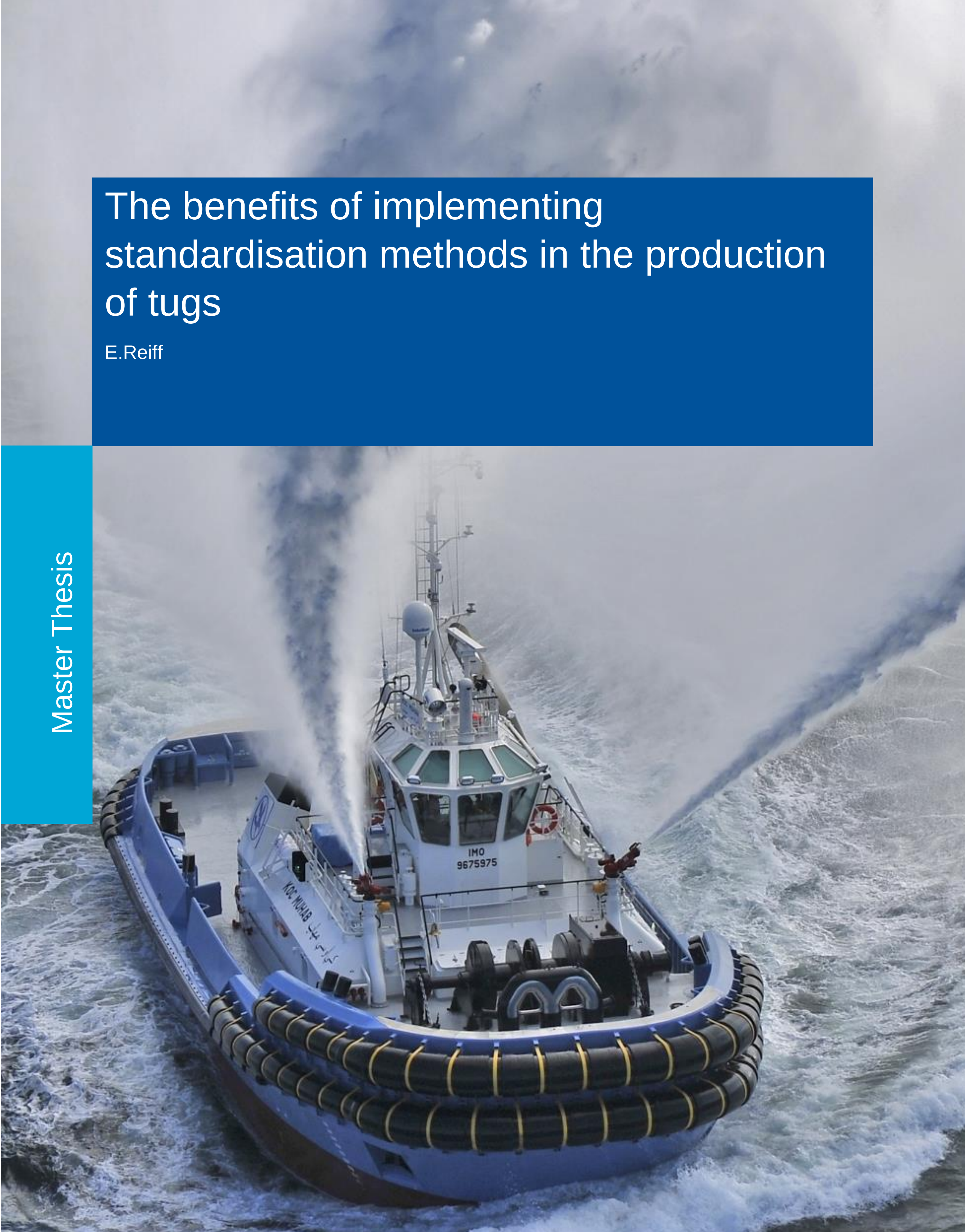
The benefits of implementing standardisation methods in the production of tugs

E.Reiff

Master Thesis



Thesis for the completion of the MSc in Marine Technology in the specialization of *Ship Production*

The benefits of implementing standardisation methods in the production of tugs

By

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Performed at

Damen Shipyards Gorinchem

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Abstract

Damen Shipyards Group is a leading shipbuilding company, delivering over 160 vessels annually from 32 shipyards worldwide with continued growing prospects. They keep over 200 hulls in stock, to guarantee quick delivery times to customers. One of Damen's corporate values is the focus on standardisation. The modular building concept has been applied for decades and still is unique in shipbuilding. However a trend has developed over the years in which the customers' buying power has increased as a result of globalisation forcing many manufacturers to produce an increasingly wide variety of products at shorter delivery times. As a result of this, together with Damen's rapid growth and its approach towards offering finished products from stock, a closer look is taken at the efficiency and advantages of Damen's traditional production strategy.

Currently Damen Shipyards applies a make-to-stock production strategy, producing standard vessels on stock in small batches. Although these vessels are based on a standard design, they can be equipped with a large range of options to meet specific requirements. However, on an individual scale these vessels contain minor deviations such as length, width and equipment which has a significant impact on the production time and cost. This production strategy could be optimised by shifting to an assemble-to-order strategy where semi-finished products are produced to stock which are assembled after a customer order. Additionally, standardisation methods can be applied to increase efficiencies of the current production strategy. One of these methods is the platform-based product development strategy, which is based on the development of modular platforms which have similar interfaces and are therefore interchangeable between different product types.

The goal of this research is to evaluate the possibility to optimise production of Damen's Product Group Tugs by implementing standardisation levels inspired by methods like platform-based product development. Therefore the main question of this research is:

"“Which levels of standardization provide Damen with the most advantages?"

This research focuses on the economical side of production strategies which includes the calculation and evaluation of potential reductions in production cost and lead times and does not go into detail concerning the design of vessels. The Damen Product Group Tugs, contains Damen's best sold vessel types based on a standard design which have the potential to benefit even more from other standardisation methods. The building strategy of one of the vessels form the Product Group Tugs is used in this research to evaluate the advantages of different levels of standardisation.

The methodology applied starts with the definition of production strategy variables, their connections and related cost. Followed by the definition of different levels of standardisation through a literature study, interviews and an analysis of the product portfolio configuration. Next, the knowledge gained is assembled in a computerised model which calculates the total production cost, time and required manhours for the production of a single vessel. This model is also used to implement different levels of standardisation to get to a standardised production strategy. With the throughput time and cost of the standardised building strategy the impact of shifting to an assemble-to-order production strategy is analysed by modeling the yearly production of tugs with standard sections stored on stock rather than complete hulls.

The total results of the mathematical model are promising; production time can be reduced with 36%, production costs with 11% and the required manhours with 24%. The total lead time can be further reduced by working in two shifts. Also, shifting to an assembly-to-order strategy with propulsion sets and standard sections held on stock will results in 56% lower stock cost.

To answer the main research question the three levels of standardisation have been ranked according to the benefits they provide for Damen shipyards. The reduced variety of the portfolio and changing to an assembly-to-order strategy with standard sections and propulsion sets held on stock will provide Damen with a huge cost benefit. Secondly, the implementation of modular outfitting will significantly reduce production cost and the total lead time. And thirdly the standardisation of components within and between vessels will mainly produce production cost but has has the potential to provide many more benefits on a service level.

Shifting to an assembly-to-order strategy has multiple advantages for Damen. Firstly, having semi-finished products, like sections on stock instead of complete hulls will save maintenance cost, because they are stored on land rather than in (salt) water. Additionally, due to the short production time, sections will be less affected by material price fluctuations such as steel compared to complete hull production. Finally, risks are taken when producing hulls on stock based on market predictions. Whereas combining sections from stock to assemble vessels according to customer's wishes has a significantly lower risk.

It is not expected that all levels of standardisation can be implemented simultaneously and within the same time frame. Therefore it is recommended to start with the implementation of modular outfitting, this is an already proven concept within Damen and has a lot more potential. Modular outfitting can be applied within single vessels, multiple ship types and even between between differen product families. Also a substantial decrease in procurement cost due to larger batches can be obtained by implementing standardisation on a component level.

It would be interesting to investigate in future research what the ideal production line and location will be of the production of standard sections on stock. Additionally, it is recommended that Damen produces ship types solely at one yard, to gain from serial production, therefore it recommended to investigate the optimal production location per ship types. It is also interesting to look into the standardisation of compartment arrangement. Finally, it would be meaningful to know to what extent modular outfitting can be implemented between multiple business units such as high Speed Craft and Offshore and Transport. This could result in the development of standard modules with the potential to be produced in large series, saving substantial time and money.

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Preface

This thesis has been performed as part of the completion of the master specialisarion Ship Production of the Maritime Technology master track ship Design Production and Operation (DPO) at the Delft University of Technology. This research has been performed in cooperation with and is conducted at Damen Shipyards Gorinchem.

The aim of this research was to optimise the traditional production strategy applied that Damen Shipyards for the production of standard tugs. Three levels of standardisation have been investigated to reduce variety and increase commonality based on standardisation methods such as platform-based product development to reduce lead times and production cost. I learned a lot about shipbuilding and manufacturing strategies, platform-based product development and the challenges of implementing them in a currently applied production process. I completed this research with a lot of enthusiasm and I hope the findings of my research will contribute to Damen's aim to continuously optimise their production strategy.

Completing this research would have been a big challenge without the greatly appreciated help of others. Therefore I would like to thank my daily supervisor at Damen Jack Teuben and at the TU Delft Jeroen Pruyn for guiding and supporting me through the process of completing my thesis. Also, I would like to thank Damen Shipyards for giving me the opportunity to complete my research as a graduate intern within an actual shipbuilding company at the Yard Support department. In addition to that I would like to thank everybody who shared their knowledge and insights on standardisation within shipbuilding at Damen with me. Finally, I would like to thank my parents who always support me and my grandfather who offered me a comfortable stay close to Damen every week.

Elouise Reiff
Gorinchem, 23th of November 2016

List of abbreviations

A	Aft
ACC	Accommodation
Act.	activity
AS	Aft Ship
ASD	Azimuth Stern Drive
ATD	Azimuth Tractor Drive
B	Block
BCG Matrix	Boston Consultancy Matrix
BiW	Body-in-White
C	Learning-curve coefficient
CGT	Compensated Gross Ton
CODP	Customer Order Decoupling Point
CoPS	Complex Product Systems
DB	Double Bottom
DH	Deckhouse
Dist.	Distribution
DPO	Design Production and Operations
DSGa	Damen Shipyards Galati
DSGo	Damen Shipyards Gorinchem
DTC	Damen Technical Cooperation
D4P	Design for Production
Eff.	Efficiency
EQ	Equipment
ER	Engine Room
F	Fender structure
FCS	Fast Crew Supplier
FiFi set	Firefighting set
GENSET	Generator Set
HVAC	Heating Ventilation and Air Conditioning
HSC	High Speed Craft
ICE	Iceclass
IDK	Integral Direct Costs
M	Midship
Mod.	Modules
MQB	Modularer Querbaukasten

NASSCO	National Steel and Shipbuilding Company
O&T	Offshore and Transport
PDM	Product Data Management
PLM	Product Lifecycle Management
RSD	Reverse Stern Drive
S	Section
SLAU	Stan Launch Tug
STu	Stan Tug
TU Delft	Technical University Delft
UAL	Unrestricted Action List
WH	Wheel House
WS	Work Shop

1
Introduction

The content of the performed master thesis will be introduced in this chapter. The problem of this research will be introduced in the first section, followed by the background information. In the third section the main research question and sub-questions will be discussed. The chapter continues with the scope and finishes with the methodology and report structure in the final sections.

1.1. Problem introduction

In 1927, two brothers began building boats in a shed in their hometown Hardinxveld-Giessendam. Over the years, the single yard grew to be the Damen Shipyards Group, currently one of the leaders in the shipbuilding world. The shipbuilding company delivers annually over 160 vessels of different types from 32 shipyards worldwide and keeping more than 200 hulls in stock, to guarantee quick delivery times, (Damen Shipyards Group, n.d.). The different ship types they produce include workboats, offshore vessels, high speed crafts, ferries, yachts, pontoons and barges, dredging vessels and naval yachts. One of Damen's fundamental corporate values is the focus on standardisation. The modular building concept has already been applied for decades and still is unique in the ship building industry. Damen has developed a standard range in each of the niche markets they operate. Although these vessels are based on a standard design, they can be equipped with a large range of options to meet specific customer requirements. When zooming in on an individual scale these standard vessels contain minor deviations such as length, width, machinery and other installations which in the end have a significant impact on the production time and cost.

As a result of increasing globalisation and customers' buying power many manufacturers have been forced to produce an increasingly wide variety of products, (Alizon et al., 2007). In traditional markets one product could answer most needs, and product development was mainly focused on the production of single products. Nowadays the market has become more fragmented and niche markets are becoming more important. With this trend, the traditional approach towards product development will increase cost and throughput times notably. With the rapid growth of Damen Shipyards, the wide variety of products they offer, and the increased customer buying power, a closer look is taken at the efficiency and advantages of their traditional production strategy.

1

1.2. BACKGROUND

Currently, the majority of the manufacturing industries strive to maximise profits by finding ways to reduce development and manufacturing cost while simultaneously satisfying diverse customer demands by keeping their product portfolios diverse. This section provides background information on how product variety and volume influence the applied production process and the platform-based product development method to reduce manufacturing cost while maintaining product variety.

1.2.1. PRODUCTION PROCESSES

It is important to get an insight in how product variety and volume influence the applied production process. Low-volume operations processes often have a high variety of products and services, and high-volume operations processes often have a narrow variety of products and services. Thus there is a trend running from low volume and high variety in job shop production to high volume and low variety with continuous flow production, on which operations can be positioned as presented in Figure 1.1. Complex one-off shipbuilding is an example of low-volume and non standard production which will be different per project also known as the job shop production process. On the the other hand refining and transportation of oil is done in high-volumes with a standard configuration of materials and ingredients which is produced according to the continuous flow production process, (Slack et al., 2010).

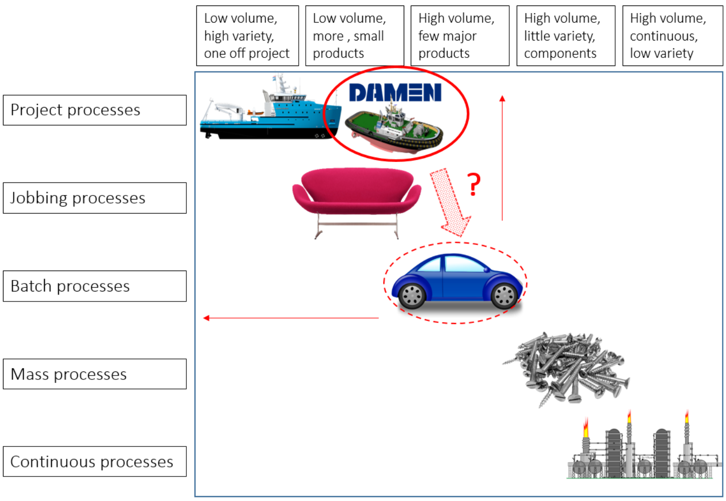

Figure 1.1: Process types for various volume and variety characteristics of the process, based on (Slack et al, 2010).

Damen's standard vessels are produced in small series ranging from one to ten vessels per year. The position of Damen products in the production process matrix is shown in Figure 1.1. Because of higher standardisation levels during production and the serial character it is positioned slightly to the right of the one-off shipbuilding example. However the production process in which Damen's vessels are being produced is job shop. Damen aims to optimise its production process towards line flow to reduce cost and time. This shift of production process has already successfully been performed in the automotive and aviation industries. Two main changes which are necessary to make this shift possible are an increase in the size of series production and a decrease in product variety.

1.2.2. PLATFORM-BASED PRODUCT DEVELOPMENT

To reduce development and manufacturing cost while keeping product portfolios diverse enough to satisfy the customer the platform-based product development method can be applied. This method is based on the production of standard platforms which have the same interfaces, are modular and therefore interchangeable between different product types. This method supports manufacturers to create a family of products which share common platforms with identical components, modules or equipment, (De Weck et al., 2003). Applying a platform product strategy can lead to multiple advantages including a reduction in overall production cost and development time. Examples from different industries which have already successfully applied line processes and platform designs for their products are the automotive industry, aircraft industry and software developers.

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1.3. RESEARCH QUESTION

Inspired by highly efficient production processes such as batch and mass production and the platform-based product development method a high level of standardisation is achievable whilst maintaining sufficient diversity within a product portfolio. Different ship types can have interchangeable standardised platforms besides the well-known levels of luxury and add-ons which are additional options. Within the numerous product portfolios that Damen boasts, it should be possible to achieve similar benefits for production, leading to overall cost reductions. This research will be an evaluation of the possibility to increase the efficiency of production by implementing the aspects of line production and the platform-based product design strategy on the Damen Product Group Tugs. Therefore the main question of this research is:

"Which levels of standardisation provide Damen with the most advantages?"

In this research multiple levels of platform integration and different degrees of standardisarion will be defined and their effect on the cost and efficiencies of production will be investigated. The focus of this research will be on the relation between three major elements; the number of equal elements, the effect of these elements on production time and cost and the flexibility of final products. This leads to the subquestions:

- *Which parameters influence::*
  - *the building cost,*
  - *and the building time?*
- *Which levels of standardisation provide good prospects for the production of tugs?*
- *How do these standardisation levels influence the:*
  - *the building cost,*
  - *the building time,*
  - *and the variety of the product portfolio?*
- *How is the Damen production strategy influenced on cost and lead time when implementing different levels of standardisation?*

This research focuses on the economical side of production strategies which includes the calculation and evaluation of potential reductions in production cost and lead times and does not go into detail concerning the design of vessels. Therefore, the wishes of the production and sales department will play a key role in this research. The portfolio should be diverse enough for the sales department to satisfy the customer's wishes. The wishes and opinions of other relevant departments such as after sales will also be taken into account. The results will be tested against a number of scenarios based on recent trends for the future of the maritime industry.

1.4. RESEARCH SCOPE

Within this research the scope is limited to the Damen Product Group Tugs. The Product Group Tugs has been chosen as the benchmark because this product group is the best sold vessel type of Damen. This product group already contains a high level of standardisation and has the potential to benefit from even higher levels of standardisation. Also, the Azimuth Asimuth Stern Drive (ASD) Tugs and Stan Tug (STu) series have the potential to benefit from standardisation strategies such as the design for operation strategy which is currently being applied on the production of ASD2913 Tugs.

Damen shipyards delivers varied, standardised tugs from the renowned ASD and Stan Tugs, to Tractor tugs, Voiths and Rotor Tugs, which can offer optimal solutions for any kind of towing operation, either in port or at sea. Damen ship handling tugs operate in ports and terminals around the world and provide different methods of assistance, depending on local conditions and situations, (Damen Shipyards Group, n.d.).

CASE STUDY

Within the research a case study will be performed on the building strategy of a specific ship type in order to calculate the potential advantages of the different levels of standardisation on an individual scale. Within this research it is assumed that;

- the applied methods can also be applied within other product groups such as offshore dredging or yachts,
- the results for this case study are sufficient to represent the complete product group Tugs,
- the results for this case study can be scaled to other ship types
- the defined standardisation levels are implementable in the building and production strategies of all tugs. This means that no design barriers are taken into account in this research.

Additionally, in this research the standardisation levels that will be defined will be implemented into a fixed current building strategy to calculate their impact on production cost and lead times without performing optimisation calculations.

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1.5. METHODOLOGY

This section presents the methodology which will be followed to answer the main research question of this research. The different steps within the process are presented in the flow diagram in Figure 1.2 below and are explained below.

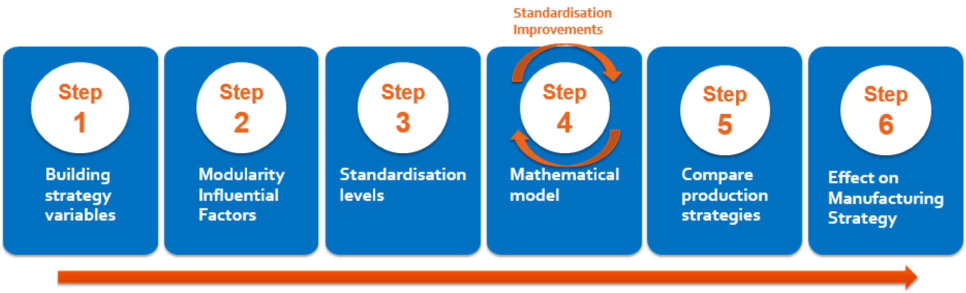


Figure 1.2: Process flow product platform design strategy

Step 1. Determine building strategy variables

In this step the different production variables, their behaviour and how they influence throughput times and production cost will be analysed through operations and financial methods. This step will answer the first sub-question, *Which parameters influence the building cost and time?*

Step 2. Explore factors influencing modularity and standardisation

In the second step the factors that influence product modularity and standardisation are determined. This is achieved by performing interviews and assessing the production strategies of tugs. The results of the assessment will contribute to the determination of common and unique modules across the Product Portfolio Tugs in later steps. This survey is an adapted version composed by Asan et al. (2014).

Step 3. Determine the levels of standardisation

When the product modularity factors and most important production variables are determined, the different levels of standardisation can be defined in the third step. This step places the product standardisation degrees into different levels depending on which production phase they influence. Steps 2 and 3 address the second sub-question, *Which levels of standardisation provide good prospects for the production of tugs?*

Step 4. Model the building strategies

The building strategy variables defined in step 2 are modeled to determine the total throughput time and production cost of a single tug. Operations and financial methods are used to connect the production variables to throughput times and cost. The results of running this model will answer the last part of the third sub-question *How do these standardisation levels influence the building cost and time and variety of the product portfolio?*

Step 5. Compare results of current and standardised production strategy
In this step the effect of implementing different levels of standardisation into the production of tugs will be determined. The differences in the throughput times, production cost and required labour show if the implementation of the modular product design has a positive effect. After completing this step the final research question is answered *How is the Damen production strategy influenced on cost and lead time when implementing different levels of standardisation?*

Step 6. Determine the effect of standardisation levels on manufacturing strategy
Once the effect of standardisation with the modular product design method on the production of a single vessel has been determined, the effect on the yearly production of the product portfolio will be examined. This will show what the overall profitability potential is of implementing modular product design on a complete product portfolio. This step will contribute to answering the final sub-question.

1.6. Report overview

This report consists of seven chapters starting with the introduction of this research followed by the theoretical background in Chapter 2 in which a detailed description is presented of the background of this research, explaining production processes in manufacturing and the principles of the platform-based product design. In the third Chapter 3 the current production strategy for one of the Damen Tugs is presented which is used as a base case in this research. The report continues with the different levels of standardisation, in Chapter 4, which can be implemented in the current production strategy to improve efficiency and reduce production cost. Once the current production strategy and potential improvements on different levels are known the mathematical model to calculate these improvements will be explained in the next Chapter 5 to calculate the impact of these potential improvements. The following Chapter 6 explains which parameters are influenced by implementing the three standardisation levels and the results per standardisation level. The conclusions, discussion and recommendations for Damen Shipyards and further research drawn from the results of this research are presented in the final Chapter 7.

2

Theoretical Background

A literature study was performed to get an in depth view on manufacturing processes and strategies, platform-based product development and how Damen Shipyards approaches these topics. This chapter does not directly answer a sub-question; however this step is important because it provides the theoretical background of this research, which places the problem entity into perspective.

The chapter is divided in five sections starting with an overview of the different production processes. Thereafter, the Customer Order Decoupling Point and manufacturing strategies are discussed. In the third and fourth sections the series effect and the platform-based product development method are presented. The final section discusses how Damen Shipyards currently manages its production process and modularity for tugs.

2.1. Production processes

Before focusing on the production process applied at Damen Shipyards some background information is provided to get an insight in how product variety and volume influence the applied production process. As explained in the Introduction 1 and presented in Figure 1.1 there is a clear movement from manufacturing in low volumes of high variety products in job shop production to high volumes and low variety between product with a continuous flow production. The different processes in this process matrix are shortly described in the following list based on the theory explained in Operations Management by Slack et al (2010).

Project processes

Project processes are usually applied for highly customised products with high variety and low volumes. The production time is often long and the resources are specialised for each product which leaves little space for product variability. Examples of project processes are shipbuilding, most construction companies, movie production companies, large fabrication operations such as turbo generator manufacturers.

Job processes

Job processes are similar to project processes with high variety products produced in low volumes but the products are usually smaller. In jobbing processes the same resources are used to produce series of products even though the products differ in their requirements. Examples of jobbing processes include specialist toolmakers, furniture restorers, tailor work, and printing jobs of for example advertisement.

Batch processes

Products with less variety and larger volumes are manufactured through batch processes. Batches of different products pass through the same sequence of production. The size and variety levels of batches can vary largely between a few and hundreds. Examples of batch processes are machine tool manufacturing, the production of food (for example dishes in a restaurants) and components for mass-produced products.

Mass processes

In mass processes goods are produced in high volumes with little variety. The products can be built up out of components in multiple variants creating many different end products. As long as the interfaces between those components are the same the production process can continue smoothly without interruption. Examples of mass processes are automobile plants, a radio production factory and food processing.

Continuous processes

The final process is even more advanced than mass production because the operation works continuously without having to stop. Continuous processes usually run for longer periods of time. Continuous processes are suitable for products with high volumes and low variety which is the case in for example petrochemical refineries, electricity utilities, steel making and paper making facilities, see Figure 1.1.

2.1.1. PRODUCTION COST AND THROUGHPUT TIME

Now that it is known how manufacturing processes match with different product varieties and volumes it is good to understand what the relation is between the different production processes and the production costs and lead times.

Processes which are applied to produce products in lower volumes with a high variety such as project and job processes usually have long lead times and high costs. Many components need to be delivered and installed by different suppliers. Also, preparation and development times such as engineering and project management take a lot of time and cost a lot of money because each final product is different. On the other hand, if variety is limited and batch sizes increase (like in batch processes) production will speed up and production costs per product will reduce. Investments in equipment and engineering is no longer required because each series of products is produced with the same tools and runs through the same process. In addition to that, with less variety, the number of suppliers will decrease and therewith logistics and transport will be simplified.

When looking at the shipbuilding industry, most yards apply the project or job processes. Varying requirements of the customer, thousands of components and long lead times require good planning, preparation and communication between the different stakeholders. This process can be improved by implementing characteristics of the other processes. To speed up the shipbuilding process and reduce production cost one should aim to reduce variety and increase the batch size. This does not necessarily mean that the batch size of the end product should be increased, but that the variety in equipment, components or even sections should be reduced. This will lead to the application of batch processes on a smaller scale with increased series sizes and reduced lead times due to higher production efficiencies.

2.2. Customer Order Decoupling Point

Another factor which concerns manufacturing and supply chain operations is the Customer Order Decoupling Point (CODP). The CODP is accoriding to Jodlbauer et al. (2012) "the point in the material flow of manufacturing where the product is tied to a specific customer order." The CODP contributes to the alignment between operations in a firm and the market requirements and is used as a reference point for deciding which manufacturing operations and supply chains to use. The main manufacturing strategies include make-to-stock, assemble-to-order, make-to-order, each with a different position of the CODP, illustrated in Figure 2.1.

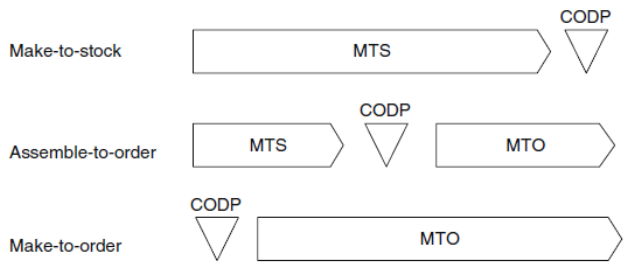


Figure 2.1: Customer Order Decoupling Point, (Jodlbauer et al., 2012)

It can be seen in the figure that the CODP can be positioned at different stages of the production. When make-to-stock is applied the COPD is positioned more towards the customer or downstream where finished goods are delivered from stock. In assemble-to-order the CODP divides the manufacturing operations into forecast-driven operations and order-driven operations. Forcast-driven operations are upstream of the CODP and customer order-driven operations are downstream of the CODP. In make-to-order and engineer to order the CODP is positioned at the start of the supply chain, where production starts after an order is placed. The relation between the CODP and the different manufacturing strategies are based on research performed by J. Olhager, (2010) and Jodlbauer et al.(2012) .

Make-to-Stock

Make-to-stock is applied for highly standardised (commodity) products which are produced in high volumes per period with little variety. In this strategy stock is held within the distribution system which can be in many forms; from raw materials at suppliers to finished goods at the manufacturer. The CODP in this case is therefore positioned downstream towards the customer. Make-to-stock is a push driven manufacturing strategy in which price plays a dominant role, where quality and delivery are major qualifiers and where flexibility is less important.

Make-to-Order

Engineer-to-order and make-to-order manufacturing strategies are applied for special and customised products which are produced in low volumes per period with a large variety. This strategy is customer focused, therefore quality, delivery and flexibility play an important role and price is often less important. Additionally, delivery speed is currently becoming more important. The CODP in this strategy is positioned upstream towards the suppliers. Make-to-order is pull driven, time-phased due to its high flexibility and low volumes per product.

Assemble-to-Order

The assembly-to-order strategy contains a mix of make-to-stock and make-to-order based on demand, volume and variability. This strategy is often applied when different types of products are manufactured. The CODP position can be either upstream or downstream and determines the choice of applying make-to-stock or make-to-order to different sections within a single production system or the supply chain.

2.3. SERIES EFFECT

One of the conclusions that can be drawn from the previous sections is that within shipbuilding, final products, components and sections should be reduced in variety and increased in batch size to make production more efficient. If batch sizes can be increased in production another phenomena comes into play which is the series effect. When a certain activity is repeated several times, less time is needed to be perform this activity after repeating it several times and the performer will become better at it. In other words, the activity is performed more efficiently due to learning. Companies and factories repeating the production of a certain product also experience improved efficiencies leading to reduced lead times and cost. This learning phenomenon was first discovered in 1936 by T.P. Wright and applied in the aviation industry. He developed a learning theory and proved that labour costs decreased with learning by applying it in airplane production, (Yelle, 1979, Heizer et al., 2011). The process of learning from repetition can be illustrated with learning curves. Learning curves show the amount of work needed to be performed to produce a certain number of units. As the number of repeated units produced increases, it can be seen that the amount of work required to complete them reduces. In Figure 2.2 a good example of a learning curve is presented. The gradient of the curve depends on the learning rate of the process. The learning rate is a percentage which states how much time of the first unit is needed to complete the double amount of units, (Heizer et al., 2011). The same rate is applied when the number of units is doubled.

It should be noticed that the learning curve and rate depend on many factors and that it can change over time. The learning curve can be disrupted by human factors, changes in the production process, or external factors such as suppliers or malfunctioning of equipment. The learning rate is different from company to company and strongly depends on the type of activity which is performed. Also the working attitude within a company can influence the learning rate. The learning curve is a useful tool for operations managers to determine future production and purchase cost standards for items produced (Heizer et al., 2011, De Weck, O.L.,2006).

The following Figure 2.1 shows different learning rates for numerous activities. When looking at these relations the shipbuilding industry will have a learning rate in the same range as the automotive and aircraft industry of approximately 80%.

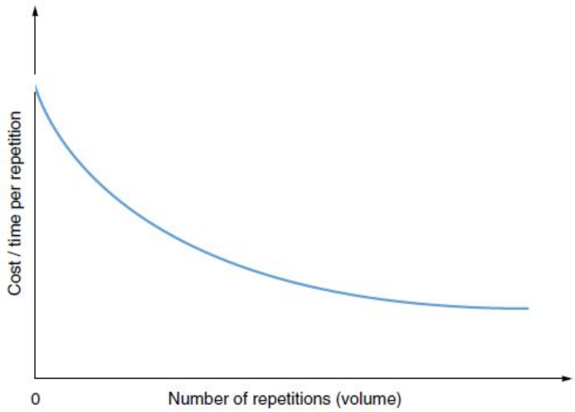


Figure 2.2: Learning Curve, (Heizer et al., 2011)

Table 2.1: Learning Rates for different activities, (Heizer et al., 2011)

	Example	Improving Parameter	Cumulative Parameter	Curve slope (%)
1	Model-T Ford production	Price	Units produced	86
2	Aircraft assembly	Direct labot-hour per unit	Units produced	80
3	Equipment maintenance at GE	Average time to replace a group of parts	number of replacements	76
4	Steel production	Production worker labor-hours per unit produced	Units produced	79
5	Integrated circuits	Average price per unit	Units produced	72
6	hand-held calculator	Average factory selling price	Units produced	74
7	Disk memory drives	Everage price per bit	Number of bits	76
8	Heart transplants	1-year death rates	Transplants completed	79

There are several ways to calculate the required amount of time to produce a desirable number of units with the learning procedure.
Firstly and most easy approach is the arithmetic approach to learning-curve problems, (Heizer et al., 2011).The down side of this methods is that it does not tell us how many hours will be needed to produce other units.
Another approach to determine the amount of work for any unit is the logarithmic approach. The logarithmic approach allows us to determine the hours required for any unit produced, but there is a simpler method.
A third method is the learning-curve coefficient technique which does not only allow to calculate the labour for any unit and any learning rate. This is done with the learning-curve coefficient (C) which depends on both the learning rate and the number of units.

