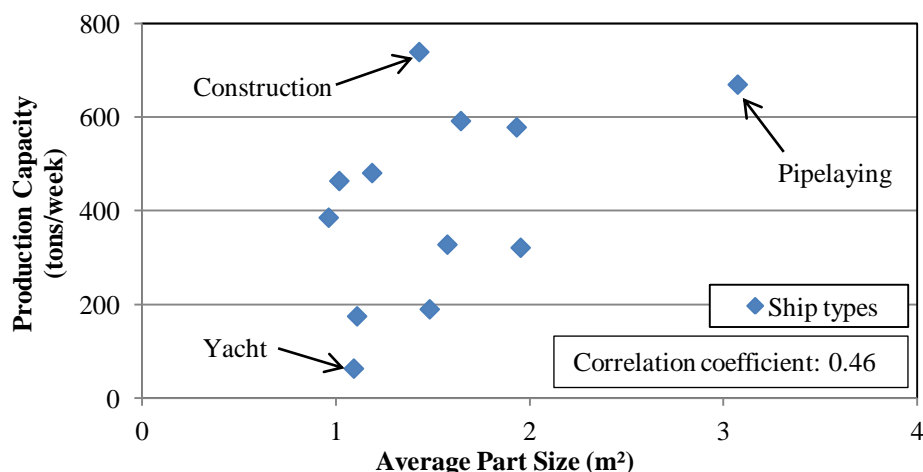


Figure 7-14: Influence of Part Size on Production Capacity

7.4.2 Plate Thickness

Figure 7-15 shows the influence of plate thickness on the production capacity of the IHC Metalix facilities in Kinderdijk. This figure shows a general, positive correlation between plate thickness and production capacity. This occurs because plate thickness has very little effect on the time required to cut, sort, and finish parts. The delivered tons of finished parts, however, are directly proportional to the plate thickness. As a result, orders with thick plates generally have a higher production capacity than orders cut from thin plates.

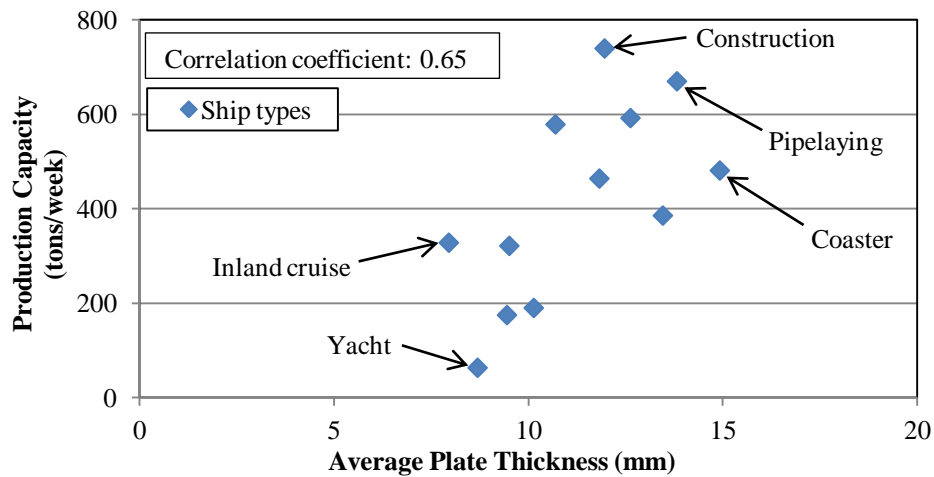


Figure 7-15: Influence of Plate Thickness on Production Capacity

7.4.3 Ratio of Plates to Profiles

Figure 7-16 shows the influence of the ratio of plate parts to profile parts on production capacity. This figure indicates no significant correlation between the number of profiles and the production capacity of the factory. The production process produces the highest tons of steel per week if the plate cutting machines and profile cutting machine are all operating near maximum capacity. If an order has too many profile parts, the profile cutting machine becomes the process bottleneck, resulting in the plate cutting machines sitting idle. Similarly, if an order has few profile parts, the profile cutting machines are not fully used, reducing the total tons of steel cut.

Figure 7-16 shows that the optimal percentage of profile parts (by weight) lies somewhere between 10% and 20%. However, several of the ship types, which fall within this range have low production capacities. This indicates that the percentage of profile parts in an order does not strongly influence the production capacity of the process.

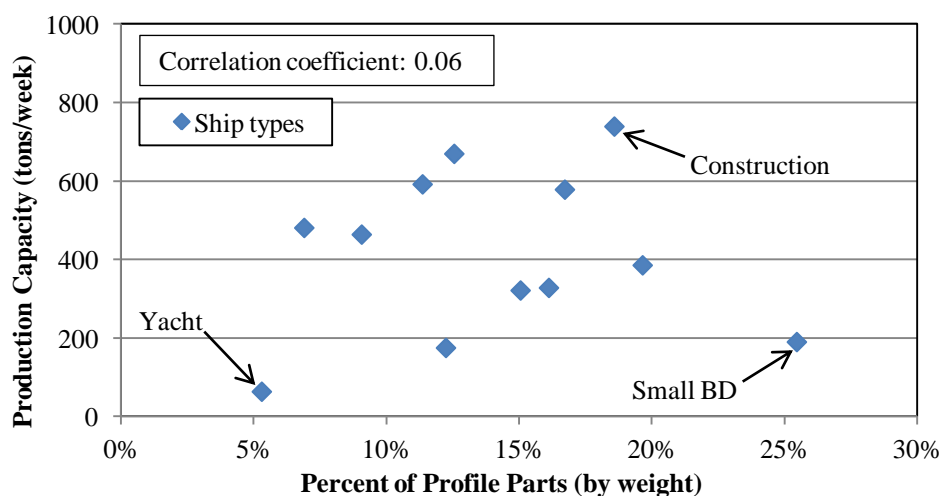


Figure 7-16: Influence of Percent of Profiles on Production Capacity

7.4.4 Bottleneck Utilization

The influence of bottleneck utilization on the production process of the steel cutting and finishing process of IHC Metalix is shown on Figure 7-17. This figure shows the data for the three sub-processes which were found to be the bottleneck for at least one of the examined ship types. Table 7-1 shows which bottleneck locations and utilizations correspond to each of the examined ship types. These processes include:

1. Plate 3-D forming
2. Profile cutting machine
3. Plate cutting machines

Only two ship types had the plate 3-D forming sub-process as the bottleneck. Therefore, not enough data exists to calculate a correlation coefficient for this sub-process. The two points indicate a positive correlation; however, more ship types with plate 3-D forming as the bottleneck are required to determine the strength of this correlation.

Figure 7-17 indicates no apparent correlation between the utilization of the profile cutting and the production capacity calculated for the ship types whose bottleneck is the profile cutting machines. Because an order is usually only composed of 10% to 20% profiles by weight, the utilization of the profile cutting machines does not strongly influence the production capacity.

Figure 7-17 also shows that a fairly strong positive correlation exists between the bottleneck utilization and production capacity for the ship types with the plate cutting machines as the process bottleneck. The plate cutting machines usually cut between 80% and 90% of the steel in an order; therefore, increasing the utilization of those machines has a positive influence on the production capacity of the IHC Metalix facilities in Kinderdijk.

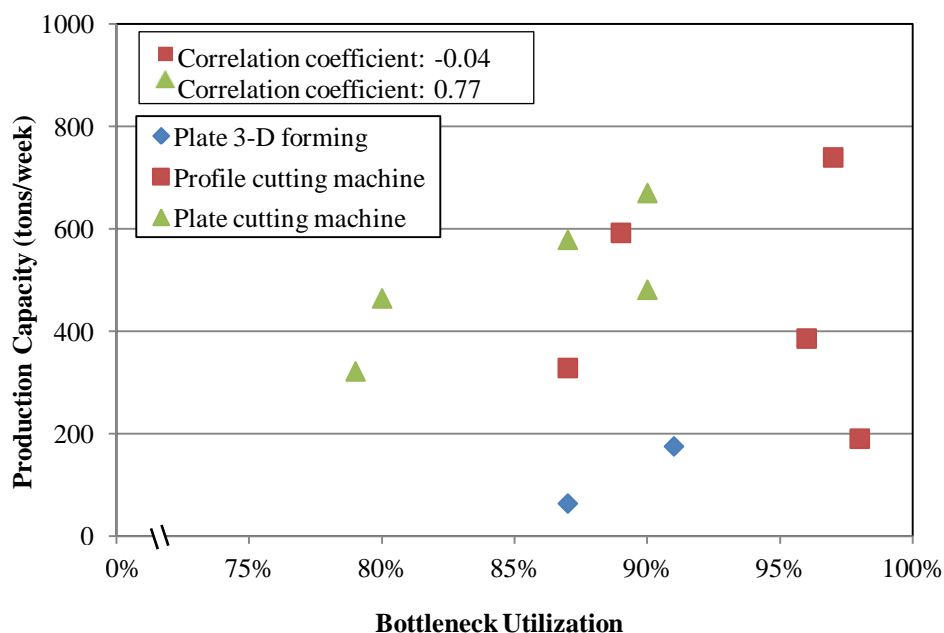


Figure 7-17: Influence of Bottleneck Utilization on Production Capacity

7.4.5 Required Plate 3-D Forming

Figure 7-18 shows the influence of the required amount of plate 3-D forming on the production process of IHC Metalix. This figure indicates very little correlation between the 3-D forming sub-process and the production capacity. This indicates that the number of plate 3-D formed parts does not strongly influence the production capacity of the process.

The one exception to this lack of correlation is yachts, which have an extremely large number of 3-D formed parts. Yachts also have a significantly lower production capacity than any other ship type. Therefore, if a ship type is composed of a very high percentage of parts which require 3-D forming, the performance of the production process becomes severely reduced.

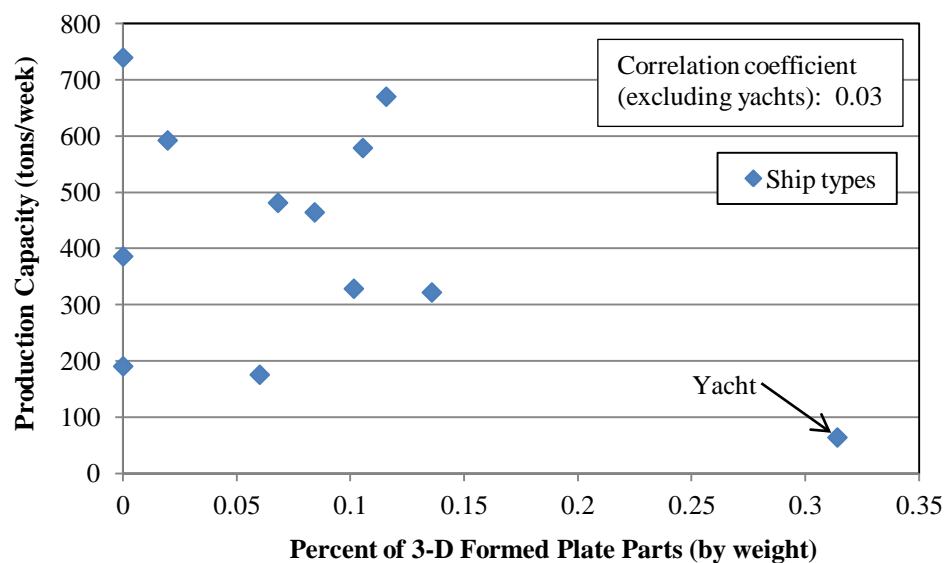


Figure 7-18: Influence of Required Plate 3-D Forming on Production Capacity

7.4.6 Conclusion

The above analyses of the factors which influence the production process of IHC Metalix produced the following general trends:

1. The production capacity is positively correlated with plate thickness.
2. Part size, percentage of profile parts, and bottleneck utilization have little effect on the production capacity.

8 CONCLUSIONS

The purpose of this research project was to determine the effect of the order portfolio on the production process of IHC Metalix, a steel cutting and finishing company which produces machined steel kits.

The characteristics of the production process were analyzed using both a Microsoft Excel based capacity calculation (preliminary process analysis) and a simulation model. The applicability of the simulation model was assessed using the methodology of verification and validation of simulation models outlined by Robert G. Sargent.

Using both the preliminary process analysis and the simulation model, the following general conclusions were formed about the production process:

1. The average production capacity of the IHC Metalix Kinderdijk facilities excluding oxyfuel cutting ranged between 460 and 520 tons per week, depending on the order portfolio being produced. If sections of only one ship type would be produced, the resulting production capacities would range from 60 to 730 tons per week.
2. When producing a variety of sections, the plate cutting machines were the process bottleneck for each of the examined order portfolios. These portfolios represented the realistic operational ranges of the production process. However, the bottleneck location could temporarily become the profile cutting machine, plate 3-D forming, profile hand process, or large part sorting crane if a large influx of sections of certain vessel types entered the process.
3. The installation of two new cranes, pallet conveyer belt, and pallet storage rack as well as the modification of an existing crane to include a magnet traverse are expected to increase production capacity by approximately 25%.
4. Grinded sections take approximately 30% longer to complete than non-grinded sections. The production capacity of the entire production process is reduced (up to 20%) when a significant number of grinded sections are introduced into the process.
5. Sections of large, simply structured ships (such as big dredgers, coasters, pipelaying vessels, and construction projects) take 140% longer to produce than sections of small, complex ships (such as yachts, tugboats, OSVs, inland cruise vessels, and beaver dredgers).
6. Midship sections are faster to produce (per ton) than bow, stern, and superstructure sections. For coasters, pipelaying vessels, and trailing suction hopper dredgers midship sections are between 50% and 80% faster to produce. For cutter suction dredgers, however, midship are only between 5% and 25% faster to produce.
7. Production capacity is positively correlated with the plate thickness of the sections being cut. Insufficient data was collected to determine the mathematical nature of this relationship.

The simulation model was also used to determine the influence the order portfolio has on the production process. The portfolio analysis performed led to the following conclusions:

1. Increasing the number of grinded sections has a negative influence on the production capacity. As the percentage of grinded sections is increased up to 70%, the large part sorting crane begins to become the process bottleneck.
2. Dredging vessels have little impact on the total production capacity. In general, sections of dredging vessels have less formed parts and more profile parts than the average section produced.
3. The production capacity is positively correlated with the number of sections in the order portfolio from pipelaying vessels.
4. The production capacity is relatively unaffected by the number of sections from coasters. Coaster sections have less formed and profile parts than the average section in the base portfolio.
5. Increasing the number of sections from yachts and inland cruise vessels in the order portfolio reduces the total production capacity. These vessels have a very high number of formed parts.
6. In general, sections from construction projects have fewer formed parts and more profile parts than other sections. Adding these sections to the order portfolio increases the achieved production capacity.

The effect of implementing several improvements to the production process was also determined using the simulation model. The following conclusions were found regarding these processes improvements:

1. Removing two large part finishing tables to make space for two additional flatrack positions would increase the production capacity by approximately 6%. In the event of a large influx for grinded parts, saw-horses could be setup in these flatrack positions to make temporary grinding tables.
2. Combining flatracks of the same section in the large part sorting area and separating these flatracks in the end sorting area could increase the production capacity by up to 6%. Implementing this improvement would increase the space required, number of lifts, and sorting complexity in the end sorting area.
3. The printing time of the vector plotter integrated in the cutting head of the plate cutting machines could be reduced by optimizing the printing algorithm. Every 10% reduction in printing time would result in approximately a 2% increase in production capacity.
4. The production capacity could be increased by approximately 18% by installing a separate plate printer. To implement this improvement, an enclosed space to house and operate the printer would be required prior to the plate cutting machines.
5. The production capacity could be increased by 34% if the plate production area was operated for three shifts. Operating three shifts would reduce the flexibility to work additional hours. Furthermore, an enclosed plate storage facility would need to be built due to local noise regulations.

It is recommended that IHC Metalix increase the number of flatrack positions. This improvement requires very little investment and the lost finishing tables can be temporarily replaced with sawhorses, if needed. Although combining flatracks could increase the production capacity, the increased load on the end sorting area could disrupt the smooth flow of the production process.

IHC Metalix should also work to optimize the printing algorithm of the vector plotters mounted on the plate cutting machines. Installing a separate plate printer should only be implemented if additional production capacity was required. An economic and market analysis would be required to determine if such an investment was financially viable.

It is not recommended that IHC Metalix permanently operate three shifts. Doing so requires a significant investment and reduces the flexibility of the process. Operating three shifts also increases the complexity required process management.

9 RECOMMENDATIONS

The following section contains recommendations for future work which could be based on the research completed for this Master's thesis.

9.1 ECONOMIC ANALYSIS

An economic analysis of the production process of IHC Metalix could further increase the company's knowledge of their production process. To fully understand the implications of shifts in the order portfolio, the relative prices of the different ship types must also be examined. Depending on the relative production characteristics and prices, producing fewer sections of more expensive ship types could be more profitable than producing more sections of less expensive ship types.

An economic analysis of the various process improvements outlined in section 7.3 *Process Improvements* would be also be necessary to evaluate the financial viability of the suggested improvements. If the return on investment (ROI) of an improvement is less than company's weighted average cost of capital (WACC), that improvement would end up costing the company money.

9.2 MARKET ANALYSIS

A market analysis of the shipbuilding industry could also be used to expand on the research presented in this report. Such an analysis could be used to help predict the future changes in prices and demand for machined steel kits in northern Europe. These factors affect the optimal operations of the IHC Metalix's Kinderdijk facilities. This information could also be paired with an economic analysis to make future investment decisions.

9.3 EXPAND CURRENT SIMULATION

A rigorous, systematic analysis could be performed using the simulation model to determine how various section properties influence the production process.

Furthermore, the simulation model created for this research project could be expanded in several ways. First, parts for additional ship types could be gathered and tested in the simulation. This would increase the applicability of this research to other machined steel kit producers which predominantly produce parts for different ship types.

The simulation model could also be further developed to include other stages of the shipbuilding process. Currently, only a portion of the pre-fabrication stage of the shipbuilding process is modelled by the simulation. Modelling more of the shipbuilding process could help show the effects of shifts in the order portfolio on the entire shipbuilding process.

Lastly, IHC Metalix is currently in the process of designing and installing additional improvements beyond those considered in this project. These include a new plate storage hall, an investigation into the profile process, and expedition area. The simulation model could be modified to determine the effect of these improvements on the production process. Future modelling efforts would be able to use much of the data collection performed for this project. The oxyfuel cutting machine and subcontractors could also be included in the model.

10 REFERENCES

- [1] "Maritime Industries: Shipbuilding Industry: An Overview of the Sector," European Commission: Enterprise and Industry, 4 February 2012. [Online]. Available: http://ec.europa.eu/enterprise/sectors/maritime/shipbuilding/index_en.htm. [Accessed 6 March 2013].
- [2] International Maritime Organization, "International Shipping Facts and Figures – Information Resources on Trade, Safety, Security, Environment," Maritime Knowledge Centre, 2012.
- [3] J.D. Caprace, "Discrete Event Production Simulation and Optimisation of Ship Block Erection Process," University of Liège, Liège, 2011.
- [4] A. Hagen, *Building of Ships and Platforms: Introduction and Primer*, Trondheim: Norwegian University of Science and Technology, 2011.
- [5] IHC Merwede, 2013. [Online]. Available: <http://www.ihcmerwede.com/>. [Accessed 6 March 2013].
- [6] IHC Metalix B.V., IHC Merwede, 2012. [Online]. Available: <http://www.ihcmetalix.com/>. [Accessed 3 December 2012].
- [7] "Production Simulation at IHC Metalix," *Ship Building Industry*, vol. II, no. 4, pp. 68-71, 2008.
- [8] "A Fresh Start: New Metalix Production Philosophy," *Ship Building Industry*, vol. II, no. 5, pp. 28-29, 2008.
- [9] "Nobiskrug," Abu Dhabi Mar, 2013. [Online]. Available: <http://www.nobiskrug.com/index.php?id=14>. [Accessed 10 April 2013].
- [10] "Damen: Markets," Damen Shipyards Group, 2011. [Online]. Available: <http://www.damen.nl/en/markets>. [Accessed 10 April 2013].
- [11] "Meyer Werft: Our Ships," Meyer Werft GmbH, 2013. [Online]. Available: http://www.meyerwerft.de/en/meyerwerft_de/schiffe/schiffe.jsp. [Accessed 10 April 2013].
- [12] "Produkte & Technologien," Blohm + Voss Shipyards, 2013. [Online]. Available: http://www.blohmvooss.com/index.php?level=1&CatID=77&inhalt_id=94. [Accessed 10 April 2013].
- [13] "Products," Flensburger, 2013. [Online]. Available: <http://www.fsg-ship.de/2-1-Products.html>. [Accessed 10 April 2013].
- [14] "Unsere Schiffe," Neptun Werft GmbH, 2013. [Online]. Available: http://www.neptunwerft.de/de/neptunwerft_de/schiffe/schiffe.jsp. [Accessed 10 April 2013].