When applying the learning-curve theory to assess future efficiencies of production attention should be paid to the following points. The gradient of the learning curve is directly linked to the production time of the first produced unit, this should therefore be handled with care and accuracy. Also keep in mind that the learning curve will not automatically apply to indirect labour and material cost.

In previous research, (Scorpecci, 2007), data was collected for the recalculation of

Compensated Gross Ton (CGT) in shipping, shipyards reported information on man-hours used for specific ship designs built in series which seemed to be linked to the series effect (or learning curve). As can be seen in Figure 2.3, this effect strongly reduced the number of man-hours involved in the building of those ships. There are clear increases in efficiency as workers become more familiar with their tasks. This research also pointed out that a similar effect, though of a smaller degree, may also be present if a shipyard is building a certain ship type with only limited size variations, as the workers then become more familiar with production details. When comparing this graph to the three calculation methods described above the amount of required work is calculated with the logarithmic approach.

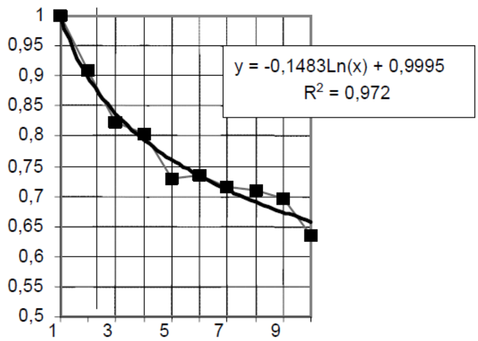


Figure 2.3: Reduction of workload (series effect) from the first to the 10th ship,(Scorpecci, 2007)

2.4. PLATFORM-BASED PRODUCT DEVELOPMENT

The objective to reduce development and manufacturing cost while keeping product portfolios diverse enough to satisfy the customer can be achieved by implementing platform-based product development. Working with platforming can lead to multiple advantages including reduced overall production costs and development time (De Weck et al., 2003, Nieuwenhuis, 2013). Platform-based product development supports the manufacturer to create a family of products which share common platforms with identical components, modules or equipment.

Over the years, many methodologies and tools have already been developed to implement the product platform strategy in practice, which are presented in the work of Alizon et al. (2007).

In this research the definition of product platform is taken from Meyer and Lehnerd (Meyer et al., 1997) and is stated as follows: *"A product platform is the set of parts, subsystems, interfaces, and manufacturing processes that are shared among a set of products, and allow the development of derivative products with cost and time."* To add to this description, a product family can also be described as *"a group of products that share similar features and functions and can be easily adapted to satisfy a wide variety of customer requirements or target specific market niches,"* by (Conner Seepersad et al., 2000).

A product platform ideally consists of a base platform from which different products can be generated by adding or removing components or units, as long as they share the same interface, (Conner Seepersad et al., 2002)
J.J. Nieuwenhuis (2013) evaluated in his dissertation the appropriateness of product platforms for engineered-to-order shipbuilding. He illustrates multiple examples of manufacturing companies which successfully switched from producing complex products in a one-of-a-kind way to mass customisation with the platform-based development approach. This stresses again that even though shipbuilding is characterised for producing one-off project based products it is not a reason to discard platform-based product development on beforehand.

According to O.L. De Weck (2004), manufacturers can reduce overall production costs and development time, while satisfying diverse customer demands by implementing a product platform strategy. However, he also states that platform-based product development should only be considered when one or more of the following criteria can be met.

- *The product family is a system with a common basic set of attributes;*
- *The product family has a long life cycle and distributed ownership;*
- *The product family has highly interconnected systems with a need for future growth and a constant update of technologies;*
- *The product family must adopt to rapidly changing environments, trends and fast clock speed technologies;*
- *The product family has a stable core functionality but has variability in secondary functions and/or external styling;*
- *The product family interfaces with an intricate peripheral customised architecture.*

When looking at the shipbuilding industry, and at literature (Nieuwenhuis, 2013) several of these criteria can be met in shipbuilding,

- Within product families, common features such as parts, components and systems can be found in the product. Additionally, within a single shipyard common production processes and engineering tools can be identified, such as the new Product Lifecycle Management (PLM) and Product Data Management (PLM/PDM) programs which have recently been launched at Damen Shipyards to standardise data, engineering and supply chain processes;
- Product families in shipbuilding have a long life cycle; some ship types are offered on the market for over a decade, like the ASD 2810 tug of Damen Shipyards;
- Also, as mentioned earlier customers in the shipbuilding industry are known to be volatile with rapidly changing requirements, due to continuous technological improvements. Therefore product families need to be able to adapt rapidly.

Besides the fact that it could be interesting to implement platform-based product development in shipbuilding, results from Damen Shipyrads internal interviews and external research show that many shipbuilders are interested in potential benefits of implementing standardisation and modularity, the two elements of platform-based design reuse. Standardisation and modularity ensure that design solutions are reusable. Additionally, the robustness of the platform determines to what extent the platform-based solution will have to be changed when design requirements change, (Nieuwenhuis, 2013, Simpson et al., 2016). Product standardisation can be achieved at many different levels including:

- Product features,
- Parts,
- Components (incl. interfaces),
- Systems,
- Arrangements,
- Design, production and assembly processes.

Even though it is not yet common practice within the shipbuilding industry a number of shipyards already (unknowingly) apply a product platform based development approach, (Nieuwenhuis, 2013). In the super yachts built at Icon Yachts the engine room, stairs and electrical spaces have fixed positions and arrangements such that a large number of yachts with varying arrangements could be developed. Additionally, trailing suction hopper dredgers produced by IHC which can be ordered in three sizes where the customer can chose from different (standard dredging packages) to be to fulfill their dredging requirements and Navy SIGMA Vessel ordered at Damen are produced from standard hull, weaponing and communication modules which can be mixed and matched according to the customer's wishes.

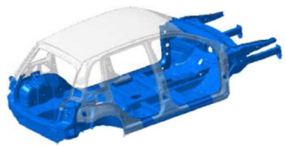
Various other product manufacturers of Complex Product Sytems (CoPS) have for many years already successfully implemented the product platform strategy. Examples from different industries which apply platform designs for their products are listed below.

2.4.1. AUTOMOTIVE

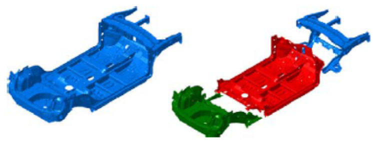
Several examples of platform applications can be found in the automotive industry of which a few are listed in this section.
Fiat Tipo simplified the car's design and assembly already in the 1980's by sharing modular pre-assembled components and modules such as doors and the cockpit across multiple Fiat marques (Pandremenos et al., 2009). Also, SMART's are built from pre-assembled modules including a fixed body frame and flexible modules such as door, body panels, glass and roofs. Its customers can combine the frames in different colours to their own taste without affecting the production process. SMART is also characterised by its outsourcing because its suppliers are totally integrated into the production plant, (Pandremenos et al., 2009).

Figure 2.4a demonstrates the Body-in-White (BiW) (Paralikas et al., 2011) case study, which compares the use of modular platforms to a fixed design of an under-body structure of a car. The top Figure represents the under-body structure of the BiW. Two alternative designs of the under-body structure of the BiW are presented in the middle picture 2.4b, a modular and an integral one. The integral under-body (left) has an inflexible architecture which makes it unsuitable for other design variants.

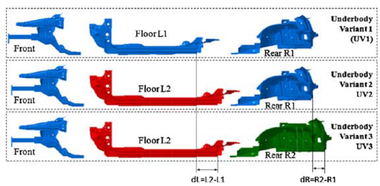
The modular design of the under-body structure is divided into three main modules: the floor, the front end and rear-end modules, see right-hand side of Figure 2.4b. These modules can be mixed and matched to create alternative design variants. Additionally, these modules can easily be scaled since only a small portion of the under-body parts will require redesigning. Based on this modularity and scalability three alternative design variants of the under-body structure can be created as can be seen in the third Figure 2.4c.



(a) under-body



(b) Integral & modular



(c) Modular variants

Figure 2.4: Modular under-body(Paralikas et al., 2011)

Another good example of platforming in the automotive industry is the Modular Transverse Matrix platform, also called MQB (Modularer Querbaukasten) developed by Volkwagen, (Volkswagen, 2016). This modular chassis forms the base for cars of different car brands including Volkswagen, Audi, SEAT and Skoda. Despite the different wheelbases, lengths and engine types this modular platform can still be used. Additionally, this makes it possible to assemble cars from different brands at the same production plant.

2.4.2. AIRCRAFT MANUFACTURING

Airbus and Boeing have both successfully applied platform-based product development in their aircraft families. Every model in their company shares multiple modules with other models. Also Dassault has been successful in used platforms for its Falcon business-jet aircrafts. This principle is most successful when the design, production, assembly and operation are of relatively similar aircrafts, (Frigant et al., 2005). Many of Falcon's aircraft models share the same wings and cockpits including identical instrument panels, piloting procedures, avionics and the other systems. The length of the fuselage maintains variable to be able to change the number of seats. The same counts for the Airbus aircrafts in the A330/A340 range which also share the same engines but the number of engines differ between 2 and 4, (Frigant et al., 2005, Fujita, 2002). These companies have accomplished to reduce production time and cost, maintain product variability and by standardising components and modules have increased the amount of outsourced work.

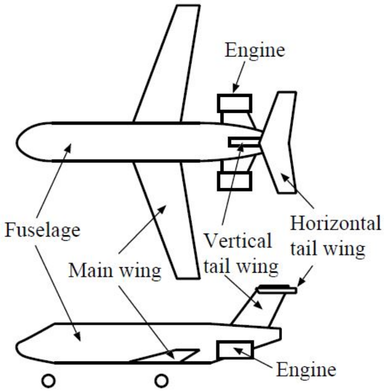


Figure 2.5: Platforms Aircraft (Fujita, 2002)

STRETCH-BASED DESIGN

The so called stretch-based design is based on the enlargement of the fuselage according to the number of seats required, This stretch-based design has been implemented for several variations of aircrafts including the DC-9 range and B-777, (Fujita, 2002, Simpson et al., 2006). The aircraft is built up out of fixed modules including main wings, tail wing and engine as presented in Figure 2.5 and only the fuselage is adjusted according to the number of seats.

Meyer et al. (2010) presents another example of products which consist of a scalable platform. The Black and Decker drills, sanders and jig saws circular saws that all share a common motor which can deliver a certain amount of power based on varying wire stack length.

2.4.3. SOFTWARE PLATFORMS

Apple is another good example of a company which implemented modular design in its products. The iPOD, iTouch, iPhone and other i-products share similar operating and software systems such as iTunes. Part of the apple system is so modular that it can also be used on Windows-based computers, (Meyer et al., 2010).

DIFFERENCES BETWEEN COMPLEX MANUFACTURING INDUSTRIES

Knowing that some industries have already successfully implemented platforming into their product development and production, it should be taken into account that the shipbuilding industry differs greatly in several aspects from these industries. The main changes between the shipbuilding and the automotive and aeronautical industry have been investigated in the dissertation of J.J. Nieuwenhuis (2013) and are listed below.

Firstly, they differ significantly in series size and development time. In general the shipbuilding series and specifically the series sizes of Damen Shipyards Tug production ranges between one and ten, with the total development times of about one to two years. In the automotive industry, series sizes can range from 10.000 to over a million units. Platforms used in the automotive industry are usually applied in the production of and multiple car types from different brands. Development time of new models can therefore take up to ten years . The series size within the aviation industry can be up to 1500 consisting out of multiple generations of platforms. Platform development time for aeronautical applications is also around ten years.

Secondly, the above mentioned industries differ in decision ownership which can also influence the appropriateness of platforming. In the automotive and aeronautical industry, the manufacturer only have ownership of main decisions, which makes the application of design reuse relatively easy. Shipbuilders have a more complicated position as the customer often influences the decision making already during product development. This makes the implantation of platform strategies more challenging. J.J. Nieuwenhuis (2013) gives examples in his research from Asian shipbuilder which only execute excessive customization for very high prices and German mechanical engineering industries which benefit from design reuse for small series of engineered-to-order products.

Thirdly customers in shipbuilding are not only involved during production development, they are also known to be volatile, and therefore design requirements frequently change and the predictability of customer requirements is perceived to be low. One of Damen's highly valued and unique selling points, based on interviews with employees from sales and design and proposal departments, is the willingness to customise a product according to customer's needs. To successfully implement the product platform approach, this high degree of product customisation should not be affected or customers should be convinced that the benefits outweigh the decreased customisation potential. It is therefore a great challenge to find the optimal ratio between reducing variety and offering customization. Within Damen, the development and success of the Schelde Naval Shipbuilding's SIGMA already prove that customer requirements can still be fulfilled by using standard modular product platforms.

The mentioned differences between shipbuilding and other industries and listed challenges can influence the way in which platform-based product development is applied within the shipbuilding industry but does not make it inappropriate. Applicability of the platform approach will increase for Damen Shipyards if requirements such as the high degree of customisation and small series sizes are met during platform strategy development. Also, due to continuous technological improvements the platforms should be easily renewable, this ensures long-term benefits from a single platform.

2.5. PRODUCTION PROCESS AND MODULARITY AT DAMEN

Damen shipyards builds complete (standard) vessels with a make-to-stock strategy based on market predictions and can therefore deliver vessels to its customers faster than its competitors. Damen's standard vessels are produced in small series between one and ten vessels per year. In Figure 1.1 Chapter 1 the position of Damen Shipyards within the production process matrix is shown and explained. Damen is likely to reduce lead time and cost if they could turn their production process more towards line flow, which is already done in the automotive and aviation industry. Two main changes which are necessary to make this shift possible are an increase in production size and a decrease in product variation.

The current Damen Standard Process Flow is shown in Figure 2.6. Increasing the level of standardization and modularisation within this stage will contribute to a shift towards a line flow production process.

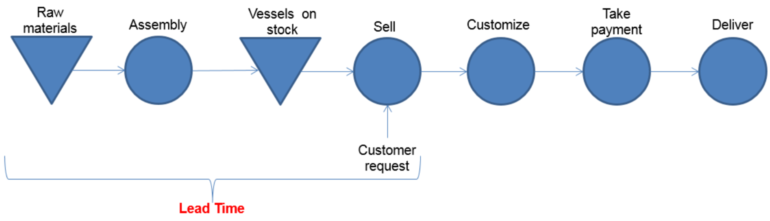


Figure 2.6: Damen standard process flow

Damen Shipyards is aware that the efficiency of their traditional production strategy needs a closer look and has recently been focusing on improving efficiency, decreasing production time and cost. Several projects and pilots have been launched to make their production process more industrial. Two of these initiatives include the integrated building strategy (bottom hat principle) and Design for production (D4P), (Teuben, 2015). D4P is based on taking production strategies into account during the design phase to smoothen production. The integrated production strategy is based on producing sections upside down in order to perform hotworks underhand, rather than uncomfortably overhand, after which the section is turned placed into position as presented in Figures 2.7 and 2.8.

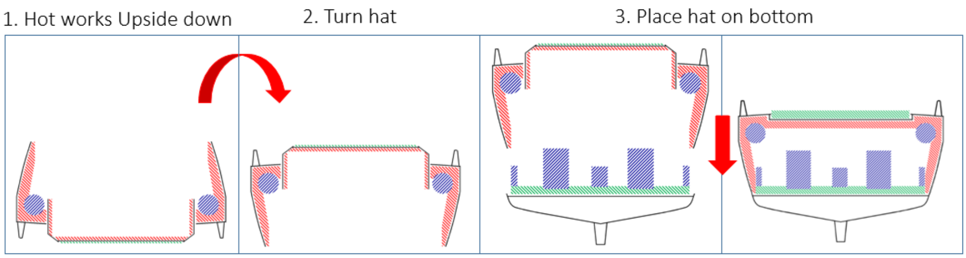


Figure 2.7: Bottom hat principle, (Teuben, 2015)

EXCELLERATE

Excellerate is another program which focuses on optimisation and standardisation of the production process at Damen shipyards. The main goal of Excellerate is to bring ‘working with standards to the next level in a multinational environment’ thereby realising shorter lead times and reduced production cost, (Damen Excellerate 2016). These standards are achieved by creating a Damen Standard Product Approach which includes clear and standard process structures, systems, solutions captured in handbooks and

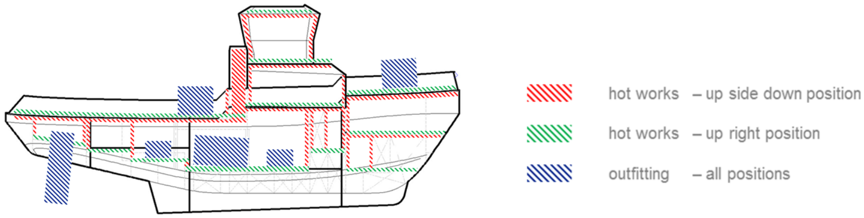


Figure 2.8: Integrated Building Strategy, (Teuben, 2015)

parts captured in a catalog. Excellerate facilitates this process by means of creating templates for standard ship types of different product groups. If this is done uniformly, a smooth and standardized shipbuilding process is created with aligned operations and supply chains. A product template is structured such, that production is maximally supported to build standard ship types in an industrial manner, without unnecessary interference.

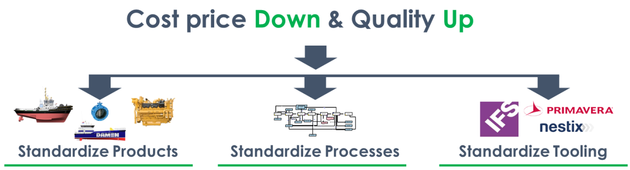


Figure 2.9: Key objectives Excellerate, (Damen Excellerate, 2016)

Getting the right materials, at the right time on the main assembly line is crucial in order to achieve the goals mentioned. If all parts on board are known, pre-purchased and double checked quality will improve. Also quality improves by the fact that processes become simple.

Not all ship types qualify for the creation of a template. Ship types of which Damen Shipyards has a large market share and a high market growth are the ones that qualify in the first place for a template, which will be further explained in Chapter 4. The ASD3212 is the first template of the product group Tugs, followed by the ASD2810 and the ASD2811 is the third template which will be developed in the near future, (Damen Excellerate 2016c).

If Damen can continue the development of these pilots and programs great improvements in the current lead times and cost will be achieved. However, the mentioned pilots and Excellerate run individually from each other without much interaction between the them. Results from interviews F show that the cooperation and communication between the two initiatives can be more harmonised to bring these potential improvements to a greater success.

DECISION MOMENTS

At Damen Shipyards efficiency is being improved and lead times and production cost are being decreased through D4P and Excellerate. However on the longer term Damen

is aiming to continue these improvements which is presented in Figure 2.10. The top bar represents the current production strategy for an average ASD2810 with a total lead time of x weeks. The second and third bar represent the effect of D4P and the integrated building strategy on the total lead time which have the potential to be reduced with 35%. By implementing different levels of standardisation and modularisation which will be investigated in this research the lead time is expected to be halved.
This figure also shows the release moment of the Unrestricted Action List (UAL) which is presented with a red sandglass. This is the moment when it is decided to build a certain vessel type or a series of vessels. The yellow sandglass represents the order moment of Long Lead Items (including thrusters, gensets and main engines). During production the delivery moments of long lead items are pointed out by red triangles. The release date of the UAL is in all projects approximately one month before the start of steel cutting. When the decision moment and delivery time for long lead items stay unchanged, it can be seen that as a consequence of the reduced lead time the order moment of the long lead items shifts to the left of the UAL. This creates a contrasting situation in which the decision moment for the production of a vessel is after the order moment of long lead items for that same vessel.

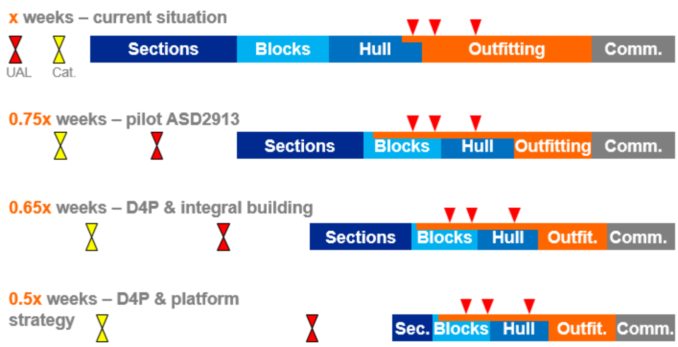


Figure 2.10: Production planning including standard platforms, (Teuben, 2015)

Figure 2.11 shows a simplified overview of the yearly production of tugs with the current production time of, UAL release dates and long lead items order and delivery dates.

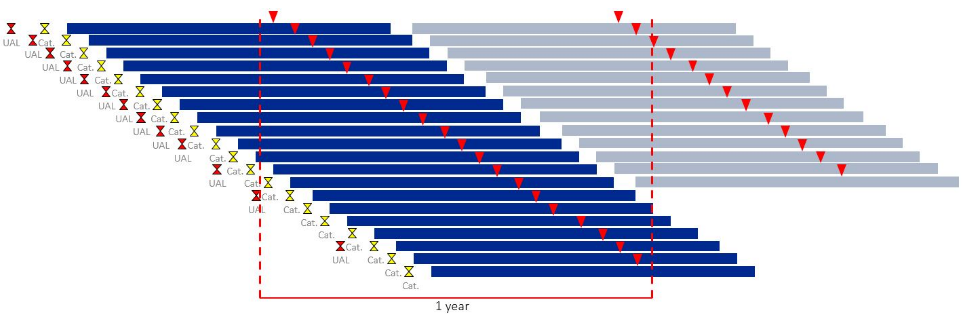


Figure 2.11: current production planning

In the next Figure 2.12 the same overview is presented with the halved production time. In the new scenario long lead items are no longer ordered per product but are taken from a stock pile of long lead items. The group of yellow, green and orange sandglasses represent the stock of different types of long lead items. When an UAL is released an order will be placed to replenish the stock. In this way production can continue without depending on delivery times and no decisions need to be made considering long lead items before the release of the UAL. The same can be done for the production of standard sections on stock which will be ordered when the UAL is released, assembled during production and replenished by a serial production line of sections. The size of the initial stock for an average yearly production should be calculated if this is beneficial.

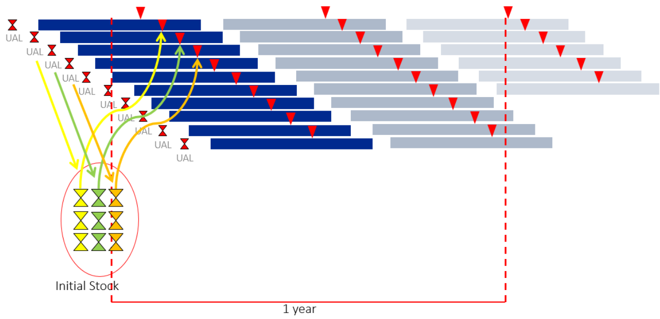


Figure 2.12: Production planning including standard platforms

When having standard sections and propulsion sets on stock, a shift from a make-to-order strategy towards an assemble-to-order strategy is noticeable. Whether this change in production strategies is beneficial for Damen or not will be investigated in the following chapters.

2.6. CONCLUSION

This chapter has given the theoretical background of this research starting with the link between product variety and volume and different production processes such as project, job, batch, mass and continuous process.

The series effect and learning curve are the following topics discussed, showing that the production of large batches in series will contribute to a learning curve, improving efficiencies and decreasing production time and cost.

Next, platform-based product development has been explained, covering the design of a product consisting of standard modules with similar interfaces to be applicable on different product types. Examples from the automotive, aviation and software industries are used to illustrate this design method.

The Customer Order Decoupling point is an important indication to decide on which production strategy to apply within a manufacturing company. Providing this background information is required to understand the current production strategy and manufacturing process applied at Damen Shipyards. Damen Shipyards produces complete hulls on stock according to a make-to-stock strategy. The production process is currently being optimised with pilots and projects such as Design for Production, the Bottom-Hat-Principle and Excellerate.

The knowledge gained in this chapter will be applied in the next chapters to answer the main research question.

3
Building Strategy

The theoretical background of this research has been presented in Chapter 2. Before exploring the different levels of standardisation, the factors which determine the production cost and lead time of the current building strategy should be known. The production cost and throughput times are influenced by building strategy variables, which are determined in this chapter using production strategy and financial data from one of Damen Shipyard's tugs. When this is done, the first sub-question is partly answered;

Which parameters influence:
- the production cost,
- and the production time?

The production strategy of the ASD2810 build at Damen Galati is used as a base case for this research. The building strategy for this vessel has already been evaluated and used in previous research, and will be applied to find the factors which determine the production cost and lead times. Once these factors are known, the effect of implementing different levels of standardisation on them can be determined.

In this chapter a theoretical model of the production of an ASD2810 built at the Damen Galati shipyard is presented, based on previous research performed by T.J. Hoekstra (2014). The chapter is divided into six sections explaining step-by-step how the production process and cost for this vessel are built up. Starting with the over all cost division of production and the main production phases, followed by all the activities which take place in the respective phases, their durations and how the activities are related to each other, ending with the production cost and a conclusion.

3.1. Production Cost

At Damen Shipyards, production cost determine to a great extent the profit that can be made. The further cost can be reduced the more profit can be made. Therefore it is important to know which parameters determine the cost and how they are linked. The piechart in 3.1 shows the different items which together form the total production cost for a vessel. The presented cost are based on information from the Damen Galati Shipyard. A lot of production process and related cost information is available from this shipyard and the ASD2810 is mostly produced at this yard.

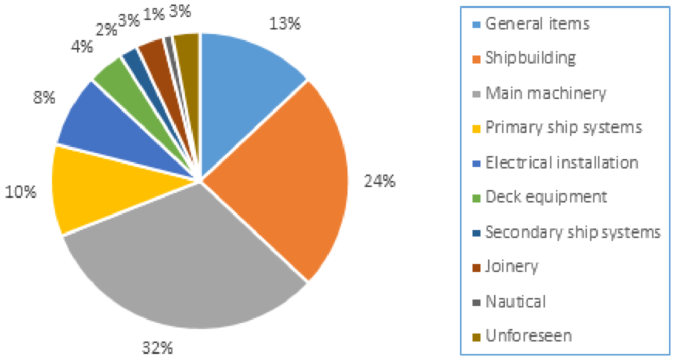


Figure 3.1: Cost division current building strategy, (Hoekstra, 2014)

The above mentioned cost are divided according to ship-systems which can be further separated into in-house cost and buy-in cost. In-house cost can differ between building strategies and most buy-in cost do not depend on building strategies.

BUILDING STRATEGY INDEPENDENT COST

Cost which are independent of the building strategy do not change but the cash flows are influenced by building strategy variables. In-house overhead cost of this cost type are generated at the main office in Gorinchem which include cost for project management, procurement, material coordination, research and engineering. Other in-house overhead cost come from the shipyard and include cost for project management, work preparation and planning.
The buy-in cost of the same type include cost from materials, services, utilities and equipment which can be divided into three groups, individual items, grouped items and general items.

- Individual items are related to the installation moment of the related item and are mainly expensive.
- Grouped outfitting items include equipment and materials that are too small to be added individually to the cash flows, They are grouped according to production activities which are related and their timing is is related accordingly to those activities.
- General items include transport, fuel and trial cost that are linked to phases of the production. These cash flows are linear throughout the duration of the production phase.

BUILDING STRATEGY DEPENDENT COST

Building strategy dependent cost mainly include cost at the shipyard to actually produce a vessel. These cost include labour and manufacturing overhead cost. Manufacturing overhead cost include equipment, facilities, utilities and indirect labour cost.

From available plannings and a value stream map, data is collected regarding production hours and activity duration. The relation between cost, cash flows and labour is explained in section 3.6.

3.2. PRODUCTION PHASES

The production process for the ASD2810 contains several phases listed below (Hengst, 1999, Hoekstra, 2014).

- Pre-fabrication / Work shop
- Sub assembly of
  - Panels
  - Sections
  - Blocks
- Final assembly
- Finishing
- Trials

The Work Breakdown Structure presented in Figure 3.2 shows the three main phases for hull production consisting of a section phase (the bottom row), a block phase (the middle row) and an assembly phase in which the blocks are assembled into 2 zones (top row) which are finally attached to form the complete hull. Workshop activities can be performed parallel to these three phases and trials are performed when production is completed. This framework forms the base for scheduling smaller activities and to determine throughput times and production cost of outfitting activities.

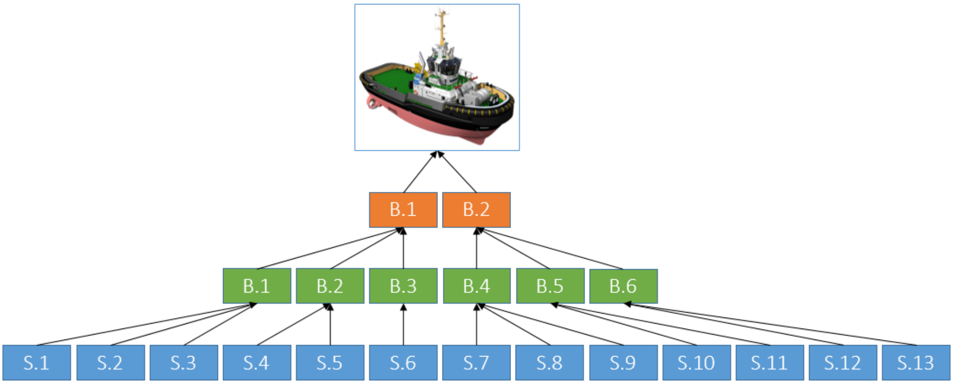


Figure 3.2: Work Breakdown Structure showing production phases

Section phase

In the section phase, mainly piping and outfitting activities can take place as long as the section is open and when it is built upside down. This provides better working conditions and good reachability for cranes and equipment.

Block phase

Sections are attached to each other to form bigger blocks in the block phase. Blocks are usually closed and are not produced upside down which makes the installation of large equipment and outfitting activities more challenging due to reduced accessibility and uncomfortable working conditions such as limited daylight and overhead welding.

Final phase

In the final phase, the blocks are assembled to form the hull, deck equipment is placed and final painting is performed. Piping and outfitting work can also be performed in the final phase, however more man-hours are required to place scaffolding and due to bad accessibility for workers, cranes and equipment.

The duration of activities, required man-hours and amount of work which can be performed parallel depends on the phase in which they take place. This is because of the different working conditions mentioned above. Efficiency factors for the three phases differ in literature. With literature and reviews from experts' efficiencies the following efficiencies have been assumed, (Hoekstra, 2014, Interview 6 in Appendix F):

- Section phase 0.25
- Block phase 0.5
- Final phase 1

3.3. ACTIVITIES

In this section the activities which are carried out in the before mentioned phases will be selected. Thousands of activities are carried out during production. However only a few activities determine the length, required work and cost of production. Activities and equipment with a price tag equal or more than 1% of the total project cost are assigned to an activity in outfitting or installation of equipment. Activities with long durations and labour requirements are also selected and where necessary, they are grouped into larger activities with the help of value stream maps and plannings of the Damen Galati yard. In total 25 outfitting activities are selected which are listed in Figure 3.1. Durations and cost for hull production activities are calculated separately from outfitting activities.

Activities can take place in multiple phases and in multiple areas, for example Hot works is split in Hot works Engine Room (ER) and hot works Accommodation and Wheel House (ACC + WH). Which activities take place in which phase is defined in Appendix C in Table C.1 for the activities in the section phase, Table C.2 for the activities in the block phase and Table C.3 for the activities in the final phase. Tables C.5 and C.6 in the same appendix show additional information including the weight and throughput times of the steelwork for the sections and block.

Table 3.1: Production Activities, (Hoekstra, 2014)

Hull production	Outfitting	Install and connect large equipment
Steel cutting Panel production Section production Block production Final assembly	1. Hot works ER 2. Hot works ACC + WH 3. Painting ER 4. Painting ACC 5. Piping ER 6. Piping ACC + WH 7. Pull cables ACC + WH 8. Insulation ACC + WH 9. Install floor ACC + WH 10. Install walls and ceilings ACC + WH 11. Install and connect small EQ ACC + WH 12. Install small EQ ER 13. Insulation ER 14. Pull cables ER 15. Connect cables ER 16. Install Deck equipment 17. Alligning ME 18. Painting ER final 19. Painting outer hull final	20. Main Engines (2x) 21. Thrusters (2x) 22. Winch 23. Generators (2x) 24. Box Coolers (2x) 25. Hydraulic power pack

3

3.4. HOURS AND DURATIONS

Identical activities which take place in multiple phases have different throughput times due to the difference in efficiency of the work performed in the respective phases. The current required labour and durations for the activities at the Galati shipyard are presented in Appendix C, Table C.7. These durations serve as a benchmark.
An activity does not necessarily need to be performed completely within the same phase, for multiple activities only part of the work is done in section building and partly during block building. For sections and blocks, a constraint is set for certain activities, which is a maximum amount of work that can be done during the section and block phase. This depends on the activity, but also on the section and block arrangement of the building strategy. Additionally, at Galati production takes place during one workshift per day. Work is weekly performed during five workdays with eight hours in each day which is equal to 40 hours per week.

3.5. RELATION BETWEEN ACTIVITIES

First, relations between sections, blocks and zones are established. A block or zone can only start when the related sections or blocks are completed; as presented in the WBS in Figure 3.2. The throughput times of sections, blocks and zones depend on the activities that are performed in them. Outfitting activities can start after a part of the structure work is finished. Relations between activities are set within a matrix, see Figure C.1, Appendix C. This Table shows the relations between all outfitting activities.

3.6. PRODUCTION COST

Production cost strongly influence the operating income that can be generated by production, therefore it is necessary to determine the building strategy variables that influence the production cost. This section shows the price of materials and equipment, cash flow behaviour and timing of the selected activities from the previous sections.

The cost have been split into shipbuilding cost for the three phases, outfitting cost for the selected activities, individual cost including large equipment and general cost which covers start-up cost and trial cost, (Hoekstra, 2014). These cost can be paid instantly or linearly. Instant cost are paid at the start of an activity and linear cost are paid weekly during the progress of that activity.

3

The cost per activity per building phase are presented in Appendix C, Table C.8. Payment cost of equipment are paid instantly, installation cost are continuously paid while an activity is being performed and are paid weekly. Cash flows for other variable production cost occur weekly for all labour that is performed within that week.
General cost include buy-in cost for steel, start-up cost and trial cost and fixed weekly overhead cost including rent, electricity and project management cost are given in Table C.9. Additional data required to determine the cost of manhours are given in Table C.10.

3.7. CONCLUSION

In this chapter the current production strategy of one of Damen's tugs, the ASD2810, has been investigated and processed into a theoretical model. The duration, cost, timing and required labour and order of the production variables are presented in this chapter to answer the sub-question;
Which parameters influence:
- the production cost,
- and the production time?

Paramaters which influence the production cost are:

- the amount of machinery involved in an activity,
- activities with a price tag which is equal or more than 1% of the total cost,
- activities which involve main machinery,
- activities which require a lot of materials,
- activities in the shipbuilding process which require a lot of labour.

Paramaters which influence the production time are:

- activities with long lead time,
- activities which require much labour,
- activities with a long delivery time, also referred to as prompt time,
- the amount of work which can be performed within each production phase,
- the order in which section and blocks are assembled,
- the number of workers available per area.

The production strategy variables are linked to each other to form 13 sections, which are assembled to 6 blocks and finally into 2 zones which will together form the hull which requires outfitting and painting activities in the final phase.
Cost, required manhours and durations are linked with equations taken from previous research and literate to the variables and activities which are connected to determine the final production cost, cashflow, duration, required labour. This theoretical model will be used as a base to develop a computerised mathematical model which simulates the current building strategy and calculates the effect of implementing different standardisation levels into the current production strategy.

4

STANDARDISING PRODUCTION

Damen Shipyards produces (standard) ship types on stock in order to deliver vessels faster than its competitors to the customer. However, Damen Shipyards is likely to reduce its lead times and cost if the current production process which Damen Shipyards applies is shifted more towards batch and mass production. They can also profit from new standardisation methods such as platform-based product development. Several methods can be turned into practice to contribute to these goals. Platform based product development and the creation of standard templates can be applied in their own way within different phases of the production process to finally achieve higher efficiencies in production and reduce cost.
This chapter discusses the implementation of the before mentioned methods on three different levels of the production process of tugs. The potential savings described in this chapter will be used to calculate the impact on production time and cost. After reading this chapter the second sub-question is answered;

Which levels of standardisation provide good prospects for the production of tugs?

In the first section potential improvements in the main assembly line will be discussed, followed by gains which can be made in the sub-assembly phase and finally on a component level. The levels vary from product portfolio management to purchasing advantages which can be gained by standardising components between different ship types, as can be seen in Figure 4.1.

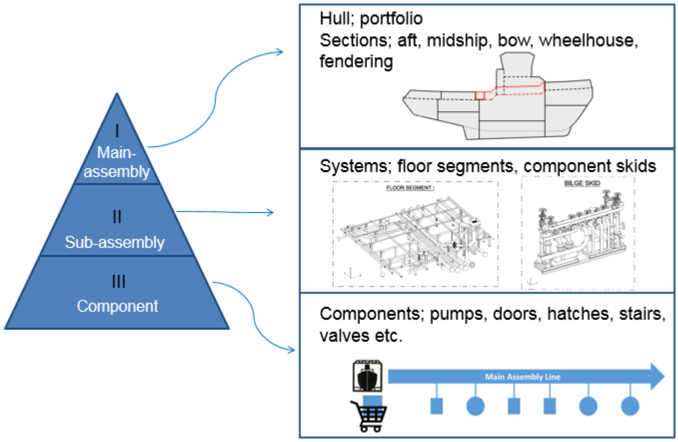
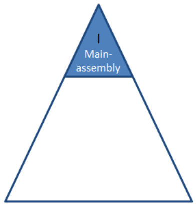


Figure 4.1: Standardisation levels

4.1. LEVEL 1 MAIN ASSEMBLY



The first level of standardisation is based on the creation of standard platforms within the main assembly line of vessel production. This level is divided into two parts; product portfolio management and the main assembly line activities.
Firstly, the Product Portfolio Tugs of Damen Shipyards is a collection of all the tug workboats which are offered to the customer. The vessel types within this product group differ in dimensions, bollard pull, engine power and crew capacities. Even vessels of the same vessel type mutually contain these deviations. Secondly, main assembly line activities include the production of sections, blocks and hulls. This section provides an assessment of how the product portfolio is managed and focuses on the development of standard modular sections which are interchangeable between different vessel types.

PRODUCT PORTFOLIO MANAGEMENT

The Product Group is responsible for the management of the product portfolio. This includes the creation and maintenance of ship types taking quality and functional requirements of the market into account. The current portfolio consists out of many different ship types including ice vessels, hybrid variants and vessel types which have been engineered but are not actively being offered from stock. Also, some vessels are being replaced by new developed ship types and will eventually be phased out of the portfolio. Therefore the actually nuber of different vessels actively offered to the customer is lower. The product portfolio is continuously being analysed and updated in order to comply with the requirements from the market. The product portfolio can be analysed with the the Boston Consultancy Matrix (BCG Matrix), which is a tool consisting of four quadrants in which the market share and market growth of the different portfolio ship types can be plotted. In Appendix B the BCG Matrix is used to analyse the current Product Portfolio of Tugs.

A combination of the BCG matrix, data provided by the sales department, future predictions for the markets by business analysts of the product group support department and interview results with Damen employees from the sales, design and proposal and engineering departments (presented in Appendix F) have been used to analyse how the Product Portfolio Tugs is configured. The analysis can be divided into three main steps presented as follows.

Step 1. Diversity analysis
A diversity analysis has been performed to compare the main dimensions, power capacity, speed, design and operational fields of the different vessels in the product group. Several observations have been done during this analysis which were used as an input for the interviews performed with Damen employees from multiple departments in the next step.

Step 2. Interviews
In total, 32 employees from sixteen different departments have been interviewed to discuss the observations found in the diversity analysis and to find out what Damen already does concerning standardisation, where the standardisation challenges are and where employees believe opportunities can be created. The set up of these interviews and main results are presented in Appendix F.

Step 3. Product portfolio analysis
With all the knowledge gained from the diversity analysis and interviews performed, the current product portfolio formation is analysed. This resulted in the development of a more compact standardised product portfolio. In the decision process several fields have been examined and multiple requirements have been taken into account:

- The proposed portfolio should have sufficient vessel types to operate in each operational field, presented in Figure 4.2, and to deliver the matching bollard pull and speed capacities. Each quadrant of the operational field contains ship-handling tugs including ASD, RSD and ATD tugs, line-handling and assistance tugs including STan and SLAU tugs and Ice class tugs including ASD and Stan tugs. Each quadrant should retain at least a ship-handling and a line-handling/assistance tug and these vessels should be able to operate in the same conditions and at the same speeds as the vessels in the current product portfolio.
- Diversity is reduced as much as possible between vessels with the same main dimensions (mainly the same width), which will be discussed more thoroughly in the next section.
- Furthermore the expected trends in the demand market are taken into account. This is done in cooperation with business analysts of Damen Shipyards who assess the market and develop a baseline which includes the predicted sales for a coming period. Based on these prediction a baseline is made showing which vessels should be produced on stock and in which numbers.

Figure 4.2: Operational field and operational profile, (Degroote, 2015)

- Finally, the diversity of vessels in the standardised portfolio should be sufficient enough to fulfill the market demand and simultaneously the variety should be reduced to make as much profit as possible of standardisation advantages. Trends in market demand are closely followed at Damen Shipyards. The popularity of a certain ship type can be checked by tracing the sales numbers per ship type and externally by keeping track of sales numbers of ship types at competitors.

The results of this analysis led to the development of a more compact configuration of the portfolio with less variety and potentially larger series sizes per vessel type, which can be seen in Figures 4.3, and 4.4. The detailed analysis that led to this result can be found in Appendix B.

It can be seen that the number of different ship types in the standardised product portfolio has decreased from with 40% in the actively offered ship types from the proposed standardised portfolio. To get to the proposed standardised portfolio, some ship types have been upgraded, other ship types are joined together to be replaced by one uniform ship type and others are replaced by a different propulsion set. Two examples of how the variety within the product portfolio has been decreased are presented in Figure 4.4. The first example (in blue) shows that the ship type V and W are joined together and are replaced by the ship type X. Ship type X is capable of performing the same activities under the same conditions and can even be applied in wider environmental conditions than the other two ship types. The second example shows that ship types H, I and J are replaced by one ship type K. These three vessel types have been offered for many years,

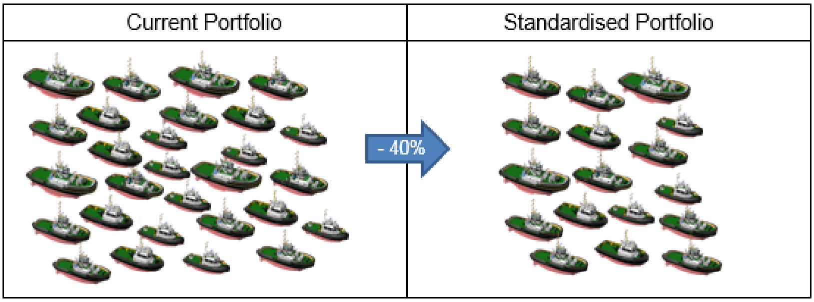


Figure 4.3: Reduce variety

perform very similar activities and are sold and produced in small series. Replacing these vessels by one ship type which fulfills the same required capacities and can be sold for the same or even a lower price would provide Damen and the customer with advantages.

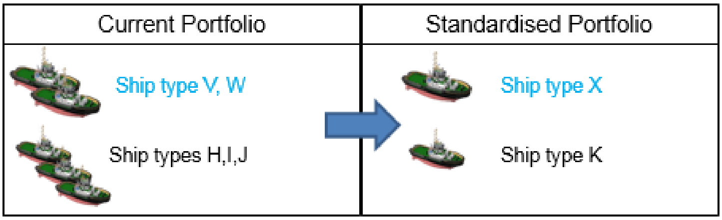


Figure 4.4: Maintain Diversity

STANDARDISING MAIN ASSEMBLY ACTIVITIES

As explained in the theoretical background in Chapter 2, the production process will be optimized when variation is decreased and batch sizes are increased to benefit from serial production advantages. In this section the potential of producing larger series of modular sections and blocks will be analysed.
After the product portfolio has been analysed, ship types with the same beam are compared to each other to find similarities in the main building blocks such as sections, blocks and zones. This is inspired by the platform-based product development method to find modular sections which can be assembled in multiple ship types. Only vessels with the same beam are compared because sections and block with varying beams cannot be connected to each other. The hulls have been divided into nine main areas as presented in Figure 4.5; aft (A), midship (M) and bow (B), bottom (A1/M1/B1) and top (A2/M2/B2) and a superstructure divided into Deckhouse(DH) and Wheelhouse(WH) and finally the fender structure (F). All vessels with the same beam will be compared on these nine sections as shown in Figure 4.6.

The similarity results with batch sizes equal to or larger than 4 have been plotted in Figures 4.7 and 4.8 for the current portfolio and the standardised portfolio. In the top figure the x-axis shows the number of sections being produced in the amounts presented

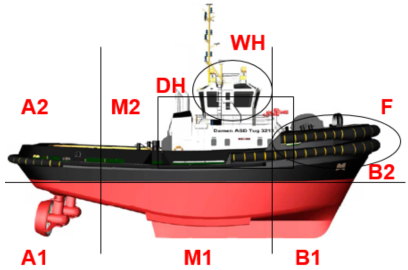


Figure 4.5: Section overview

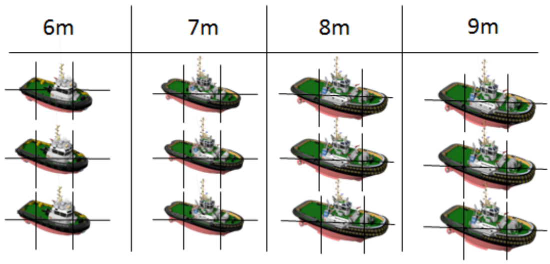


Figure 4.6: comparing sections

in the bars. On top of each bar the vessel types to which those sections belong are written. In the bottom figure the x-axis also shows the number of sections being produced in the amounts presented in the bars. The names on top of the bars present which sections are produced in these numbers or to which vessel type they belong. Some remarkable observations were done during this evaluation.

- When looking at the potential for serial production of sections in the current portfolio one can see that only four vessel types have been sold over four times in the past year (2015). This means that only the sections in those four vessels can be produced in larger series. When looking at the compact portfolio one can see that a lot more sections can be produced in series and that the batch size of these series can be as high as 44 for example for the wheelhouse type B.
- Sections which have too much variance and have little to no potential for serial production are the fenders and midship sections. Midship sections include the engine room, which has relatively more customised items than other sections.
- It has also been studied whether the ICE class vessels and the regular condition vessels have similar sections. The shape of the hulls for example of the STu1907 and the STu1907 ICE are very similar. Therefore afts, fendering, deckhouses and wheelhouses are for all the vessels with an ICE Class variant the same. However, after posing the possibility for producing these sections in the same way to increase the series batch, for example by applying thicker steel around the ice-belt or apply double spacing in all hulls to be able to increase batch size for serial production at the engineering department this seems challenging. Not only is the steel thicker for ICE Class vessels around the ice belt, it is also a different (more expensive) type of steel. Additionally, class requirements vary to such an extent that the construction of the two vessels is completely different; ICE Class vessels have for example smaller frame spacing and more stiffeners. To turn the production of both regular and ICE Class section into an regular production process into practice will probably cost a lot of effort and investments. As this research is not a design research, it has been assumed that this challenge can be solved. For ICE class vessels and regular condition vessels with similar sections it is assumed that these sections can be produced in the same way without complications.

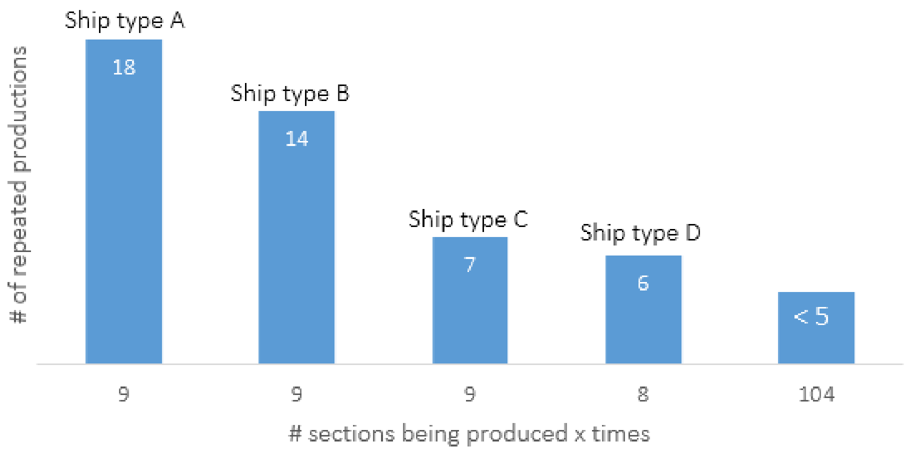


Figure 4.7: Series production of sections in current portfolio

It has also been investigated whether it is beneficial to have blocks (assemblies of sections) on stock. The only block which has the potential to be build on stock is the superstructure, because both the deckhouse and the wheelhouse are suitable for serial production. However, the assembly time required to attach these two sections is very small which makes it not beneficial to attach them before the start of production. This makes relocation of the sections easier as there is no need for large cranes and leaves space for variation in attaching different deckhouses with wheelhouses.

OPPORTUNITIES

The development of a more compact product portfolio leads to less variation and greater volumes of the end products. This will contribute to a faster and smoother production process and will lead to shorter lead times and lower production cost. Additionally, especially the wheelhouse and deckhouse sections have the potential to be produced in even higher volumes when they are produced as standard sections which can be placed on multiple ship types.

Having sections on stock rather that hulls also has several advantages. Firstly, building sections on stock which can be assembled according to the customer's wishes has a reduced risk of building the wrong vessel types on stock. Customization is increased and delivery times will remain reasonable due to standardised production processes. This makes it easier to anticipate to changes in demand. Additionally, producing a vessel on stock during high steel prices may lead to high production cost which is no longer a risk when smaller units are produced on stock. Also having complete hulls on stock in (salt) water requires a lot of maintenance which cost money. This is not the case for storing sections in dry spaces. The production of sections on stock rather than hulls results in a switch from make-to-stock to an assemble-to-order production strategy.

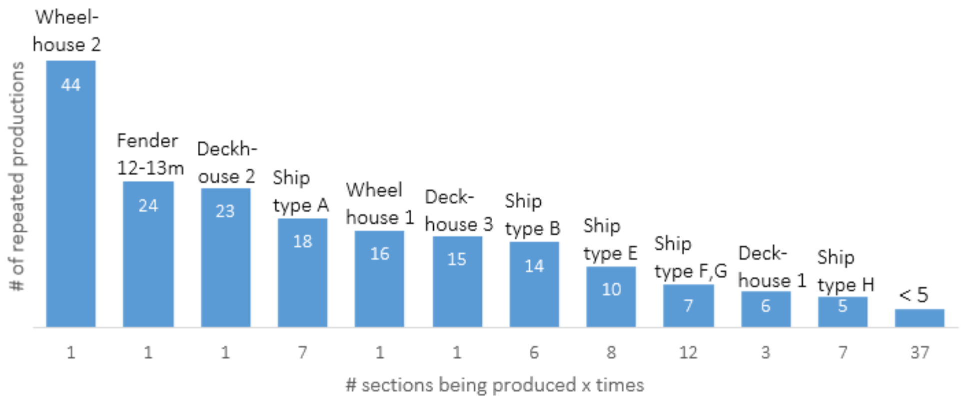
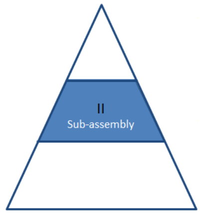


Figure 4.8: Sereis production of sections in proposed standardised portfolio

INVESTMENTS

It should be kept in mind that the above mentioned actions need some investments to be implemented. For example the development of a new ship type such as the ASD3012 requires extra engineering and development cost. Also switching to a batch process implies development cost for a new production process and training for employees. Additionally, the production of standard sections will be shifted to a separate production line. This production line will run simultaneous to the main assembly of the vessels. There are several options for the operation of this assembly. The production of standard sections (platforms) can be executed at a fixed location from which the modules will be transported to the yards who need them or it can be a fixed process at each yard. In the second option the series size will be smaller because certain ship types are produced at different yards. This is a topic which is left for further research. However, for this research it is assumed that 75% of the series size of standard sections will be produced in one production line (to profit from serial production) at the same location and that no further transport of the sections is required before assembly.

4.2. LEVEL 2 SUB ASSEMBLY



Within the shipbuilding industry a significant amount of the production time is spent on outfitting which is partly done during the section phase and mainly done in the block phase and final phase, where a lot of outfitting is performed after launching. Pipe spools, ventilation ducts, foundations and cable traces are examples of structures which are fabricated in a shipyard's workshops and which are sent to the outfitting location, followed by their installation at the appropriate stage. After completing the outfitting process the outfitted structure usually still needs painting which is a time consuming and costly job due to bad accessibility around the outfitted components. (Rubesa et al., 2011). Further improvements of advanced outfitting have been investigated in literature by for example introducing larger standardised, unitised and typified modules based on platform-based product development, which are pre-assembled in the workshop during the sub-assembly process of ship production. In this section the potential advantages of implementing advanced modular outfitting based on platform-based product development will be discussed.

4

OUTFITTING

Hull construction is divided into pre-fabrication, panel fabrication, section production and assembly, block assembly and hull assembly. Outfitting work is the installation of non-structural components (which includes components which do not take care of the overall strength of the ship) such as pumps, engines, vales, including pipelines, cabling and ducts, on the supporting structural steel construction, (Nieuwenhuis, 2013). Outfitting activities can be performed on open sections during the section phase, on closed blocks during the block phase and on board during final outfitting. The duration of outfitting is to a large extent determined by the number of actions performed such as transportation, installation and commissioning of components. Literature also shows that learning effect and employee and company experience contribute to the duration of outfitting, (Nieuwenhuis, 2013). Lastly, the available space to perform outfitting activities also affects the duration of outfitting, which has already been discussed in Chapter 3.

MODULAR OUTFITTING

Modular outfitting is one of the concepts in shipbuilding which is seen as an area with potential progress. Applying modular outfitting causes a shift of outfitting work which is traditionally performed on sections, blocks and during final-outfitting after launching the vessel to the workshop in earlier stages of the building process, (Rubesa et al., 2011, Fafandjel et al., 2008).

The assembly of common equipment, systems and outfitting components are identified and will be fitted on outfit assemblies, on-unit and on-block outfits, which can be seen in Figures 4.9, 4.10, 4.11.These assemblies and units can be completed in the workshop, and will be constructed simultaneously with the hull construction. Also, these unit are developed to be easily lifted without exceeding crane-lifting capacities during installation.

One unit can contain a single piece of equipment mounted on a common supports and ready for installation on panel, on-block or on-board, or can contain a complex assembly of equipment, piping, floors, cable traces, wirings or other systems all pre-mounted on a structure. The integration of these construction and assembly units and building blocks can therefore even create a complete engine room arrangement including standard locations of system units, walkways, monorails, pipelanes, cableways, and structural interfaces from unit to unit, (Jaquith et al., 1998).
Design strategies such as platform-based product development can be used for these outfitting units to allow standardisation of such machinery units and their structural and system interfaces across different ship types and sizes, (Jaquith et al., 1998). J.J. Nieuwenhuis (2013) describes the intention of a platform-based modular approach as follows: "The intention of a platform-based modular approach is to develop a module that can be used for a number of ships within the family, or even for the complete family."

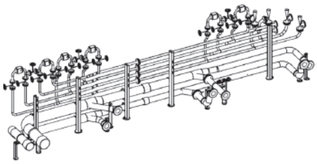


Figure 4.9: Outfit assembly, (Rubesa et al., 2011)

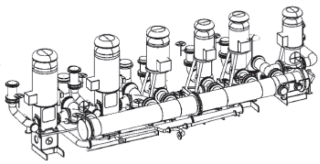


Figure 4.10: On-unit assembly, (Rubesa et al., 2011)

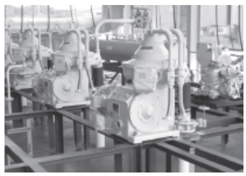


Figure 4.11: On-block assembly, (Fafandjel et al., 2008)

The first step in applying a platforming approach in outfitting is to identify common systems on board and across a family of ships. J.J. Nieuwenhuis (2013) performed this study for a family of patrol vessels. A list of about 70 systems which are frequently applied within a family of patrol vessels was found ranging from fuel oil systems, anchoring and mooring systems to bilge and ballast systems. This list was reduced to 50 after removing systems with bad accessibility. These results are promise and encouraging to apply the platform approach in the product family tugs at Damen Shipyards.

More research projects have been performed where shipyards have been observed to investigate what the impact is of implementing modular outfitting on shipbuilding. N. Fafandel et. al, (2008) states in his paper that, "The long term statistics in observed shipyard show that the cost of work performed in the workshop compared with the same work performed on section, on-board or in final outfitting is related as 1 : 3 : 5 : 7." This can be seen in Table 4.1. It means that cost can be up to seven times multiplied if the work that could have been done in the workshop but is performed during final outfitting. It should be possible to accomplish a decrease of shipbuilding cost up to 15%, as well as shortening the time of shipbuilding process up to 31%, (Rubesa et al., 2011).

Additionally, as part of the Standard Machinery Unit development project (Jaquith et al., 1998), a business assessment of potential cost and schedule impacts was accomplished by three U.S. shipyards; Avondale, Bath Iron Works, and National Steel and Shipbuilding Company (NASSCO). The results show a significant reduction in pipe and cable footage, along with a small structural weight increase.
Also, this analysis shows a clear increase in on-unit completion levels in multiple cat-

Table 4.1: Efficiency of performing work in the workshop (Fafandjel et al., 2008)

Location	WS hrs: S/B/Z hrs	eff. shifted hrs to WS
Work in the workshop	1:1	-
Work performed on section	1:3	67%
Work performed on board	1:5	80%
Work performed during final outfitting	1:7	86%

egories (Mechanical Equipment, Electrical Equipment, Pipe, Ventilation, Cable Power, Automation, Lighting, Test), with a corresponding decrease in on-board work scope for Standard Machinery Unit development relative to the current outfitting situation. All shipyards agreed that there were potential savings in the order of 50-60% in engineering and planning, 35-50% in production, and 15-20% in material procurement over a series of several ship contracts. Finally, in the same research, the assessment of the potential schedule improvement shows a lead ship schedule of 19 months for the ship designed and constructed with standard machinery units compared to a schedule of 24 months for the ship with conventional design and construction.

MODULAR OUTFITTING AND MATERIAL FLOW

The production process consists of the physical realisation of a ship. During production all procured material is manufactured (steel, piping) and assembled into a complete hull (steel, sections, engines, installation of pumps, etc.). Figures 4.12 and 4.13 illustrate the material flow within the different production phases of this process. The top figure illustrates from top to bottom the production phases, outfitting activities which take place during production and the workshop activities which take place during production. In the workshop small components, pipes and electrical components are assembled into modules in the dark grey layer. These modules are painted in the painting workshop and assembled during production. The bar on the left shows relatively the amount of materials entering the different production stages.

Figure 4.13 presents the amount of material included at each production stage. During hull assembly (in blue) steel plates are cut into many plates and profiles which are assembled into a reduced amount of panels which form the 13 sections and finally the 6 blocks resulting in one hull. In the workshop (in light grey) materials such as wood and steel are cut into smaller parts which are in the final step assembled into piping and frame assemblies. Most outfitting material (in orange) is included in the outfitting phase, which is outfitted on board in the respective phases. Currently (the bottom-left chart), the material is only partly assembled into modules with each module containing a certain amount of materials. With modular outfitting (the bottom-right side) a lot more modules are assembled with each module containing many more parts then in the current situation because pipes, cables, equipment and systems are already installed on the modules. This will lower the peak in outfitting during final outfitting and reduce the amount outfitting work to be performed on board.

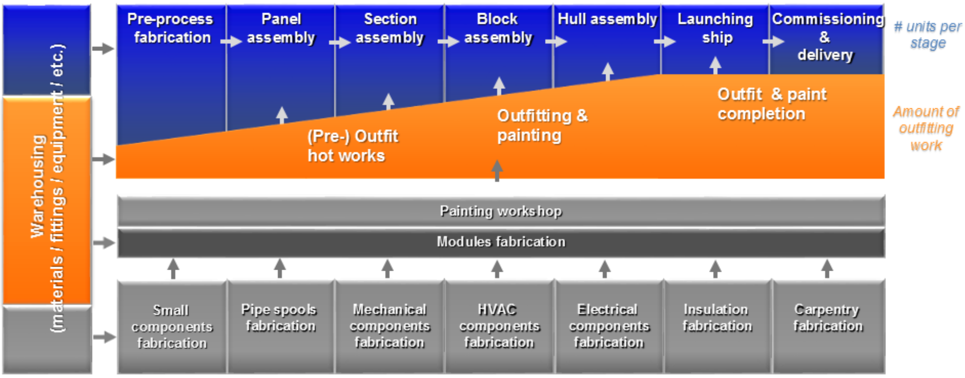


Figure 4.12: Production flow

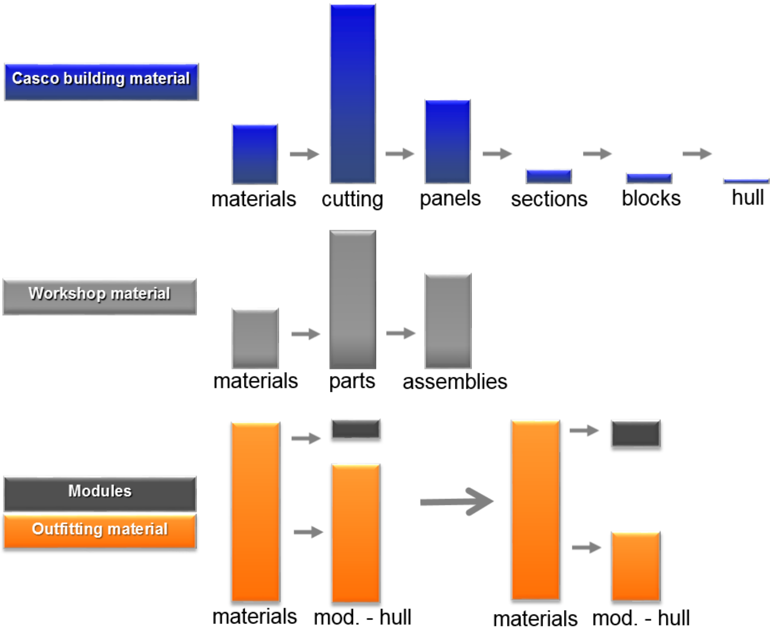


Figure 4.13: Material numbers in production flow

OUTFITTING AT DAMEN SHIPYARDS

The current building strategies of Damen include some modular outfitting. A good example applied within Damen is the frame for the firefighting (FiFi) set which is present on board of the majority of the tugs within the Product Group Tugs. The customer can choose from three different sizes of FiFi sets. The frame is designed in such a way that those three FiFi set types can be installed on the same frame. The number of outfitting modules however is limited and the materials per outfitting unit is small. Expanding the number of standard frames which can serve multiple types or sizes of equipment would make it possible to continue production without having to wait for a requirements list of the customer, which also gives the customer more time to decide on which equipment he would like. Damen has recently introduced modular outfitting by implementing modular skids and frames in the engine room for the ASD2913 as a follow-up from the integrated production strategy which has been explained in Chapter 2. The pilot includes the shift of hotwork activities to the workshop by implementing modular outfitting. The assemblies and unit within this pilot include floor- and component skids for pipes, equipment and systems positioned in the engine room. The engine room is a very suitable area to implement modular skids because this area contains a lot of functional systems, equipment and pipes suitable to be assembled onto these modules and tested in the workshop, (Fafandjel et al., 2008, Rubesa et al. 2011, Atlic et al., 2003). The floor and component skids are being produced in the workshop. This enables outfitting activities to be performed parallel and components and systems in skids to be tested and painted before being installed on board.