- [15] W. Vlasblom, "Lecture Notes on Dredging Equipment and Technology," Central Dredging Association, 4 December 2007. [Online]. Available: <http://www.dredging.org/content.asp?page=105>. [Accessed 6 December 2012].
- [16] "IHC Beaver Dredgers," IHC Merwede, [Online]. Available: <http://www.ihcbeaverdredgers.com/>. [Accessed 6 December 2012].
- [17] "Combi Coaster," Damen Shipyards Group, 2011. [Online]. Available: <http://www.damen.nl/markets/combi-coaster?type=2500>. [Accessed 6 December 2012].
- [18] IHC Merwede, "IHC Offshore and Marine," IHC Merwede B.V., 2012. [Online]. Available: <http://www.ihcmerwede.com/offshore/>. [Accessed 3 December 2012].
- [19] R. P. de Graaf, Interviewee, [Interview]. 25 February 2013.
- [20] C. Hoffman, "On Board the World's Most Powerful Tugboat," Popular Mechanics, 22 February 2010. [Online]. Available: <http://www.popularmechanics.com/technology/engineering/extreme-machines/4346840>. [Accessed 6 December 2012].
- [21] Abhishek Solutions, "Big Ship Small Tug," Marine Knowledge, 21 June 2011. [Online]. Available: http://www.marine-knowledge.com/types_of_ships/tug-boat-engines.html/attachment/big-ship-small-tug-2. [Accessed 6 December 2012].
- [22] "Viking River Cruises," 2012. [Online]. Available: <http://www.vikingrivercruises.com/>. [Accessed December 6 2012].
- [23] "Tital Travel," 7 Night Cruise, 2012. [Online]. Available: <http://www.titantravel.co.uk/europe/germany/the-rhine/castles-along-the-rhine/ship-details.aspx>. [Accessed 6 December 2012].
- [24] E. Macguire, "Want to live like a billionaire? Charter their superyacht," Central News Network, 30 March 2012. [Online]. Available: <http://edition.cnn.com/2012/03/30/sport/superyachts-charter/index.html>. [Accessed 6 December 2012].
- [25] American Bureau of Shipping, "Maritime Safety Committee's 83rd Session," October 2007. [Online]. Available: <http://www.eagle.org/eagleExternalPortalWEB/ShowProperty/BEA%20Repository/References/Regulatory/2007/83rdSession>. [Accessed 3 2012 December].
- [26] G. Lloyd, "Protective Coatings (IMO PSPC)," Germanischer Lloyd, 2012. [Online]. Available: http://www.gl-group.com/pdf/protective_coatings_imo_pspc.pdf. [Accessed 20 March 2013].

- [27] Occupational Safety and Health Administration, "Guidelines for Shipyards: Ergonomics for the Prevention of Musculoskeletal Disorders," 2008. [Online]. Available: <http://www.osha.gov/Publications/OSHA3341shipyard.pdf>. [Accessed 3 December 2012].
- [28] H. P. T. Jellema, Interviewee, [Interview]. 17 December 2012.
- [29] Y. Okumoto, "Simulation Based Production Using 3-D CAD in Shipbuilding," Kinki University, Higashihiroshima, 2006.
- [30] FlexSim, *FlexSim Brochure*, Flexsim Software Products, Inc., 2012.
- [31] R. G. Sargent, "Verification and Validation of Simulation Models," in *Winter Simulation Conference*, 2007.
- [32] International Association of Dredging, "Dredging in Figures 2011," 2011. [Online]. Available: <http://www.iadc-dredging.com/ul/cms/fck-uploaded/documents/PDF%20Dredging%20in%20Figures/dredging-in-figures-2011.pdf>. [Accessed 3 December 2012].
- [33] IHC Merwede, "IHC Dredging," IHC Merwede B.V., 2012. [Online]. Available: <http://www.ihcmerwede.com/dredging/>. [Accessed 3 December 2012].
- [34] M. V. de Velde, "Dredging: The Past Two Decades," *The Art of Dredging*, 2008. [Online]. Available: <http://www.theartofdredging.com/20years.htm>. [Accessed 20 March 2013].
- [35] "Global Offshore Oil-2: Growth expected in global offshore crude oil supply," *Oil and Gas Journal*, 12 March 2007. [Online]. Available: <http://www.ogj.com/articles/print/volume-105/issue-10/exploration-development/global-offshore-oil-2-growth-expected-in-global-offshore-crude-oil-supply.html>. [Accessed 3 December 2012].
- [36] Niestern Sander, "Delivery m.v. Sanaborg," Niestern Sander, 8 August 2012. [Online]. Available: http://www.niesternsander.com/en/233/delivery_m_v_sanaborg.html?viewNewsItem=75. [Accessed 3 December 2012].
- [37] "About the Industry: Global Trade," World Shipping Council, 2012. [Online]. Available: <http://www.worldshipping.org/about-the-industry/global-trade>. [Accessed 14 December 2012].
- [38] L. Perignon, "The (Super)Yachting Index," Camper and Nicholson's, July 2010. [Online]. Available: <http://www.camperandnicholsons.com/publications/document/view%3Ffn%3D45>. [Accessed 3 December 2012].

- [39] T. Mee, "The (Super)Yachting Index," Camper & Nicholson's, July 2011. [Online]. Available: <http://www.camperandnicholsons.com/publications/document/view?fn=48>. [Accessed 3 December 2012].
- [40] K. Schapiro, "PR Newswire," 1 August 2012. [Online]. Available: <http://www.prnewswire.com/news-releases/despite-slowing-economic-growth-luxury-goods-names-could-pamper-investors-returns-164594906.html>. [Accessed 3 December 2012].
- [41] World Maritime News, "World Maritime News," 23 August 2012. [Online]. Available: <http://worldmaritimenews.com/archives/63880>. [Accessed 3 December 2012].
- [42] A. M. Law, "How the ExpertFit Distribution-Fitting Software Can Make Your Simulation Models More Valid," in *Winter Simulation Conference*, 2002.
- [43] M. DeGroot, Probability and Statistics, Boston: Addison-Wesley, 2012.

11 APPENDICES

11.1 SUB-PROCESS CHARACTERISTICS

The following appendix shows the process input values used in the preliminary process analysis (PPA) and indicates how these values were determined.

Crane Lifts and Sorting Tasks

In order to determine the time required to perform each crane lift and sorting task, measurements were taken directly from the process. The crane lift and sorting times used in the PPA are the averages of the recorded measurements. No distributions were created for the crane lift and sorting times due to the relatively low variance between the recorded measurements. The table below contains the average crane lift times used in the PPA as well as some characteristics of the recorded measurements.

	Average time (min/part)	Measurements taken	Standard deviation (min/part)	Highest recorded time (min/part)	Lowest recorded time (min/part)
Cutting crane, pre-cutting lift	2.2	6	0.4	2.6	1.6
Cutting crane, post-cutting lift	2.7	5	0.6	3.3	2.0
Plate sorting, small parts	0.5	2	0.1	0.5	0.4
Plate sorting, medium parts	1.9	4	0.7	2.4	0.9
Plate sorting, large parts	2.1	9	0.5	3.1	1.4
Scrap removal	2.9	3	1.3	3.8	1.4
Profile hand process	1.8	6	0.2	2.1	1.5
Pre-profile cutting machine	0.7	11	0.3	1.3	0.5
Profile sorting	1.1	17	0.4	2.0	0.5

Working Speeds

In order to determine speed of a beveling machine, the specifications of the beveling machine were examined. Depending on the bevel characteristics, the speed the machine operates at varies between 0.1 and 0.3 meters per second. For this analysis, it was assumed that the machine operates at an average of 0.2 meters per second.

To determine grinding and painting speeds, measurements were taken directly from the process. For each measurement, the total time required to grind/paint a given part was recorded. The grinding/painting speed was calculated by dividing the required time by the grinded length. An average was taken over these measurements to determine the grinding and painting speeds used in the PPA. No distributions were set up for the working speeds due to the relatively low variance between the recorded measurements. The table below contains the working speeds used in the PPA as well as the number of measurements taken.

	Average speed (m/min)	Measurements taken
Beveling speed	0.2	-
Grinding speed	1.0	3
Painting speed	2.1	3

Pallet and Profile Bundle Weights

In order to calculate the average weight of a pallet and a profile bundle, measurements were taken from pallets and bundles. Although it would be possible to create a distribution from these values, for the purpose of the PPA only an average is required. Moreover, when creating a simulation model of the process, the exact weight of a pallet and profile bundle can be calculated from the contents of that pallet or bundle. The table below contains the average pallet and profile bundle weights used in the system analysis calculation as well as some characteristics of the recorded measurements.

	Average weight (tons)	Measurements taken	Standard deviation (tons)	Highest recorded weight (tons)	Lowest recorded weight (tons)
Pallet	0.42	10	0.51	1.54	0.05
Profile bundle	0.41	8	0.34	0.96	0.06

Process Times (without distributions)

Several processes of the Metalix production process are very systematic and repeatable. In general, there is fairly low variance in the time required to complete these processes. For these processes, only the average time required to complete the process was input into the PPA. In order to determine the average process times for these processes, measurements were taken directly from the process. An average was taken over these measurements to determine the average process times used in the system analysis calculation.

Several processes are included in this section for which insufficient data was collected to create a distribution. These processes include profile bending and profile hand cutting with an acetylene torch. Collecting more data for these processes is very time consuming, and therefore only average values were computed. These average values were input into the PPA.

Furthermore, plate 3-D forming is included in this section. A previous study had been conducted by IHC Metalix and determined that the average time to 3-D form a part is 155 minutes. Unfortunately, the data used in this study has been lost. Because it takes over 2 hours to collect a new data point, it was not in the scope of this project to accurately construct a distribution to represent the 3-D forming process. Therefore, only the average value found in the previous study was used in the PPA.

The table below contains the process times used in the PPA as well as some characteristics of the recorded measurements.

	Average time (min/part)	Measurements taken	Standard deviation (min/part)	Highest recorded time (min/part)	Lowest recorded time (min/part)
Pallet wrapping	6.4	4	0.6	7.2	6.0
Profile bundling	1.8	2	0.4	2.0	1.5
Marking parts	0.3	3	0.1	0.5	0.2
Grinding sawhorse setup	0.7	3	0.3	1.00	0.50
Profile hand cutting (bandsaw)	5.2	5	1.1	7.0	4.5
Profile hand cutting (torch)	16.3	3	0.5	16.8	16.0
Profile bending	39.8	4	13.2	59.0	29.5
Plate 3-D forming	155	-	-	-	-

Process Times (with distributions)

The following section contains the processes which have high variance with respect to process times and for which it was possible to collect sufficient data to construct distributions. For each of the processes, the ExpertFit software (which is bundled with the FlexSim 6.0 simulation software) was used to determine the best fit distribution. ExpertFit is a statistical data fitting software specifically designed for data sets which will be input into a simulation model [42]. The table below contains an overview of the measurements taken for these processes.

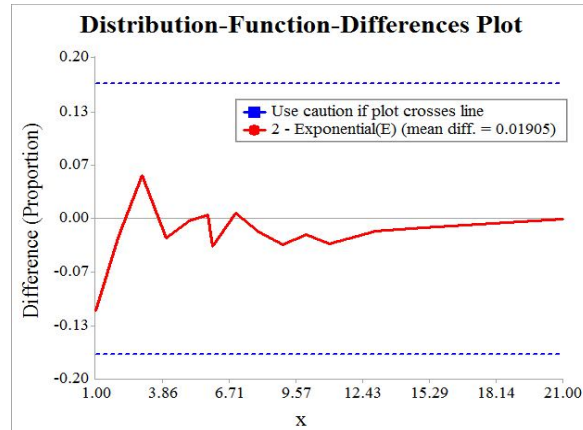
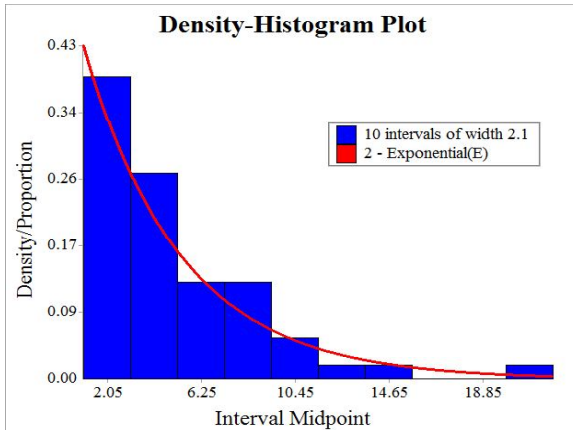
	Average time (min/part)	Measurements taken	Standard deviation (min/part)	Highest recorded time (min/part)	Lowest recorded time (min/part)
Pressbrake	4.9	57	4.0	21.0	1.0
Beveling setup	9.6	31	6.4	24.1	1.8
Profile cutting machine	8.0	32	3.7	16.9	4.1

For each of the process times a density-histogram plot and distribution-function-differences plot is shown. The density-histogram shows the chosen distribution overlaid onto a histogram of the gathered data. This plot can be used to visually confirm that the selected distribution is appropriate for the sample data [42]. The distribution-function-differences plot graphs the differences between the collected sample data and the chosen statistical distribution. As long as the difference line is within the blue bounds shown on the plot the fit is deemed to be satisfactory [42].

Pressbrake

For this process, an exponential distribution with a location parameter was selected. The location parameter indicates the amount the distribution is shifted. The table below contains the parameters of the selected distribution. The figures below show the selected distribution overlaid over a histogram of the collected data and the difference between the sample data and the selected distribution.

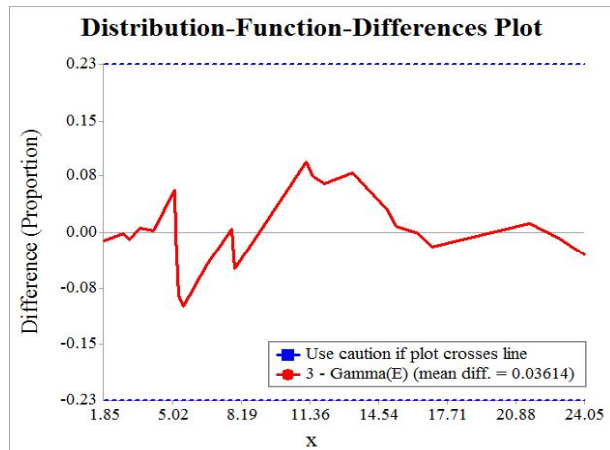
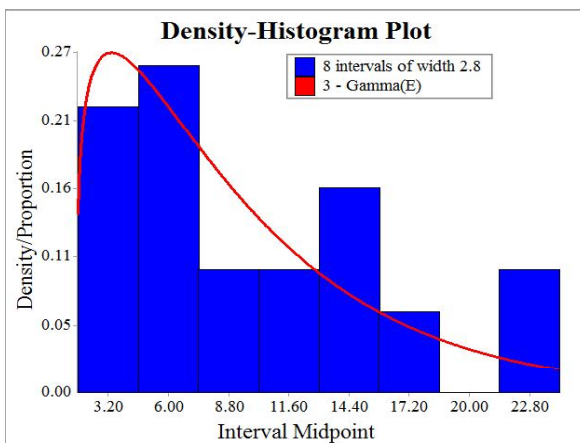
Table of Parameters	
Location parameter	0.51
Mean	4.41



Beveling Setup

For this process, a gamma distribution with a location parameter was selected. The location parameter indicates the amount the distribution is shifted. The table below contains the parameters of the selected distribution. The figures below show the selected distribution overlaid over a histogram of the collected data and the difference between the sample data and the selected distribution.

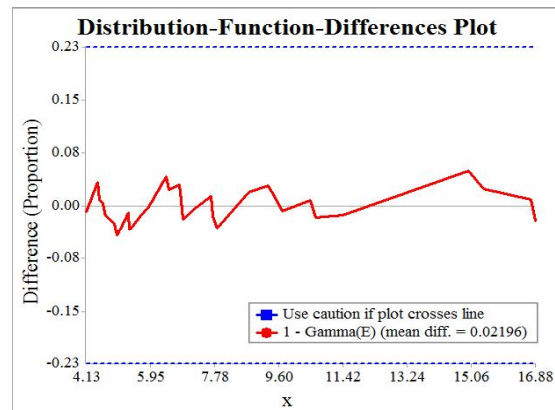
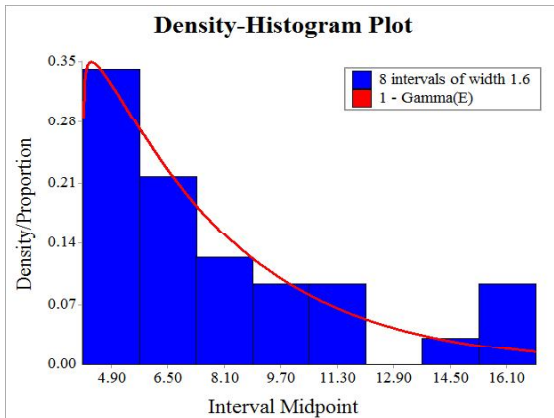
Table of Parameters	
Location parameter	1.74
Alpha	1.26
Beta	6.26



Profile Cutting Machine

For this process, a gamma distribution with a location parameter was selected. The location parameter indicates the amount the distribution is shifted. The table below contains the parameters of the selected distribution. The figures below show the selected distribution overlaid over a histogram of the collected data and the difference between the sample data and the selected distribution.

Table of Parameters	
Location parameter	4.09
Alpha	1.06
Beta	3.71



Because each un-cut profile can contain multiple profile parts, it is necessary to know the average number of parts created per profile machine cut to determine the average output of the profile cutting machine. The average number of parts per profile machine cut was calculated from approximately 7000 profile parts. The table below contains the average parts per profile machine cut used for the PPA. For any subsequent simulation work, it is easy to determine the exact number of parts which belong to an uncut profile. Therefore, this average was not necessary for the creation of any simulation models.

Average parts per profile machine cut	3.81
---------------------------------------	------

11.2 SECTION INDEPENDENT PROPERTIES

The following appendix shows the section independent input values used in the preliminary process analysis (PPA) and indicates how these values were determined.

Plate Characteristics

In order to calculate the average plate cutting machine output, plate weight, and scrap percentage, the cutting data from approximately 1,700 plates was examined. From these data the average for these three values was calculated. This average was used in the PPA. Although it would be possible to create a distribution from these values, for the purpose of the PPA only an average is required. Moreover, when creating a simulation model of the process, the exact cutting time, plate weight, and scrap percentage can be easily calculated. The table below contains the average output, plate weight, and scrap percentage used in the system analysis calculation.