Opportunities

The ASD2913, produced at Damen Shipyards Galati (DSGa) is the first ship type of the Product Group Tugs to be outfitted with modular units in the engine room. The first results are promising; a reduced lead time of approximately 25% and reduction of 3000 man-hours was measured since the first of series of the ASD2913 produced in 2013 until the 7th of the series produced in 2016. Hull assembly lead time reduced with 14% with an increased physical progress of 11%, which is an over all improvement of 29%, (Teuben, 2016).

A result of the floor skids and a screen-shot of a pre-engineered piping frame and its result after production in the workshop are shown in Figures 4.14 and 4.15, (Teuben, 2016). The developed skids for components on the ASD2913 can potentially be placed on board of other ship types of different sizes, even of different product groups as long as the interfaces on all vessels are the same. Development time and cost for these interchangeable units only need to be performed once. Additionally, material procurement and construction time will be reduced due to serial production. However, the floor skids which include a lot of piping are more dependent on the dimensions of the engine room and are therefore also dependent on the main dimension of the ship. When the floor skids are fully standardised and modular they might be applicable on multiple ship types. The component skids can be placed on all vessels which use the same components, (Rubesa et al., 2011, Fafandjel et al., 2008).

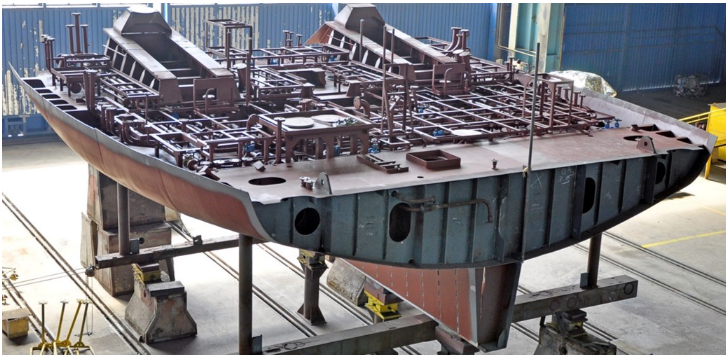


Figure 4.14: Pre-engineered and produced floor skids in engine room ASD2913, (Teuben, 2016)

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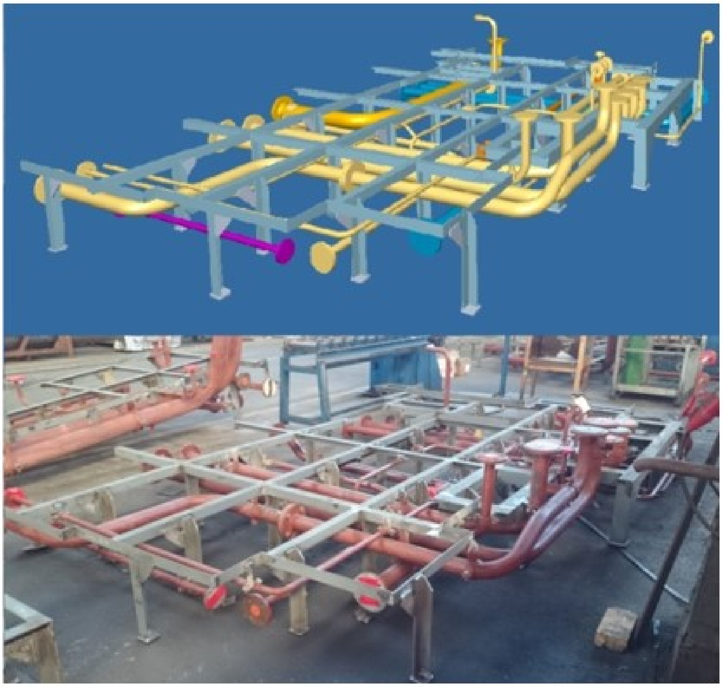


Figure 4.15: Pre-engineered piping frame with result after constructing in workshop, (Teuben, 2016)

The pilot for the ASD2913 only includes skids and frames for the floor construction of the engine room. There are many more potential areas within the vessel where modular outfitting could be applied to increase efficiency and reduce production time and cost. Bas Dammen, project manager of the ASD2913 Pilot, states in an interview (Interview 5 in Appendix F) that still a lot of piping is done in the 'hat' of the engine room without the use of skids or frames. Also, the HVAC installation, AC ducting, accommodation, roofs and other areas with hotworks serve as a potential for modular outfitting.

Several visits have been paid to vessels in the production area at Damen Gorinchem to get an impression of the activities which have the potential to be performed with modular outfitting. Dozens of examples can be found to benefit from moving outfitting activities to the workshop. Three clear examples are explained below.
The first example concerns the bilge-water system which has been installed after section production, with its current frame being attached to the hull construction. This system could have been placed on a frame produced in the workshop, tested in the workshop and installed during section building before the hat would be placed on the bottom.

Secondly, Figure 4.16 shows a bundle of pipes which have been installed individually during final outfitting. These pipes could have been produced on a frame in the workshop and could have been assembled on board, in one go during section building, saving a lot of time.

Figure 4.16: Pipe bundle which could have been produced on a frame in the workshop

Finally, a perfect example is given of the where a floor skids could have been placed. In this situation the floor had been installed during hull assembly. Stiffeners, pipes and cables are spread over the floor. Many employees work simultaneously in this space, which makes this area dangerous with an increased chance of getting injuries and decreased working conditions which makes the work done less efficient. Also, on the side plates several frames and pipes were placed during block assembly. These items could also haven been assembled on piping and system frames in the workshop and installed on the bottom and side plates of the section before placing the floor skids and the hat on the bottom.

When analysing the potential of applying modular outfitting caution should be taken with the installation of skids and frames on board. The hull structure, frames and stiffeners may not be affected by the assembly of these modules. The above mentioned examples are only a few of the many possible applications of modular outfitting and serve as an illustration. In this research the theory presented by Fafandjel et al.(2008) is applied to show the effect of modular outfitting on the production hours per production phase (section, block and final outfitting).

It is expected that modular outfitting will provide Damen with many more advantages which have been summed up in the following list:

- Outfitting manhours will be reduced due to improved working conditions in the workshop where employees can work in comfortable working positions, equipment is always in reach and there is sufficient light. This will contribute to reduced total throughput time and cost.
- Another ease of modular outfitting is that the equipment and systems can be tested and painted in the workshop before being installed on board. Modular outfitting also leads to fewer items to be installed and reduces the number of actions to be made (Fafandjel et al., 2008).
- Modular outfitting also increases efficiency of maintenance activities because it is easy to remove and replace equipment from the modular units (Jaquith et al., 1998).
- Due to a shift of activities to the workshop and no actual changes in the type of work performed there are no big investments needed to be done on new equipment and facilities, (Fafandjel et al., 2008).
- Furthermore, modular outfitting can be made flexible because the workshops can be either a part of the shipyard or a part of outsourcing. This has two advantages; firstly in busy periods with a lot of orders the workshop activities can be outsourced to suppliers. Secondly, increasing the participation of suppliers will lead to shared responsibilities. Suppliers will be involved in more advanced developments which can lead to improved quality of their products and reduced cost, (Fafandjel et al., 2008).
- Modular outfitting will also reduce engineering and development cost, because this only needs to be done once, (Nieuwenhuis, 2013)
- Another advantages of modularising ship systems are the reduces purchase cost because of increased purchase volumes
- Quality and experience of maintenance engineers is very important to keep a customer satisfied after selling a product. Predicting maintenance and repair cost for ships, is difficult, because vessels encouter unexpected events during their lifetime. With modular outfitting detailed service and maintenance analyses can be improved and give a good estimate of the availability of a system and the maintenance cost during its operational life, (Nieuwenhuis, 2013).

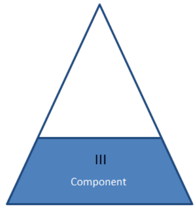
On the long-term a library can be developed which contains standard machinery unit construction arrangements and details supports detail design which includes the development of standard owner options such as modular FiFi sets will contribute to making production modular and more efficient.

Investments

It should be kept in mind that applying modular outfitting requires several investments and challenges. These considerations are listed in this section.

- The development of modular units requires an investment in design, engineering and construction works, (Fafandjel et al., 2008).
- The amount of work performed in the workspace is increased, therefore the more space might be required to complete the construction work.
- Modules are heavier than in conventional outfitting and will require more space, due to stronger supports and foundations. J.J.Nieuwenhuis (2013) performed an analysis on platforming on board of patrol vessels which resulted in an increase of required area between 10% and 20% and an average system weight increase around 10% due to the implementation of platforming. The effect of this is limited as long as the displacement is not affected because that would also influence design aspects such as speed.
- The increased weight and dimensions of a module can also effect the handling of the component and arrangement of the compartment. Sufficient space should be available for maintenance around the components in the module. Additionally, removal routes and space requirements for the handling of the modules themselves should be taken into account, (Nieuwenhuis, 2013).
- Another challenge which can be faced with modular outfitting is the alignment of piping and therefore detailed and accurate measuring and outlining is essential. This means that there is an increased necessity of higher quality and detail of documentation of outfit assemblies because measurements need to be accurate, (Rubesa et al., 2011).
- In addition to the previous challenge there is an increased risk of rework if measuring is not accurate enough which could lead to increased production cost. Therefore accuracy and first-time-right principles need high priority in the primary stage of implementation, (Rubesa et al., 2011).
- Lastly, with fast developing technology, systems and designs become quickly outdated. Therefore the modules should be easily changed to upgrade a product (Nieuwenhuis, 2013).

4.3. LEVEL 3 COMPONENTS



The third level of the pyramid focuses on standardization on a component level within and between different ship types. Literature shows that in shipbuilding and especially for complex ships the value of purchased materials and components is very important and contributes for a major part to the overall product cost, (Nieuwenhuis & Nieunhuis, 2004, Nieuwenhuis, 2013).

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The standardisation of components can also be achieved by applying platforming in combination with modular outfitting. For platforming to be successful it is important to obtain benefits for the purchase process, (Nieuwenhuis, 2013). Standardising components starts with defining which products within a product family are important to the customer. In most cases this concerns the payload items of the vessel, which therefore should maintain variety and customisation to keep the customer satisfied. Non-payload components are suitable to be standardised. Also cost drivers can be used to determine where to standardise on a component level. In shipbuilding the most commonly used cost drivers are the component capacity and component weight to calculate purchase cost. J.J. Nieuwenhuis (2013) has identified additional cost drivers which include:

- Make and type: The main driver here is the pricing differences between different different suppliers, however without taking into account quality differences.

- Order volume: When purchase volumes can be increased, this will most likely lead to lower purchase cost.

- Number of suppliers: By standardising and therewith reducing the number of suppliers a purchasing advantage can be gained. Examples presented in literature, from the Oil and Gas Industry and the Dutch Process Industry report savings of up to 30% due to the reduction of the number of suppliers through better suppliers relations and frame contracts. However, some shipyard managers expect a negative effect of reducing the number of suppliers, because of a reduction of negotiation possibilities, (Nieuwenhuis & Nieunhuis, 2004).

- Additionally, the location of suppliers can influence purchase cost and especially delivery times of components. Local sourcing of component suppliers can lead to significantly reduced delivery times and close cooperation considering spare parts and inventory sizes of component. However, this will require good research and time to to find local high quality suppliers and to build up a strong relation.

In addition to the last item mentioned above,an increased amount of work is being subcontracted in current shipbuilding, as shipyards are more and more becoming “system integrators” like the automotive industry. Suppliers have become more integrated into the process because the engineering, production, supplying and often also the installation of a significant amount of components and systems is done by the supplier. Therefore, shipyards coordinate and integrate the activities of an increasing number of suppliers and sub-contractors. In other words, the responsibility of the supplier has increased over the years. When implementing platform-based product development this will most likely positively affect and the processes and interaction of the yard's suppliers and subcontractors with the yard, (Nieuwenhuis, 2013).

EXCELLERATE

Damen Shipyards is concerned about the advantages which can be achieved on this level and recently started several pilots to turn these advantages into practice. This section covers standardisation on a component level and how Damen Shipyards covers this through the Excellerate program. The Damen Excellerate program develops a Damen Standardization Approach, as explained in Chapter 2. The main goal of Excellerate is to bring 'working with standards to the next level in a multinational environment' thereby realising the strategic goal to stay competitive in Damen's chosen markets by making use of the industrialization concept. Excellerate does this by means of creating templates for standard ship types. With these templates people from Product Groups, Engineering, Purchase, Supply Chain and the Yard are supported in a smooth and standardized shipbuilding process. A new role of product group in this process includes the creation and maintenance of ship type templates taking quality and functional requirements of the market into account. The products realised from these templates should be build in an efficient way against pre-defined cost (Damen Excellerate, 2016).
Excellerate manages the process from order to installation on a component level by generating required parts which are entered in a part catalog including lead times and suppliers. Next, blankets will specify who orders where within the supply chain resulting in the specification of transportation time and automatic calculation of due dates. This standardised process will lead to a simplification of planning and reduction of manual labour, (Damen Excellerate, 2016b) .

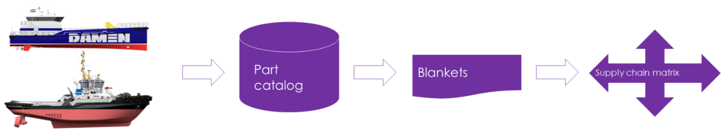

Figure 4.17: Template components (Damen Excellerate, 2016a)

Excellerate has also taken into account how to take advantage of using components which are interchangeable between different ship types. Figure 4.18 zooms in on the relation between the unique number of parts and the number of templates within the same series. In the first template of a ship type each part counts individually and will add up to approximately 2000 parts in total. For each following template in the same product family the number of identical parts between templates will increase and the number unique parts per template will decrease. Eventually the number of unique parts per template is expected to decrease below 400 parts after the fifth template. The first ASD type templetised in the Product Group Tugs, has around 2000 unique parts. The second template in the product group has only 500 unique parts, which means that they have an overlap of approximately 1500 parts. This shows an even bigger overlap than expected in the figure. If this trend continuous, the third template will have even more common parts with the other two templates.

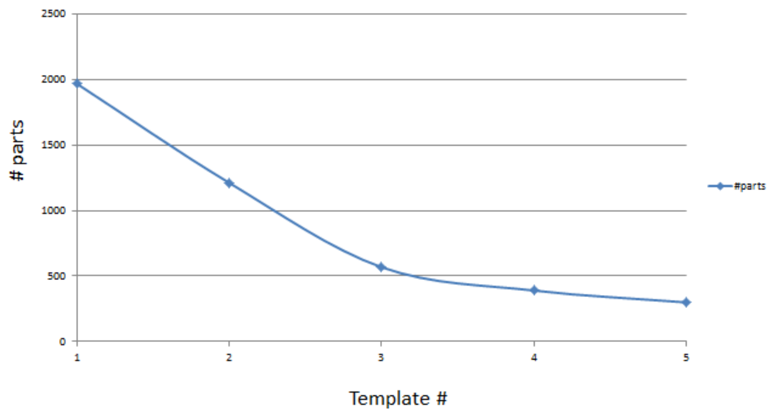

Figure 4.18: Relation between number of adjusted parts in a product-family, and nr. of templates, (Damen Excellerate, 2016a)

Excellerate has already successfully assisted in the development of a standard ship type template for one of the Damen Fast Crew Suppliers(FCS). The cost breakdown for this vessel produced with the Damen Standard Approach, shows that a total financial gain of 16% can be achieved. When standardising components within ship types a purchasing advantage of 7.5 % can be achieved. An additional material saving of 7.5% can be achieved by joint product design. Production has achieved a saving of 25% serial production and another 10% through production optimization by applying line and lean methods (Interview 14, Appendix F)).

The purchasing potential of 7.5%, production potential of 25% and time savings have successfully been established for the production of a series of Fast Crew Suppliers. These percentages can generally be accepted for other shiptypes based on an interview (Interview 14, Appendix F), and will be used to calculate the potential savings for the templates for the ASD tugs.

OPPORTUNITIES

The use of templates and standard parts and solutions will make the processes of the product groups, engineering, supply chain and the yards more efficient and capable of handling a higher workload. This section lists all the potential advantages of standardisation and modularisation on a component level.

- Standardisation on a component level will directly save the product group and central engineering resources by preventing them from doing double work.
- By ordering common parts for different ship types simultaneously, a considerable purchasing advantage can be gained due to larger batch sizes.
- Also by reducing component variety, preparation installation time and cost will also decrease.

- After identifying identical parts within a vessel and between different ship types in the product family, fewer parts need to be stocked in inventory for providing the same level of availability compared to storing spare parts for each unique part (Simpson et al., 2006)

In addition to the above advantages, from an interview with the services department (Interview 19, 20, Appendix F) it became clear that currently, employees have to invest a lot of time in getting acquainted with all the different types and brands of components and systems to be able to perform maintenance and repair work. Also the interaction between certain components in systems is not known due to the high level of variety, which makes it difficult to make life-cycle assessments and maintenance schedules. When the variety in equipment types and brands will be reduced, the product knowledge will increase, maintenance can be improved and better life-cycle assessments can be made, which will be great advantages for the customer on the long term. The listed advantages that can be achieved on this level for both the short and the long term are also listed in the work of M.T. Tedesco (1994) who did research on the standardisation of naval equipment and components.

INVESTMENTS

It should be taken into account that besides all the savings an investment is required to develop and maintain standardisation of components.

- Firstly, extra engineering hours are needed to develop a standard product approach. Engineering will be able to realize a template for a standard ship type in an average of 5000 extra engineering hours. Realizing the engineering package of a repeat of the same vessel will save 50-60% of the engineering time of an average ship build template which is equal to 1600 manhours (Damen Excellerate, 2016).
- Also a higher level of accurate documentation is required including the lead times, transportation routes, suppliers, installation time and maintenance of components.
- Another challenge is the documentation of differences in for example routes, production processes, currencies between the different yards and countries where production takes place.
- Furthermore, clear documentation is needed for the overlap of components between ship types of different product families
- Lastly, the procurement process will have to change, when platforming in implemented on a component level. Platforming can only be successful in reducing purchase cost when the purchase department agrees with a platforming approach and is willing to change its position in the procurement process, (Nieuwenhuis, 2013)

4.4. CONCLUSION

This chapter answers the second sub-question:
Which levels of standardisation provide good prospects for the production of tugs?
Three levels of standardisation have been defined in this chapter to answer this sub question.

Level 1. Main Assembly
The first and highest level of standardisation is on a main assembly level including the standardisation of the product portfolio and main assembly blocks of the vessel. Reducing variety between ship types and increasing the commonality between them will increase efficiency and reduce production time and cost.

4

Level 2. Sub Assembly
The second level of standardisation includes standardisation of outfitting. Outfitting activities are no longer performed during section or block assembly and during final outfitting but in the workshop. Hotworks, piping activities, the production of skids for equipment and floor frames will be pre-produced and tested in the workshop and assembled on board as a whole. These modular serve multiple component types and sizes and have similar interfaces and fit on board of multiple ship types. However, this requires a high level of detailed measuring and pre-engineering for the development of these units, but will significantly reduce production time and cost. On the long term these assembly units can cover the total range of system capacity on board of different ship types across multiple product groups.

Level 3. Components
The third and most detailed level of standardisation is on a component level. Damen is already concerned with this topic and is currently implementing this standardisation level through the Excellerate program. By reducing the variety of component types and making them interchangeable between different vessel types, purchase advantages can be gained and installation and maintenance time and cost can be reduced.

The three levels of standardisataion explained in this chapter will be implemented and analysed for the current building strategy of Damen Shipyards in the following chapters.

5

Mathematical Model

In the previous chapters a lot of information is gained concerning building strategies and variables. Chapter 3 explained the current building strategy, the building variables, the main cost items and throughput times. After that, Chapter 4 presented three levels of standardardisation which have the potential to improve the current production strategy applied at Damen. The first level covers the standardisation on a higher level including a reduction in the variation of the product portfolio and an increase in serial production of standard sections. At level 2 it is explained that production be optimised by moving outfitting activities from section, block and final outfitting to the workshop by producing standard assembly modules. The third level promotes a higher level of standardisation of components which can lead to purchasing advantages. Additionally, the question has raised whether it is beneficial to switch from a make-to-stock production strategy to a make-to-order strategy.

In order to prove that the implementation of these standardisation levels into the current production strategy and switching to an assembly-to-order strategy will provide Damen with shorter lead times, reduced cost and more flexibility a mathematical model is required. This model should be capable of:

- calculating the production cost, lead times and required manhours for the current production strategy applied at Damen,
- calculating the effect of implementing the three standardisation levels on production cost, lead times and manhours,
- calculating the initial stock required when switching to an assembly-to-order strategy in which propulsion sets and sections are held on stock,
- giving a financial indication of having propulsion sets and sections on stock compared to complete hulls.

This chapter describes a computerised mathematical model which consists out of two sub-models; the building strategy model and the production strategy model. The model descriptions presented in this chapter do not directly answer a sub-question; however this step is important in the process of calculating which level of standardisation will provide Damen with the most advantages.

The first section describes the building strategy model which is used to calculate the current and standardised lead time and cost for a single vessel. The results of these calculations are used in a second model which calculates the initial stock values of sections and propulsion sets on a portfolio scale for a yearly production of tug series. In the third section the calculation of the yearly stock cost when switching to an assembly-to-order production strategy are explained. The final section presents the validation and verification procedures of the mathematical model.

Figure 5.1 presents the setup of the calculation model which consists of two submodels and an excel calculation.

- The *building strategy model*, connects the production strategy variables and cost explained in Chapter 3 to calculate the total lead time, cost and required manhours for the current production of a single vessel. This is done in seven steps which will be explained in the next section. When this is done, the standardisation levels from the previous chapter can be implemented into the same model to calculate the lead time, cost and required manhours for the standardised building strategy.

- The output of the first model is used as input for the *production strategy model* which calculates the initial stock values for sections and propulsion sets for the yearly production of a complete product portfolio. This is done in five steps which will be discussed later in this chapter.

- The output of the first model is also used for the *stock value calculation* of the current production strategy and the stock cost for an assemble-to-order strategy where sections and propulsion sets are kept on stock.

The results of this calculation model include the total lead times, cost and required manhours for a single vessel built with the current and standardised building strategy, the yearly stock cost of the having hulls on stock for the current production strategy, the yearly stock cost of having sections and propulsion sets on stock for an assembly-to-order production strategy and the initial stock values of sections and propulsion sets for a yearly production of tugs.

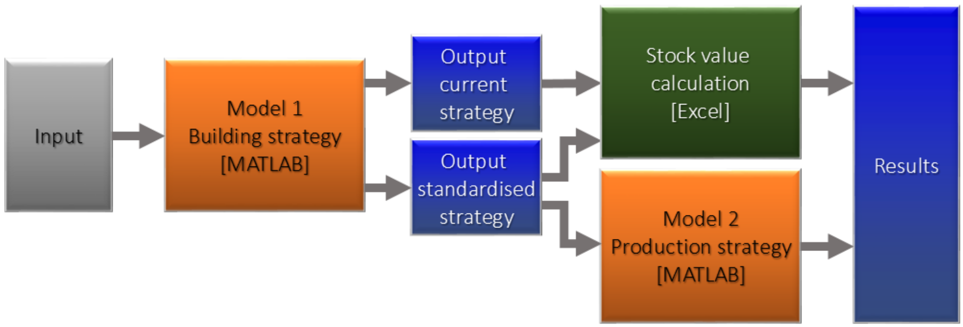

Figure 5.1: Model Setup

5.1. BUILDING STRATEGY MODEL

It is good to know how the cost of producing of a vessel are built up when looking at the total production cost. This can be done with a cash flow pattern. A cash flow pattern is strongly related to the sequence of production variables and therefore a scheduling model is required. This model links the variables and places them in the right order. The different variables and order of activities to make this model have been explained in Chapter 3. Required manhours and cost have to be linked to activities and the timing of cost should also be taken into account. Cost can take place instantly or linearly through the duration of an activity. Also, activity durations and the amount of work done parallel should be combined to derive correct throughput times. To implement the different standardisation levels, the number of variables, relation between them and the cost should be easy to change. In order to reinforce these actions a mathematical model is required.

In previous research T.J. Hoekstra (2014) has developed a mathematical model in the software package MATLAB to calculate the lead time and cost of a single vessel produced at different shipyards for various building strategies. In his research the mathematical model optimised the building strategy for each yard. His model has been used in this research as a base for the building strategy model to calculate the lead times and cost of a single vessel. However, in this research the the building strategy is fixed and not optimised. The model is used to calculate the total lead times, cost and required manhours for two strategies; the current building strategy and the standardised building strategy. The building strategy is based on the production of an ASD2810 produced at the Damen Galati shipyard (DSGa). In this section the principles of this mathematical model and the adjustments made to it to fit this research will be explained.

Within the building strategy model changes can easily be made in the section arrangements, in the amount of and relations between variables and it is easy to adjust external parameters in order to run different building strategies. These adjustments can easily be made because the model has been created in MATLAB. The advantage of using MATLAB over for example excel is that calculations are not distorted when variables or the order of activities are changed. These changes can for example be made in Tables C.1 to C.10, Appendix C. The input parameters, the seven calculation steps of the building strategy model (shown in Figure 5.1) and the required output from this model will be explained next in detail.

INPUT BUILDING STRATEGY MODEL

The input for the first model consists of the production variables and their relations. Several input data for the base case provided by T.J. Hoekstra (2014), have been slightly adjusted to get the results for the current production strategy (three years later). Firstly, the maximum amount of pre-outfitting performed on each phase has been adjusted with the help of an expert, (Interview 6, Appendix F). Secondly, it is assumed that all activities take place as early as possible. Next, the phase parameters are given. The ASD2810 consists of 13 sections, 6 blocks and 3 zones, which was the new proposed section arrangement from yard support in the research of T.J Hoekstra (2014). The production activities have

been divided into 25 activities which are listed in Table 3.1 and are left the same as in the original model.
Identical activities which take place in multiple phases have different throughput times due to the difference in efficiency of the work performed in the respective phases. The current required labour and durations for the activities on the Galati shipyard which serve as a benchmark are presented in Appendix C in Table C.7. These benchmark manhours and throughput times are normalised for further calculations in the model according to Equation 5.1, (Hoekstra, 2014).

$$Normalised\ manhours(activity) = \frac{\sum current\ hours(activity, phase)}{Phase\ efficiency} \tag{5.1}$$

The information flow to obtain the hours per activity per phase is illustrated below and will be explained in detail in the following calculations. Finally, financial data is required to calculate and plot the production cash flow and cost.

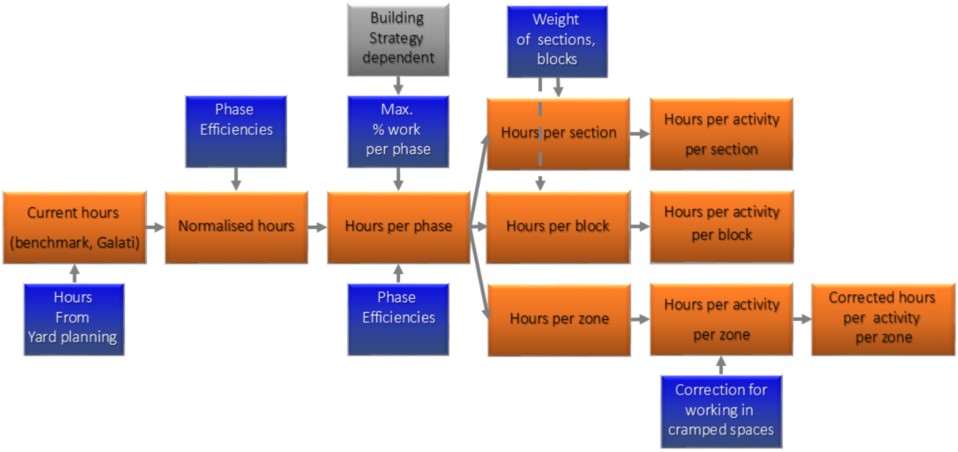

Figure 5.2: Flow of hour calculation

CALCULATIONS BUILDING STRATEGY MODEL

There are seven calculation steps in the building strategy model which are explained below. The calculation steps can be divided into three main parts. In the first part the throughput times of the phases, sections, blocks, zones and outfitting activities are determined. In the second part the correct order of the phases and activities is calculated and finally the cost are linked to the activities.
It should be taken into account that this model does not perform an optimisation for the building strategy and only calculates the total lead time, required manhours and cost for the production of a single vessel. The given input will be used directly to calculate the output and no further yard restrictions for delays, rework or lack of capacity are taken into account during the calculations. Also the activities are performed as early as possible.

1. Firstly, the distribution of the activities over the three phases (section, block and final) are determined. Then, activities are assigned to the individual sections, blocks and zones. This is done with the following equations. Equation 5.2 is applied to determine the throughput time of an activity, depending on the amount of work that will take place in the respective phase.

$$Phase\ hours(activity) = norm.\ hours * phase\ eff. * \%work(activity) \quad (5.2)$$

When labour is distributed among the phases, it will be further divided among the sections, blocks and zones. This is done according to weights, see Equation 5.3. Durations are not adjusted to weights and are equal to the durations from Equation 5.1 and 5.2. An example of how the durations and throughput times are calculated can be found in Appendix D.

$$Hours\ section(activity) = \frac{\sum Hours(activity) * Weight(section)}{\sum Weight(section)} \quad (5.3)$$

2. In the second step, the throughput times and required manhours per activity are calculated with the normalised hours and durations from the Galati yard data. The implementation of modular outfitting is performed manually because the duration of each activity within each section is changed individually, which is not done automatically within the model.

3. Next, the start time of all activities relative to the section, block or zone in which they are positioned are calculated. The sequence of the activities containing the relations between activities (Figure C.1, Appendix C) is required to fulfill this step.

4. Now that it is known which activities are performed simultaneously in the respective phases, the number of workers and the correction for working in cramped spaces can be calculated. During final outfitting many activities take place parallel in cramped areas which influence the productivity and duration. The increased throughput time and man-hours are calculated with Equation 5.3. The number of workers per area available at Galati are presented in Appendix C, Table C.10

$$Activity\ duration = measured\ duration * x^{-0.422} \quad (5.4)$$

5. The start times, durations and end times of the activities are used in this step to calculate the duration of the sections blocks and zones.

6. With the relations between all sections, blocks, and zones, their respective start times can be determined in the sixth step.

7. Once the schedule of all activities is known the cost can be linked to the production process to calculate the cash flow of the vessel. Any additional cash flows are assigned to the production phases. Pre-fabrication hours and fixed cost such as engineering and project management cost are made variable in the model in this research as they will change with the implementation of the standardisation levels.

Output Building Strategy Model

The output delivered by the first model include the total production cost, total required manhours, delivery time in weeks and the cash flow showing a weekly overview of how cost are divided over time for a single vessel.

5.2. Production Strategy Model

Now that the lead time and cost are known, the calculation can be performed to find out whether is it beneficial to produce sections and have long lead items on stock and to switch to an assembly-to-order production strategy as explained in Chapter 2. The reduced lead time calculated in the previous model is used as input for the lead time in the second model (see Figure 5.1) in which the required stock for long lead items and sections is calculated for the yearly production of tugs.

This model takes the yearly production of the complete range of tugs into account. Collecting data and calculating the lead times and cost for each individual ship type in the portfolio takes too much time and a large amount of this data is not available. To still model this with the available data and within the set time a simplification step is done. The production data of a single vessel provided by the building strategy model is used to model the production of the complete product range. This means that the ASD2810 epresents all tug types produced in 2015. Even though the duration and cost for each phase, section, activity and item are the same, the ship types, sections and long lead items are separated by type. Long lead items in this model only concern the propulsion train which are the main engines, thrusters and generator sets. For example a series production of five RSD2513 tugs is modeled as a series of five ASD2810's with the same lead time and cost but its ship type, section types and propulsion type are defined with specific type numbers. Through this simplification step it is possible to give an indication of the initial stock levels of the different sections and propulsion sets at the start of the year.

In short, this means that each vessel including all sections have the same total lead time, production cost and that the ship, section and propulsion types are specified by a type number in this model to calculate the required stock levels for a yearly production.

Input Production Strategy Model

The input data for the model which is derived from the building strategy model consists of several parameters.