The scrap percentage is defined as follows: $\text{Scrap \%} = \text{Weight of scrap} / \text{Initial weight of plate}$

	Average
Plate cutting machine output (tons/week)	213
Weight of plate (tons)	1.87
Scrap percentage	19.5%

Beveling Characteristics

In order to determine the beveling characteristics, part drawings were consulted. The beveled length of each part and if the part required turning during the beveling process was measured directly from the part drawings. The average values from these measurements were used in the PPA. Distributions were also created for the beveling length. For each part size, the ExpertFit software (which is bundled with the FlexSim 6.0 simulation software) was used to determine the best fit distribution. ExpertFit is a statistical data fitting software specifically designed for data sets which will be input into a simulation model [42]. The table below contains the beveling characteristics used in the PPA as well as some characteristics of the recorded measurements.

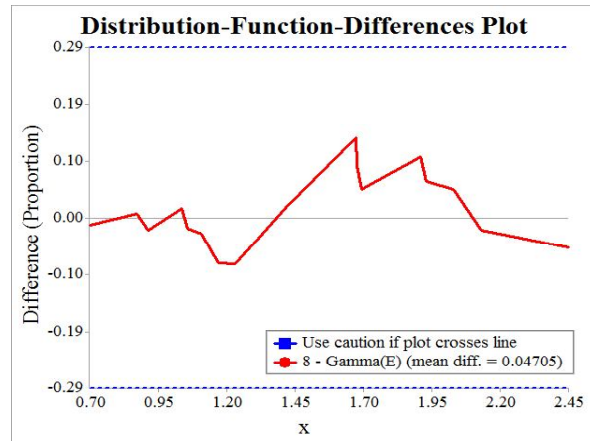
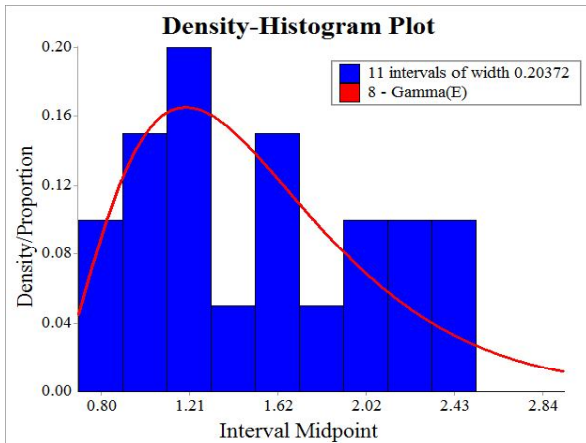
	Average	Measurements taken	Standard deviation	Highest recorded value	Lowest recorded value
Sml/med part beveled length (m)	1.54	20	0.5	2.5	0.7
Large part beveled length (m)	7.02	37	5.7	21.5	1.2
Turning required (small/med parts)	7%	14	-	-	-
Turning required (large parts)	32%	15	-	-	-

For each of the characteristics a density-histogram plot and distribution-function-differences plot is shown. The density-histogram shows the chosen distribution overlaid onto a histogram of the gathered data. This plot can be used to visually confirm that the selected distribution is appropriate for the sample data [42]. The distribution-function-differences plot graphs the differences between the collected sample data and the chosen statistical distribution. As long as the difference line is within the blue bounds shown on the plot the fit is deemed to be satisfactory [42].

Beveled Length (small/medium parts)

For the beveled length of a small/medium part, a gamma distribution with a location parameter was selected. The location parameter indicates the amount the distribution is shifted. The table below contains the parameters of the selected distribution. The figures below show the selected distribution overlaid over a histogram of the collected data and the difference between the sample data and the selected distribution.

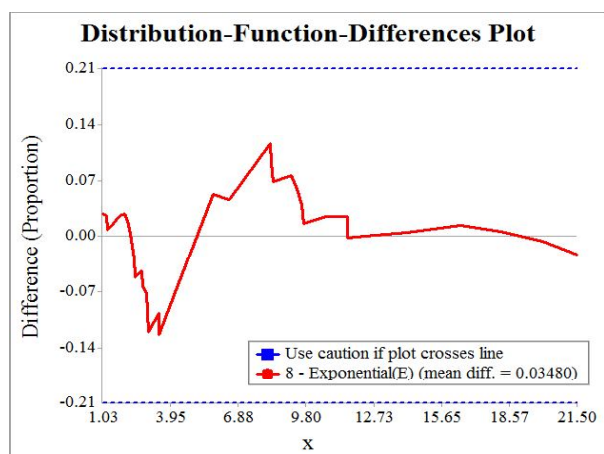
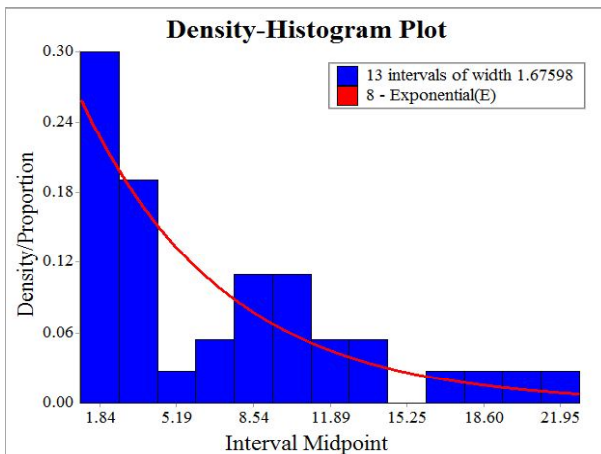
Table of Parameters	
Location parameter	0.543
Alpha	2.93
Beta	0.338



Beveled Length (large parts)

For the beveled length of a large part, an exponential distribution with a location parameter was selected. The location parameter indicates the amount the distribution is shifted. The table below contains the parameters of the selected distribution. The figures below show the selected distribution overlaid over a histogram of the collected data and the difference between the sample data and the selected distribution.

Table of Parameters	
Location parameter	0.753
Mean	6.269



Grinding Characteristics

In order to determine the grinding characteristics, part drawings were consulted. The grinded length of each part was measured directly from the part drawings. The percent of grinded parts and profiles was also determined for a series of grinded sections. The average values from these measurements were used in the PPA. Distributions were created for both the grinded length and percent of parts which needed grinding. For each case, the ExpertFit software (which is bundled with the FlexSim 6.0 simulation software) was used to determine the best fit distribution. ExpertFit is a statistical data fitting software specifically designed for data sets which will be input into a simulation model [42]. The table below contains the beveling characteristics used in the PPA as well as some characteristics of the recorded measurements.

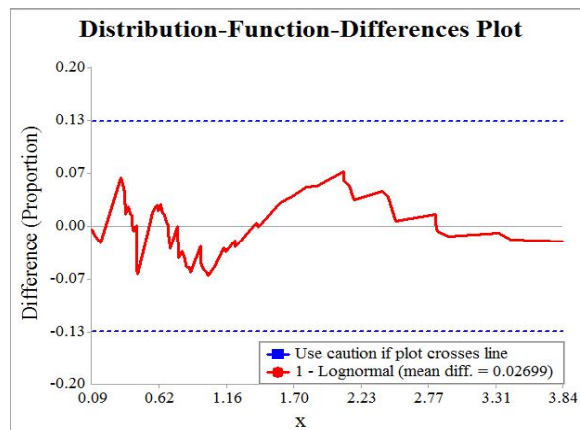
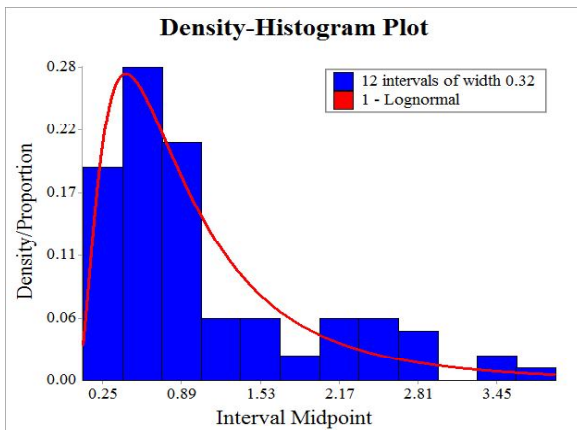
	Average	Measurements taken	Standard deviation	Highest recorded value	Lowest recorded value
Small/med part grinded length (m)	1.1	90	0.9	3.8	0.1
Large part grinded length (m)	5.7	49	3.5	17.5	0.2
Profile grinded length (m)	0.4	52	0.2	1.1	0.1
Number of grinded parts (%)	77%	19	8%	94%	64%
Number of grinded profiles (%)	87%	20	15%	100%	57%

For each of the characteristics a density-histogram plot and distribution-function-differences plot is shown. The density-histogram shows the chosen distribution overlaid onto a histogram of the gathered data. This plot can be used to visually confirm that the selected distribution is appropriate for the sample data [42]. The distribution-function-differences plot graphs the differences between the collected sample data and the chosen statistical distribution. As long as the difference line is within the blue bounds shown on the plot the fit is deemed to be satisfactory.

Grinded Length (small/medium parts)

For the grinded length of a small/medium part, a lognormal distribution was selected. The table below contains the parameters of the selected distribution. The figures below show the selected distribution overlaid over a histogram of the collected data and the difference between the sample data and the selected distribution.

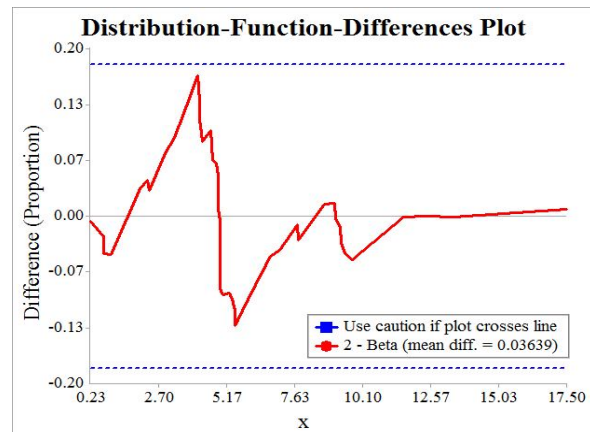
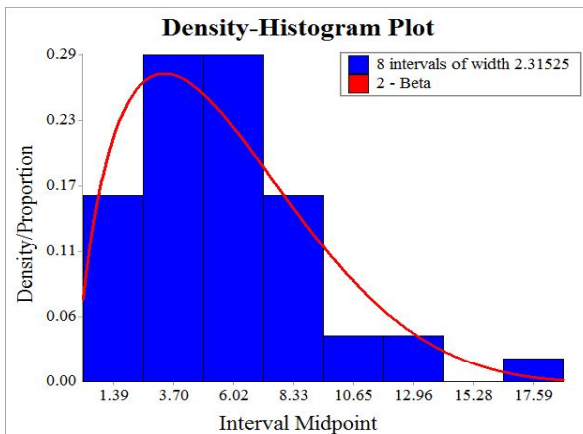
Table of Parameters	
Mean	0.813
Standard deviation	0.785



Grinded Length (large parts)

For the beveled length of a large part, a beta distribution was selected. The table below contains the parameters of the selected distribution. The figures below show the selected distribution overlaid over a histogram of the collected data and the difference between the sample data and the selected distribution.

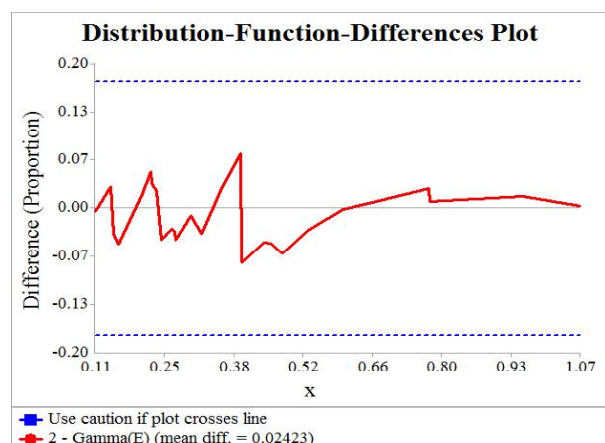
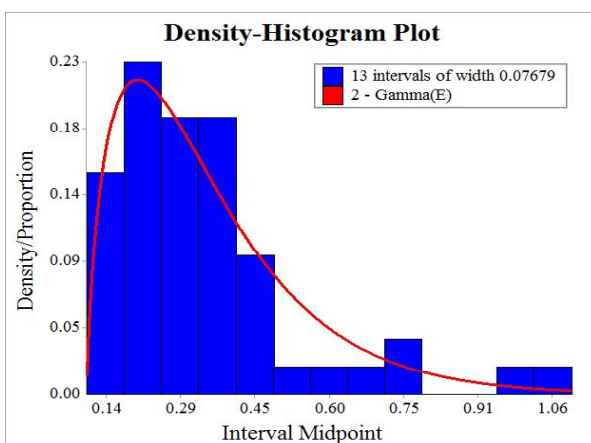
Table of Parameters	
Lower endpoint	0.001
Upper endpoint	23.15
Alpha	1.722
Beta	5.227



Grinded Length (profiles)

For the grinded length of a profile, a gamma distribution with a location parameter was selected. The location parameter indicates the amount the distribution is shifted. The table below contains the parameters of the selected distribution. The figures below show the selected distribution overlaid over a histogram of the collected data and the difference between the sample data and the selected distribution.

Table of Parameters	
Location parameter	0.0992
Alpha	1.716
Beta	0.148

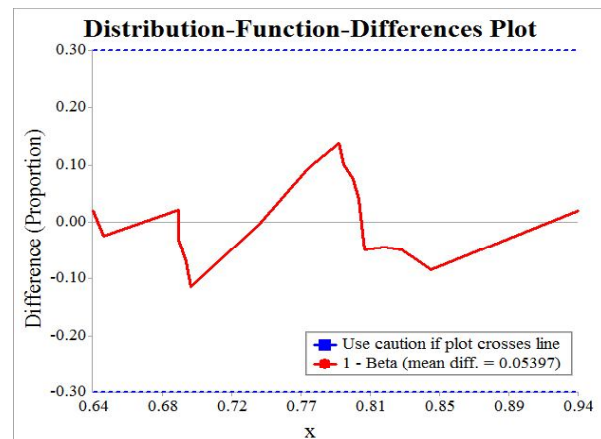
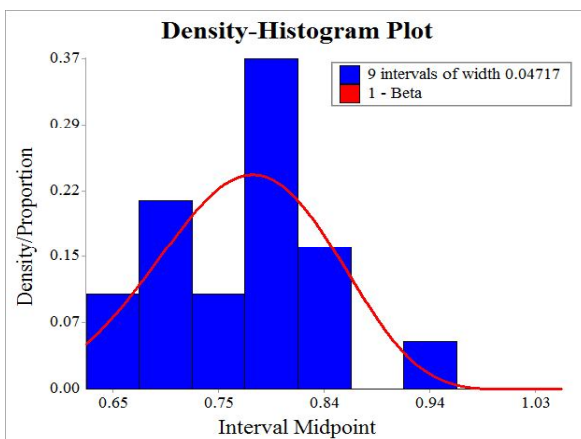


Percent Grinded Parts

The percent grinded parts refers to the percentage of parts within a section that need to be grinded. For example, if a section is composed of 100 parts and the section is 80% grinded parts, then a total of 80 parts of that section need to be grinded.

For the percent of grinded parts, a beta distribution was selected. The table below contains the parameters of the selected distribution. The figures below show the selected distribution overlaid over a histogram of the collected data and the difference between the sample data and the selected distribution.

Table of Parameters	
Lower endpoint	0.338
Upper endpoint	1.00
Alpha	11.55
Beta	6.35



The grinded parts in a section are not uniformly distributed between small/medium parts and large parts. Less large parts require grinding since a shell plates do not require grinding and shell plates are almost exclusively large parts. Therefore, an adjustment factor was created to compensate for the uneven distribution of grinded parts. The adjustment factor was determined by examining the proportional difference in grinding requirements for several sections. The adjustment factor used in the calculation was determined by averaging the measured values. The table below contains the adjustment factor used in the PPA as well as some characteristics of the recorded measurements.

	Average	Measurements taken	Standard deviation	Highest recorded value	Lowest recorded value
Grinding adjustment factor	15.9%	5	8.7%	27.9%	4.3%

The grind adjustment factor specifies by what percentage the percent of large grinded parts should be decreased. The percent of small/medium grinded parts must also be increased to ensure that the total percent of grinded parts remains at the original percent. The following example illustrates how this calculation should be done:

Sample Grinding Adjustment Calculation

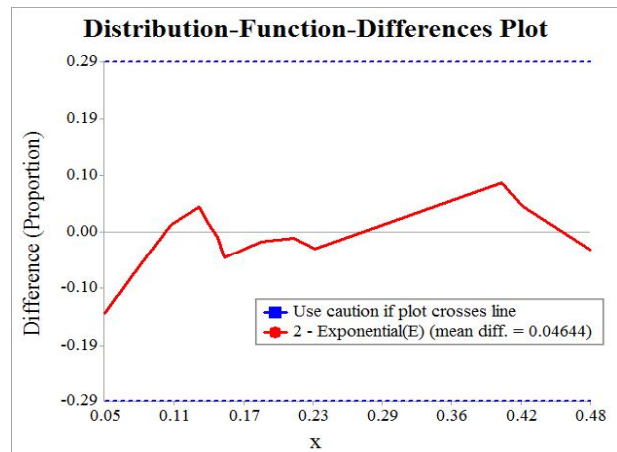
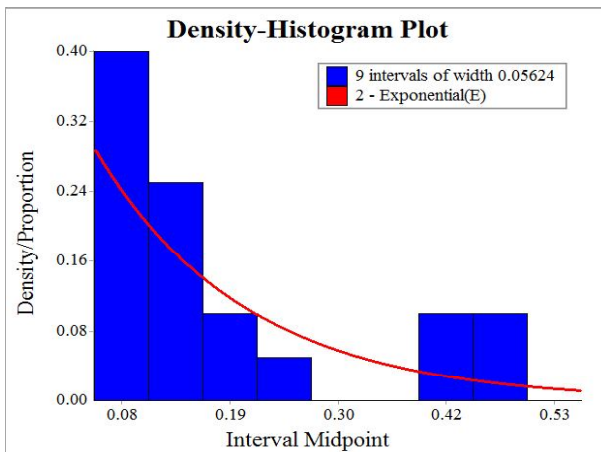
Percent grinded parts	80%	(given)
Percent large parts	30%	(given)
Percent large grinded parts	64.1%	= Percent grinded parts - Grinding adjustment factor
Percent s/m grinded parts	86.8%	= (% grinded/ parts - % large parts * % large grinded parts) / (1 - % large parts)

Percent Grinded Profiles

The percent grinded parts refers to the percentage of profiles within a section that need to be grinded. For example, if a section is composed of 100 profiles parts and the section is 90% grinded profiles then a total of 90 profile parts of that section need to be grinded.

Due to the nature of the data, it was easier to fit a distribution to the number of un-grinded profiles. For the percent un-grinded profiles, an exponential distribution with a location parameter was selected. The location parameter indicates the amount the distribution is shifted. The table below contains the parameters of the selected distribution. The figures below show the selected distribution overlaid over a histogram of the collected data and the difference between the sample data and the selected distribution.