- Firstly the vessel types which will be produced in the period of one year are represented by a ship type number and their bollard pull in tons.
- The different sections to be produced on stock are also determined by a type number.
- Another input variable is the initial stock value of each long lead item type and section type.
- Finally the delivery date of each vessel is given as input.

The ship types, bollard pulls, sections, delivery dates and initial stock values are sufficient to calculate the required stock of long lead items and sections for a yearly production.

CALCULATIONS PRODUCTION STRATEGY MODEL

The calculation for the production strategy model consists out of five steps which are explained below.

1. In the first step the propulsion set type is determined. The bollard pull of each vessel given in the input is used to determine the required propulsion set type. The bollard pulls have been divided into ten groups with a variance in bollard pull of ten tons within each group. Group one pulls between 0 and 10 ton, group two between 10 and 20 tons, etc. All vessels in the same Bollard Pull range have the same propulsion set. This has been done in consultation with the supply chain manager propulsion (Interview 29, Appendix F). The price for the propulsion set is assumed to be the same for each ship types (see Table C.8, Chapter C). Also in this step the ship types are linked to the section which they require to come from stock.

2. In the next step the different milestones for the production of the vessels are linked. This model contains the same milestones as described in Figure 2.10; the release date of the Unrestricted Action List (UAL), order and delivery moment of long lead items, start steel cutting and delivery ex-yard per vessel. All milestones are calculated with the results of the standardised production strategy model and with delivery times and payment terms of long lead items provided by procurement, (Interview 29, Appendix F).

3. After all the milestone dates have been linked, the number of vessels simultaneously in production is being tracked. This is a daily overview in which a vessel is added to the number of vessels in production at the start of steel cutting and removed after vessel delivery. The same is done for the payment of vessels. One week after delivery the payment of a vessel needs to be fulfilled. At this moment a vessel is added to the payment list.

4. The model also tracks the moment that sections and long lead items from stock are being assembled and installed which is done in this step. The deckhouses and sheelhouses are assembled and paid at the same time. The moment of payment of the Long Lead Items is defined with a payment period after delivery.

5. In the fifth step the daily levels of stock are determined for the sections and long lead items. This is done by adding stock at delivery and subtracting stock at assembly and installation. Also the moment that commitment to the payment of the propulsion set is done (which is at the release date of the UAL) is recorded.

OUTPUT PRODUCTION STRATEGY MODEL

The output of the model gives a daily overview of the vessels in production, the stock levels of the propulsion sets and sections and the financial commitment per propulsion set type and section type. The results provide an overview of the initial stock, intermediate stock levels and whether the initial stock is large enough to cover the yearly production.

5.3. STOCK VALUE CALCULATION

During the literature study the question arose whether it would be beneficial for Damen to produce standard sections on stock which are assembled after an order is placed instead of producing completely outfitted hulss on stock. This section will present the calculation of the stock values for producing sections and hulls on stock.

Several assumptions have been made to express and compare the cost of having vessels and sections on stock. Firstly it is assumed that there is a constant stock of one vessel per ship type. This means that when a certain vessel is sold, a new vessel is added to stock, keeping the stock constant to one vessel. The same is done for the sections of the standardised portfolio, a constant stock of one per section type is present at all times. Secondly, the following Equation 5.5 is applied to calculate the mean yearly stock value assigned to a respective vessel. This equation is also applied to calculate the stock value of sections. The results of this calculation give an indication of the financial benefit which could be gained by having sections on stock.

$$Stock\ Value = Vessel\ price\ (€) * \frac{1}{\#\ vessel\ type\ is\ sold\ in\ 1\ year} \tag{5.5}$$

5.4. VERIFICATION AND VALIDATION

The simulation model of this research has been validated and verified according to the verification and validation methods described by Robert G. Sargent (2013). In his article he describes model verification as "ensuring that the computer program of the computerised model and its implementation are correct." He describes the validation of a model as the "substantiation that a computerised model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model."

Figure 5.3 represents the different methods of validating and verifying a simulation, (Sargent, 2013). These methods include conceptual model validity, computerised model verification, operational validity, and data validity and will be discussed in this section.

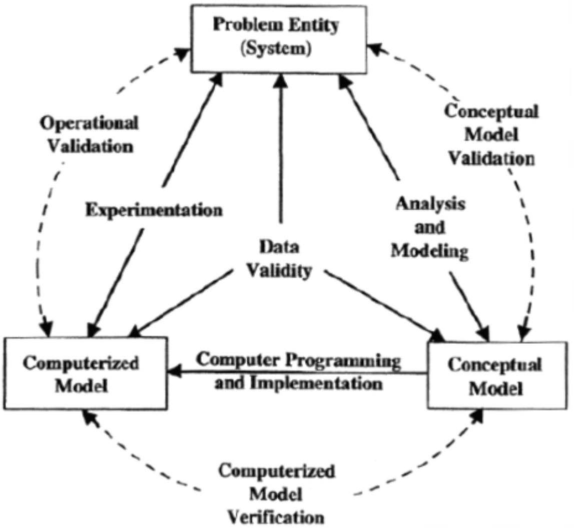

Figure 5.3: Verification and Validation Methods (Sargent, 2013)

DATA VALIDITY

The simulation model calculates the lead time and cash flow solely of Damen's ASD2810 tug. This is the best sold (standard) vessel of the Product Group Tugs which has high potential to benefit even more from the platform based design strategy. The ASD2810 has been built over 100 times, has a stable production and a lot of data on the production and cost of this vessel are available from previous research. Part of the data gathered for the thesis research of T.J. Hoekstra (2014) has been used for the model in this research. He also performed extensive validation on the collected data. As his research was performed two years prior to this research, the data was checked whether it was not outdated with the help of specialists from different departments. The yard support department was interviewed concerning the building strategy (Interview 5, 6, Appendix F). Planning, procurement and supply chain management on the milestone planning and delivery times and purchase cost of expensive equipment (Interview 16, 29, Appendix F).

Finally, sales and business analysis data and interviews were used for the past and future sales prospects of the Product Portfolio Tugs (Huethorst,2016, Visser, 2016, Interview 17, 18, 23, 24, Appendix F) .

The value stream maps and building strategies provided by T.J. Hoekstra (2014) were analysed and if needed adjusted to the current building strategy. The base case for this research, is the current production strategy of the ASD2810 which consists of 13 sections, 6 blocks and 3 zones produced without the use of any of the improvement initiatives mentioned in Chapter 2. Phase efficiencies were also checked with experts and were unchanged. The phase efficiency has also been taken into account in the sensitivity analysis which will be presented in Chapter 6.
Pre outfitting levels were defined with experts from the yard support department for the current and standardised production strategy (Interview 5, 6, Appendix F). The pre-outfitting levels for the standardised production strategy are based on intermediate results of ASD2913 pilot (Teuben, 2016) and expectations based on literature studies and results of other ship yards such as NASSCO (Atlic et al., 2003).

CONCEPTUAL MODEL VALIDATION

The conceptual model is the base of the computerised model in which the building strategy is theoretically analysed. The conceptual model contains the theories, assumptions and formulas which will be used in the computerised model. The activities, their durations cost and how they are connected to each other are determined in this model. The information gathered for the base of the conceptual model comes from T.J. Hoekstra's (2014) research as this forms the base for the mathematical model. Additionally, the building strategy has been adjusted to the current situation with knowledge from experts (Interview 5, 6, Appendix F) and literature such as (Hengst, 1999).
The information gathered for the standardised production strategy comes mainly from literature. The shifting of outfitting hours from the respective phases to the workshop come from (Rubesa et al, 2011, Fafandjel et al. 2008, Baade et al, 1998). Also the intermediate results of the ASD2913 pilot (Teuben, 2016) have been taken into account to improve the current production strategy. The influence of the series effect is taken from (Scorpecci, 2007, Yelle, 1979) and the Excellerate department (Damen Excellerate, 2016). Finally, in consultation with experts from Damen Shipyards Ir J.J.B. Teuben and Dr.ir. J.F.J. Pruyn the model was validated.

COMPUTERISED MODEL VERIFICATION

The computerised model contains the theory of the conceptual model and calculates the actual lead times and cost for the ASD2810 for the current and standardised production strategy. In this step the computerised model is verified on mathematical correctness. It is also checked if the activities are linked correctly and if the (intermediate) results correspond to what is expected of the model. The verification of the computerised model is done in two ways.

Firstly a simplified example is used to show the different calculation steps of the computerised model which can be checked manually. This process is performed in the same way as the verification performed by T.J. Hoekstra (2014), however with different parameters and five different scenarios, to make sure the model is still correct without faults. The simplified example runs with exactly the same code as the building strategy model described earlier in this chapter. The example represents a vessel which consists of two sections, two blocks and three zones. Two outfitting activities take place during the production process; activity 1 and activity 2. The input data for this example consists of the same items as in the building strategy model and is shown in the tables presented on the next page.

The scenarios which have been checked are listed in Table 5.1 below. The step-by-step explanation of the verification is presented in Appendix D.

Table 5.1: Explanation verification scenarios

Run	Item	Change
1	Explained in text	
2	Sequence	No more interdependency between activities 1 and 2
3	Start week section building Outfitting in section	Changed to week 2 Activity 1 can be outfitted during section phase
4	Steel duration section Steel duration block General cost block Workshop hours	Changed to 5 weeks Changed to 5 weeks Changed to 40,000 euros Panel, section + Block, Assembly changed to 500 hours
5	Section Block Zone data Max- pre-outfitting	Activity 1 can be performed during section 1 and section 2. Activity 2 can only be performed during section 1 Activity 1 can be performed in block 1 and block 2. Activity 2 can only be performed in block 2. Activity 1 can be performed in zone 1 and zone 2. Activity 2 can be performed in zone 2. 50% of activity 1 can be performed in the section phase, 60% of activity 1 can be performed in the block phase, 50% of activity 2 can be performed in the section phase, 75% of activity 2 can be performed in the block phase.

Secondly, each intermediate calculation step is checked manually to verify if the calculations and intermediate results correspond to what is expected of the model to calculate. In this step also different scenarios with altering input data and restrictions are checked to see if the model reacts as expected. This is shown in the example of the equations presented in Chapter 3 and the sensitivity analysis presented in Chapter 6. The manual and model results correspond, so the model is validated.

GENERAL INPUT (1)

Transport time	0	weeks
Steel speed	1	
Outfit speed	1	
Manhour cost	I 10.00	
Work days/ week	5	
Double shifts	0	1 = yes, 0 = no

TPT CORRECTION TO # OF WORKERS (2)

Zone workers ER measure	10
Zone workers ACC measure	10
Zone workers hull measure	10
Zone workers ER build strat	10
Zone workers ACC build strat	10
Zone workers Hull build strat	10

GENERAL COSTS (3)

COSTS FOR STEEL	Costs	Distribution	
Section	I 20,000.00	0	(1 = constant)
Block	I -	1	(0 = instant)
Assembly	I 20,000.00	1	
GENERAL COSTS			
Start	I -	0	
Production	I -	1	
Trials	I 50,000.00	0	
INHOUSE OVERHEA	I -	1	
FIXED COSTS / WEE	I 1,000.00	1	

STRUCTURE AND WORKSHOP HOURS (4)

Prefabrication	1000
Panel	0
Section + Block	0
Assembly	0
Workshop hotworks	0
Workshop piping	0

SECTION DATA (5)

Section #	Section 1	Section 2
Assign to block (#)	1	2
Weight (tons)	10	10
Start (week)	10	10
TPT Steel (weeks)	10	10
Act 1 ?	1	0
Act 2 ?	1	0

BLOCK DATA (6)

Block #	1	2
Weight (tons)	10	10
TPT Steel (weeks)	10	10
Act 1 ?	1	0
Act 2 ?	1	0

ZONE DATA (7)

Zone #	Zone 1	Zone 2	Zone 3
Act 1 ?	1	0	0
Act 2 ?	1	0	0

ASSEMBLY CONSTRAINTS (8)

Block #	AS	MS
AS	0	0
MS	1	0

BLOCK – ZONE ASSIGNMENT (9)

	Block 1	Block 2
Zone 1 ER	1	1
Zone 2 ACC	1	1

ACTIVITY RELATIONS (10)

Activity :	Activity 1	Activity 2
Activity 1	0	0
Activity :	1	0

ACTIVITY DATA (11)

	Activity 1	**Activity 2**
Section hours	0	0
Block hours	0	0
Final hours	4000	4000
Eff sect (hours)	0.25	0.25
Eff block (hours)	0.5	0.5
Eff final (hours)	1	1
Sect tt	0	0
Block tt	0	0
Final tt	10	10
Max pre-outfit section	50%	100%
Max pre-outfit block	50%	100%
BS parameter Section	0	0
BS parameter Block	1	0
Material cost	I 100,000	I 100,000
Cost Dist	0	0
Single act?	0	0
Cost Timing (+weeks)	0	0
Transport DSGO?	0	0

Also the second model, the production strategy model has been simplified to manually check is the calculations have been performed correctly. The input data consists of general input data which include milestone dates which are kept constant. Variable input data include the production and delivery times and the assembly and installation moments of the sections and long lead items. These variables have been altered to see the effect and check the working of the model. The input data are presented in the tables below and the different scenarios are presented in Appendix D. No, discrepancies were found in the results of this validation step.

Durations INPUT	Days #
Delivery DH	1
Delivery WH	2
Delivery LLI	5
Payment time LLI	Del LLI + 3

Install moment INPUT	Days #
Assmble DH & WH	1
Install LLI	3

General INPUT	Day #
Release UAL	St St Cut - 1
Start steel Cutting	0
Delivery ex. Yard	5
Pay vessel	Del. ExYard + 1

Vessel INPUT

BP	Shiptype	Delivery ExYard
38.7	5	7/1/15
20	1	9/1/15
64	2	10/1/15
5	4	12/1/15
60	6	15/1/15
60	6	16/1/15
64	2	20/1/15
64	2	21/1/15
20	1	22/1/15
70	3	25/1/15

OPERATIONAL VALIDITY

The results of the computerised model are validated in this final step. The results of running the computerised model for the current production strategy can be checked with historical data. The data for the results of the building strategy model are presented in Table 5.2 illustrated below. The data for the production strategy and excel calculation are based on these results and do not need further validity.

Table 5.2: Historical data validity

	Total manhours	**Total cost**	**Delivery (wks)**
Results Model compared to data Galati	2.8%	-0.4%	-1.2%

It can be seen that results are similar which is expected because the input data and production strategy calculations are based on the production of an ASD2810 produced in Galati. Minor differences come from the normalisation of manhours and throughput times and the correction formula for working in narrow spaces 5.4 which was taken from literature.

The operational results for the standardised production strategy is more challenging because this is a production strategy not yet performed at Damen Shipyards. However the intermediate results of the modular outfitting pilot on the ASD2913, (Teuben, 2016) provide a good reference point or trend of the improvements which will follow from improving standardisation.

5.5. Conclusion

In this chapter the conceptual model has been turned into a computerised mathematical model which simulates the production process for a single vessel and calculates the total lead times, cost and required labour. The variables of this model can be adjusted to implement the three standardisation levels to calculate their influence on the current production process, which will be done in the next chapter. Additionally, a second computerised model is developed to calculate the stock level of sections and propulsion sets for the yearly production of tugs.

The first model calculates the production cost, the lead time, required manhours and cash flow. The second model determines the stock levels required at the start of a yearly production of tugs. The models have been validated and verified according to the methods presented by Robert G. Sargent (Sargent, 2013).

The description of these models in this chapter does not directly answer a sub-question. However, the results gained by running different scenarios will contribute to answering the main research question. This is done in the next chapter.

6 Results

In this chapter all the information gained combined with the results of the models explained in the previous chapters will be used to answer the final two sub-questions of this research:

How do the different levels of standardisation influence:
- the production cost,
- the production time
- and the variety of the product portfolio?

How is the Damen production strategy influenced on cost and lead time when implementing different levels of standardisation?

In Chapter 3 the different variables determining the total lead time and cost of the production for the ASD2810 have been explained. This knowledge serves as the theoretical base for the development of the computerised models discussed in Chapter 5. The results of running these models are used to answer the above sub-questions. This chapter explains how the three standardisation levels are implemented into the mathematical models and how production variables are affected by this implementation. Additionally, the impact of implementing the standardisation levels on the total production time, cost and required labour will be explained in this chapter.

The chapter starts by presenting the results of the current building strategy, followed by a step-by-step implementation of the three standardisation levels with intermediate results on the total production cost, lead time and manhours. The implementation of the standardisation levels is divided into three parts; its influence on the relation between activities, on the duration of activities and the impact on the activity cost. Once the results for the current and standardised production strategy are known additional improvements for the building strategy are proposed. The next section shows a sensitivity analysis showing the impact of the main parameters on the operational results of the model. Finally, with the results from the production strategies the shift in manufacturing strategy from make-to-stock to assemble-to-order for the yearly production of tugs is presented.

6.1. RESULTS CURRENT BUILDING STRATEGY

The hull of the ASD2810 is built up out of three zones, six blocks and thirteen sections which are assembled together according to the production strategy presented and explained in Chapter 3. This production strategy represents all vessels for the current product portfolio and is therefore assumed to be the same for all ship types.

The results of the current production strategy consist of the total lead time, production cost, required labour and weekly cash flow for the ASD2810.

The weekly cash flow plotted against the lead time of the current production strategy is illustrated in the following Figure 6.1. The blue dot in the cash flow represents the moment that the hull production is finished. If hulls are build to stock this is the moment where that the hull is ready to go to stock.

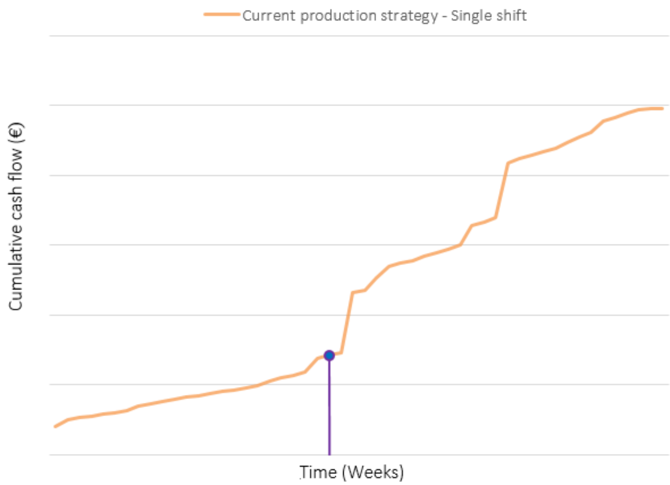

Figure 6.1: Cash flow current building strategy

In the following sections the implementation and results are presented per standardisation level, starting with level 3 components, followed by level 2 sub assemblies and level 1 main assembly. The results of the current production strategy will be used as a reference point in the following sections, presented in the colour orange.

6.2. LEVEL 3. COMPONENTS

As explained in Chapter 4, Damen shipyards is already concerned about the advantages that can be derived from implementing standard components and systems which are interchangeable between multiple ship types. This has already to a large extent been investigated and mapped out through the Damen Excellerate program and has recently proved to be successful on the FCS2610.

6.2.1. IMPLEMENTATION

Within the Product Group Tugs, Excellerate is developing pilots for the ASD2810, ASD3212 and the ASD2913 to create a Standard Product Templates. Within these templates, material, equipment and other components are aimed to be standardised within and between different ship types. The factors which are affected by the implementation of modularity components are discussed in this section.

ACTIVITIES

The implementation of standard components will not directly effect the order or timing of building activities. However they will have a noticeable impact on life-cycle management and after sales, as explained in Chapter 4. If the variety in component types is reduced the knowledge about the products is increased leading to better life cycle assessments and improved maintenance plans which results in better service to the customer.

HOURS AND DURATION

The throughput times and durations of activities will not directly be affected by standardisation on a component level. On the other hand, a higher the level of standardised components will indirectly lead to less complications and reduced variety in the matching skids. This means that less engineering and construction hours are required to produce skids and frames in the workshop. To achieve this reduction in throughput time, one time extra engineering hours are needed to develop a standard product approach, which is approximately 5000 extra hours, explained in Chapter 2. When realising the engineering package of a repeat of the same vessel, this will save 50-60% of the engineering time of an average ship build template, (Damen Excellerate, 2016). This has been taken into account in the in-house overhead cost calculation and is presented in the last column of Table 6.1. The added engineering hours are included in the results of level 2 in the next Section 6.3.

COST

According to Excellerate a purchasing advantage of 7.5% can be achieved for equipment and materials for outfitting activities by standardising components. The material cost for the current and standardised situation of all outfitting activities presented in Chapter 3 are listed in Appendix C, Table C.8 (Damen Excellerate, 2016a).
Additional cost reductions can be achieved in in-house overhead cost; procurement cost and material coordination cost can both be reduced. Also a reduction in cost for general items including transport cost of material and small parts can be achieved according to Excellerate (2016a). These cost reductions are presented below in Table 6.1.

Table 6.1: Cost reductions through Excellerate

Cost item	**Reduction**
Material cost	7.5%
In-house overhead	
Procurement cost	20.0%
Material coordination	20.0%
General items	
Transport cost	5.0%
Small parts	7.5%
Engineering hours*	+ 5000 development hours, then -50.0% for repeat

6.2.2. RESULTS

When implementing the standardisation of components into the current production strategy a reduction solely in cost is visible due to the purchase advantage of standardised materials and components and a reduction in in-house and general cost. The results are illustrated in the bar charts in Figure 6.2. A great drop in cost of 5% can be seen in the second bar chart.

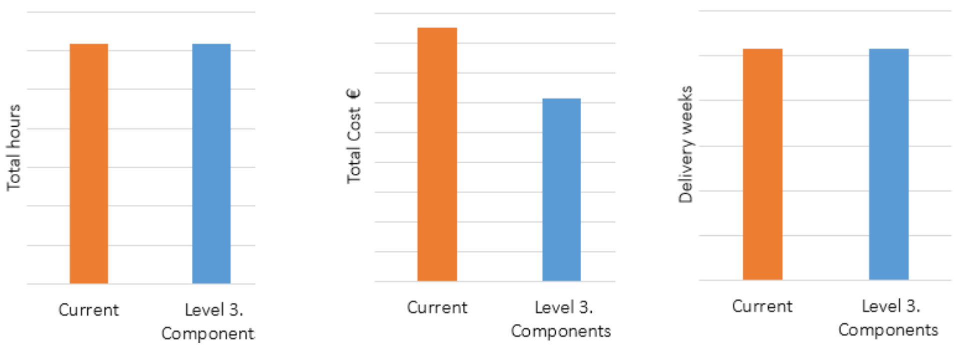

Figure 6.2: Results of implementing standardisation level 3 Components

6.3. LEVEL 2. SUB ASSEMBLY

This level of standardisation is based on the implementation of standard skids and frames produced in the workshop, which can be placed on multiple ship types and can be used for different categories of equipment. As explained in Chapter 4 some activities are (partly) moved to the workshop where those skids and frames will be produced during early stages of production. This section explains which activities are affected by modular outfitting, how it affects durations and cost and what the effect is on the total production time, cost and hours.

6.3.1. IMPLEMENTATION

By combining the observations made at the Damen Shipyards Gorinchem and methods presented in literature in Chapter 2, an estimation is made of which activities will be moved to the workshop, what the shift of manhours is and what the efficiency improvement will be of shifting those hours.

ACTIVITIES

Activities which include hotworks, piping or installation of equipment can partly be performed in the workshop. Piping installations, equipment and systems are examples of items which can be placed or produced in a pre-fabricated skid or frame. When this is done, the only work to be performed on board during the respective phases is the assembly of the pre-produced skids and frames. Of the 25 outfitting activities presented in Table 3.1, Chapter 3 nine activities have the potential to be partly performed in the workshop which are listed below;

- Hot works ER
- Hot works ACC + WH
- Piping ER
- Piping ACC + WH
- Pull cables ACC + WH
- Install floor ACC + WH
- Install and connect small EQ ACC + WH
- Install small EQ ER
- Pull cables ER

The nine activities listed above which are currently performed in one or multiple of the three production phases (section, block and/or zone) are partly moved to the workshop, partly moved to earlier phases and partly left in the phase they originally were performed. The rearrangement of work in relation to the original amount of work performed per phase is based on the research of Fafandjel et al (2008) and is presented in Table 6.2.

As a result of moving work to the workshop and earlier phases other activities can be performed faster. These activities and improvements are analysed with experts and are listed in Table 6.4 and will be explained in the next section. An overview of which activities move from the respective phases to the workshop, which activities will be performed more efficiently and which activities remain unchanged is presented in Figure 6.3.

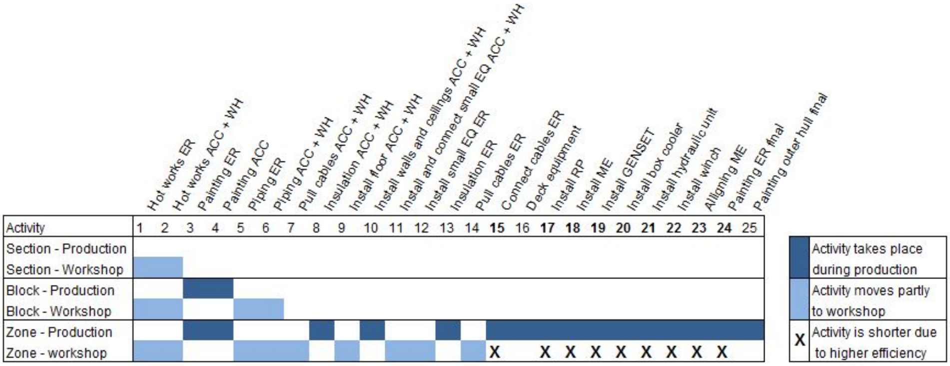

Figure 6.3: Activities moving to workshop

HOURS AND DURATION

This section presents the percentages of the hours which are shifted from the nine previously listed activities to the workshop and to earlier phases. Table 6.2 shows per phase what percentage of the work will remain in the respective, shown in the first column, move to block or section phase in the second and third column and what percentage will move to the workshop in the last column. For example, the nine outfitting activities which currently take place in the zone phase will remain in this phase for 25% of the hours, 50% of the hours will move to the block phase and 25% of the hours will move to the workshop.

Table 6.2: Percentages of activities moving between phases and to workshop

	Stays in current phase	Moves to block phase	Moves to section phase	Moves to workshop
Zone	25%	50%	-	25%
Block	50%	-	25%	25%
Section	50%	-	-	50%

As explained in Chapter 4 the work which is moved to the workshop will be performed in better working conditions resulting in higher working efficiencies and therefore less working hours. These efficiencies are stated to be as high as 80% for work which was shifted from the zone phase to the workshop as can be seen in Table 4.1. Nevertheless, these efficiencies seem very optimistic according to experts at Damen Shipyards 6, Appendix F), therefore three scenarios have been selected for those efficiencies which are shown in Table 6.3. The first scenario represents the efficiencies in an early stage of implementing modular outfitting and the third scenario represents the situation where modular outfitting has been fully developed.

Six activities have been determined which can be performed faster due to the implementation of modular outfitting with the insights of experts Ir. B. Damman and Ir J.J.B. Teuben 5, 6, Appendix F) from the Yard Suport department , see Table 6.4 . The percent-

Table 6.3: Scenarios for efficiency of activities moving to workshop

	Scenarios workshop hours efficiency		
	1	2	3
Section/Block hours to WS	25%	45%	65%
Zone hours to WS	35%	55%	75%

ages with which those activities can be optimised are shown in Table 6.4. The presented changes in duration and position of activities are applied in the computerised model for each activity.

Table 6.4: Activities with higher efficiencies as a result of modular outfitting

Activity	Efficiency
15. connect cables ER	10%
18. Install ME	50%
19. Install GENSET	50%
20. Install box cooler	20%
21. Install hydraulic unit	50%
24. painting ER final	25%

COST

The changes on the sub-assembly level of the current production strategy mainly include reductions in the lead time and required man hours rather than cost, because the cost for man hours are relatively small compared to the material and equipment cost. However, there is one general items on which 10% can be saved due to the implementation of skids and frames which is outsourced engineering. This is a result of in-house engineering of standard skids and frames for equipment and systems.

6.3.2. RESULTS

Modular outfitting has been implemented in steps to show its influence on cost and lead time. The variables affected by the different improvements have been explained above. A summary of the steps is given in Table 6.5 and will be explained in more detail later in this section. The total production cost, total manhours and delivery time in weeks after implementing each step, relative to the current production time, cost and delivery weeks (in orange) are illustrated in the bar charts in Figure 6.6. The savings achieved on level three have already been implemented in the following steps.

STEP 1 - CURRENT PRODUCTION STRATEGY

The first step presents the results for the current strategy which is the base or reference point for the results of each standardisation step and is presented in orange.

Table 6.5: Improvement steps current production strategy

Step	Description	Scenario
1	Current strategy	current
2	New strategy with rearranged pre outfit	current
3	New strategy with rearranged hours	0
4		1
5		2
6		3
7	New strategy with reduced steel throughput times	2

STEP 2 - MAXIMUM PRE-OUTFITTING

The second step represents a first step towards the standardised building strategy. The amount of pre-outfitting to be completed per activity in each production phase (section, block and zone) has been changed according to Table C.11 in Appendix C. The division of pre-outfitting has been determined in cooperation with experts (Interview 6, Appendix F). It can be seen that this step has an significant impact on the total production cost, hours and time. This can be explained by the fact that the model does not take yard restriction into account and performs all activities on time without any delays. This means that if an activity is performed for 50% during the section phase, it will be performed in that way even though there would not be sufficient space or workers available to do so. Also it should be noticed that the computerised model does not optimise the building strategy but that it is based on experience and knowledge of experts out of the field.

STEP 3 TO 6 - MODULAR OUTFITTING

In the third step the hours are shifted between and from the respective phases to the workshop due to the implementation of modular outfitting. As explained above, three scenarios were defined for the efficiency of working hours which are moved from the respective phases to the workshop. The three scenarios represent an efficiency of 25%, 45% and 65% for the work moved from sections and blocks to the workshop and 35%, 55% and 75% for the hours moved from the zones to the workshop. The third step shows the effect of the rearrangement of hours without efficiencies, therefore scenario 0. The fourth, fifth and sixth steps represent the those three scenarios with efficiencies. The current and new amount of hours per activity per phase are presented in Appendix C Tables C.12, C.13, C.14, C.15. It can be seen that the mainly the total cost and hours are affected by shifting hours from the respective phases to the workshop and that the delivery time is not affected that much. In the following steps, scenario 2 is taken as an input for the outfitting hours.

STEP 7 - STEEL THROUGHPUT TIME

The next step shows the result of implementing a reduction in the throughput time of steelwork for the sections and engine room block due to higher efficiencies. A reduction of 20% can be achieved in the throughput time of the steel construction work according to expert Ir. B. Damman (2016). The new throughput times are presented in Appendix C Tables C.16 and C.17. The throughput time of sections is determined by the outfitting activities performed in that phase and the steel construction work. The steel construction work takes more time to complete than the outfitting activities and therefore determines the total throughput time of the section phase. For that reason it can be seen that this mainly affects the delivery time and not the cost and hours.

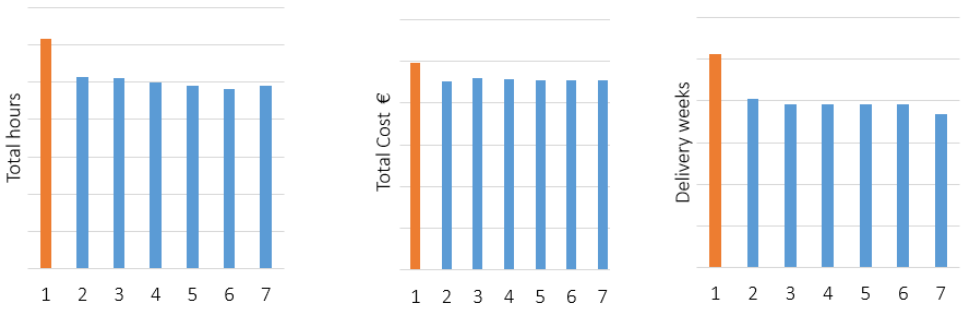

Figure 6.4: Total hours, cost and delivery time after implementing standardisation on level 2

6.4. LEVEL 1. MAIN ASSEMBLY

As explained in Chapter 4, the product portfolio configuration has been assessed and re-arranged on a main assembly level reducing product variety and increasing batch sizes of vessel production and modular section production. This level of standardisation will therefore mainly influence the variables of the second mathematical model in which the stock levels of standard sections and propulsion sets for a yearly production are calculated.

6.4.1. IMPLEMENTATION

The amount, timing and duration of sections being produced on stock in the production strategy model are affected in this section.

ACTIVITIES

Activities involved in section production are being shifted forwards to a separate production line which runs parallel with the main production line. This production line produces standard sections such as the wheelhouse, deckhouse and afts to stock. Main assembly activities such as the steel construction of the sections will be performed faster with serial production. The sections with the highest potential to be produced on stock according to predictions and the product portfolio analysis are presented in Chapter 4.

6

HOURS AND DURATION

With the reduced variety and increased batch sizes, Damen can benefit from a serial production line and the series effect. The throughput times of activities will be shortened as explained in Chapter 2. Formula 6.1 for the series effect will be applied in the duration calculations of the production of these sections and blocks.

$$Required\ work\ to\ be\ done = -0.1483 Ln(x) + 0.9995 \tag{6.1}$$

COST

Serial production influences cost in two ways. Firstly, it has influence on the fixed cost of producing a vessel type multiple times. Additionally, it influences the variable cost of producing sections in series.
Currently, ship types are being built on multiple shipyards. The ASD2810 for example is being produced at four different yards. Additionally, each yard produces different ship types throughout the year. With this manufacturing strategy little to no advantage will be taken from a serial production line. However, Damen Shipyards has the intention for the coming years to produce individual ship types on a maximum of two different shipyards. With this taken into account, it is assumed that a maximum of 75% of the series size can be produced in series at the same yard and that 25% of the series size of a certain ship type will be build at a different yard. When serial production can take place, meaning that a continuous production of a vessel type or section is taking place, a series effect will arise reducing production time and cost. However, it is challenging to take the series effect into account because it is difficult to choose a series size over a certain period of time as production is expected to continue over the years without interruption. To take some profit into account for this research a series size of two for complete vessels and

two for each section will be taken into account to calculate the production cost and lead times for the standardised production strategy. Other series sizes will be presented to show the effect of the series size but will not be used for further calculations.

Several in-house overhead cost items including shipyard overhead cost, project management cost and engineering cost will be reduced due to serial production. Their cost are adjusted according the the Equation 6.1. The amount of money saved depends on the series size of the produced vessels and sections. It should be taken into account that this equation represents the saved amount of work for the overall production of a vessel.

The variable production cost for producing sections on stock will decrease in two ways. Firstly, by increasing the badge size of the buying standard components at a limited number of different suppliers. Secondly, by standardising outfitting which will reduce engineering, production and outfitting cost. However, warehouse cost will most likely increase because the produced sections will be stored on land rather than in the water which induces higher cost for buying or renting extra land. However, there are many uncertainties to determine these cost because the rent of land differs per country and the duration of storage will also completely depend on the demand. Also it cannot be assured that storage space will be taken from production space or that new land should be rented or bought to store semi-finished products on. Due to the high level of uncertainty of the warehouse cost of sections and blocks it is decided to keep warehouse cost unchanged.

6.4.2. RESULTS

The implementation of level 1 standardisation is done step-by-step as shown in Table 6.6 below the table, each step is explained and the results are presented in Figure 6.5.

Table 6.6: Implementation steps level 1 Main assembly

Step	Description	Scenario	Series size vessel	Series size sections
1	Current strategy	current	-	
2	New strategy with series effect fixed and variable cost	2	2	1 every section
3		2	9	1 every section
4		2	3	9 aft
5		2	3	9 mid
6		2	3	9 bow
7		2	3	12 fendering
8		2	3	12 deckhouse
9		2	3	23 wheelhouse
10		2	2	2 every section
11		2	3	average

STEPS 1 TO 11 - SERIES EFFECT

The first step again shows the current production hours, cost and time. In the next step, the effect of serial production is implemented into the mathematical model. As explained above, serial production and the series effect will affect fixed cost and variables cost. Step 2 runs the smallest series production for a vessel type which is two and a series size of one for each section to show the impact on the fixed cost. In step 3 the largest series production for a vessel type is presented which is nine. Again the series size for sections is left to one to show the impact on the fixed cost. In steps 4 to 9 the average series size of a vessel type is taken, which is three, to keep the effect on the fixed cost constant. Steps 4 to 9 represent the maximum series size for each section, which is nine for the afts, midships and bows, twelve for the fendering and accommodation and 23 for the wheelhouse. Step 10 shows the impact of producing the minimal of series for vessels and sections which is two for all of them. The final step illustrates the average production of vessels which is three and the average series of the sections which is four for most sections except for the accommodation it is eight and for the wheelhouse it is thirteen. The results of each step can be found in figure 6.5 below.

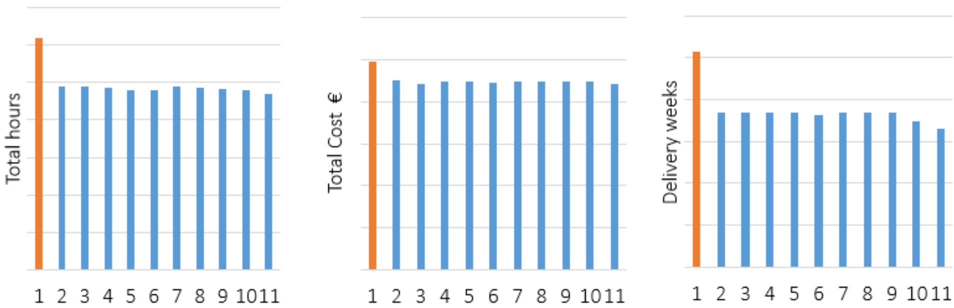

Figure 6.5: Total hours, cost and delivery time after implementing standardisation on level 1

In step 3 the impact on the fixed cost by increasing the series size for the production of complete vessels is with a reduction of 1.5% the largest of all steps. Furthermore, the different steps show a small impact on the delivery time of the vessel and cause a slight decrease of the total cost and hours. The last step, which is an ideal case shows a decrease in cost, and especially in hours and delivery weeks.

A closer look is taken at the results of step 10. In this step scenario 2 for the rearranged manhours is taken into account, a purchase advantage of 7.5% on material cost, 20% reduction in steel construction work and a minimum series size of two for vessel-production and two for section production are taken into account. The situation created in this step is taken as the standardised production strategy. The standardised production cash flow and current cash flow have been plotted together in Figure 6.6. The moment that the production of sections is completed for stock is presented with a dot and a dotted vertical line in blue for the standardised strategy and in orange for the current strategy. Sections in the standardised strategy will contain a lot more outfitting that in the current strategy because the amount of pre-outfitting is significantly higher due to the implementated standardisation levels. The moment that the hull is completed for stock is illustrated with a blue and orange undisturbed line for the standardised and current strategy. More detailed results concerning cost items and hours are presented in Figure 6.7 and Table 6.7.

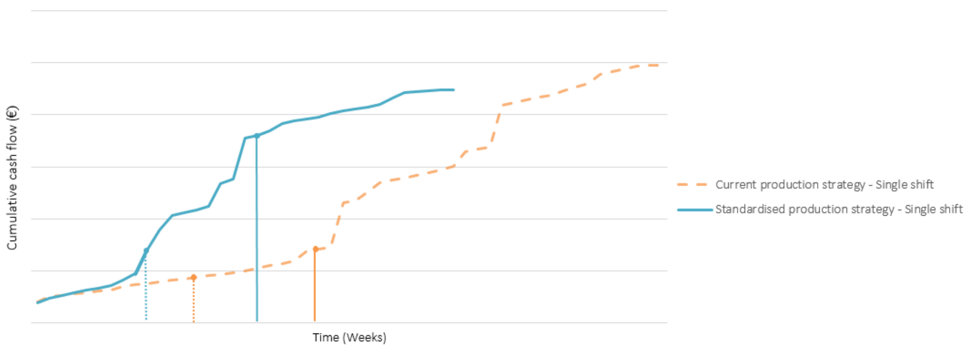

Figure 6.6: Total cost, manhours and delivery in weeks after implementing standardisation steps

It can be seen that the implementation of the different standardisation levels has effect on several cost items such as "general cost" which is reduced by 8%, an 8% reduction on procurement, and a 50% reduction in manhours in production. Workshop hours are increased due to the shift of manhours. The shift of manhours from final outfitting and the block phase lead to an increase in work performed during section and block production. On the other hand this also leads to a reduction of work performed during final outfitting, which is currently the least efficient phase in which work is performed, and therefore a great improvement. The total reduction in manhours that can be achieved is 40%.

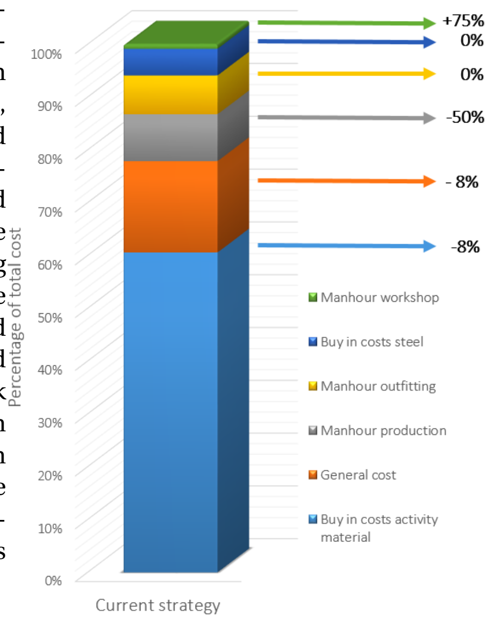

Figure 6.7: Cost division and results

Table 6.7: Difference in hours

Hour difference	Current strategy	Standardised strategy
HW WS	1400	3200
Pipe WS	1700	2200
section hours	1400	1700
block hours	4100	7000
zone hours	26600	7400
Total hours	35200	21500

6.5. MAINTAINING CUSTOMER SATISFACTION

The results of implementing the three levels of standardisation presented in the previous section are promising for Damen as a shipbuilding company. However, Damen is a customer driven company and without offering what the customer wants, there are no new orders and no profits. Therefore it is also important to evaluate how the customer will benefit from the implementation of those three standardisation levels.
In level 1 the main assembly of vessel production is adjusted, including the configuration of the product portfolio. Reducing the variation in the product portfolio will affect the customer. This section illustrates how a customer is affected when he requests a vessel which is no longer offered in the standardised portfolio and instead is forced to buy a larger vessel.
In this example the customer is interested in buying Ship type V or Ship type W, which are an ASd and an ATD vessel to guide large vessels in his port area. Both of these vessel types are popular and have been part of the top four sold vessels of the past three years. However, in the proposed standardised portfolio, both these vessel types are replaced by a new vessel type, Ship type X, which is an RSD vessel. This is a longer and wider vessel with a different propulsion configuration. ASD vessels have thrusters which can be rotated 360 degrees which serves for good maneuverability. ASD vessels sail backwards when they guide large vessels in port areas. When guiding large (container) vessels from the front it is important to have sufficient space and water between between the thrusters of the tug and the vessel.

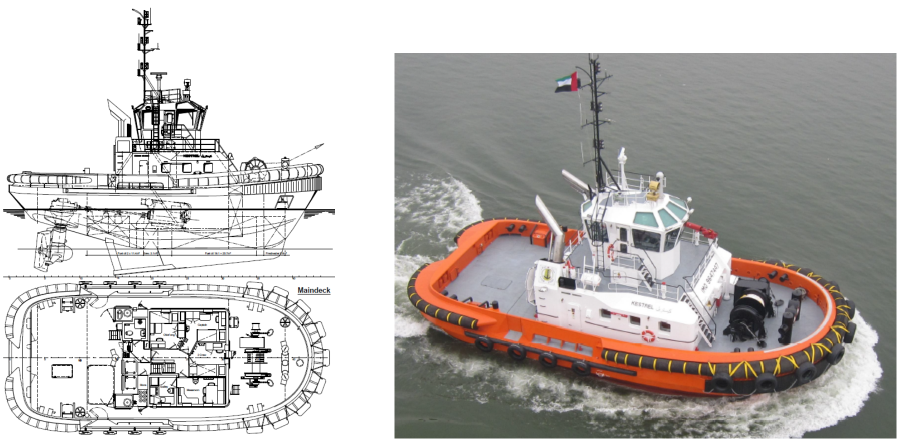

Figure 6.8: Ship type V

Vessels with an ATD propulsion system have two thrusters positioned at the front of the hull, this makes forward maneuvrability possible when guiding large vessels. ATD vessels can therefore only be used to guide large vessels from the front.

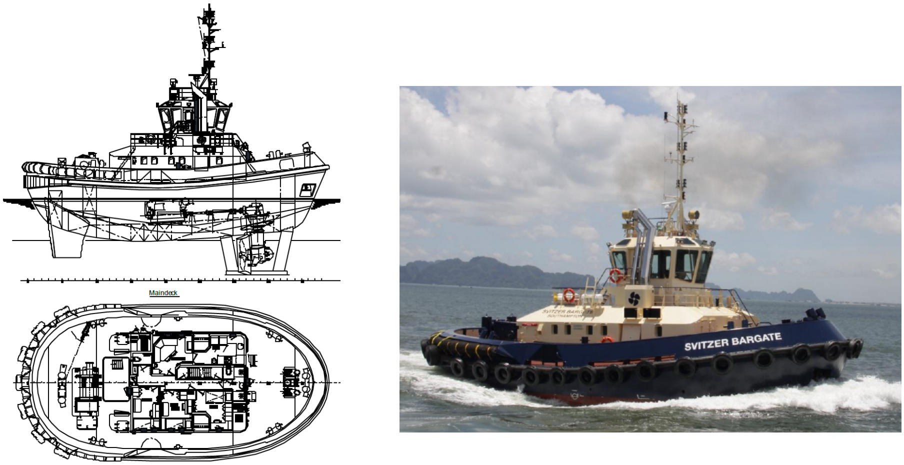

Figure 6.9: Ship type W

RSD vessels are designed to have two 'bows', making it possible to maneuver forwards at any time which created flexibility for use of these vessels.

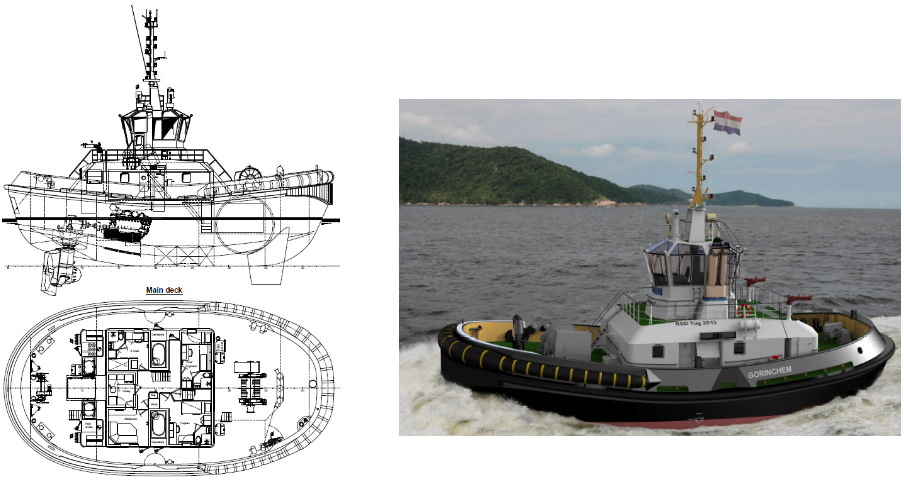

Figure 6.10: Ship type X

The baseline of august 2016 has been taken to determine the sales numbers per ship type for the coming year. By replacing these three vessel types by one, the series size will double compared to the largest current series size of the individual ship types. As explained in the above section for the implementation of level 1, it is assumed that 75% of the series is produced at the same yard. Taking this into account together with the implementation of the other standardisation levels the total hours, cost and lead times can be reduced as presented in Table 6.8.

The reductions for the lead times, cost and hours presented in 6.8 have been implemented on ship type X.

Table 6.8: Improvements for ship type X with standardised production

	Delivery (weeks)	Total Cost (mln EUR)	Total Hours
Standardisation reductions	47%	13%	30%

The results for Ship type X show that even though the number of hours will go up, the total cost and lead time reduce below the current values for vessel types V and W. Also, when looking at power and maneuverability, ship type X can be used in more situations compared to the other ship types.

6.6. ADDITIONAL IMPROVEMENTS

The total production time for the delivery of an ASD2810 can be reduced with 33% as a result of the implementation of the three standardisation levels. The aim of the yard support department is to reduce the production time to 50% of the current production time with the different optimisation projects as explained and illustrated in Chapter 2, Figure 2.10. This 50% can be achieved by working in two shifts rather than one as currently done at Galati. This change can of course also be implemented in the current situation.

The implementation of a second shift requires some investments. Night shift hours are more expensive than day shift hours, therefore the manhour cost is increased with 50%. This results in an increase of 25% on the average manhour cost. Additionally, some time is lost when transferring work to the next shift, it is assumed that this loss is equal to 20%. This percentage is probably a conservative assumption, because changing shifts will not take 20% of the shift, however this also covers reduced efficiencies for work in the second shift.

The results on the total cost, manhours, delivery time and cash flow are illustrated in Figures 6.11 and 6.12. The vertical solid lines represent the moment the hulls are ready for stock for the respective production strategies and the dotted vertical lines represent the moment sections are ready for stock for the respective production strategies. The total production time decreased to 44% of the current production time, which is even fastter then the aimed 50%. The total cost and required manhours increase compared to the standardised single shift building strategy. When comparing them to the current single shift building strategy, both values are lower. The total lead time of the two shift standardised building strategy is less than half compared to the lead time of the current single shift strategy with 7% less required labour and at 4% lower cost. Also, when zooming in on the moment that hulls and sections are ready for stock it can be seen that for the standardised production strategies the sections will be ready earlier than with the standardised single shift and current production strategy. The same is visible for the finish moment of the hull.

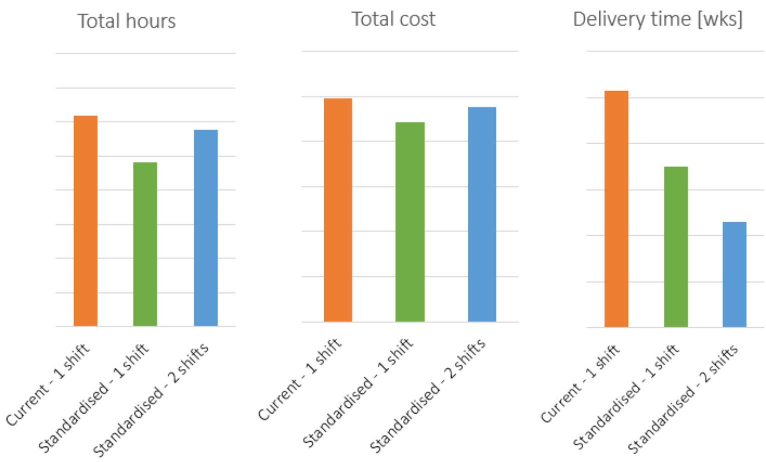

Figure 6.11: Result of doubling shift on total production cost, hours and delivery time

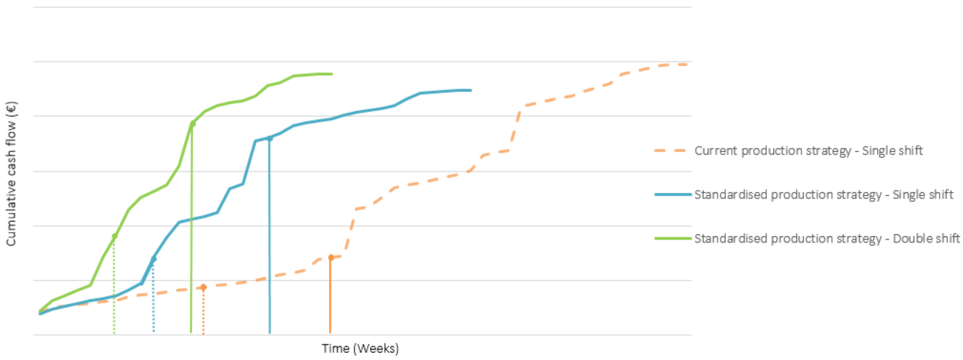

Figure 6.12: Cash flow of doubling shift

6.7. SENSITIVITY ANALYSIS

In this section the input parameters of the mathematical model are being varied in order to know how robust the answers are to various assumptions made throughout the modeling framework outlined in Chapter 5. Then, those assumptions are modified to gauge its effect on the total production time, cost and required labour.
Once again it should be taken into account that the model does not perform an optimisation of the input data. The given input will be used directly to calculate the output and no further yard restrictions for delays, rework or lack of capacity are taken into account during the calculations. Five variables have been tested in this analysis including manhour cost, the number of zone workers per phase, the phase efficiency, the prompt time of long lead items, the maximum percentage of work to be completed in the different phases.

MANHOURS COST

Changing the manhour cost will only influence the total cost, since the model does not perform an optimisation. However, to show the impact on the results, three values for the manhour cost have been selected.
Firstly, the average manhour cost in Galati. Secondly, the manhour cost at the Damen Changde yard which is 35% lower and thirdly, the salary paid at Damen Gorinchem which is 210% higher. The results of the two scenarios are illustrated in the barcharts of Figure 5.1 and graphs 6.14 and 6.15. Indeed only the total cost are affected for the lower and higher salary input values.

Figure 6.13: Results of sensitivity manhour cost

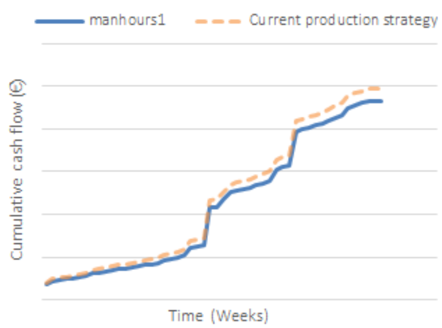

Figure 6.14: Results for manhour cost Galati

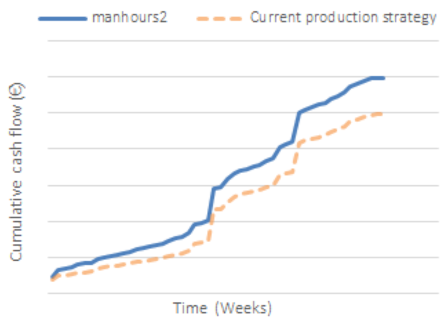

Figure 6.15: Results for manhour cost Gorinchem

For each analysed parameter that will follow in this analysis the total manhours, cost, delivery times and cash flows are plotted together with the current production strategy values in the same way as done for the manhour cost. These Figures can be found in Appendix E.

WORKERS PER AREA

In the current production strategy the number of workers that can work simultaneously in a certain area during final outfitting are set according to the data of Galati. The areas are divided into the Engine Room (ER), Accommodation (ACC) and Hull. The Galati numbers are the base numbers of workers which will be used to calculate the correction described in Chapter 3, Equation 5.4. Both the input number of workers and the base workers have been altered to see the sensitivity of the calculations. The different scenarios are presented in Table 6.9 and the results in the barcharts and graphs in Appendix E, Figures E.1,E.2 and E.3.

Table 6.9: Scenarios for the sensitivity of workers per area

Scenario	ER	ACC	hull	ER base	ACC base	hull base	Total hours	Total cost	Delivery time [wks]
1	0.4	0.5	0.6	1.0	1.0	1.0	0.85	0.98	1.17
current	1.0	1.0	1.0	1.0	1.0	1.0	1.00	1.00	1.00
2	2.1	2.2	2.4	1.0	1.0	1.0	1.24	1.04	0.89
3	0.4	0.5	0.6	0.4	0.5	0.6	1.23	1.05	1.25
4	2.1	2.2	2.4	2.1	2.2	2.4	0.84	0.97	0.86

Changing the number of workers per area mainly influences the total manhours and delivery times. The more base workers are available, the lower the total hours and delivery time. The total cost on the other hand stay stable, this is because either the manhours become more, or the number of workers to be paid becomes more.

PHASE EFFICIENCY

The phase efficiencies for the current production strategy are 0.25 for the section phase, 0.5 for the block phase and 1 for final assembly. In this step of the sensitivity analysis the efficiencies and the relations between them have been changed to find their influence on the results. The scenarios are given in Table 6.10 and the results in the barcharts in Figures E.6 and the graphs of Figures E.7 and E.8 in Appendix E .

Table 6.10: Scenarios for phase efficiency

Scenario	section	block	zone	Total hours	Total cost	Delivery time [wks]
1	0.125	0.25	1	1.08	1.02	1.12
current	0.25	0.5	1	1.00	1.00	1.00
2	0.33	0.66	1	0.99	1.00	1.01

The phase efficiency mainly influences the required manhours. This can be explained by the normalisation of the base hours, which depends on the phase efficiency. The cost and delivery times are only affected sightly.

PROMPT TIME PROPULSION SET

6

The prompt time for the long lead items belonging to the propulsion set is 9 weeks in the current production strategy. This is the moment that the cost for a long lead item is added to the cash flow. This is not necessarily the moment of payment but the moment that Damen commit themselves to do the payment. The long lead items included are; the main engine, the genset, cooler and the hydraulic unit. In the first scenario the prompt time is decreased with 5 weeks weeks and in the second scenario the prompt time in increased with 5 weeks. See Table 6.11 for the different input scenarios and Appendix E, Figures E.9, E.10 and E.11 for the results. It can be seen that none of the values are changed. Only the timing of cash flow has changed which can be seen in the appendix.

Table 6.11: Scenarios for prompttime propulsion set

Scenario	Main Engine	GENSET	Cooler	Hydraulic unit	Total hours	Total cost	Delivery time [wks]
1	0.44	0.44	0.44	4	1.00	1.00	1.00
current	1.00	1.00	1.00	9	1.00	1.00	1.00
2	1.56	1.56	1.56	14	1.00	1.00	1.00

MAXIMUM PERCENTAGE OF PRE-OUTFITTING

The maximum amount of pre-outfitting performed in the section and the block phase have been altered according to the scenarios presented in 6.12. The results can be found in Figures E.12, E.13 and E.14 of Appendix E.

Table 6.12: Scenarios for maximum pre-outfitting section and block phase

Scenario	**Current**	**1**	**2**
Phase	**section block**	**section block**	**section block**
Outfitting activities	Little standardisation is taking place in outfitting activities	Outfitting is in starting phase of implementing standardiasation levels	Optimial outfitting when implementing standardisation levels

Table 6.13: Results for scenarios for maximum pre-outfitting section and block phase

Scenario	**Total hours**	**Total cost**	**Delivery time [wks]**
1	1.08	1.02	1.18
current	1.00	1.00	1.00
2	0.90	0.98	0.93

The maximum amount of outfitting that can be performed during the respective phases has a significant effect on the total hours, total cost and the delivery time. The more work that can be completed during the earlier phases (section and block) the lower the total manhours and delivery time will be. It should be stressed specifically with these input values, that the model does not perform an optimisation of the input data and that the output is calculated by performing activities as early as possible without taking further yard restrictions for delays, rework or lack of capacity into account.

The impact on the total cost is less significant. Adjusting these parameters will greatly influence the results of the model.

Parameters which influence production cost are mostly the manhour cost, but also the amount of pre-outfitting performed at each phase. Parameters influencing the number of manhours and delivery time are the number of workers per area, phase efficiency and the amount of pre-outfitting work performed. The latter greatly influences the delivery time. Parameters which hardly affect the results are the production order of blocks and the weight of sections and blocks.

Care should be taken when changing the outfitting percentages per phase and the prompt-time of the propulsion set.

6.8. MANUFACTURING STRATEGIES

Now that the lead times and cost for the standardised production strategy have been calculated the effect of storing propulsion systems and producing standard sections on stock is determined. The yearly production of the product portfolio for the year 2015 has been modeled to gain this information. When changing the portfolio into the proposed standardised portfolio with the standardised building strategy with reduced production time and cost, the number of different vessel types will be reduced with 48%. As explained in Chapter 4, the wheelhouse and deckhouse have the most potential to be produced on stock. With the new product portfolio and standardised propulsion sets there will be a stock of nine different propulsion systems, four deckhouse variants and three types of wheelhouses. With the pre-production of wheelhouses and deckhouses the total lead time will be reduced according to their production and assembly time. The model calculates the size of the initial stock needed to fulfill all the production requirements on time. The initial stock level required for the propulsion systems is shown in Figure 6.16. The stock values range between 1 and 11. The highest initial stock value is 11 for propulsion set type 2.

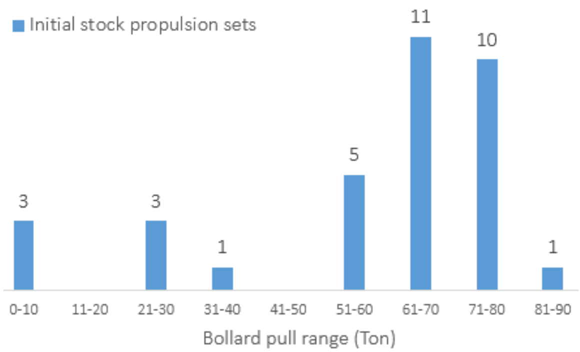

Figure 6.16: Initial stock for propulsion sets

When specific dekchouses and wheelhouses are ordered from stock at the release date of the UAL, the production for the replenishment of those sections starts. However, the production of those sections is completed before the sections have been removed from stock for assembly. This implies that for the production of wheelhouses and deckhouses, no stock is required. It can be concluded from these results that only sections which are needed before the production is completed should be held on stock. For example afts are required at the start of production. In the validation calculations the production time and assembly moment of sections have been altered, presented in Appendix D. In this calculation it can be seen that the longer the production takes and the earlier the sections are assembled, the higher the initial stock has to be.

6.8.1. ASSEMBLY-TO-ORDER

In Chapter 2 it was stated that the manufacturing strategy and CODP are closely related and that Damen might gain from switching from a make-to-stock to an assembly-to-

order production strategy. This section will present the impact of this switch.
Equation 5.5 is used to calculate the cost of having sections on stock and of having vessels on stock. The vessel price for all vessels is assumed to be the same for each ship type in the portfolio and excluding trial cost. For the sections it is calculated separately in the same way with Equation 5.5. It should be noticed that this seems not logic as the number of sections being assembled is much larger than complete hulls. When sections can be produced more than ten times in a year they have the potential to be produced in series, delivering sections every x weeks, depending on the demand. In this way no stock cost are required at all. However this is an advantage on the long term and if the sections are produced at one location transport cost need to be taken into account which are not known. Therefore it has been decided to use Equation 5.5 to give an indication of how stock cost will be affected by changing to an assemble-to-order strategy.
The Damen Baseline for the coming year has been taken as the input for this calculation. The baseline consists of fewer vessels than the previous years, this is due to reduced demand from the market as a result of the low oil price. Equation 5.5 has been applied to each vessel type in the baseline for the current portfolio, each vessel type in the baseline for the standardised portfolio and for each section present in the baseline of the standardised portfolio.

Table 6.14 shows the total stock value for having vessels on stock for the current product portfolio, standardised portfolio and for having sections on stock for the standardised portfolio. It can be seen that the stock value decreased by 56% when having sections on stock compared to having vessels on stock.

6

Table 6.14: Total stock value comparison

Portfolio	Total stock value	Reduction of cost
Current - hulls	100%	-
Standardised - hulls	72%	28%
Standardised - sections	44%	56%

In Figures 6.17, 6.18 the stock value per vessel type for one year for the current and standardised portfolio are shown. Figure 6.19 shows the number of sections present in a certain stock value range. For example 7 sections have a stock value of €X and 20 sections have a stock value of €0.05X or less.

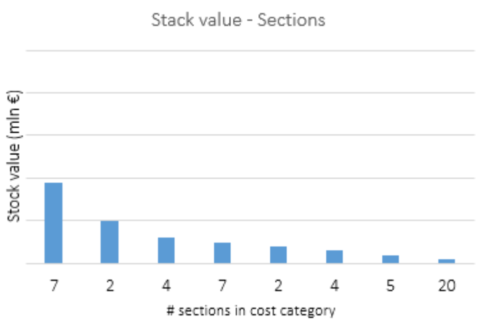

Figure 6.19: Standardised Stock Value per section

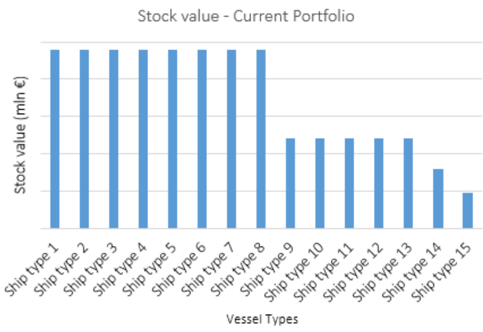

Figure 6.17: Current Stock value per ship type

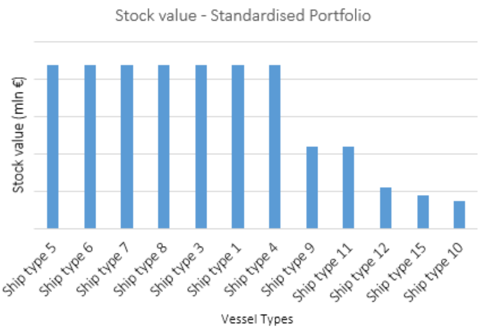

Figure 6.18: Standardised Stock Value per ship type

These results show that an assembly-to-order manufacturing strategy where sections are produced to stock which are assembled after the CODP is at least for the stock cost 56% cheaper than having vessels on stock. On the other hand, the delivery of the final product will take longer than delivering a complete vessel from stock, however after implementing all the standardisation levels, production will be reduced significantly and the delay for the assembly of the final product will be minimal.