Table of Parameters	
Location parameter	0.0172
Mean	0.159



The following equation was used to calculate the percent of grinded profiles from the percent of un-grinded profiles:

$$\text{Percent grinded profiles} = 100\% - \text{Percent un-grinded profiles}$$

11.3 CONFIDENCE INTERVALS FOR PRELIMINARY PROCESS THROUGHPUT

The 95% confidence interval and the maximum difference between the real mean and the calculated mean was calculated using the following equation [43]:

$$W = 2 * X\% * \mu = \frac{Z_{0.95} * \sigma}{\sqrt{n}}$$

Where:

W = confidence interval width (there is a 95% chance that true mean falls between $(\mu - W/2)$ and $(\mu + W/2)$)

X% = maximum percent difference between true mean and calculated mean

μ = sample mean

σ = sample standard deviation

$Z_{0.95} = 1.96$ for 95% confidence interval

The 95% confidence interval and maximum difference between real and calculated mean was determined for each combination of ship and section type for the old process, non-grinded condition:

Ship type	Section type	Number of sections	Mean throughput (tons/week)	Standard deviation of throughput (tons/week)	Max difference between real and calculated mean	95% confidence interval width (tons/week)
Yacht	-	53	45	46	13.8%	12
Tug	-	32	110	43	6.9%	15
Offshore support	-	52	206	118	7.8%	32
Inland cruise vessel	-	95	266	133	5.0%	27
Beaver dredger (sml)	-	18	185	37	4.6%	17
Beaver dredger (lrg)	-	46	298	103	5.0%	30
Backhoe dredger	-	75	219	159	8.2%	36
TSH dredger	-	341	376	236	3.3%	25
Cutter suction dredger	-	290	364	127	2.0%	15
Coaster	-	360	338	212	3.2%	22
Pipelaying vessel	-	125	510	186	3.2%	33
Construction	-	44	375	209	8.3%	62
TSH dredger	Bow	75	224	111	5.6%	25
TSH dredger	Mid	120	510	251	4.4%	45
TSH dredger	Stern	35	197	114	9.6%	38
TSH dredger	Super	52	291	201	9.4%	55
Cutter suction dredger	Bow	46	295	94	4.6%	27
Cutter suction dredger	Mid	138	392	92	2.0%	15
Cutter suction dredger	Stern	12	303	86	8.0%	49
Cutter suction dredger	Super	38	359	174	7.7%	55
Coaster	Bow	57	327	146	5.8%	38
Coaster	Mid	80	516	218	4.6%	48
Coaster	Stern	35	219	129	9.8%	43
Coaster	Super	20	244	75	6.8%	33
Pipelaying	Bow	21	372	152	8.7%	65
Pipelaying	Mid	57	618	179	3.8%	46
Pipelaying	Stern	12	384	71	5.2%	40
Pipelaying	Super	22	392	74	4.0%	31

It was assumed that for the preliminary process analysis a sufficient number of sections were collected if the difference between the real mean and calculated mean was less than 10%. All ship and section type meet this requirement with the exception of yachts. The percentage difference between the real mean and calculated mean of yachts was so high because the value of the mean throughput of yachts was significantly smaller than for the other vessel types. The confidence interval of yachts was actually the lowest of all ship and section types. Therefore, it was determined that a sufficient number of yacht sections had been collected, even though the percentage difference between the real mean and the calculated mean was above 10%.

11.4 PRELIMINARY PROCESS ANALYSIS RESULTS

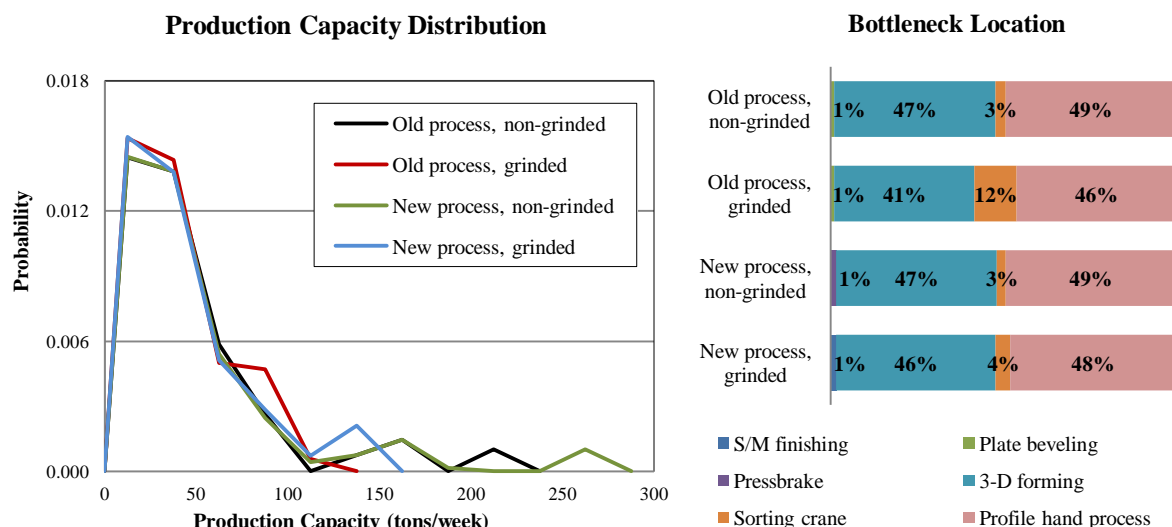
This appendix contains the production capacity distribution and bottleneck location graphs created for each ship type during the preliminary process analysis. A detailed description of the methodology used to construct these figures can be found in *section 5.3 Preliminary Process Analysis: Description of Analysis*.

Production capacity distributions display the probability that the production process has of achieving a given production capacity for a specific section type. The area under production capacity distribution is equal to one. The further the production capacity distribution is shifted to the right, the higher the average production capacity of the section type.

For each ship type, the production capacity distributions are shown for both grinded and non-grinded sections processed by both the old and new process. These graphs visually depict the influence of grinding and the upgrades to the production process at IHC Metalix on the production capacity of the process.

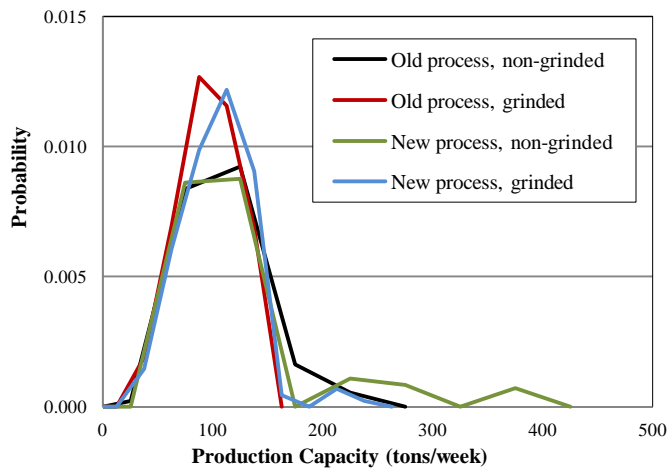
The bottleneck location graphs show the probability that each production sub-process has of being the process bottleneck for a given section type. These figures show the distribution of bottleneck locations for the sections examined for each ship type. For example, consider a ship type where the bottleneck location was the bevelling tables 50% of the time and the plate 3-D forming process 50% of the time. This means that for half of the sections, if the production process at IHC Metalix was only producing that specific ship type, the bevelling tables would be the bottleneck locations. For the other half of the sections, the plate 3-D forming sub-process would be the bottleneck if the production process was only producing any one of those sections. These bottleneck location figures do not necessarily indicate what bottleneck location would occur in the production process of IHC Metalix if a variety of sections were being produced.

11.4.1 Yacht

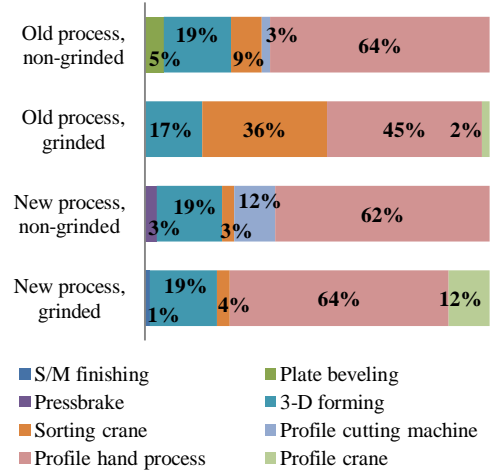


11.4.2 Tugboat

Production Capacity Distribution

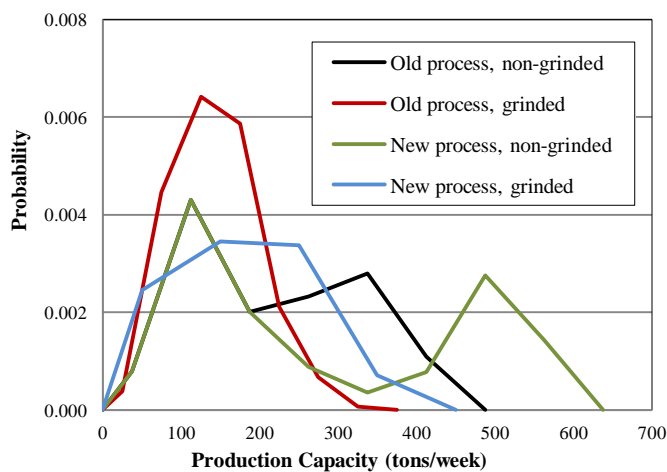


Bottleneck Location

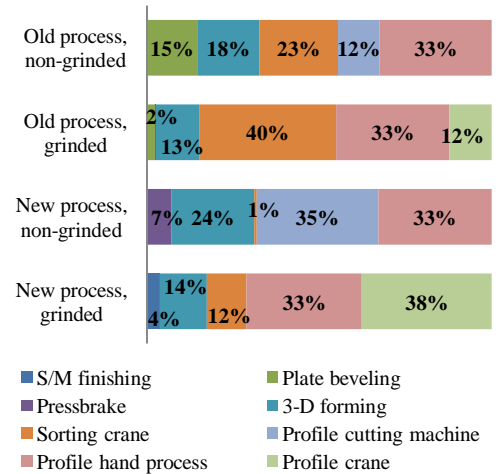


11.4.3 Offshore Support Vessel

Production Capacity Distribution

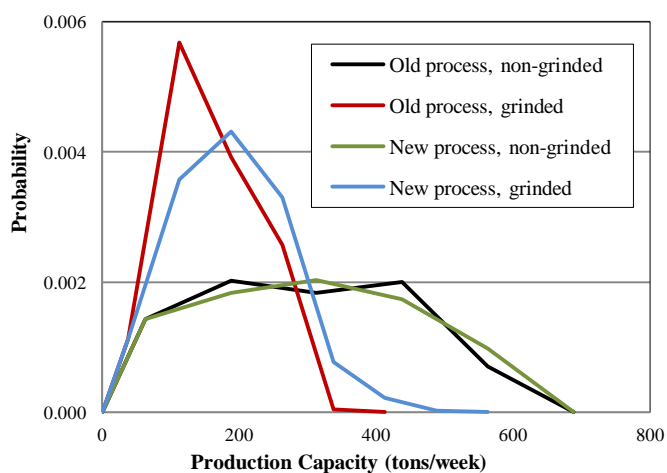


Bottleneck Location

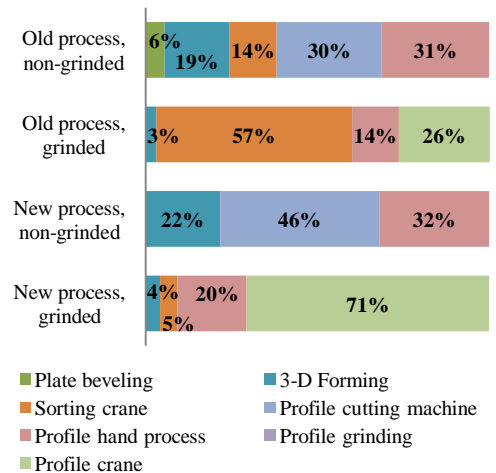


11.4.4 Inland Cruise Vessel

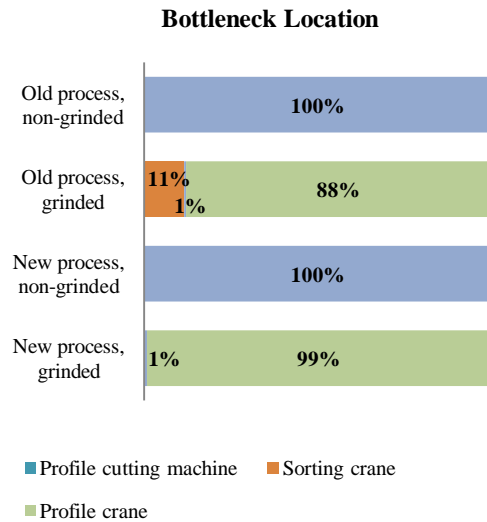
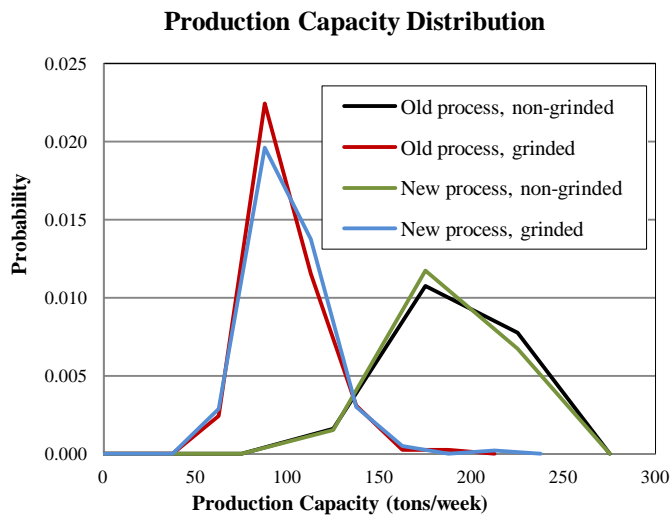
Production Capacity Distribution



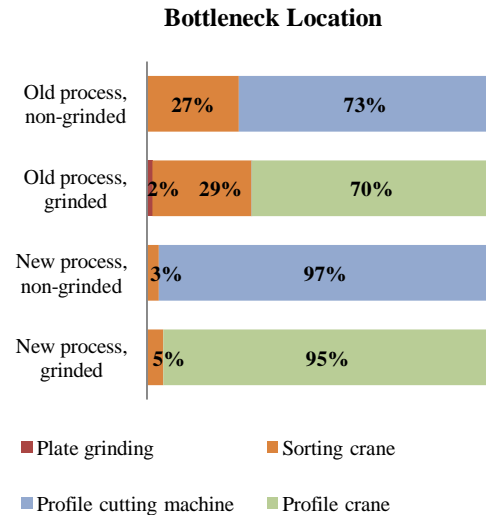
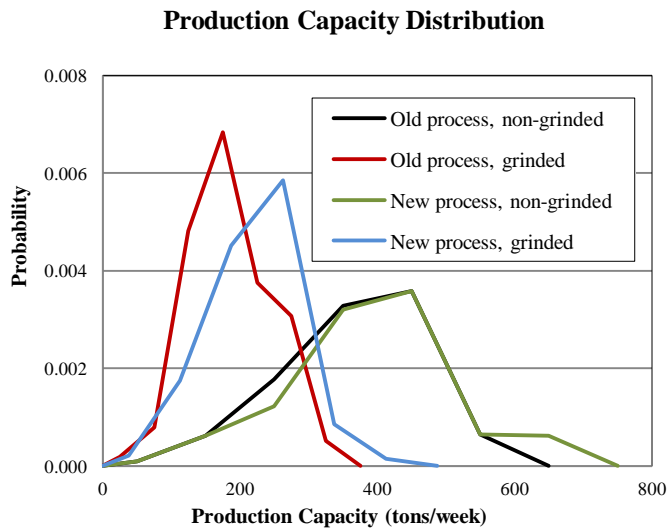
Bottleneck Location



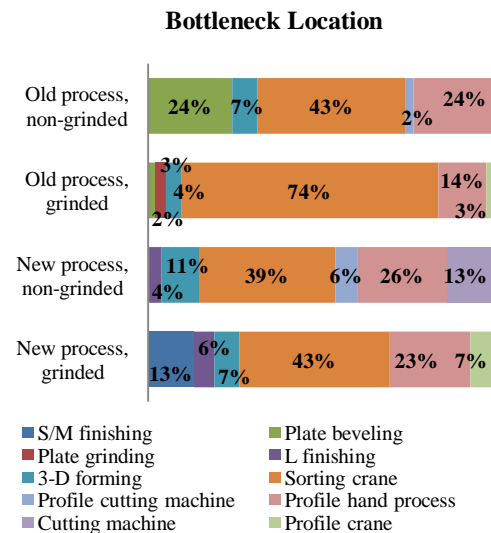
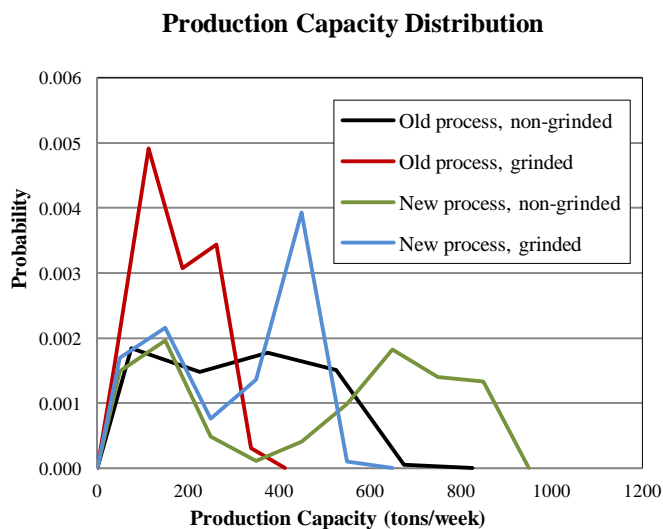
11.4.5 Small Beaver Dredger



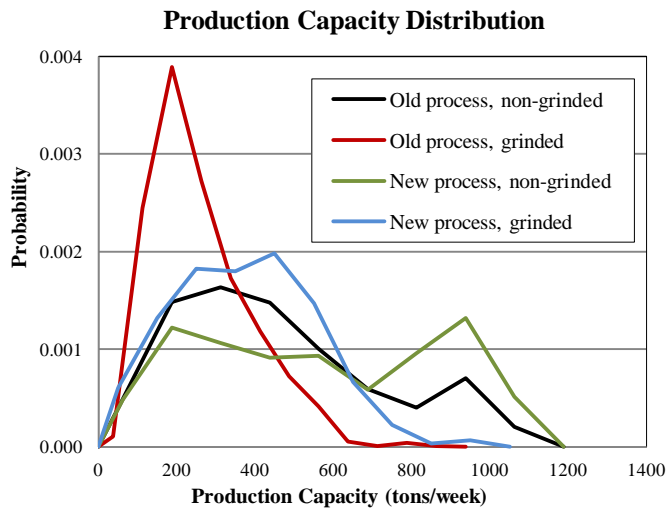
11.4.6 Large Beaver Dredger



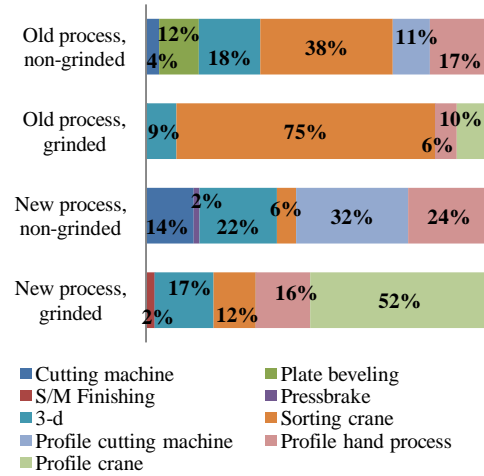
11.4.7 Backhoe Dredger



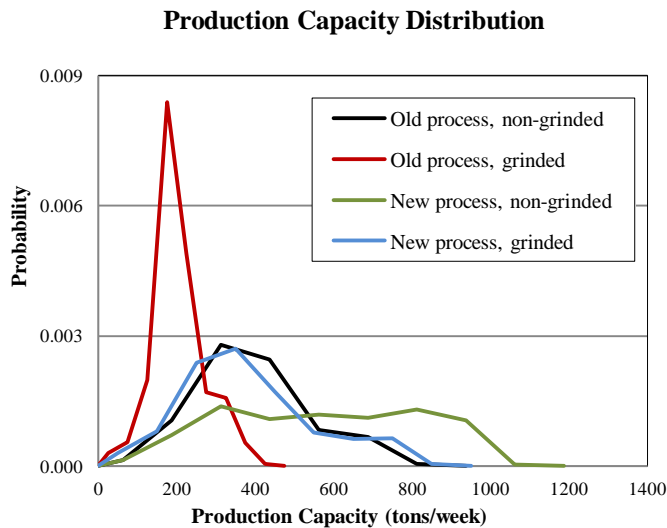
11.4.8 Trailing Suction Hopper Dredger



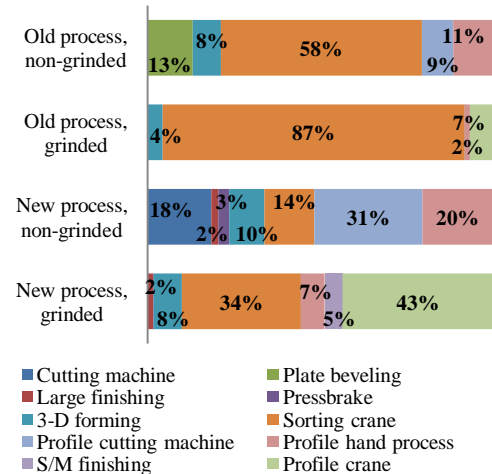
Bottleneck Location



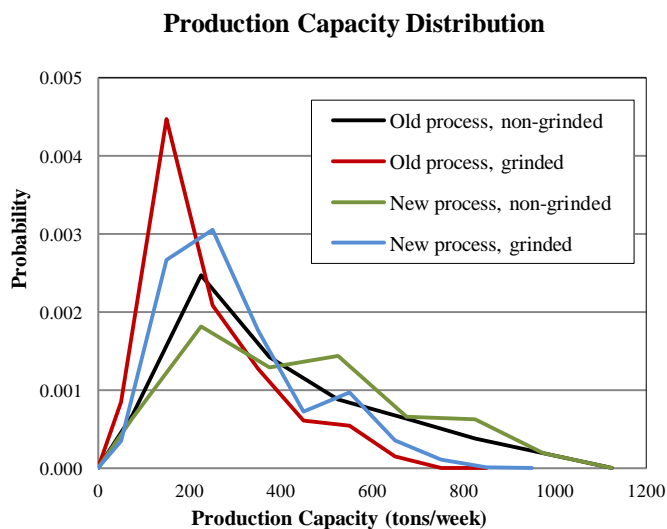
11.4.9 Cutter Suction Dredger



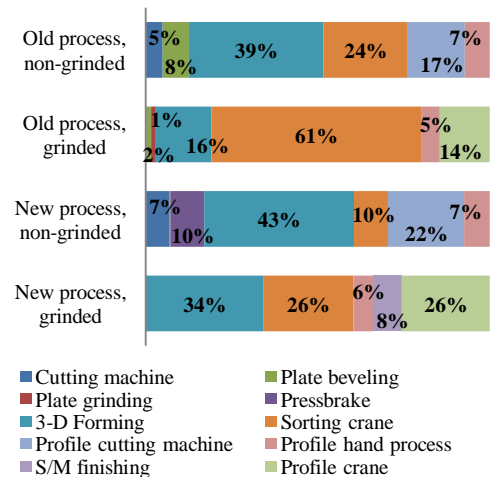
Bottleneck Location



11.4.10 Coaster

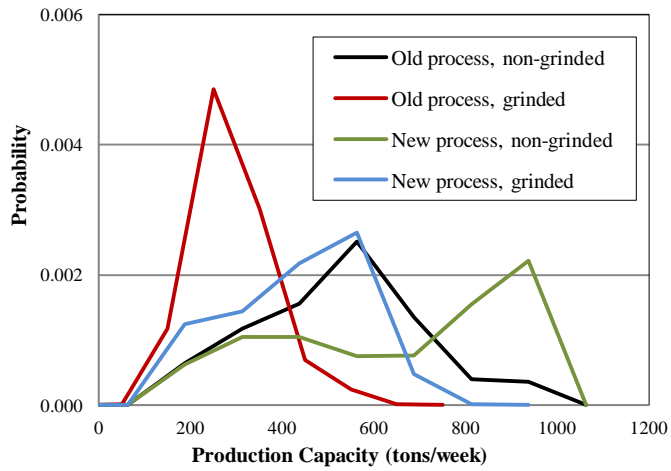


Bottleneck Location

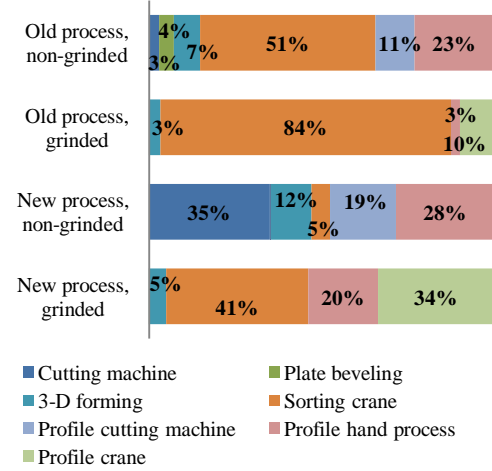


11.4.11 Pipelaying Vessel

Production Capacity Distribution

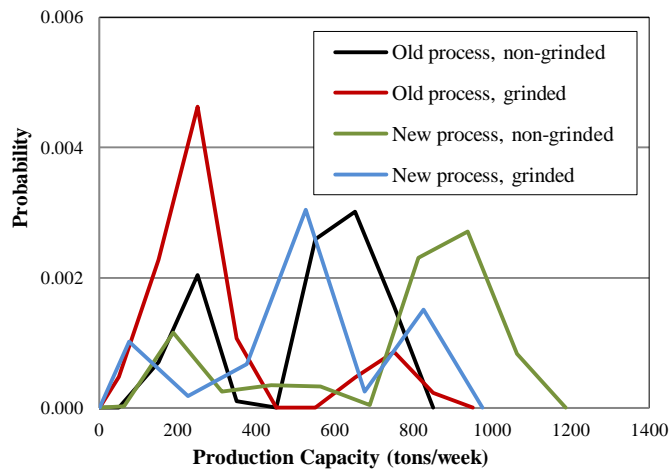


Bottleneck Location

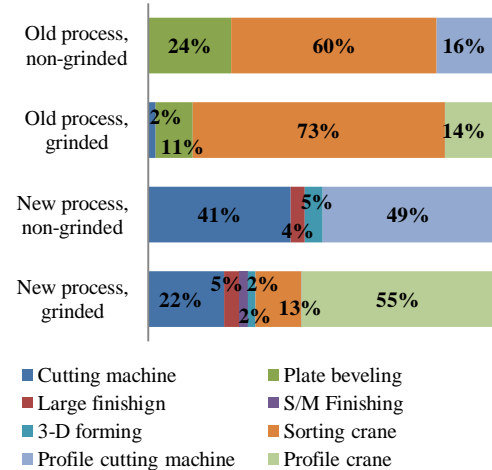


11.4.12 Construction

Production Capacity Distribution



Bottleneck Location



11.5 DESCRIPTION OF SIMULATION

The following appendix provides a detailed description of the different parts of the simulation model used for this project. The simulation model is broken down into twelve different areas, based on both location and functionality. A labelled screenshot of the simulation model is included for each area.

The purpose of this appendix is not to explain the logic used when coding the simulation model. Instead, a detailed process flow diagram was created to explain this logic. The process flow diagram of the simulation model can be found in appendix 11.6.

11.5.1 Flowitem Generation Area

The sections, uncut plates, uncut profiles, plate parts, and profile parts which are processed by the simulation model are created in the flow item generation area. This area also combines these flowitems together. The unprocessed sections are held in this area until the simulation is ready to process the sections.

Figure 11-1 shows a screenshot of the flowitem generation area from the simulation model. A brief description of the different elements within this area can be found below the figure.

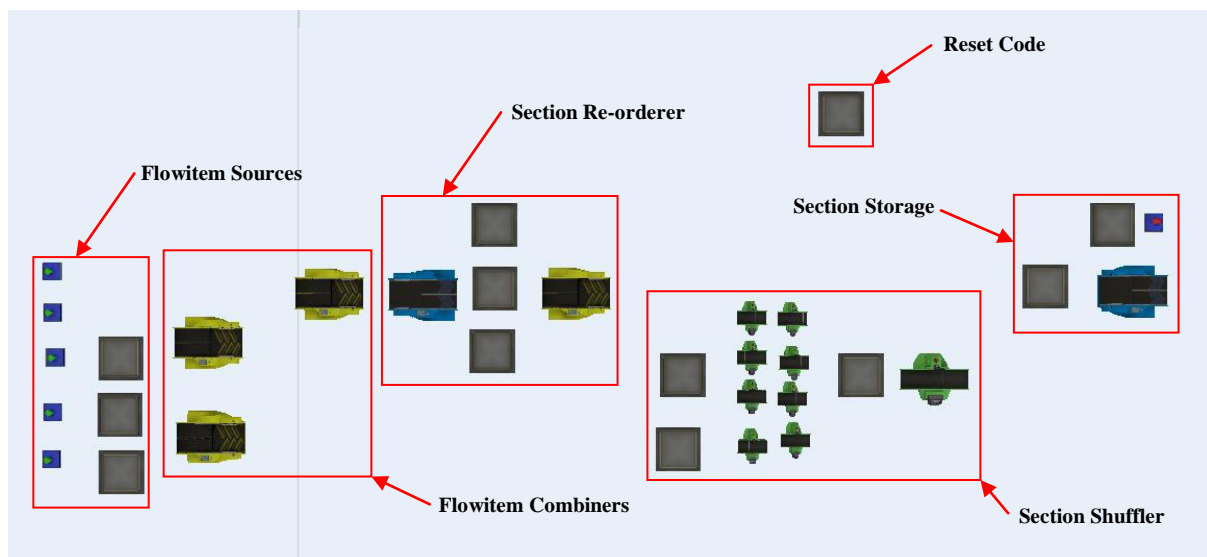


Figure 11-1: Flowitem Generation Area

11.5.1.1 Flowitem Sources

The user inputs the data for the sections, uncut plates, uncut profiles, plate parts, and profile parts into the flowitem sources. When a simulation run is started, these sources generate all of these flowitems. The queues after the sources are used to hold the flowitems before they are combined. These queues also contain triggers which assign certain random

properties to the flowitems (such as finishing times) and update a global table (Flatrack Status) that keeps track of all of the parts in the system.

11.5.1.2 Flowitem Combiners

The plate and profile combiners combine all of the plate and profile parts into the corresponding uncut plates and profiles. The uncut plates and profiles are then combined into the corresponding sections.

11.5.1.3 Section Re-orderer

The order of the uncut plates and profiles is combined into the sections in the reverse order by the flowitem combiners of what is specified by the pre-processing worksheet. The section re-orderer fixes reverses the order of these uncut plates and profiles to match the order output by the pre-processing worksheet.

11.5.1.4 Section Shuffler

The section shuffler optionally shuffles the order sections are processed by the simulation. The “Section Shuffler” global table is used to indicate whether the sections are to be shuffled. The order of the sections can also be optionally shuffled during pre-processing.

11.5.1.5 Section Storage

The section storage area stores all of the sections which are to be process by the simulation until the production process is ready to receive those sections. When the process is ready to process an additional section, a section is released from the section storage area.

11.5.1.6 Reset Code

The reset code queue contains a series of commands which are triggered when the simulation model is reset. The purpose of these commands is the reset certain cells of the global tables to the appropriate starting values.

11.5.2 Plate Park & Plate Cutting Area

The plate park is used to hold the uncut plates which are to be cut by the simulation. The plates are held in the plate part until the cutting hall is ready to process the plates. The plate cutting area contains the four plasma cutting machines.

A labelled screenshot from the simulation model of the plate park and plate cutting area is shown on Figure 11-2. The sections below the figure describe each of the items labelled in Figure 11-2.

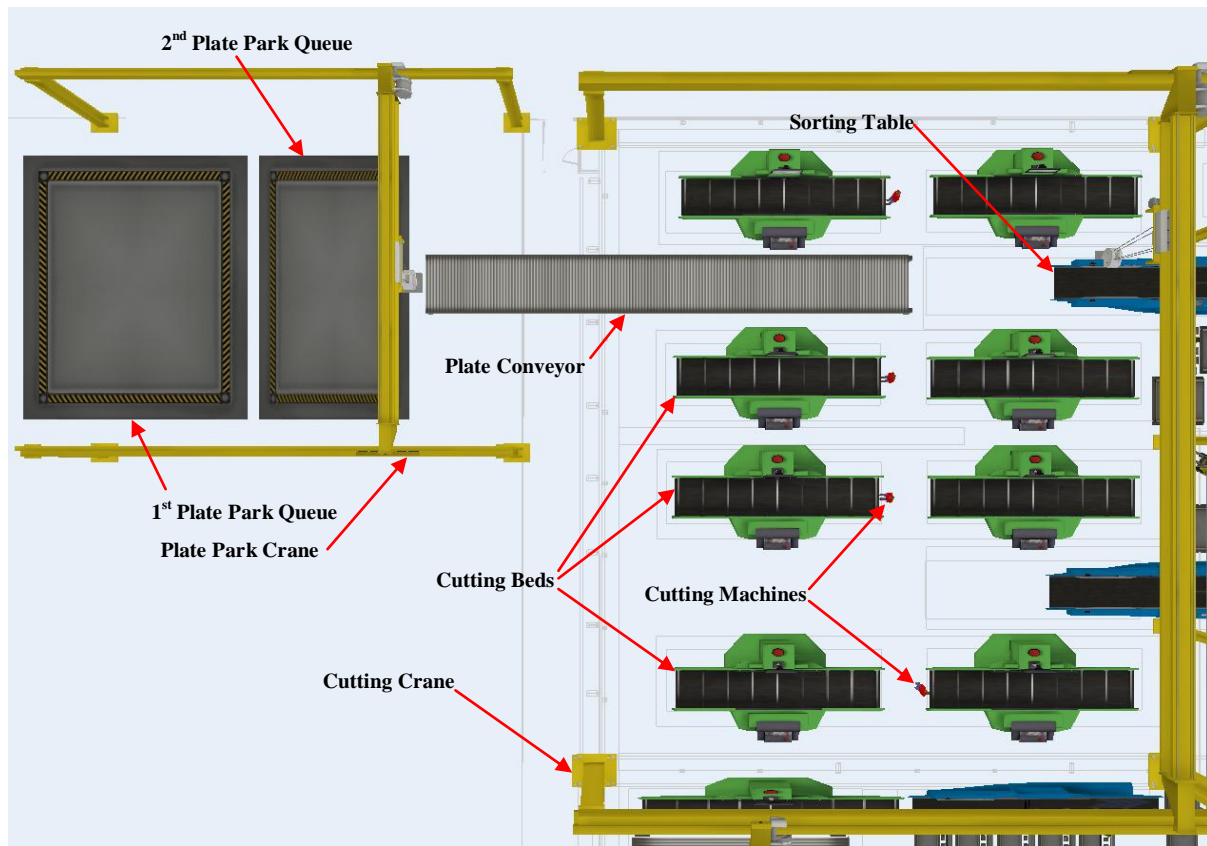


Figure 11-2: Plate Park & Plate Cutting Area

11.5.2.1 1st Plate Park Queue

All plates which are to be cut initially enter the first plate park queue. If the cutting area is ready to cut a plate, the plate leaves the first plate park queue and enters the second plate park queue. The cutting area is only ready to cut a plate if the large part sorting area has enough flattrack positions available to sort each of the large parts nested in a plate.

11.5.2.2 2nd Plate Park Queue, Plate Park Crane, and Plate Conveyor

The second plate park queue holds all of the plates which are ready to be cut. The plates are lifted onto the plate conveyor by the plate park crane. The plate conveyor transports these plates into the plate cutting hall.

11.5.2.3 Cutting Machines and Cutting Beds

The cutting area contains eight cutting beds and four cutting machines. Each cutting machines can cut plates on two of the cutting beds. The cutting beds can each hold one plate at a given time. After a plate has been cut by the cutting machines, it is removed from the cutting beds by the cutting crane and placed onto a sorting table.

11.5.2.4 Cutting Crane

The cutting crane moves the uncut plates from the plate conveyor to the cutting beds. This crane also moves the cut plate parts and scrap from the cutting beds to the sorting tables.

11.5.3 Small Part Sorting Area

The small parts sorting area removes the small parts from the sorting tables. These parts are placed onto pallets, which are removed from the area using a conveyor belt. Figure 11-3 contains a screenshot of the small part sorting area. The main features of this area are labelled on the figure. A description of these features is also included below the figure.

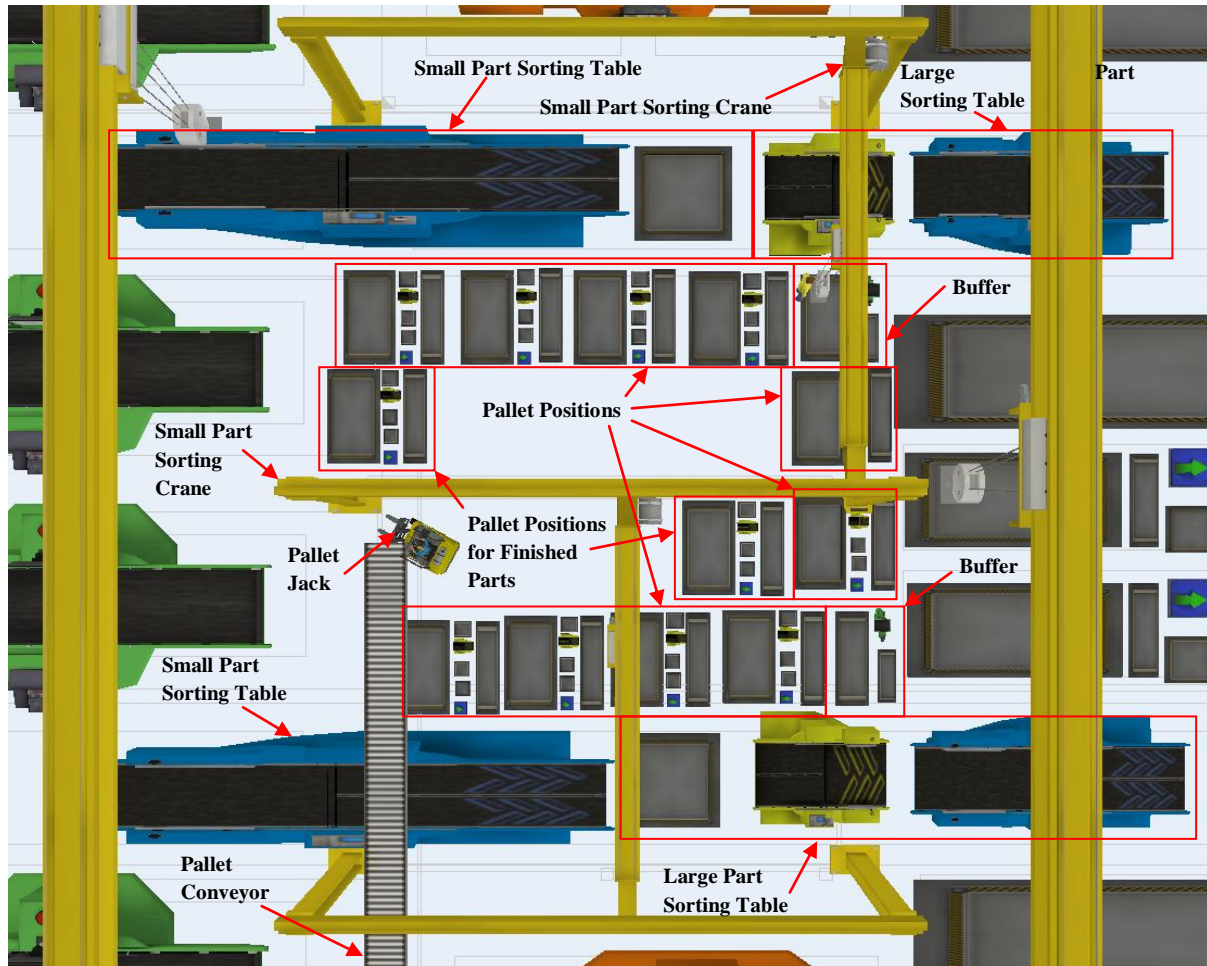


Figure 11-3: Small Part Sorting Area

11.5.3.1 Small Part Sorting Tables & Small Part Sorting Cranes

The small part sorting tables split the plates into the plate scrap and each of the parts contained within that plate. The time required to chalk mark the parts and move the sorting table is taken into account in the processing time of the separation task of the small part sorting tables.