6

6.9. CONCLUSION

In this chapter the three standardisarion levels are implementated into the current production strategy. The effect of implementing the different levels on activity relations, durations and cost are discussed and will be used as new input parameters for the computerised model.

Level 1. Main assembly

The first level of standardisation mainly influences the series size of vessel types, sections and propulsions sets being produced, assembled and ordered on stock. On an activity level it influences the activities involved in the production of sections on stock. Also, increased batch sizes makes serial production possible which leads to reduced lead times due to a series effect. Decreased production time and lower value of items being stored on stock will lead to lower cost.

Level 2. Sub assembly

On a sub assembly level, the implementation of modular outfitting will affect the order of activities. Outfitting activities which include hotworks and piping will partially be shifted to earlier phases and to the workshop. Work in the workshop is performed faster due to higher efficiencies, better working conditions and equipment can be tested before being installed on board. Other activities will be performed with higher efficiencies because more space and better working conditions are created by moving work to the workshop. Investments are required to train employees, perform detailed engineering for the design of the modular skids and frames, however this will be paid back on the longer term.

Level 3. Components

On a component level primarily money can be saved by making components standard and interchangeable between different ship types so they can be purchased in larger batches. This will lead to reduced purchasing cost and lower transport cost. Also if the variety between components is reduced the in-house knowledge about the products is increased, leading to better maintenance programs and less investments to train maintenance workers. Finally, when using components of fixed dimensions, installation and production of skids will require less manhours, reducing production time.

The results of the computerised model for the current and standardised production strategies are presented in this chapter. By implementing the three levels of standardisation the current building strategy for tugs can be significantly optimised, reducing production time by 36%, production cost by 11% and required manhours by 24%. The total lead time can be further reduced by working in two shifts. It is also proven that shifting from a make-to-stock to an assembly-to-order strategy with propulsion sets and standard section held on stock will result in 56% lower stock cost. The impact of the results on the main research question will be discussed further in the next chapter.

7
Conclusion and Recommendations

Damen shipyards delivers over a hundred vessels annually from many shipyards all over the world, keeping hulls in stock, to guarantee quick delivery times. One of Damen's fundamental corporate values is the focus on standardisation. However, as a result of increasing globalisation and customers' buying power many manufacturers including Damen, have been forced to produce an increasingly wide variety of products. With the rapid growth of Damen Shipyards, the wide variety of products they offer, and the increased customer buying power, a closer look is taken at the efficiency and advantages of their traditional production strategy.
The goal of this research is to evaluate the possibility to increase the efficiency of production by implementing aspects of line production and the platform-based product design strategy on the Damen Product Group Tugs. Therefore the main question of this research is:

"Which levels of standardisation provide Damen with the most advantages"

The scope of this research was limited to the Damen Product Group Tugs. The product group Tugs was chosen as the benchmark because it contains Damen's best sold (standard) vessel types and it has potential to benefit even more from standardisation strategies.

In this research three levels of standardisation have been defined with the help of standardisation methods and platform-based product development to increase production efficiency, decrease production cost and throughput times. These standardisation levels have been implemented in the current production strategy for the Damen ASD2810 with a computerised model in order to define their impact on the production cost and throughput time.

Three levels of standardisation which provide good prospects for the production of tugs have been evaluated and implemented in the computerised mathematical model to calculate their impact on production time and cost. The following enumeration presents the results which are listed according to their impact, starting with the largest impact on Damen's production strategy.

LEVEL 1. MAIN ASSEMBLY

The first and highest level of standardisation is on a main assembly level including the standardisation of the product portfolio and main assembly blocks of the vessel. Reducing variety in ship types being offered to the customer and increasing the commonality between them will increase efficiency and reduce production time and cost.

1. Being critical about the configuration of the product portfolio, reducing the variety in offered ship types and increasing the commonalities, such as the development of standard deckhouses and wheelhouses led to the production of larger series of vessels and its sections. Shifting to an assembly-to-order strategy in which propulsion sets and standard sections are held on stock rather than complete vessel will have a huge impact on Damen's production strategy which is currently make-to-stock. Up to 56% can be saved on stock value when keeping standard section on stock and assemble them when an order comes in. Apart from the financial advantage will shifting to an assembly-to-order strategy provide Damen Shipyards with multiple other advantages. Firstly, having semi-finished products, like sections on stock instead of complete hulls will save maintenance cos, because they are stored on land rather than in (salt) water. Additionally, due to the short production time, sections will be less affected by material price fluctuations such as steel compared to complete hull production. Finally, producing hulls on stock based on market predictions has a great risk with it. Whereas combining sections from stock to assemble vessels according to customer's wishes has a significantly lower risk.

LEVEL 2. SUB ASSEMBLY

This level of standardisation is based on the implementation of standard skids and frames produced in the workshop, which can be placed on multiple ship types and can be used for different categories of equipment. This means that outfitting activities are no longer performed during section, block and final outfitting, but in the workshop where standard skids and frames are produced to be installed on board of multiple ship types. Work can be performed more efficiently in the workshop than on board due to better working conditions. Hotworks, piping activities, the production of skids for (large) equipment and floor frames will be pre-produced and tested in the workshop and assembled on board as a whole. This requires a high level of detailed measuring and pre-engineering for the development of these units, but will significantly reduce production time and cost.

2. The effect of modular outfitting on the amount of outfitting work that can be completed in a respective phase (section, block, final outfitting) influenced the production time and requires manhours the most. The total delivery time can be reduced with 28% and the required hours with 20%. Cost will also reduce but with a lower rate of 4%. The impact of implementing modular outfitting has the potential to be much larger for Damen when developing standardised modular assembly units, skids and frames which can be placed on board of tugs and other ship types of

multiple business units. This promotes serial production and purchase advantages which will lead to further reductions in cost and production time. Also, the implementation of standard modular assembly units does not require large investments nor large changes in the production strategy and can be implemented on a short term.

Level 1. Main assembly

3. As a result of reducing variety in the product portfolio and increasing commonalities between vessels and sections the batch sizes of production will increase. When vessels and sections can be produced in larger series, Damen will benefit from serial production. Especially delivery times will reduce due to serial production. The total throughput time of vessel delivery will reduce with 10% when taking the average series size of the yearly production of vessels and sections for the proposed standardised product portfolio. An additional cost reduction of 5% and hour reduction of 2% can be achieved with serial production leading to the third best opportunity for Damen Shipyards.

Level 3. Components

The third and most detailed level of standardisation is on a component level. Damen is already concerned with this topic and is currently implementing this standardisation level through the Excellerate program. By reducing the variety of component types and making them interchangeable between different vessel types, purchase advantages can be gained and installation and maintenance time and cost can be reduced.
Standardising components between multiple ship types and therewith gaining a purchase advantage has great impact on the total production cost.

4. Standardising components within ship types and between them and reducing the number of suppliers will provide Damen mainly with a cost advantage. A drop in cost of 5% can be achieved due to a purchasing advantage which an be achieved by ordering more components at less suppliers. Even though the implementation of this level of standardisation provides Damen with the least advantages, it contributes greatly to the other levels of standardisation and has a lot of potential to increase its impact. When components become standardised, it is easier to develop standard assembly units and the batch size will increase, which will lead to lower development time and cost. Standardising components will also lead to a higher degree of knowledge of the products which helps to do better life cycle asessments leading to better, faster and higher degree service and maintenance programs. Additionally, by sourcing components locally transport time and cost can be saved. Finally, if Damen were to reduce the number of suppliers and increase standardisation of its components Damen can benefit from closer cooperation with suppliers. This can be done for example by including them in the product development phase. This will help Damen to gain more knowledge of their products and maintain their position as as a shipbuilder using high quality state of the art technology.

Total results for standardised production strategy

The prospects of implementing all three levels of standardisation into the current building strategy for the production of tugs are promising. Production time can be reduced with 36%, production cost with 11% and the required manhours with 24%. The total throughput time can be further reduced by working in two shifts.

Discussion

This section covers the decisions and assumptions made in this research and specifically in the simulation model of this research.

- Firstly, the production strategy for the single vessel (the ASD2810) was chosen as a base case and represents the complete Product Portfolio Tugs. This includes a large range of different ship types. It is assumed that the results for this vessel are scalable to other ship types considering lead times and cost of activities. The ASD2810 is the best sold vessel of this product family and its price is close to the average price of the complete product group, which is represented with the red striped box in Figure 7.1. However, as can be seen in the same Figure is that the ASD3212 is bigger and more expensive and the STU1004 is smaller and a lot cheaper than the ASD2810. For that reason the results cannot directly be used for all other ship types in the Product Group.

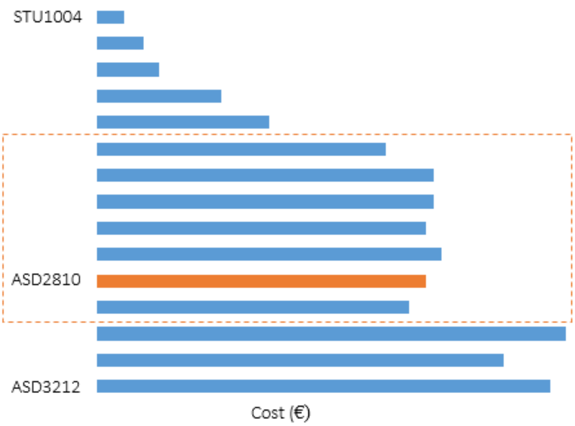

Figure 7.1: Base case ASD2810 representing the complete product portfolio

- In addition to that the durations and cost for the building strategy applied at the Damen Galati shipyard has been taken into account in this research. In reality Tugs are built at multiple yards spread over the world with varying building strategies.

- As already stated in the introduction, it should be kept in mind that this research is an economical feasibility study and does not take detailed design and engineering requirements into account. This means that assumptions have been made concerning the design of the vessels. For example, that 60% of the vessel types in the new portfolio share the same wheelhouse and that ice class vessels and regular condition vessels share common sections. In reality this is not so easy to execute because pipes and exhaust systems run from the hull to the wheelhouse and material types and the construction of ice and regular vessels differ greatly. However, it is assumed that these engineering and design challenges can be overcome.

- Thirdly, it is assumed that all activities in the simulation model are performed as planned, without delays, rework or other additional cost or delays, which is usually not the case in reality. In reality a significant amount of rework and changes in design and engineering is done, this is based on results from interviews and stated in literature, (Nieuwenhuis, 2013)

- Additionally, it should be taken into account that the efficiency improvements for performing outfitting activities in the workshop and gains from the purchase advantage will only take place after training of employees. It is expected that the learning effect is noticeable on the longer term and when serial production is taking place and not instantly. This is why three scenarios have been selected with increasing efficiency between the first and third scenario.

- Also, operational cost and benefits of applying standardisation and platform methods have not been taken into account. It is mentioned that the standardisation of systems in standard modules and the standardisation of components will lead to better life cycle analysis and better maintenance and customer service (Nieuwenhuis, 2013) but no further calculations have been performed to prove that this will lead to reduced cost.

- An interesting point of discussion is the standardisation of suppliers. As mentioned in Chapter 4, J.J. Nieuwenhuis (2013) has performed a literature study on the potential of reducing the number of suppliers. Several examples the Oil and Gas and Dutch Process Industry have experienced savings up to 30% through frame contracts. Costs will also reduce due to larger series size of ordered product and better relationships between the yard and the supplier. Even though this seems promising, he also states in his research that shipyards fear that this will result in a reduction of negotiation possibilities (Nieuwenhuis & Nienhuis, 2004).

- Moreover, in this research only the stock of long lead items concerning the propulsion train have been taken into account. However, in reality, production is often delayed due late deliveries of other long lead items such as; windows and winches. Storing other long lead items might also be an opportunity for Damen.

- Another point which should be kept in mind when using platform-based development is that they should be designed to fit updates. Shipbuilding design solutions can quickly become outdated due to technological progress or regulatory changes. Therefore a product platform is successful when the platform is designed for potential expansion. The design solution should be prepared to meet future customer (regulatory) requirements.

- Finally, the production and storage of sections and propulsion sets have been based on a baseline, which is a prediction of the market demand for the coming year. Demand may increase when the economy will improve, which would result in different numbers for the stock value.

Recommendations

In this section several recommendations for Damen Shipyards and further research are presented. It is not expected that all levels of standardisation can be implemented simultaneously and within the same time frame. Therefore it is recommended to start or actually continue with the implementation of modular outfitting. The pilot for the ASD2913 has already implemented skids and frames for the engine room produced in the workshop with promising results considering throughput times and cost. The number of skids and frames can be significantly increased and they should have a modular design to be interchangeable between different ship types. It is expected that this will have the largest impact on the shortest term. The development of standard modules is associated with standardisation on a component level. This will lead to a substantial decrease in procurement cost due to larger purchase batches.
Another recommendation is to harmonise the cooperation between the different optimisation pilots and programs running within Damen. Results from interviews show that many initiatives are running to increase efficiency, however individually. Collaboration between the initiatives from different product groups, yard support and Excellerate will lead to the best achievements.

Several observations have been made during this research which are interesting for further research. It has been proven that serial production of sections on stock will decrease the stock value considerable. It would be interesting to investigate how and where the production line of these sections should take place to take maximum advantage of this implementation. Additionally, it has been mentioned that Damen should produce ship types solely at one yard, again to gain from serial production. It would be valuable to investigate the optimal location for production of the respective ship types. Furthermore, it would be meaningful to know to what extent modular outfitting can be implemented on ship types from other business units such as high Speed Craft (HSC) and Offshore and Transport (O&T).
While performing the diversity analysis, it was noticed that tank arrangements, engine room arrangement and the position of stairs and doors varied greatly between ship types but also between individual vessels of the same ship type. Standardising compartment arrangement has not been included into this research but would be valuable to take into account in further research and will most likely save engineering time. When doing this, especially for the standardisation of tank arrangements, special attention should be paid to the construction and stability of the vessel, as the arrangement of tanks plays an important role in ballasting the vessel (Nieuwenhuis, 2013, Interview 3 Appendix F).

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A

Product Group Tugs

This appendix, presents the configuration of the current product portfolio Tugs. The portfolio is split in two ways, firstly by ship types and secondly by the ship capacity (bollard pull, operations field, etc.).

- STAN Tugs
  The Damen Stan Tugs Series are seagoing tugboats of modern design. Stan Tugs have slightly raised foredecks to improve seagoing abilities. Stan Tugs are ideal ship handling tugs in harbours.

- ASD Tugs
  The Damen ASD Tug is compact, powerful and is a very reliable, proven product. ASD Tugs are designed for push-pull, harbour assisting and escort towing operations up to 150 tons towline forces as well as fire-fighting, salvage, oil pollution, hose handling and anchor handling operations. Since 1992, Damen has built more than 500 ASD Tugs, which enjoy an excellent reputation based on their maneuverability, sailing proficiency, efficiency and user friendliness.
- RSD Tugs
  The Damen RSD Tug Series is the ultimate ship handling tool. The RSD Tug is a simple, efficient, compact ship handling tool, that performs excellently in both sailing directions, as a bow tug as well as a stern tug and contains three dedicated designs for 50, 70 and 90 tons bollard pull.

- ATD Tugs
  The Damen Azimuth Tractor Drive Tug (ATD) and Damen Voith Tractor Drive Tug (VTD) Series offer a complete and extensive range. ATD Tugs, VTD Tugs and Rotor Tugs have excellent maneuverability, high indirect towing forces and great stability.

Additionally the vessel types can be arranged by different operating conditions such as in harbour waters or in coastal waters which is shown in Figures A.1 and A.2.

A

Figure A.1: Work area (Degroote, 2015)

Figure A.2: suitable Tug variants (Degroote, 2015)

B

Product Portfolio Management

In this appendix the Product Portfolio Tugs is analysed using the BCG matrix. The Figure below provides a brief description of the four quadrants.

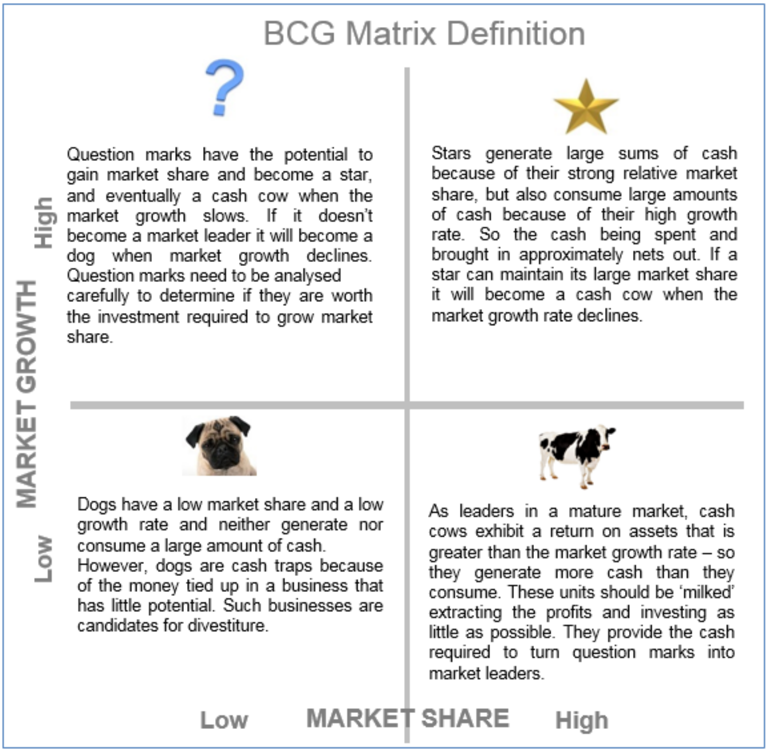

Figure B.1: Boston Consulting Matrix Definition (Damen Excellerate, 2016a)

The BCG matrix is used to analyse the Product Group Tugs to get an impression of the market share and market growth of the different ship types. The portfolio configuration is analysed by discussing the different ship types in each quadrant.

Question marks

The top left quadrant represents the slow movers or question marks which include vessels that are sold less then five times a year to more than one customer or vessels sold more then five times to one customer. New vessel types which will most likely replace end-of-life vessels or fulfill a change in customer demand in the (near) future.

Stars

In the top right quadrant the fast movers, also known as stars represent standard ship types which are sold more then five times per year to more than one customer and are currently or have the potential to be successful in the market.

Dogs

The bottom left quadrant contains vessel types which are non-standard or one-offs which have been built for one customer and for which no repeated orders for the exact same type are expected. The products in this quadrant are also known as dogs.

Cash Cows

Finally, the bottom right quadrant shows ship types also known as cash cows as they have proven to be successful in the market. Some of these ship types are end-of-life ship types which are slowly losing their market share and will no longer be offered or built in the near future. Of other ship types it is expected that they will maintain or even increase their market share.

The complete product portfolio contains 37 different vessel types, with currently 24 vessel types which are being offered to customers and build on stock (Degroote, 2015, Visser, 2016). Figures 4.3 and 4.4 shown in Chapter 4 give an overview of the reduction in variety of ship types and the vessel types which have been mostly sold over the year 2015.

In addition to the above assessment, a diversity analysis has been performed on the current product portfolio as explained in Chapter 4. The different ship types have been evaluated on how similar they are in different fields such as performance, operating area, dimensions and capacity. This led to promising similarities between multiple ship types which have been discussed in the interviews leading to the following conclusions. Ship types H, I, J and K have such similar operating characteristics that they can be replaced by a single vessel type, in this case Ship type K. Ship type K fulfills all the requirements for this groups of vessels without decreasing customers satisfaction. Also Ship type M and N have very similar operating capabilities with minor changes in their operating areas which is at sea for ship type N because its length is over 30 m and in sheltered waters for Ship type N because it is less then 30 m. These two vessels could be replaced by one ship type which can easily maneuverer in both waters without changing the price and requirements. This conflict is solved in two ways. Firstly, Ship type V will be replaced by a slightly larger vessel which can operate both in open and sheltered waters. This vessel has not yet been developed but will have a length of 30m and its width has to be defined by further research, therefore it is called the ASD30XX. Secondly, Ship type N and Ship type P have another conflicting challenge which is the need for more power without increasing the dimensions and reasonably priced. The answer to this problem is the development of Shiptype Q, which is smaller but delivers more power than both these vessels.

Taking the above observations into account, three scenarios for a more compact product portfolio have been configured. The most compact product portfolio contains 40% less ship types compared to the current product portfolio.

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BUILDING STRATEGY PARAMETERS

The activities taking place in the section phase are presented in Table C.1. Outfitting activities which do not take place in this phase are left out.

Table C.1: Activities taking place during section phase

		Hot works ER	Hot works ACC + WH	Painting ER	Painting ACC	Piping ER	Piping ACC + WH	Pull cables ACC + WH	Insulation ACC + WH
Section #	Description	A1	A2	A3	A4	A5	A6	A7	A8
Skeg	101	0	0	1	0	0	0	0	0
Skeg	102	0	0	1	0	0	0	0	0
DB ER	201	1	0	1	0	1	0	0	0
AS	301	1	0	1	0	1	0	0	0
AS	302	1	0	1	0	1	0	0	0
ER	303	1	0	1	0	1	0	0	0
FS	304	0	1	0	0	0	1	0	0
FS	401	0	1	0	0	0	1	0	0
Bulwark	501	0	0	0	1	0	0	0	0
Bulwark	502	0	0	0	1	0	0	0	0
Bulwark	503	0	0	0	1	0	0	0	0
Deckhouse	601	0	1	0	1	0	1	0	1
Steerhouse	701	0	1	0	1	0	1	0	1

The following two tables present the activities taking place in the block and zone phases. The meaning of the abbreviated activities is given in Table C.4.

Table C.2: Activities taking place during block phase

Block #	Name	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25
1	ER	1	0	1	0	1	0	0	0	0	0	0	1	1	1	1	0	1	1	1	1	1	0	1	0	0
2	AS1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
3	AS2	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
4	FS1	0	1	0	1	0	1	0	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
5	FS2	0	1	0	1	0	1	0	1	1	1	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0
6	Superstruct	0	1	0	1	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table C.3: Activities taking place during final phase

Zone #	Name	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25
Zone 1	ER	1	0	1	0	1	0	0	0	0	0	0	1	1	1	1	0	1	1	1	1	1	0	1	1	0
Zone 2	Acc + WH	0	1	0	1	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zone 3	Outside	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1

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Table C.4: Activity abbreviations

Abbreviation	Activity name	Abbreviation	Activity name
A1	Hot works ER	A14	Pull cables ER
A2	Hot works ACC + WH	A15	Connect cables ER
A3	Painting ER	A16	Deck equipment
A4	Painting ACC	A17	Install RP
A5	Piping ER	A18	Install ME
A6	Piping ACC + WH	A19	Install GENSET
A7	Pull cables ACC + WH	A20	Install box cooler
A8	Insulation ACC + WH	A21	Install hydraulic unit
A9	Install floor ACC + WH	A22	Install winch
A10	Install walls and ceilings ACC + WH	A23	Alligning ME
A11	Install and connect small EQ ACC + WH	A24	Painting ER final
A12	Install small EQ ER	A25	Painting outer hull final
A13	Insulation ER		

The following table shows to which block the sections belong, what the weight of each section, the start week of production of the section and the throughput time (tpt) of the steel construction for the sections.

Table C.5: Section parameters

Section #	Description	Block (#)	Weight (tons)	Start (week)	TPT Steel (weeks)
Skeg	101	1	2.6	2	8
Skeg	102	4	2.6	2	8
DB ER	201	1	25.5	2	10
AS	301	2	18.3	2	12
AS	302	3	18.3	2	12
ER	303	1	25.5	2	6
FS	304	4	24.6	2	12
FS	401	5	24.6	2	10
Bulwark	501	2	5.8	2	5
Bulwark	502	4	2.5	2	5
Bulwark	503	5	7.5	2	5
Deckhouse	601	6	14.5	2	4
Steerhouse	701	6	4.5	2	6

Table C.6: Block parameters

Block #		Weight (tons)	TPT Steel (weeks)
ER	1	53.6	1
AS1	2	24.1	0
AS2	3	18.3	0
FS1	4	29.6	0
FS2	5	32.0	0
Superstruct	6	19	0

Table C.7: Activity durations

Hours and throughputtimes activities	Section hours	Block hours	Final hours	Sect tpt	Block tpt	Final tpt
Hot works ER	-	-	-	2	5	18
Hot works ACC + WH	-	-	-	4	5	1
Painting ER	-	-	-	0	1	2
Painting ACC	-	-	-	0	1	2
Piping ER	-	-	-	0	4	22
Piping ACC + WH	-	-	-	0	4	3
Pull cables ACC + WH	-	-	-	0	0	4
Insulation ACC + WH	-	-	-	0	0	3
Install floor ACC + WH	-	-	-	0	0	1
Install walls and ceilings ACC + WH	-	-	-	0	0	7
Install and connect small EQ ACC + WH	-	-	-	0	0	7
Install small EQ ER	-	-	-	0	0	3
Insulation ER	-	-	-	0	0	5
Pull cables ER	-	-	-	0	0	6
Connect cables ER	-	-	-	0	0	7
Deck equipment	-	-	-	0	0	20
Install RP	-	-	-	0	0	6
Install ME	-	-	-	0	0	2
Install GENSET	-	-	-	0	0	1
Install box cooler	-	-	-	0	0	1
Install hydraulic unit	-	-	-	0	0	1
Install winch	-	-	-	0	0	2
Alligning ME	-	-	-	0	0	3
Painting ER final	-	-	-	0	0	1
Painting outer hull final	-	-	-	0	0	3

Table C.8: Activity cost current and standardised building strategy and cash flow behaviour

	Activity	Cost current	Cost standardised	Cash flow Behaviour
	Shipbuilding costs			
	Section building	€ -	€ -	Instant
	Block assembly	€ -	€ -	Linear
	Final assembly	€ -	€ -	Linear
	Grouped outfitting costs			
1	Hot works ER	€ -	€ -	Linear
2	Hot works ACC + WH	€ -	€ -	Linear
3	Painting ER	€ -	€ -	Linear
4	Painting ACC	€ -	€ -	Linear
5	Piping ER	€ -	€ -	Linear
6	Piping ACC + WH	€ -	€ -	Linear
7	Pull cables ACC + WH	€ -	€ -	Linear
8	Insulation ACC + WH	€ -	€ -	Linear
9	Install floor ACC + WH	€ -	€ -	Linear
10	Install walls and ceilings ACC + WH	€ -	€ -	Linear
11	Install and connect small EQ ACC + WH	€ -	€ -	Linear
12	Install small EQ ER	€ -	€ -	Linear
13	Insulation ER	€ -	€ -	Linear
14	Pull cables ER	€ -	€ -	Linear
15	Connect cables ER	€ -	€ -	Linear
16	Deck equipment	€ -	€ -	Linear
17	Painting outer hull final	€ -	€ -	Linear
18	Painting ER final	€ -	€ -	Linear
	Individual outfit cost			
19	Rudder propeller	€ -	€ -	Instant
20	Main engines	€ -	€ -	Instant
21	Generaters	€ -	€ -	Instant
22	Box coolers	€ -	€ -	Instant
23	Hydraulic units	€ -	€ -	Instant
24	Winch	€ -	€ -	Instant
25	Alligning ME	€ -	€ -	Linear
	General Items			
	Start production	€ -	€ -	Linear
	Linear start - commissioning	€ -	€ -	Linear
	Commissioning & trials	€ -	€ -	Linear

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Activity after \ activity	Hot works ER	Hot works ACC + WH	Painting ER	Painting ACC	Piping ER	Piping ACC + WH	Pull cables ACC + WH	Insulation ACC + WH	Install floor ACC + WH	Install walls and ceilings ACC + WH	Install and connect small EQ ACC + WH	Install small EQ ER	Insulation ER	Pull cables ER	Connect cables ER	Deck equipment	Install RP	Install ME	Install GENSET	Install box cooler	Install hydraulic unit	Install winch	Alligning ME	Painting ER final	Painting outer hull final
Hot works ER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot works ACC + WH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Painting ER	0.5	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Painting ACC	0	0.9	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Piping ER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Piping ACC + WH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pull cables ACC + WH	0	1	0	1	0	0.5	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Insulation ACC + WH	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Install floor ACC + WH	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Install walls and ceilings ACC + WH	0	0	0	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Install and connect small EQ ACC + WH	0	1	0	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Install small EQ ER	0.5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Insulation ER	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pull cables ER	0.7	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Connect cables ER	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0
Deck equipment	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Install RP	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Install ME	0.5	0	1	0	0.6	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
Install GENSET	0.5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Install box cooler	0.5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Install hydraulic unit	0.5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Install winch	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Alligning ME	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Painting ER final	1	0	1	0	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	1	0	0
Painting outer hull final	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure C.1: Relations between activities

Table C.9: General Cost Items

Steel	Costs	Distribution
Section	€ -	0
Block	€ -	1
Assembly	€ -	1

General	Costs	Distribution
Start	€ -	0
Production	€ -	1
Trials	€ -	0
Inhouse overhead	€ -	1
Fixed weekly production	€ -	1

Table C.10: Input data

Input Production data		
Transport time	4	weeks
Manhour cost	€ -	
Work days/ week	5	
Double shifts	0	1 = yes, 0 = no
Zone workers ER base	-	
Zone workers ACC base	-	
Zone workers hull base	-	
Zone workers ER	-	
Zone workers ACC	-	
Zone workers Hull	-	

Table C.11: Maximum amount of pre-outfitting current and standardised stragey

	Current building strategy				Standardised building strategy			
Activitiy	**Max sect**	**Max block**	**On sect**	**On block**	**Max sect**	**Max block**	**On sect**	**On block**
Hot works ER	22%	72%	1	1	70%	95%	1	1
Hot works ACC + WH	60%	90%	1	1	80%	95%	1	1
Painting ER	0%	50%	0	1	20%	70%	1	1
Painting ACC	25%	85%	1	1	25%	85%	1	1
Piping ER	20%	45%	1	1	60%	80%	1	1
Piping ACC + WH	25%	75%	1	1	50%	95%	1	1
Pull cables ACC + WH	0%	0%	0	0	0%	80%	0	1
Insulation ACC + WH	10%	15%	1	1	0%	80%	0	1
Install floor ACC + WH	0%	0%	0	0	0%	50%	0	1
Install walls and ceilings ACC + WH	0%	0%	0	0	0%	50%	0	1
Install and connect small EQ ACC + WH	0%	0%	0	0	0%	60%	0	1
Install small EQ ER	0%	10%	0	1	0%	80%	0	1
Insulation ER	0%	10%	0	1	0%	60%	0	1
Pull cables ER	0%	0%	0	0	0%	25%	0	1
Connect cables ER	0%	0%	0	0	0%	25%	0	1
Deck equipment	0%	0%	0	0	0%	50%	0	1
Install RP	0%	0%	0	0	0%	100%	0	1
Install ME	0%	0%	0	0	0%	100%	0	1
Install GENSET	0%	0%	0	0	0%	100%	0	1
Install box cooler	0%	0%	0	0	0%	100%	0	1
Install hydraulic unit	0%	0%	0	0	0%	100%	0	1
Install winch	0%	0%	0	0	0%	0%	0	0
Alligning ME	0%	0%	0	0	0%	50%	0	1
Painting ER final	0%	0%	0	0	0%	0%	0	0
Painting outer hull final	0%	0%	0	0	0%	0%	0	0