The small part sorting cranes move the small parts which are too heavy to be moved by hand from the small part sorting table to the appropriate pallet position. The parts which are light enough to be moved by hand are moved by a worker within the small part sorting area.

The large parts and plate scrap are sent onward to the large part sorting table. No transportation is used for this movement, since these parts stay on the same sorting table. The movement time of the sorting table is taken into account in the separation processing time of the large part sorting table.

11.5.3.2 Large Part Sorting Tables

The large part sorting tables combine the plate scrap and large parts from the small part sorting tables back together. These parts are then separated during the large part sorting task.

11.5.3.3 Pallet Positions & Pallet Jack

Each side of the small part sorting area has five pallet positions. Parts which do not need any finishing for a given flatrack are collected on a pallet position. Once the weight limit of the pallet position is reached or if all of the parts of a given flatrack are collected, the pallet is released from the pallet position. A pallet jack is used to move the completed pallet from the pallet position to the pallet conveyor. Once the pallet is removed, parts from a different flatrack can be collected on the pallet position.

11.5.3.4 Pallet Positions for Finished Parts

Parts which require beveling, grinding, pressing, or forming are collected on the pallet positions for finished parts. Once the weight limit of these pallets is reached or if all of the parts of a given flatrack which require finishing are collected, the pallet is moved from the pallet position for finished parts to the plate conveyor using the pallet jack.

11.5.3.5 Buffers

If a part does not belong to the same flatrack as any of the parts on any of the pallet positions and no pallet positions are available, the part is placed in a floor buffer. Once a pallet position is able to accommodate a part in a buffer, the part is moved from the buffer to that pallet position.

11.5.3.6 Pallet Conveyor

The pallet conveyor is used to transport completed pallets from the small part sorting area to the small part finishing area.

11.5.4 Large Part Sorting and Finishing Area

The large part sorting and finishing area transports the plate scrap and large parts from the large part sorting tables to the appropriate flatracks. The required bevelling and grinding tasks are also performed for these large parts.

Figure 11-4 shows a labelled screenshot of this area. A description of the main elements of the large part sorting and finishing area is located below Figure 11-4.

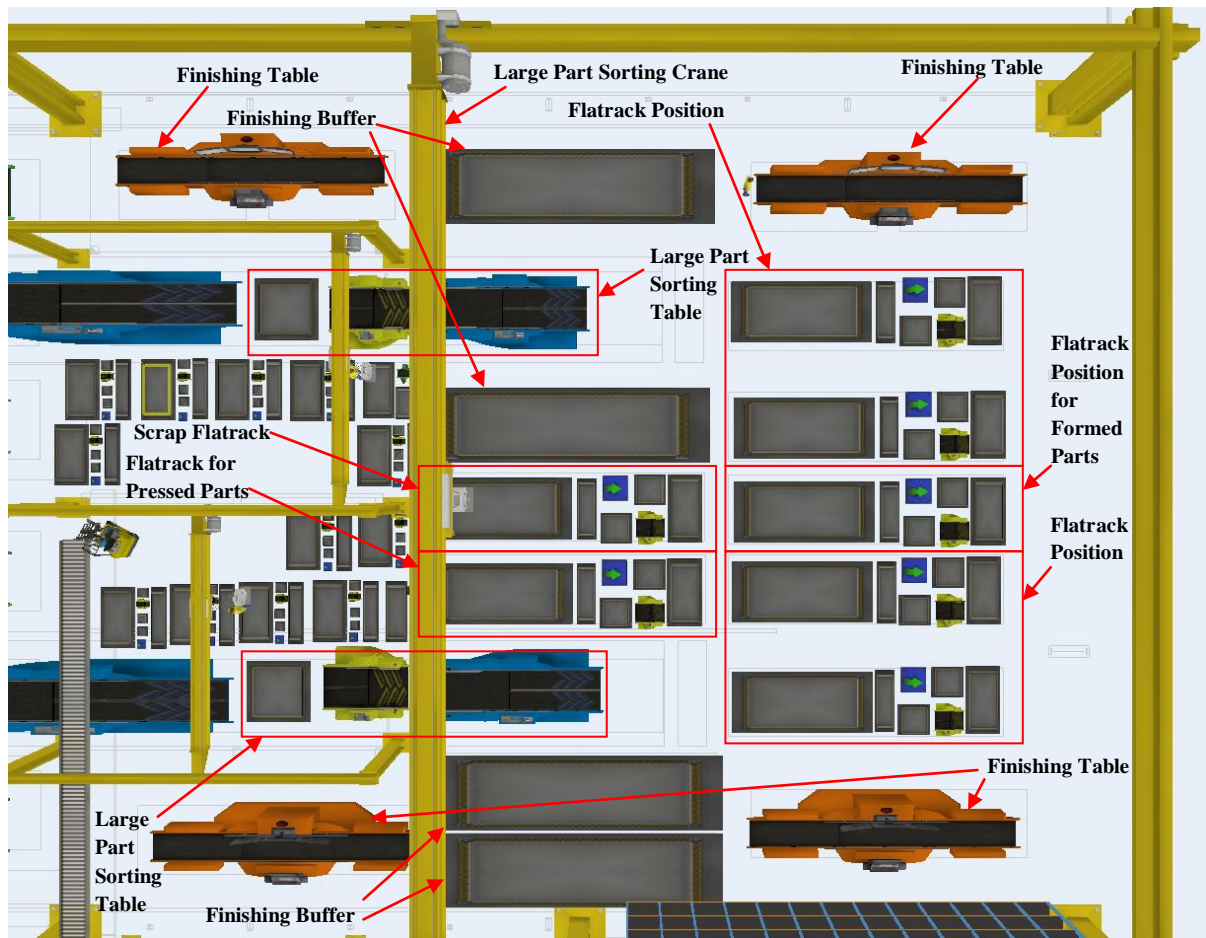


Figure 11-4: Large Part Sorting and Finishing Area

11.5.4.1 Large Part Sorting Table & Large Part Sorting Crane

The large plate parts and plate scrap are transported from the large part sorting tables to the appropriate flatrack or buffer positions by the large part sorting crane.

11.5.4.2 Finishing Buffers & Finishing Tables

Large parts which require beveling or grinding are stored in the finishing buffers if no space is available on the large part finishing tables. Each finishing buffer corresponds to one of the four flatrack positions. Only parts belonging to one flatrack are stored on a finishing buffer at any given point in time.

Large parts are beveled and grinded on the finishing tables. The large part sorting and finishing area contains four finishing tables.

11.5.4.3 Flatrack Positions

Large plate parts are placed onto one of the four flatrack positions after the parts have been beveled and grinded. If the plates do not require any finishing, the parts are moved to the flatrack positions directly from the large part sorting tables. Once all of the large parts of a flatrack are collected on a flatrack position, the flatrack is removed from the flatrack

position. At this point the flatrack position is available to receive large parts from a different flatrack.

11.5.4.4 Flatrack Position for Pressed Parts

Large parts which require the pressbrake are collected on the flatrack position for pressed parts. Once all of the pressed parts of a flatrack are collected, the flatrack is moved from the position to the pressbrake.

11.5.4.5 Flatrack Position for Formed Parts

The flatrack position for formed parts is used to collect large parts which require 3-D forming. The flatrack in this position is sent to the 3-D forming area once all of the large parts which require forming of a flatrack are collected.

11.5.4.6 Scrap Flatrack

The plate scrap is collected on the scrap flatrack. Once the weight limit of the scrap flatrack is reached, the flatrack is removed from the scrap flatrack position.

11.5.5 Small Part Finishing Area

The purpose of the small part finishing area is to bevel and grind all of the small parts which require these finishing tasks. Small parts which require forming or pressing are sent from this area to the appropriate areas after the required bevelling and grinding tasks are performed on those parts.

A labelled screenshot from the simulation model of the small part finishing area is shown in Figure 11-5. A description of the labelled items in the figure is included after the figure.

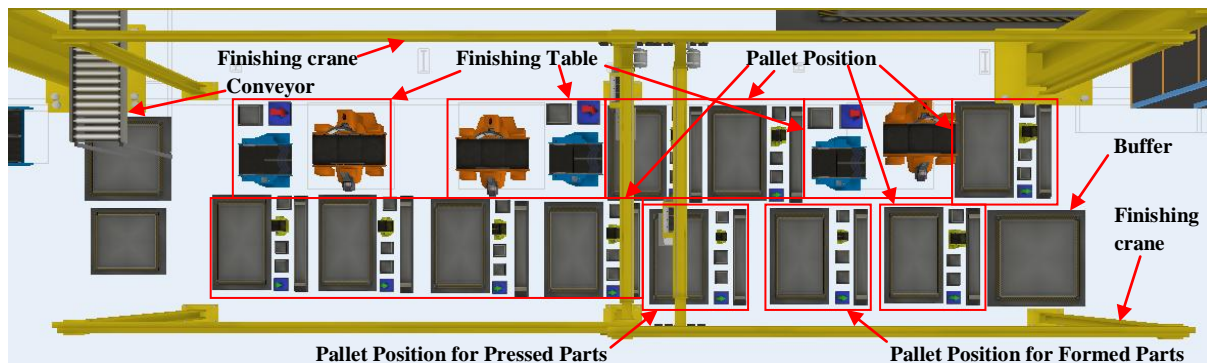


Figure 11-5: Small Part Finishing Area

11.5.5.1 Conveyor

The conveyor transports pallets from the small part sorting area to the small part finishing area. Pallets which contain parts that do not require finishing are moved to the pallet storage area. Pallets which contain parts that require finishing are moved to one of the finishing tables.

11.5.5.2 Finishing Tables & Finishing Crane

The small parts are beveled and grinded on the finishing tables. After these tasks are performed, the parts are moved to one of the pallet positions. The parts are moved by hand if they are light enough. If the parts weight too much to be moved by hand, the finishing crane is used. The finishing crane is also used to lift heavy parts onto the finishing tables.

11.5.5.3 Pallet Positions

Small parts that have been beveled and grinded but do not require the pressbrake or 3-D forming are collected on the pallet positions. Once all of the small parts of a flatrack are collected on a pallet, the pallet is moved from the pallet position to the pallet storage area.

11.5.5.4 Pallet Position for Pressed Parts

The pallet position for pressed parts collects small parts which require pressing. Once all of the small parts for a flatrack that require the pressbrake are collected, the pallet is moved to the pressbrake.

11.5.5.5 Pallet Position for Formed Parts

Small parts which require 3-D forming are collected on the pallet position for formed parts. The pallet on this pallet position is moved to the 3-D forming stations once all of the small parts of a flatrack which require forming are collected.

11.5.5.6 Buffer

If no pallet position is available for a small part after leaving the finishing table, the part is placed into the buffer. Once pallet position becomes available, the part is moved from the buffer to that position.

11.5.6 Profile Park and Cutting Area

Profiles enter the production process through the profile park. The profiles are then either cut by the profile cutting machines or by the profile hand cutting process. Figure 11-6 contains a labelled screenshot from the simulation model of the profile park and cutting area. The sections below Figure 11-6 contain a description of the items labelled in the figure.

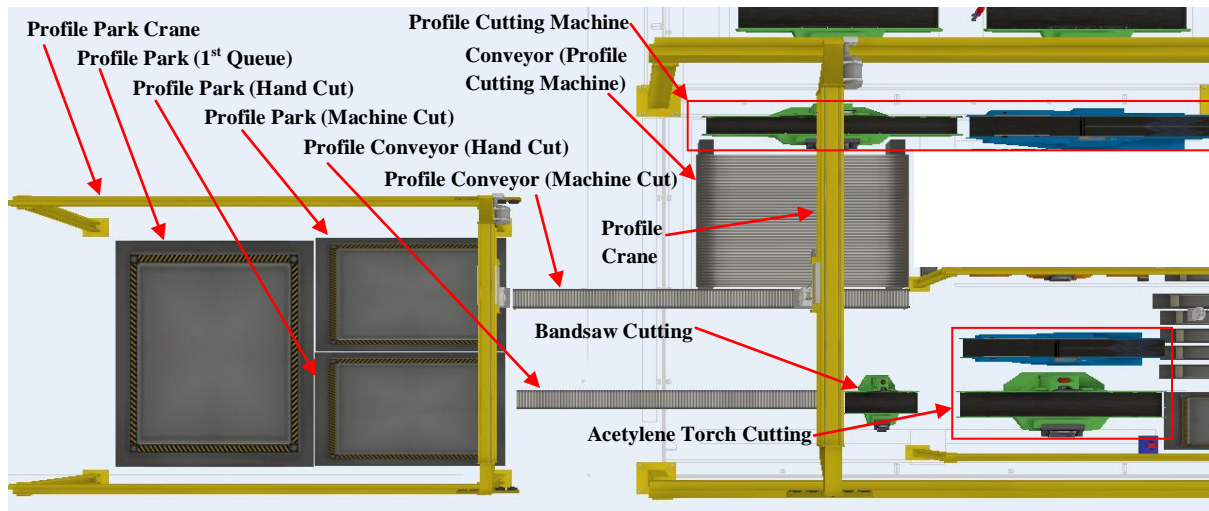


Figure 11-6: Profile Park and Cutting Area

11.5.6.1 Profile Park & Profile Park Crane

All profile parts initially enter the 1st queue of the profile park. Profiles which will be cut by the profile cutting machine move to the machine cut queue and profiles which will be cut by the hand cutting process move to the hand cut queue. The profile park crane moves the uncut profiles from the latter two queues to the corresponding profile conveyors.

11.5.6.2 Profile Conveyors (Hand Cut & Machine Cut & Profile Cutting Machines)

The hand cut and machine cut profile conveyors move profiles from the profile part into the cutting hall. The hand cut profile conveyor moves profiles to the hand cutting profile process while the machine cut profile conveyor moves profiles to the profile cutting machine.

The profile cutting machine conveyor feeds profiles directly into the profile cutting machine. This conveyor can hold approximately ten uncut profiles at a time.

11.5.6.3 Profile Crane

The profile crane moves uncut profiles from the profile conveyor (machine cut) to the conveyor (profile cutting machine).

11.5.6.4 Profile Cutting Machine

The profile cutting machine processes the uncut profiles. The cut profile pieces are sorted directly from the right half of the profile cutting machine.

11.5.6.5 Bandsaw Cutting & Acetylene Torch Cutting

Handcut profiles are first cut to the correct length using a bandsaw. If the profiles do not require bending, then the profiles are also cut to their final shape using an acetylene torch.

11.5.7 Profile Sorting & Grinding Area

Machine cut profile parts are sorted and grinded in the area shown in Figure 11-7. This figure also contains labels which indicate the important elements of the area. A description of these elements can be found below the figure.

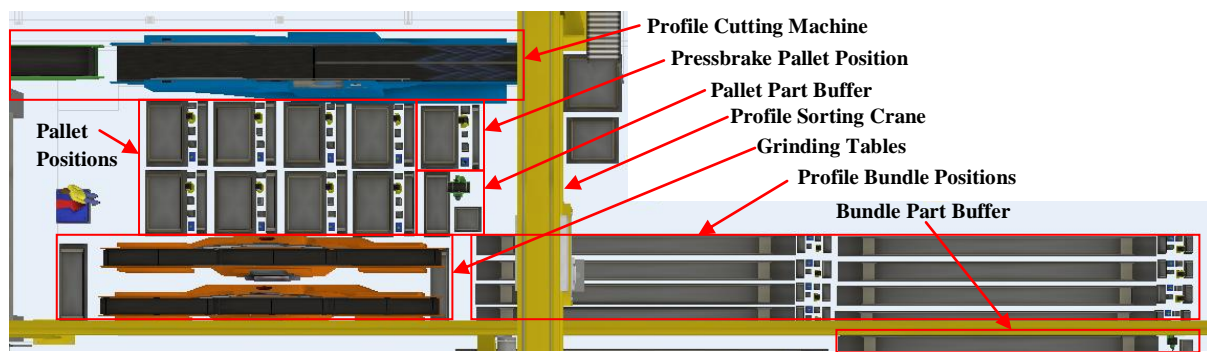


Figure 11-7: Profile Sorting & Grinding Area

11.5.7.1 Profile Cutting Machine & Profile Crane

Machine cut profile parts are sorted from the right half of the profile cutting machine. If the parts require grinding, they are moved to one of the grinding tables. Otherwise, the parts are moved to either a pallet or bundle position, depending on the length of the profile.

The profile parts are moved by hand if they are light enough. Otherwise these parts are moved by the profile sorting crane.

11.5.7.2 Pallet Positions

Small profile parts are collected on the profile pallet positions. The profiles are sorted on the pallet positions by the flatrack to which the profiles belong. Once the weight limit of the pallet is reached or all of the small profile parts of a flatrack are collected on a pallet position, the pallet is moved to the pallet storage area. The pallet position is then available to receive small profile parts from a different flatrack.

11.5.7.3 Pressbrake Pallet Position

Profile parts which require the pressbrake are collected on the pressbrake pallet positions. The pallet is moved to the pressbrake once all of the profile parts of a given flatrack are collected on the pressbrake pallet position.

11.5.7.4 Pallet Part Buffer

If no profile pallet position can accommodate a small profile part, that part is placed in the pallet part buffer. The part is moved to a pallet position once a pallet position becomes available.

11.5.7.5 Grinding Tables

Profile grinding is performed on the profile grinding tables. The profile parts are moved to the appropriate pallet or bundle position after being grinded.

11.5.7.6 Profile Bundle Positions

The profile bundle positions are used to collect large profile parts. Only profile parts of one flatrack are collected on a given profile bundle position. Once the weight limit of a

bundle is reached or if all of the large profile parts of a flatrack are collect, the profile bundle is moved away from the profile bundle position.

11.5.7.7 Bundle Part Buffer

If a large profile part cannot be placed in any of the profile bundle positions, the profile part is place in the bundle part buffer. Once a profile bundle position becomes available, the large profile part is moved from the buffer to that position.

11.5.8 Profile Bending Area

Profile parts are 3-D formed in the profile bending area. A labelled screenshot from the simulation model of this area is shown in Figure 11-8. The sections below the figure contain descriptions of the labelled items.

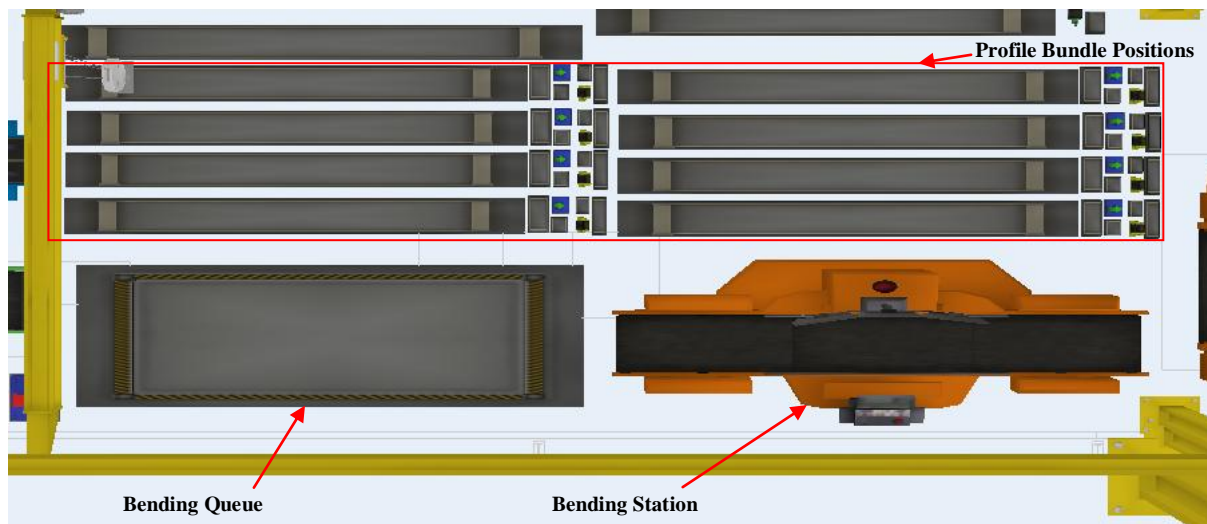


Figure 11-8: Profile Bending Area

11.5.8.1 Bending Queue

Profile parts which require bending first enter the profile bending queue. These parts wait in this queue until the profile bending station becomes available.

11.5.8.2 Bending Station

Profile parts are 3-D formed and cut to the correct shape using an acetylene torch in the profile bending station. After being formed and cut, the parts are moved to the profile bundle positions.

11.5.8.3 Profile Bundle Positions

Bent profile parts of a given flatrack are collected together on a profile bundle position. Once all of the bent profile parts of a flatrack have been collected, the profile bundle is moved to the end sorting area.

11.5.9 Pallet Storage Area

Pallets are stored in the pallet storage area until they are required in the end sorting area. Figure 11-9 contains a labelled screenshot from the simulation model of the pallet storage area. A description of the labelled items is located beneath the figure.

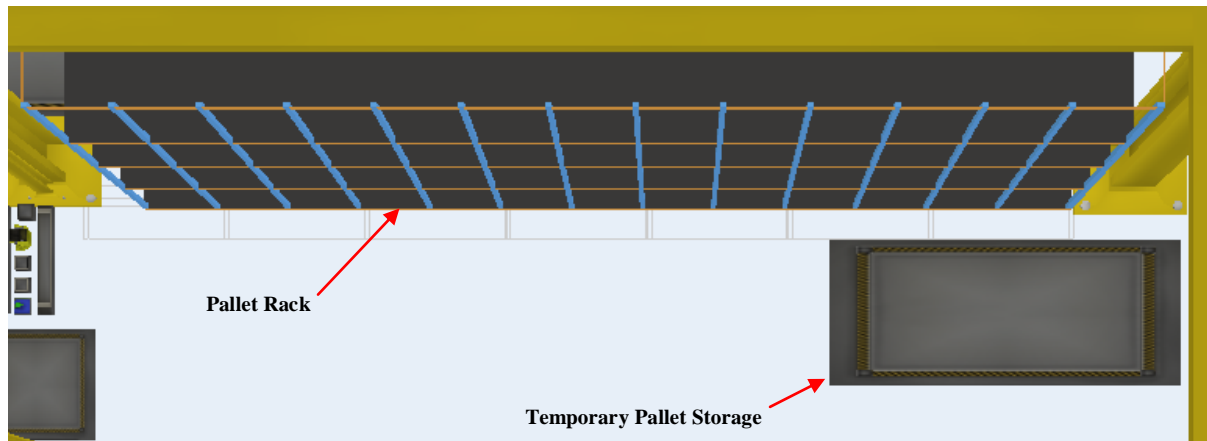


Figure 11-9: Pallet Storage Area

11.5.9.1 Pallet Rack

Completed pallets are stored in the pallet rack. Pallets are stored in the pallet rack until the flatracks corresponding with the parts on the pallets have completed the endsorting process. These pallets are loaded onto flatracks using a forklift.

11.5.9.2 Temporary Pallet Storage

Pallets which contain parts that still need to be beveled or grinded are stored in the temporary pallet storage if all of the small part grinding tables are occupied when those pallets exit the pallet conveyor.

11.5.10 Pressbrake Area

Plate and profile parts which must be pressed are processed in the pressbrake area. A labelled screenshot of the pressbrake area is shown in Figure 11-10. A description of the items labelled in Figure 11-10 is included after the figure.

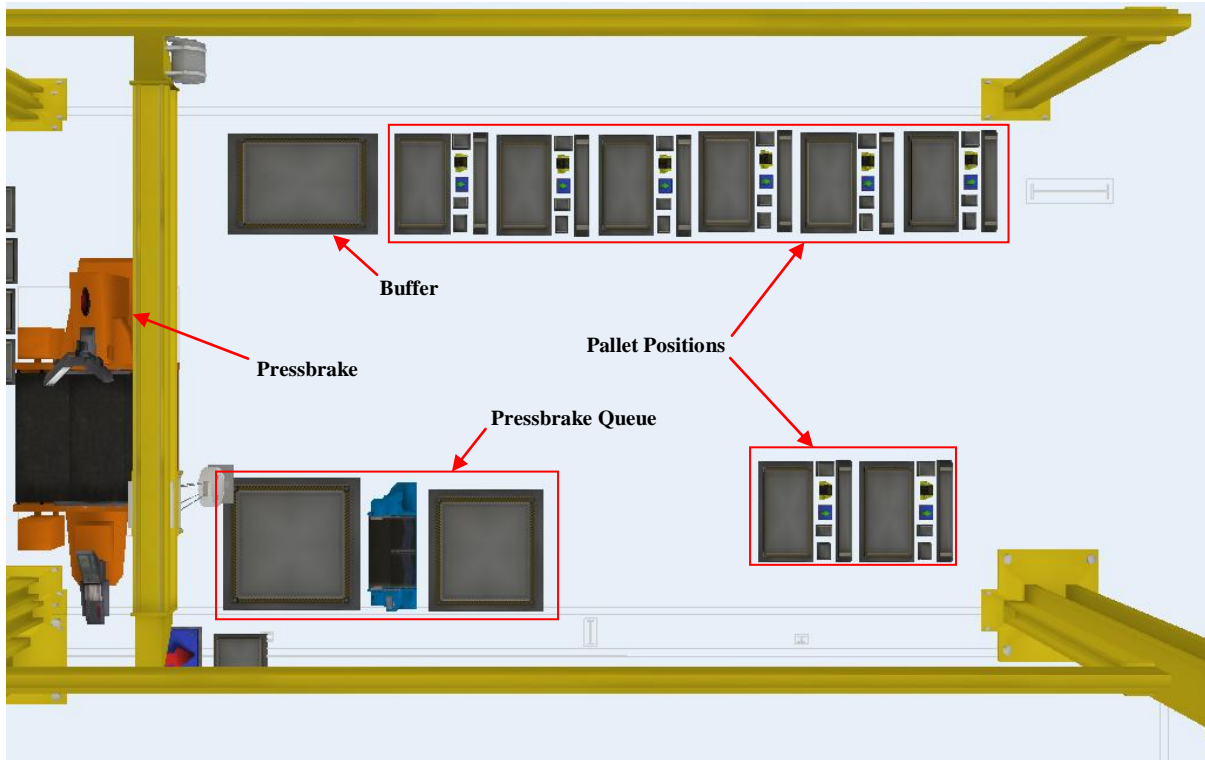


Figure 11-10: Pressbrake Area

11.5.10.1 Pressbrake Queue

Parts and profiles which need to be pressed are stored in the pressbrake queue. These parts are moved to the pressbrake once the pressbrake becomes available.

11.5.10.2 Pressbrake

The pressbrake is used to press plate and profile parts. Once the parts are pressed, they are moved to a pallet position.

11.5.10.3 Pallet Positions

Pressed parts and profiles are sorted on the pallet positions based on the flatrack with which the parts and profiles are delivered. Once all of the pressed parts and profiles of a flatrack are collected on a pallet position, that pallet is moved from the pressbrake area to the pallet storage area.

11.5.10.4 Buffer

If a pressed part or profile cannot be placed on any of the pallet positions, that part or profile is placed on the buffer position. Once a pallet position becomes available, the part or profile is moved from buffer to that pallet position.

11.5.11 Plate 3-D Forming Area

Plate parts are 3-D formed in this area. A labelled screenshot of this area is shown in Figure 11-11. A description to accompany the figure is included below the figure.

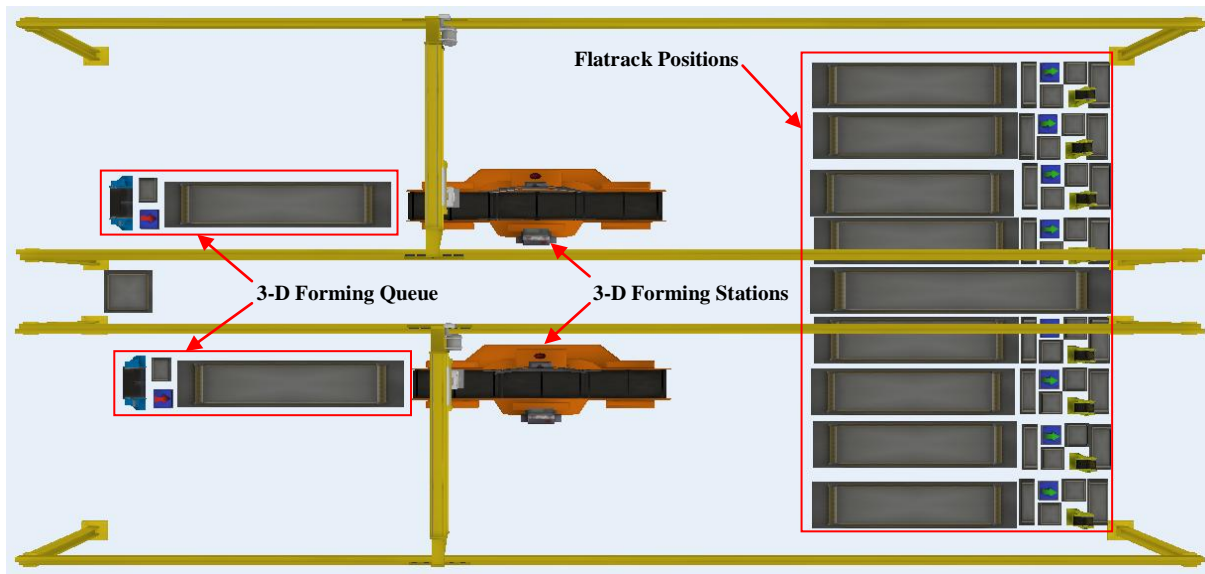


Figure 11-11: Plate 3-D Forming Area

11.5.11.1 3-D Forming Queue and Stations

Plate parts wait in the 3-D forming queues until the accompanying 3-D forming station becomes available. Once the station becomes available, the parts are lifted from the queues onto the forming stations. The 3-D forming process is completed on these stations.

11.5.11.2 Flatrack Positions

After being 3-D formed, the plate parts are moved to one of the flatrack positions. Once all of the parts of a given flatrack which require 3-D forming are collected, the flatrack is removed from the 3-D forming area.

11.5.12 End Sorting Area

Figure 11-12 contains a labelled screenshot of the end sorting area of the production process. In this area, flatracks, pallets, and profile bundles are combined to create the flatracks which will be delivered to the customer. The lifts required to arrange plates on the flatracks in any order are also performed in this area. A description of the labelled items is included below the figure.

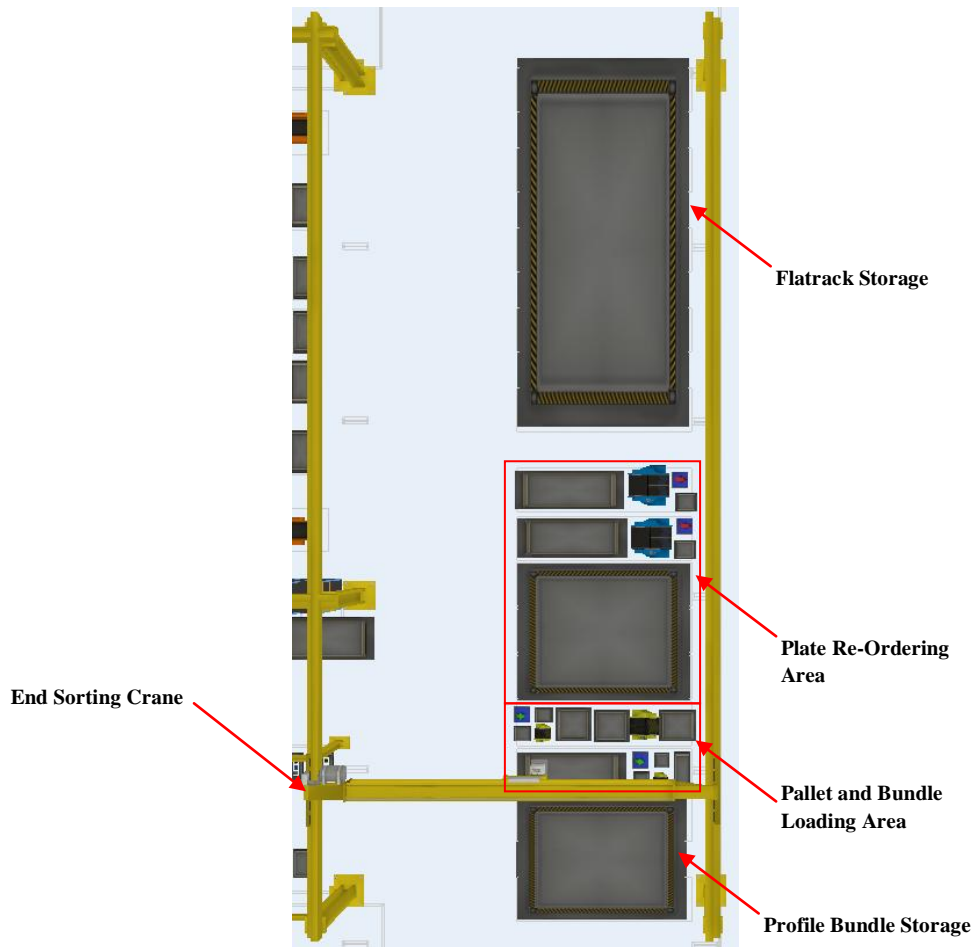


Figure 11-12: End Sorting Area

11.5.12.1 Flatrack Storage & Profile Bundle Storage

Profile bundles and flatracks are stored in the end sorting area until all of the components of a flatrack have been collected.

11.5.12.2 Plate Re-Ordering Area & Pallet and Bundle Loading Area & End Sorting Crane

The required lifts to reorganize the plates on a flatrack into any order are performed in the plate re-ordering area by the end sorting crane. This crane is also used to load the profile bundles and pallets onto the flatracks in the pallet and bundle loading area.

11.5.13 Dashboard

The dashboard is used to dynamically show the status of the simulation model as a model run occurs. The dashboard shows the production capacity achieved by the process, the total elapsed time, the percentage of sections cut, and the utilization of each sub-process. The dashboard can be used to determine the production capacity and bottleneck location of the simulation model for each run. Figure 11-13 contains a screenshot of a sample dashboard output.

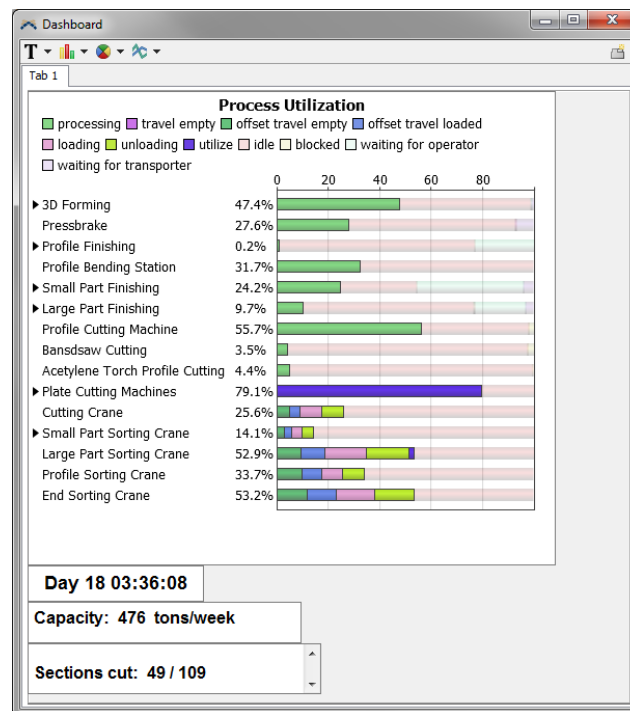
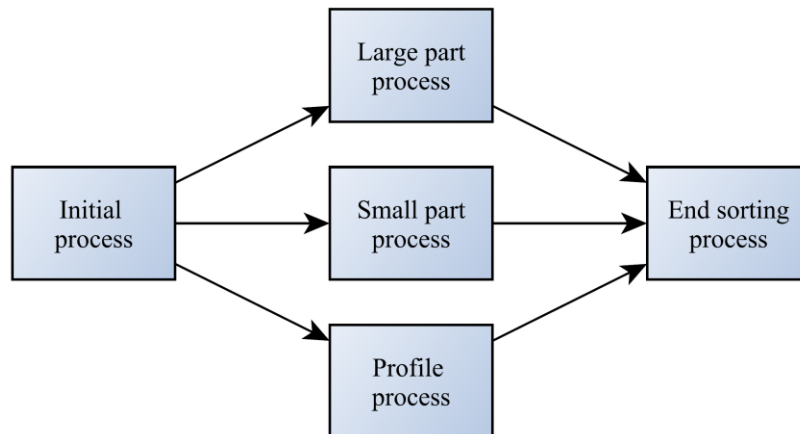


Figure 11-13: Sample Dashboard Output

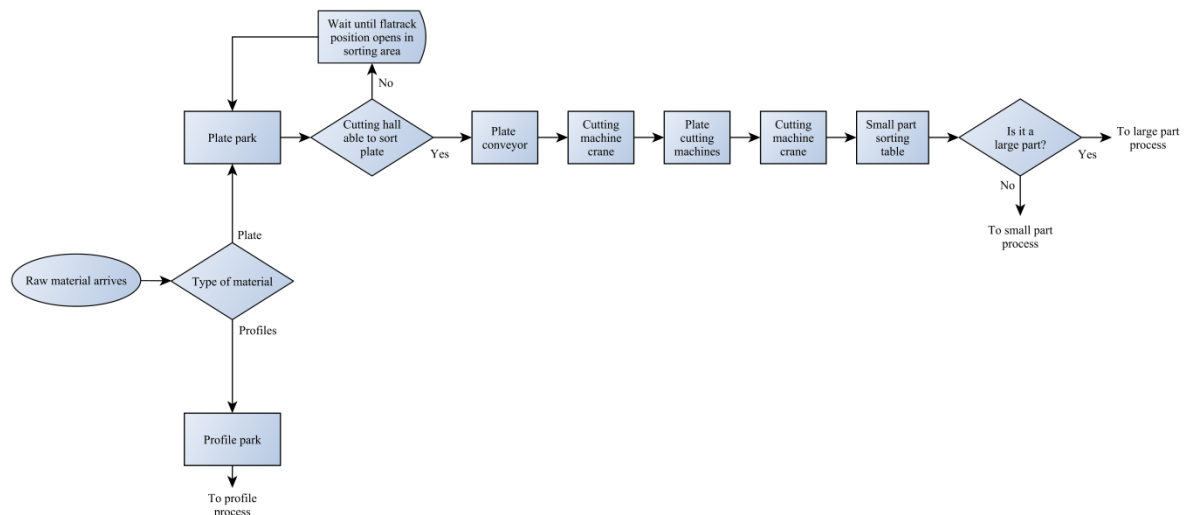
11.6 PROCESS FLOW DIAGRAM USED FOR SIMULATIONS MODEL

The following appendix contains a process flow diagram of new process of IHC Metalix. The process flow diagram is broken down into five sub-diagrams. The figure below shows the names and relationships of the sub-diagrams.

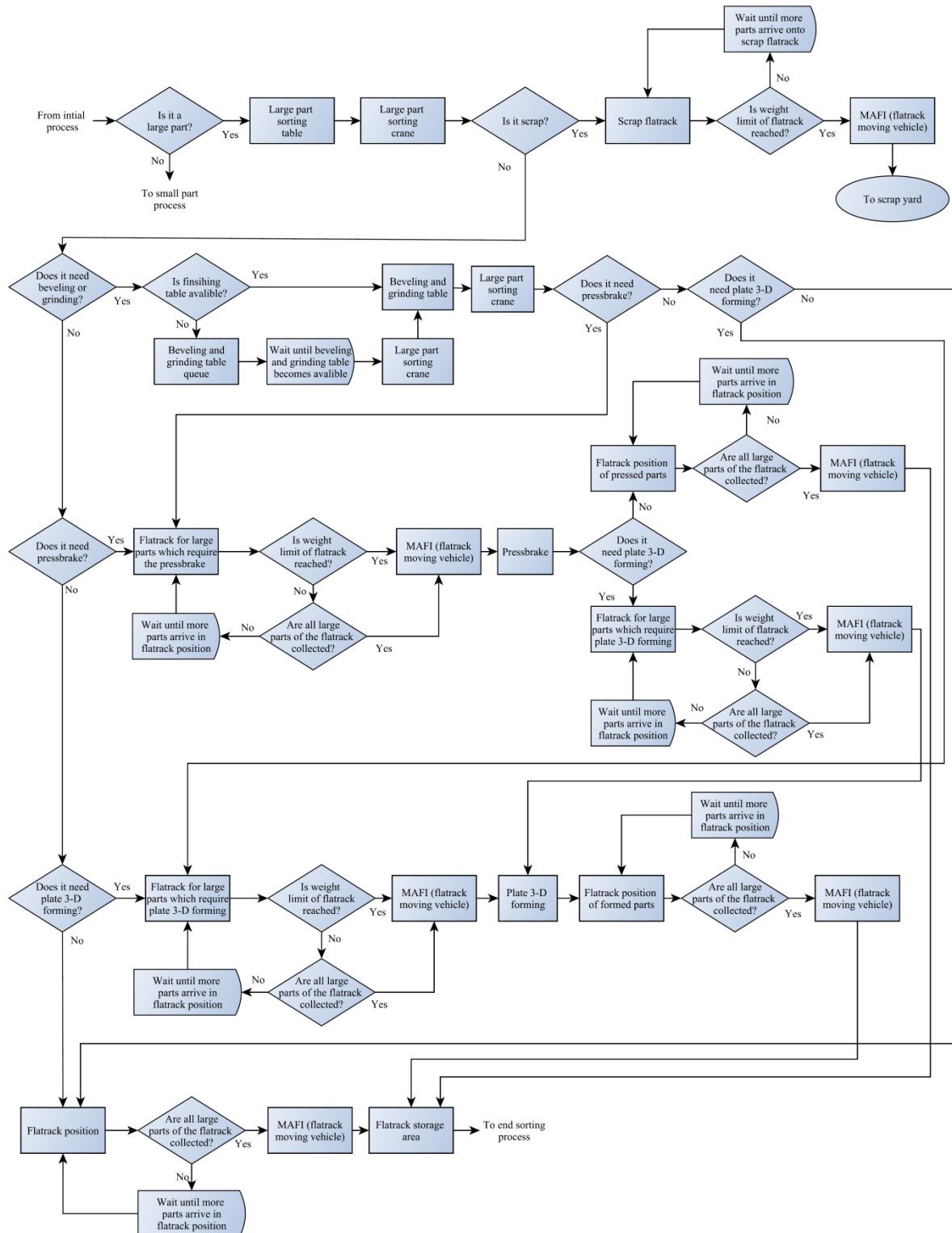


The next five sections contain these sub-diagrams. These process flow diagrams were used as a basis for the logic coded into the simulation model constructed for the new process of IHC Metalix.

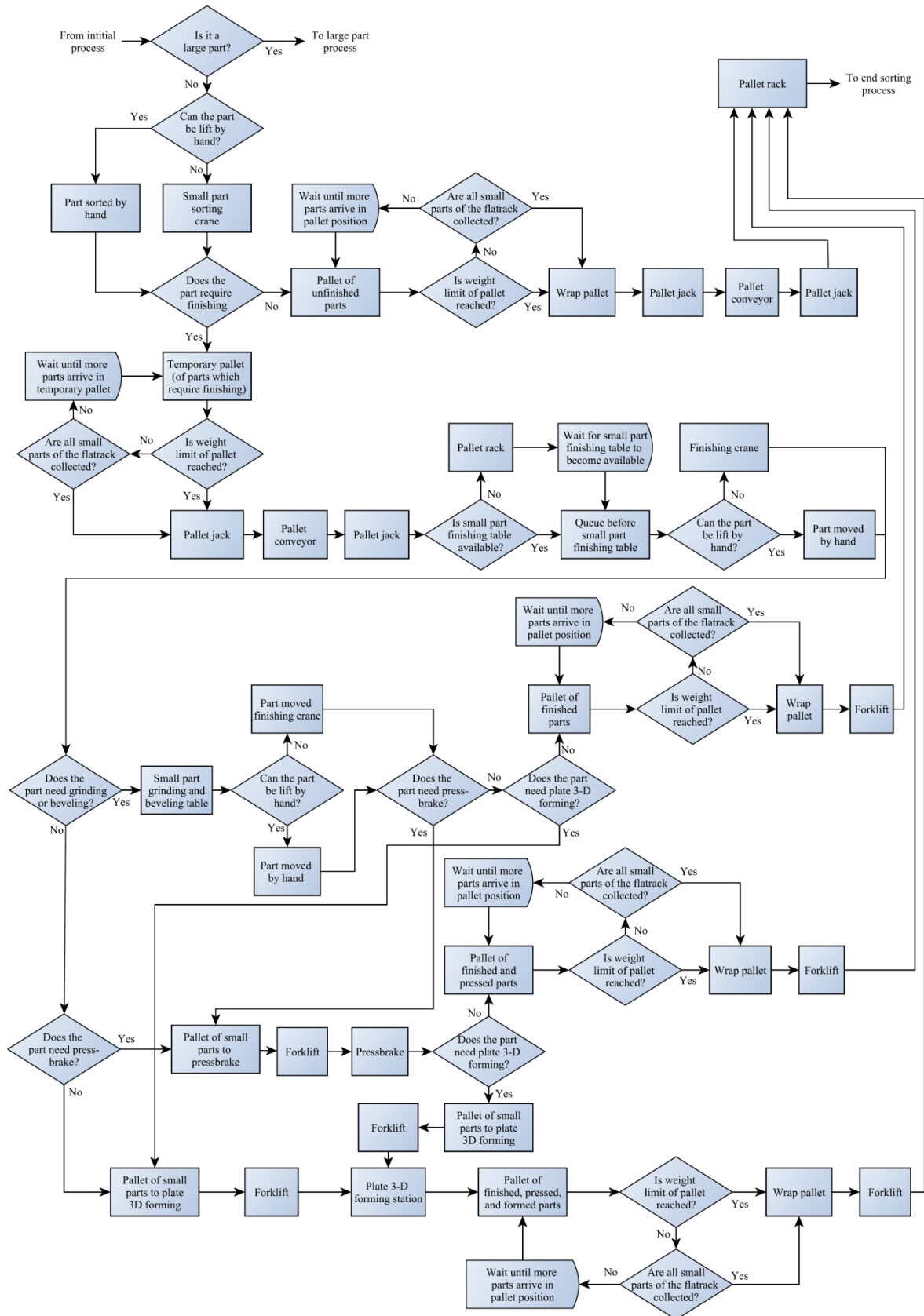
11.6.1 Initial Process



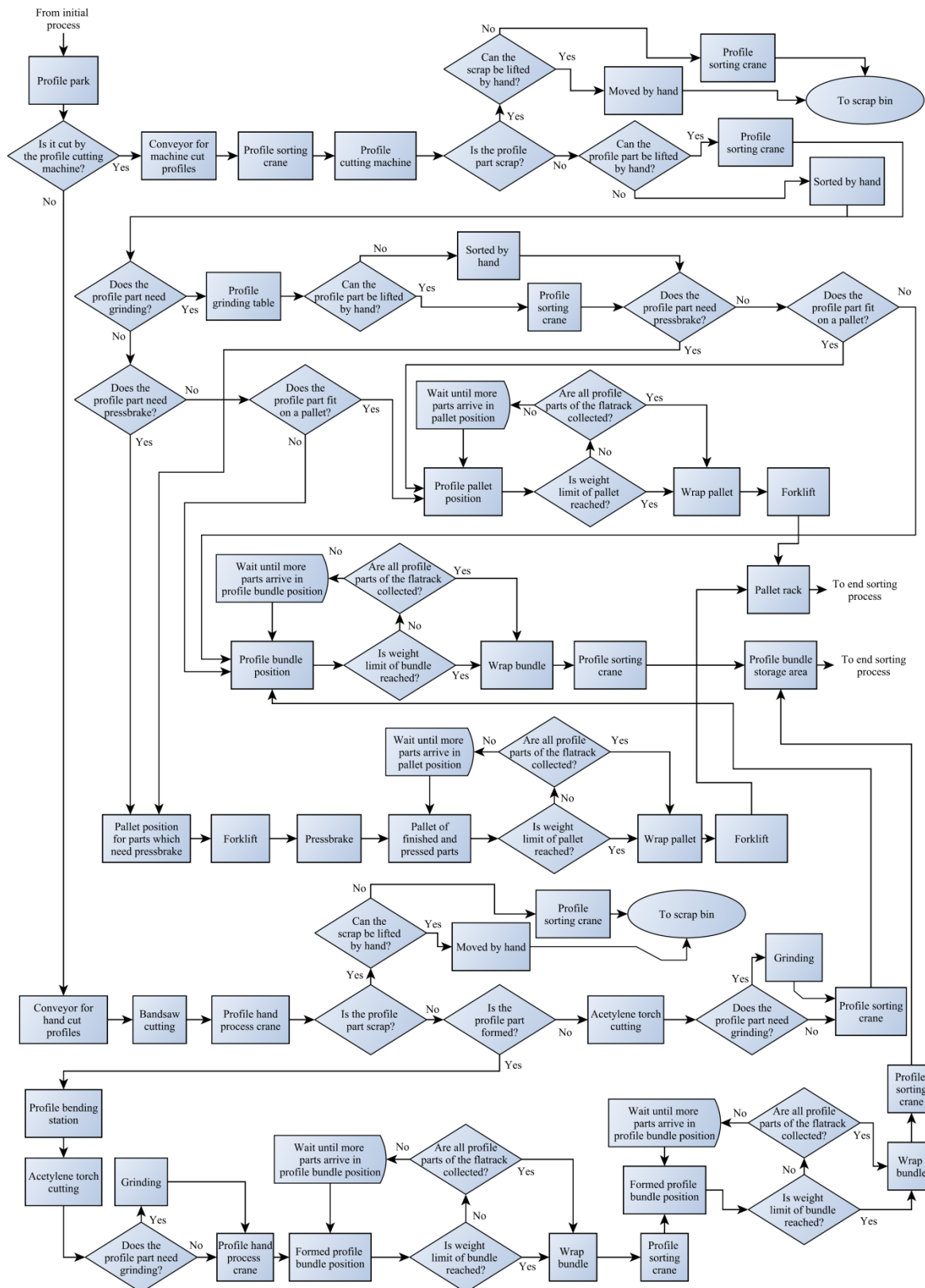
11.6.2 Large Part Process



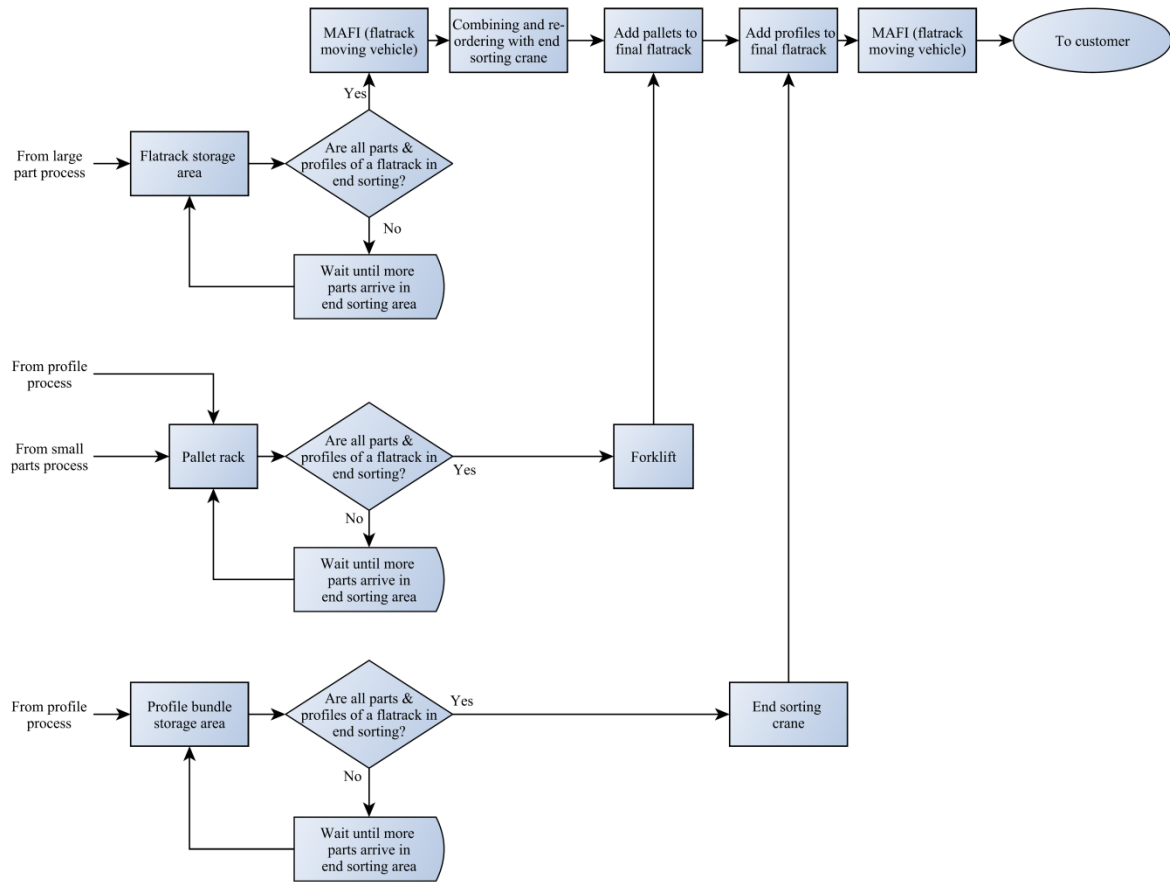
11.6.3 Small Part Process



11.6.4 Profile Process



11.6.5 End Sorting Process



11.7 DATA COLLECTION PROCEDURE

The following table contains a summary of the methodology used to collect the data used in this project. Detailed information regarding the data collected can be found in appendices 11.1 and 11.2.

Data Point	Collected from	Collected by	Collection start point	Collection end point
Cutting crane, pre-cutting lift	Production process	C. Rose	Crane touches part	Crane touches next part
Cutting crane, post-cutting lift	Production process	C. Rose	Crane touches part	Crane touches next part
Plate sorting, small parts	Production process	C. Rose	First part is lifted	Last part is in box/pallet
Plate sorting, medium parts	Production process	C. Rose	Crane touches part	Crane touches next part
Plate sorting, large parts	Production process	C. Rose	Crane touches part	Crane touches next part
Scrap removal	Production process	C. Rose	Crane touches part	Crane touches next part
Profile hand process	Production process	C. Rose	Crane touches part	Crane touches next part
Pre-profile cutting machine	Production process	C. Rose	Crane touches part	Crane touches next part
Profile sorting	Production process	C. Rose	Crane touches part	Crane touches next part
Beveling speed	Machine manual	R. Voorend	-	-
Grinding speed	Production process	C. Rose	Worker looks at drawing	Worker picks up paint
Painting speed	Production process	C. Rose	Worker picks up paint	Worker puts down paint
Pallet weight	Production process	C. Rose	-	-
Profile bundle weight	Production process	C. Rose	-	-
Pressbrake	Production process	IHC Metalix	Unknown	Unknown
Beveling setup	Production process	IHC Metalix	Unknown	Unknown
Profile cutting machine	Production process	C. Rose	Gripper reached back position	Gripper reached back position
Pallet wrapping	Production process	C. Rose	Worker goes to get wrapping material	Worker returns wrapping material
Profile bundling	Production process	C. Rose	Worker goes to get bundling material	Worker returns bundling material
Marking parts	Production process	C. Rose	First part is marked	Last part is marked
Grinding sawhorse setup	Production process	C. Rose	Saw horses start being moved	Part in position on sawhorses
Profile hand cutting (bandsaw)	Production process	C. Rose	Profile starts moving to saw	Next profile starts moving to saw
Profile hand cutting (torch)	Production process	C. Rose	Worker starts marking for torch cutting	Completed part is placed in floor
Profile bending	Production process	C. Rose	Worker examines drawing	Worker starts marking for torch cutting
Plate 3-D forming	Nestix	R. Voorend	-	-
Plate cutting machine output	Nestix	C. Rose	-	-
Weight of plate	Nestix	C. Rose	-	-
Sml/med part bevelled length	Work prep drawings	C. Rose	-	-
Large part bevelled length	Work prep drawings	C. Rose	-	-
Turning required (small/med parts)	Work prep drawings	C. Rose	-	-
Turning required (large parts)	Work prep drawings	C. Rose	-	-
Sml/med part grinded length	Work prep drawings (00844 and 00845)	C. Rose	-	-
Large part grinded length	Work prep drawings (00844 and 00845)	C. Rose	-	-
Profile grinded length	Work prep drawings (00844 and 00845)	C. Rose	-	-
Number of grinded parts	Work prep drawings (00844 and 00845)	C. Rose	-	-
Number of grinded profiles	Work prep drawings (00844 and 00845)	C. Rose	-	-

11.8 SAMPLE TRACE VERIFICATION OUTPUT

This appendix contains a sample output from the trace validation used on the simulation model. The trace validation was used to ensure that a given part followed the correct path through the production process of IHC Metalix. When the specified part entered each station, the time of entry was recorded in a table. This appendix also contains a description of the part corresponding to the sample trace output.

Part Description	
Type	Plate
Size	Small
Beveled	Yes
Grind	No
Pressbrake	No
Formed	No

Sample Trace Output	
<u>Location</u>	<u>Time</u>
In plate park	202.3
In profile park	-
On plate conveyor	225.28
On profile conveyor	-
On cutting bed	367.4
In profile cutting machine	-
In profile hand process	-
On small part sorting table	498.57
On large part sorting table	-
In pallet position	559.64
On pallet conveyor	566.89
On flatrack position	-
In profile pallet position	-
In profile bundling position	-
On small part finishing table	719.91
On large part finishing table	-
On profile finishing table	-
In pressbrake	-
In 3-D forming station	-
In flatrack storage	-
In profile bundle storage	-
On pallet rack	1453.94
In end sorting area	1464.96
Delivered to customer	1558.55