Table C.12: Hour division current building strategy

section_hours_current	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25
Skeg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Skeg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DB ER	112	0	0	0	72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AS	80	0	0	0	52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AS	80	0	0	0	52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ER	112	0	0	0	72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FS	0	221	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FS	0	221	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bulwark	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bulwark	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bulwark	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deckhouse	0	130	0	33	0	9	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steerhouse	0	40	0	10	0	3	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	384	612	0	80	249	40	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
block_hours_current	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25
ER	975	0	246	0	347	0	0	0	0	0	0	28	38	0	0	0	0	0	0	0	0	0	0	0	0
AS1	438	0	110	0	156	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AS2	333	0	84	0	119	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FS1	0	225	0	141	0	59	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FS2	0	243	0	153	0	64	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Superstruct	0	144	0	90	0	38	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1746	612	440	384	622	160	0	30	0	0	0	28	38	0	0	0	0	0	0	0	0	0	0	0	0
zone_hours_current	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25
Zone 1 ER	2266	0	994	0	2764	0	0	0	0	0	0	501	694	730	561	0	952	780	174	130	43	0	403	309	0
Zone 2 ACC + WH	0	437	0	212	0	184	2640	1205	197	2752	3872	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zone 3 Zone	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1792	0	0	0	0	0	183	0	0	1861
Total	2266	437	994	212	2764	184	2640	1205	197	2752	3872	501	694	730	561	1792	952	780	174	130	43	183	403	309	1861

Table C.13: Standardised hours after changing pre-outfitting

section_hours_current	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25
Skeg	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Skeg	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DB ER	356	0	24	0	217	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AS	256	0	17	0	156	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AS	256	0	17	0	156	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ER	356	0	24	0	217	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FS	0	294	0	0	0	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FS	0	294	0	0	0	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bulwark	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bulwark	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bulwark	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deckhouse	0	174	0	33	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steerhouse	0	54	0	10	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1222	816	88	80	746	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
block_hours_current	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**	**A12**	**A13**	**A14**	**A15**	**A16**	**A17**	**A18**	**A19**	**A20**	**A21**	**A22**	**A23**	**A24**	**A25**
ER	487	0	246	0	278	0	0	0	0	0	0	224	228	90	70	0	246	400	80	60	20	0	90	0	0
AS1	219	0	110	0	125	0	0	0	0	0	0	0	0	0	0	104	110	0	0	0	0	0	0	0	0
AS2	167	0	84	0	95	0	0	0	0	0	0	0	0	0	0	79	84	0	0	0	0	0	0	0	0
FS1	0	112	0	141	0	53	0	179	18	253	427	0	0	0	0	128	0	0	0	0	0	0	0	0	0
FS2	0	122	0	153	0	57	0	193	20	273	462	0	0	0	0	139	0	0	0	0	0	0	0	0	0
Superstruct	0	72	0	90	0	34	1056	115	12	162	274	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	873	306	440	384	498	144	1056	486	50	688	1162	224	228	90	70	450	440	400	80	60	20	0	90	0	0
zone_hours_current	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**	**A12**	**A13**	**A14**	**A15**	**A16**	**A17**	**A18**	**A19**	**A20**	**A21**	**A22**	**A23**	**A24**	**A25**
Zone 1 ER	396	0	563	0	895	0	0	0	0	0	0	130	225	359	269	0	0	0	0	0	0	0	181	294	0
Zone 2 ACC + WH	0	207	0	211	0	35	537	284	98	1376	1560	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zone 3 Zone	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	989	0	0	0	0	0	183	0	0	1861
	396	207	563	211	895	35	537	284	98	1376	1560	130	225	359	269	989	0	0	0	0	0	183	181	294	1861

Table C.14: Hours after modular outfitting

section_hours_modular	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25
Skeg	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Skeg	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DB ER	221	0	24	0	154	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AS	155	0	17	0	94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AS	149	0	17	0	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ER	221	0	24	0	154	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FS	0	166	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FS	0	167	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bulwark	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bulwark	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bulwark	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deckhouse	0	93	0	33	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steerhouse	0	33	0	10	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	745	459	88	80	491	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
block_hours_modular	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**	**A12**	**A13**	**A14**	**A15**	**A16**	**A17**	**A18**	**A19**	**A20**	**A21**	**A22**	**A23**	**A24**	**A25**
ER	343	0	246	0	363	0	0	0	0	0	0	217	228	202	63	0	246	200	40	48	10	0	90	0	0
AS1	109	0	110	0	62	0	0	0	0	0	0	0	0	0	0	104	110	0	0	0	0	0	0	0	0
AS2	83	0	84	0	47	0	0	0	0	0	0	0	0	0	0	79	84	0	0	0	0	0	0	0	0
FS1	0	77	0	141	0	30	0	179	28	253	554	0	0	0	0	128	0	0	0	0	0	0	0	0	0
FS2	0	81	0	153	0	32	0	193	30	273	580	0	0	0	0	139	0	0	0	0	0	0	0	0	0
Superstruct	0	46	0	90	0	19	993	115	16	162	322	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	536	205	440	384	473	81	994	486	74	688	1456	217	228	202	63	450	440	200	40	48	10	0	90	0	0
zone_hours_modular	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**	**A12**	**A13**	**A14**	**A15**	**A16**	**A17**	**A18**	**A19**	**A20**	**A21**	**A22**	**A23**	**A24**	**A25**
Zone 1 ER	99	0	563	0	224	0	0	0	0	0	0	32	225	90	242	0	0	0	0	0	0	0	181	221	0
Zone 2 ACC + WH	0	52	0	211	0	9	134	284	24	1376	390	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zone 3 Zone	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	989	0	0	0	0	0	183	0	0	1861
	99	52	563	211	224	9	134	284	24	1376	390	32	225	90	242	989	0	0	0	0	0	183	181	221	1861

Table C.15: Workshop hours per scenario

	Current outfitting	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Section/block hoursefficiency	0%	0%	25%	45%	65%
Zone hours efficiency	0%	0%	35%	55%	75%
Hotworks workshop zone	-	-	-	-	-
Hotworks workshop block	-	-	-	-	-
Hotworks workshop section	-	-	-	-	-
Piping workshop zone	-	-	-	-	-
Piping workshop block	-	-	-	-	-
Piping workshop section	-	-	-	-	-

Table C.16: Throughput time steel work sections

		Current	Standardised
Section	**Description**	**Throughput time Steel (weeks)**	**Throughput time Steel (weeks)**
Skeg	101	6.4	4.8
Skeg	102	6.4	4.8
DB ER	201	8	6
AS	301	9.6	7.2
AS	302	9.6	7.2
ER	303	4.8	3.6
FS	304	9.6	7.2
FS	401	8	6
Bulwark	501	4	3
Bulwark	502	4	3
Bulwark	503	4	3
Deckhouse	601	3.2	2.4
Steerhouse	701	4.8	3.6

Table C.17: Throughput time steel work blocks

		Current	Standardised
Block	**Description**	**Throughput time Steel (weeks)**	**Throughput time Steel (weeks)**
ER	1	0.8	0.6
AS1	2	0	0
AS2	3	0	0
FS1	4	0	0
FS2	5	0	0
Superstruct	6	0	0

D

VERIFICATION CALCULATIONS

This chapter shows how the computerised model is being verified. The input parameters for the building strategy and production strategy model have been simplified in order to recalculate all the intermediate values manually.

D.1. BUILDING STRATEGY MODEL

This section shows step-by-step how the building strategy model is being verified.The steps are the same as described in Chapter 5.

1. Firstly, the distribution of the activities over the three phases (section, block and final) are determined. Then, activities are assigned to the individual sections, blocks and zones.

Input

Section parameters	Section 1	Section 2
Weight (tons)	10	10
Act 1	1	0
Act 2	1	0

Block parameters	Block 1	Block 2
Weight (tons)	10	10
Act 1	1	0
Act 2	1	0

Zone parameters	Zone 1 ER	Zone 2 ACC	Zone 3 Hull
Act 1	1	0	0
Act 2	1	0	0

strategy parameters	Activity 1	Activity 2
Max pre-outfit section	50%	100%
Max pre-outfit block	50%	100%
BS parameter Section	1	0
BS parameter Block	1	0

Output

Activity progress	Activity 1	Activity 2
Section 1	50%	0%
Section 2	0%	0%
Block 1	0%	0%
Block 2	0%	0%
Zone 1	50%	100%
Zone 2	0%	0%
Zone 3	0%	0%

2. In the second step, the throughput times and required manhours per activity are calculated with the normalised hours and durations from the Galati yard data.

Input

Activity progress	Activity 1	Activity 2
Section 1	50%	0%
Section 2	0%	0%
Block 1	0%	0%
Block 2	0%	0%
Zone 1	50%	100%
Zone 2	0%	0%
Zone 3	0%	0%

Phase efficiencies for durations	
Section	0.25
Block	0.5
Zone	1

Activity durations	**Activity 1**	**Activity 2**
Section hours	0	0
Block hours	0	0
Final hours	4000	4000
Sect duration	0	0
Block duration	0	0
Final duration	10	10

Intermediate Results

Normalised durations	Activity 1	Activity 2
Normalised hours	4000	4000
Normalised throughputtime	10	10

Output

	Activity 1		**Activity 2**	
Durations	Hours	Duration	Hours	Duration
Section 1	500	1.25	0	1.25
Section 2	0	0	0	0
Block 1	0	0	0	0
Block 2	0	0	0	0
Zone 1	2000	5	4000	10
Zone 2	0	0	0	0
Zone 3	0	0	0	0

3. Next, the start time of all activities relative to the section, block or zone in which they are positioned are calculated. The sequence of the activities containing the relations between activities is required to fulfill this step. In the sequence table, the row can start when the column is completed.

Input

	Activity 1		**Activity 2**	
Durations	Hours	Duration (wks)	Hours	Duration (wks)
Section 1	500	1.25	0	1.25
Section 2	0	0	0	0
Block 1	0	0	0	0
Block 2	0	0	0	0
Zone 1	2000	5	4000	10
Zone 2	0	0	0	0
Zone 3	0	0	0	0

sequence	Activity 1	Activity 2
Activity 1	-	0
Activity 2	1	-

Output

Activity start	Activity 1	Activity 2
Section 1	0	1.25
Section 2	0	0
Block 1	0	0
Block 2	0	0
Zone 1	0	5
Zone 2	0	0
Zone 3	0	0

4. Now it is known which activities are performed silultaneously in the respective phases, the number of workers and the correction for working in cramped spaces explained in Equation 5.4 in Chapter 3 can be calculated. How many people work simultaneously at each section, block, and zone at each moment, throughput times and required labour for the activities are adjusted here using this information.

Input

Activity start	Activity 1	Activity 2
Zone 1	0	5
Zone 2	0	0
Zone 3	0	0

Intermediate Results

Normalised durations	Activity 1	Activity 2
Zone 1	10	10
Zone 2	0	0
Zone 3	0	0

	Activity 1		**Activity 2**	
Durations	Hours	Duration (wks)	Hours	Duration (wks)
Zone 1	2000	5	4000	10
Zone 2	0	0	0	0
Zone 3	0	0	0	0

Workers from data and in building strat.	#
Zone workers 1 measure	10
Zone workers 2 measure	10
Zone workers 3 measure	10
Zone workers 1 build strat	10
Zone workers 2 build strat	10
Zone workers 3 build strat	10

Output

	Activity 1			**Activity 2**		
Durations	Hours	Duration (wks)	Workers (#)	Hours	Duration (wks)	Workers (#)
Zone 1	2000	5	10	4000	10	10
Zone 2	0	0	0	0	0	0
Zone 3	0	0	0	0	0	0

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5. The start times, durations and end times of the activities are used in this step to calculate the duration of the sections, blocks and zones.

Input

	Activity 1		Activity 2	
Durations	Start	Duration (wks)	Start	Duration (wks)
Section 1	0	1.25	1.25	1.25
Section 2	0	0	0	0
Block 1	0	0	0	0
Block 2	0	0	0	0
Zone 1	0	5	5	10
Zone 2	0	0	0	0
Zone 3	0	0	0	0

Output

Duration	weeks
Section 1	10
Section 2	10
Block 1	10
Block 2	10
Assembly	2
Zone 1	15
Zone 2	0
Zone 3	0
Trials	4

Duration steel work	weeks
Section 1	10
Section 2	10
Block 1	10
Block 2	10
Zone 1	0
Zone 2	0
Zone 3	0

Parameters Assembly	weeks
Durations	2

Duration	weeks
Trials	4

D

6. With the relations between all sections, blocks, and zones, their respective start times can be determined at in the sixth step.

Intput

Duration	weeks
Section 1	10
Section 2	10
Block 1	10
Block 2	10
Assembly	2
Zone 1	15
Zone 2	0
Zone 3	0
Trials	4

Output

Start	weeks
Section 1	2
Section 2	2
Block 1	12
Block 2	12
Assembly	22.2
Zone 1	24.2
Zone 2	29.4
Zone 3	24.2
Trials	39.2

Start	week
Section 1	2
Section 2	2

Relation Sesction, Block	Block 1	Block 2
Section 1	1	0
Section 2	0	1

Parameter Assembly	weeks
Wait before start	0.2

Relation Block, Block	Block 1	Block 2
Block 1	0	0
Block 2	1	0

Relation Block, Zone	Block 1	Block 2
Zone 1	1	1
Zone 2	1	1
Zone 3	1	1

7. Once the schedule of all activities is known the costs can be linked to the production process to calculate the cash flow of the vessel. Any additional cash flows are assigned to production phases.

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Intput

Start	start (wk)	duration (wks)
Section 1	2	10
Section 2	2	10
Block 1	12	10
Block 2	12	10
Assembly	22.2	2
Zone 1	24.2	15
Zone 2	29.4	0
Zone 3	24.2	0
Trials	39.2	4

	Activity 1			**Activity 2**		
Durations	Start	Duration (wks)	Hours	Start	Duration (wks)	Hours
Section 1	0	1.25	500	1.25	1.25	0
Section 2	0	0	0	0	0	0
Block 1	0	0	0	0	0	0
Block 2	0	0	0	0	0	0
Zone 1	0	5	2000	5	10	4000
Zone 2	0	0	0	0	0	0
Zone 3	0	0	0	0	0	0

Activity cost data	Activity 1	Activity 2
Buy-in costs	€ 100,000	€ 100,000
Distribution	Instant	Instant
Payment time	+ 0 weeks	+ 0 weeks
Transport	No	No

General Costs	
Start	€ -
Production	€ -
Trials	€ 50,000
Fixed weekly cost	€ 1,000
Labour rate	€ 10
Transport time	0 weeks

General production costs	hours
Prefabrication steel	1000
Workshop	0

Buy-in cost steel	
Sections	€ 20,000
Blocks	-
Zones	€ 20,000

Output

Total manhours	Total cost	Delivery (wks)
7500	€ 408,200	43.2

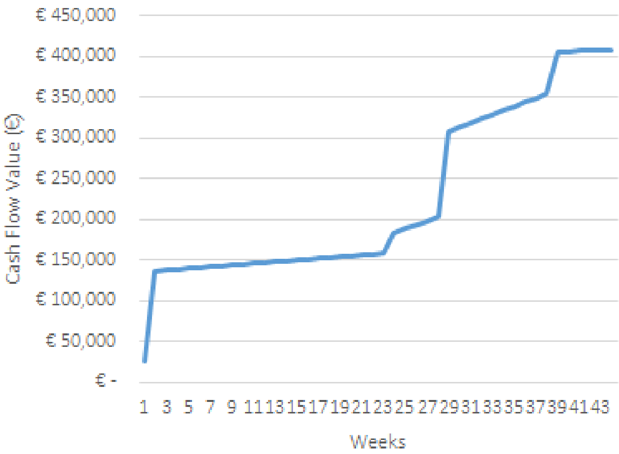

Figure D.1: Cashflow verification step 7

CALCULATING THE REQUIRED HOURS PER ACTIVITY

Equations 5.1, 5.2 and 5.3 are explained in this section with the production time of the first outfitting activity "Hot works ER". The benchmark hours for this activity per phase (section, block and zone) and the phase efficiencies are presented in the table below.

Benchmark (hrs)	Section	Block	Zone
Hot works ER	400	1920	1544
Phase efficiency	0.25	0.5	1

These benchmark hours are normalised with Equation 5.1, illustrated in the following calculation.

D

$$Normalised\ hours = \frac{400}{0.25} + \frac{1920}{0.5} + \frac{1544}{1} = 6984\ hours$$

Next, the normalised hours are divided over the respective phases section, block and zone according to Equation 5.2 as presented below.

$$Section\ hours = 6984 * 0.25 * 0.22 = 384\ hours$$
$$Block\ hours = 6984 * 0.5 * (0.72 - 0.22) = 1746\ hours$$
$$Zone\ hours = 6984 * (1 - 0.72) = 1956\ hours$$

Once the hours for the three phases are known the hours are divided over the different sections, blocks and zones with Equation 5.3. Only the weights of the sections in which the activity takes are taken into account for this calculation. The following row of calculations shows this step for the hour division of the first activity over the different sections within the section phase. The activity Hot works ER takes place in the Double Bottom of the Engine Room (DB ER), Aft Ship 1 (AS1), Aft Ship 2 (AS2) and within the Engine Room (ER). This is done in the same way for all other activities and other phases.

$$Hours\ Section\ DB\ ER,\ Act.\ 1 = \frac{384 * 25.5}{25.5 + 18.3 + 18.3 + 25.5} = 112\ hours$$
$$Hours\ Section\ AS1,\ Act.\ 1 = \frac{384 * 18.3}{25.5 + 18.3 + 18.3 + 25.5} = 80\ hours$$
$$Hours\ Section\ AS2,\ Act.\ 1 = \frac{384 * 18.3}{25.5 + 18.3 + 18.3 + 25.5} = 80\ hours$$
$$Hours\ Section\ ER,\ Act.\ 1 = \frac{384 * 25.5}{25.5 + 18.3 + 18.3 + 25.5} = 112\ hours$$

D.2. PRODUCTION STRATEGY MODEL

This section shows how the production strategy model is being verified. The production of a vessel consists of several milestones including the UAL release date, start steelcutting, delivery and payment of long lead items and delivery and payment of the vessel. These milestones have been pointed out in the time-line presented in Figure D.2. The aim of this model is to calculate the initial stock level of standard sections and long lead items (which is in this research limited to propulsion related items). Therefore the figure also shows the milestones for the deckhouse (DH) and wheelhouse (WH). The blue items in the time-line are fixed and the ornage items are variable. In this validation calculation three scenarios will be checked in which the delivery time, assembly and installation and payment moments for deckhouses, wheelhouses and long lead items (LLI) are altered.

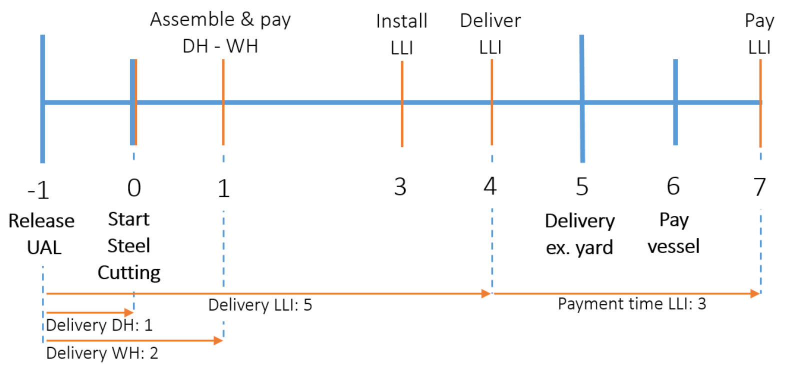

Figure D.2: Milestones, delivery and installation moments

This validation model consists of ten vessels including six different vessel types, five propulsion set types, four deckhouse types and three wheelhouse types. The input for the first scenario is presented in the follwing tables.

SCENARIO 1	
Durations INPUT	Days #
Delivery DH	1
Delivery WH	2
Delivery LLI	5
Payment time LLI	Del LLI + 3
Install moment INPUT	Days #
Assmble DH & WH	1
Install LLI	3
General INPUT	Day #
Release UAL	St St Cut - 1
Start steel Cutting	0
Delivery ex. Yard	5
Pay vessel	Del. ExYard + 1

Vessel INPUT

BP	Shiptype	Delivery ExYard
38.7	5	7/1/15
20	1	9/1/15
64	2	10/1/15
5	4	12/1/15
60	6	15/1/15
60	6	16/1/15
64	2	20/1/15
64	2	21/1/15
20	1	22/1/15
70	3	25/1/15

Initial stock INTPUT

ME type	Initial stock LLI	Deckhouse type	Initial stock DH	Wheelhouse type	Initial stock WH
1	1	0	1	1	1
2	1	1	1	2	2
3	1	2	2	3	0
4	1	3	0		
5	1	4	0		

The Tables on the next page present the input data for scenarios two and three in which the variable parameters have been altered.

The results of the first scenario have been plotted in Tables D.1, D.2 and D.3. From top to bottom these tables present a daily overview with the vessels in production and how many vessels have been paid. After that one row per type follows for when a LLI/DH/WH is delivered and added to stock and when a section or LLI is assembled or installed. The stock levels per day are presented after that and finally an overview of the total items in stock, total items paid and the net number of items paid. The "in stock" values are used to determine is the initial determined stock at input was sufficient. If the cell is coloured yellow this means the stock level has reach a value of zero items. It the is coloured red, there is insufficient stock present. At the end of each "in stock" row the minimal level of stock reached throughout production is given. If this number is zero there was exactly sufficient stock present at the start of production to fulfill a yearly demand of sections or propulsion sets. If this value is more than one, the stock level could have been lower at the start of the year. This can be seen in Table D.2. The third deckhouse type has had a minimal value of two during the yearly production, this means that the initial stock value can be lowered with two. This will result in a zero for the minimal value in the next run. The stock levels after correcting them are presented in the first table below. The results for the other two scenarios presented in the following tables have been achieved in the same way as the results for scenario one.

SCENARIO 2

INPUT durations	Days #
Delivery DH	**3**
Delivery WH	**4**
Delivery LLI	**7**
Payment time LLI	Del LLI + 3

INPUT installations	Day #
Assmble DH & WH	1
Install LLI	3

General INPUT	Day #
Release UAL	St St Cut - 1
Start steel Cutting	0
Delivery ex. Yard	5
Pay vessel	Del. ExYard + 1

SCENARIO 3

INPUT durations	Days #
Delivery DH	**4**
Delivery WH	**3**
Delivery LLI	**4**
Payment time LLI	**Del LLI + 2**

INPUT installations	Day #
Assmble DH & WH	1
Install LLI	**2**

General INPUT	Day #
Release UAL	St St Cut - 1
Start steel Cutting	0
Delivery ex. Yard	5
Pay vessel	Del. ExYard + 1

SCENARIO 1
Initial stock OUTPUT

ME type	Initial stock LLI	Deckhouse type	Initial stock DH	Wheelhouse type	Initial stock WH
1	1	0	0	1	0
2	1	1	0	2	0
3	1	2	0	3	0
4	1	3	0		
5	1	4	0		

SCENARIO 2
Initial stock OUTPUT

ME type	Initial stock LLI	Deckhouse type	Initial stock DH	Wheelhouse type	Initial stock WH
1	1	0	1	1	1
2	1	1	1	2	2
3	1	2	1	3	0
4	2	3	0		
5	1	4	0		

SCENARIO 3
Initial stock OUTPUT

ME type	Initial stock LLI	Deckhouse type	Initial stock DH	Wheelhouse type	Initial stock WH
1	1	0	2	1	1
2	1	1	1	2	2
3	1	2	2	3	0
4	4	3	0		
5	1	4	0		

Table D.1: Output scenario 1 LLI

OUTPUT SCENARIO 1 LLI

date	1/1	2/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1	12/1	13/1	14/1	15/1	16/1	17/1	18/1	19/1	20/1	21/1	22/1	23/1	24/1	25/1	26/1	27/1	
vessels in prod.	0	1	1	2	3	3	4	3	3	3	3	3	2	2	3	3	3	3	3	4	3	2	1	1	1	0	0	
vessels paid	0	0	0	0	0	0	0	0	1	1	2	3	3	4	4	4	5	6	6	6	6	7	8	9	9	9	10	
add order (1)	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
add order (2)	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	
add order (3)	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
add order (4)	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0	
add order (5)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	
installation (1)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
installation (2)	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	
installation (3)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
installation (4)	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	
installation(5)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	
in stock (1)	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**0**
in stock (2)	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	**0**
in stock (3)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**0**
in stock (4)	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	1	0	0	1	1	1	1	1	1	1	1	**0**
in stock (5)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	**0**
total in stock	5	5	5	5	4	5	4	4	5	4	5	5	4	4	5	5	5	4	4	4	5	5	4	5	5	5	5	
total paid stock	5	5	5	5	5	5	5	5	6	6	7	8	8	9	9	9	10	11	11	11	11	12	13	14	14	14	15	
net paid units	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	

D

Table D.2: Output Scenario 1 Deckhouse

OUTPUT SCENARIO 1 DH

date	1/1	2/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1	12/1	13/1	14/1	15/1	16/1	17/1	18/1	19/1	20/1	21/1	22/1	23/1	24/1	25/1	26/1	27/1	
vessels in prod.	0	1	1	2	3	3	4	3	3	3	3	3	2	2	3	3	3	3	3	4	3	2	1	1	1	0	0	
vessels paid	0	0	0	0	0	0	0	0	1	1	2	3	3	4	4	4	5	6	6	6	6	7	8	9	9	9	10	
add order (0)	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	
add order (1)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	
add order (2)	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
add order (3)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
add order (4)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
assembly (0)	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	
assembly (1)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	
assembly (2)	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
assembly (3)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
assembly (4)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
in stock (0)	1	1	1	2	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	**1**
in stock (1)	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	**1**
in stock (2)	2	2	2	2	2	2	3	2	2	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**2**
in stock (3)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
in stock (4)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
total in stock	4	5	4	5	5	4	5	4	4	5	5	4	4	4	5	5	5	5	5	6	5	5	5	5	5	5	5	
total paid stock	4	4	5	5	6	7	7	8	8	8	9	10	10	10	10	11	12	13	13	13	14	14	14	14	14	14	14	
net paid units	4	4	5	5	6	7	7	8	7	7	7	7	7	6	6	7	7	7	7	7	8	7	6	5	5	5	4	

D

Table D.3: Output scenario 1 Wheelhouse

OUTPUT SCENARIO 1 WH																												
date	1/1	2/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1	12/1	13/1	14/1	15/1	16/1	17/1	18/1	19/1	20/1	21/1	22/1	23/1	24/1	25/1	26/1	27/1	
vessels in prod.	0	1	1	2	3	3	4	3	3	3	3	3	2	2	3	3	3	3	3	4	3	2	1	1	1	0	0	
vessels paid	0	0	0	0	0	0	0	0	1	1	2	3	3	4	4	4	5	6	6	6	6	7	8	9	9	9	10	
add order (1)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	
add order (2)	0	0	1	0	0	1	0	1	0	0	1	1	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	
add order (3)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
assembly (1)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	
assembly (2)	0	0	1	0	0	1	0	1	0	0	1	1	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	
assembly (3)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
in stock (1)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**1**
in stock (2)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**2**
in stock (3)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
total in stock	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
total paid stock	3	3	4	4	5	6	6	7	7	7	8	9	9	9	9	10	11	12	12	12	13	13	13	13	13	13	13	
net paid units	3	3	4	4	5	6	6	7	6	6	6	6	6	5	5	6	6	6	6	6	7	6	5	4	4	4	3	

E

Results Sensitivity analysis

Workers per area

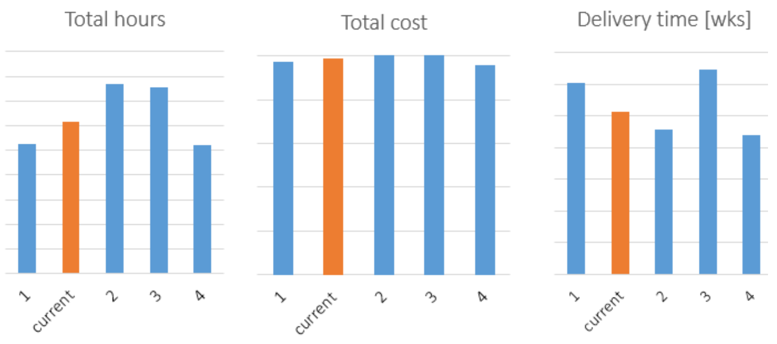

Figure E.1: Results of sensitivity zone workers

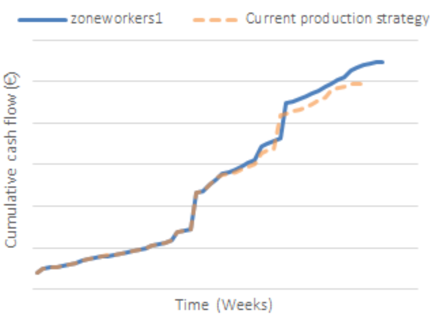

Figure E.2: Cash flow scenario 1 zone workers

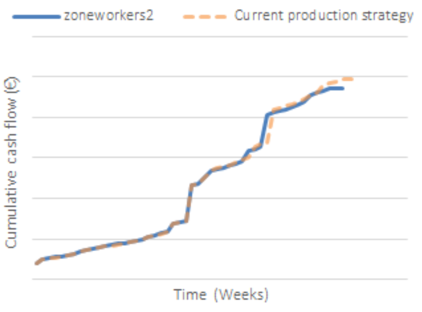

Figure E.3: Cash flow scenario 2 zone workers

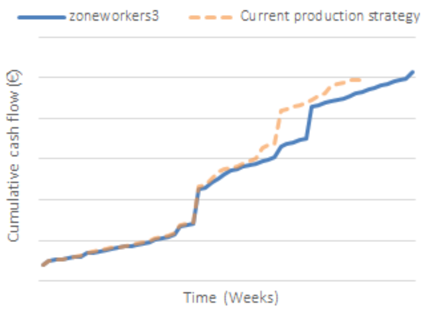

Figure E.4: Cash flow scenario 3 zone workers

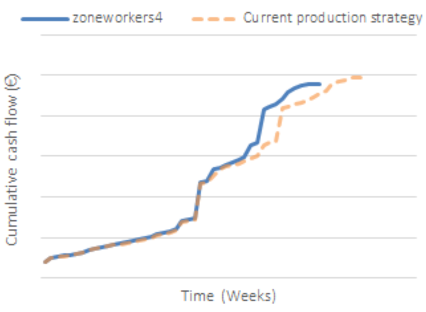

Figure E.5: Cash flow scenario 4 zone workers

PHASE EFFICIENCY

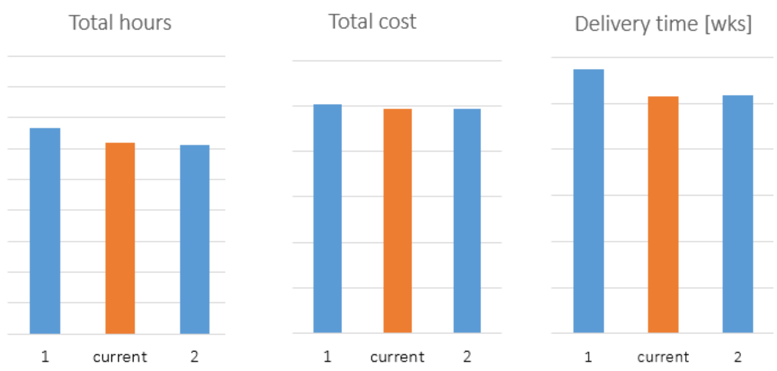

Figure E.6: Results of sensitivity phase efficiency

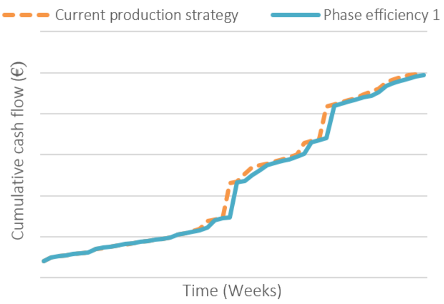

Figure E.7: Cash flow scenario 1 phase efficiency

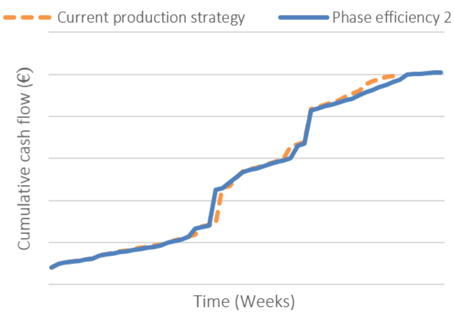

Figure E.8: Cash flow scenario 2 phase efficiency

PROMPT TIME PROPULSION SET

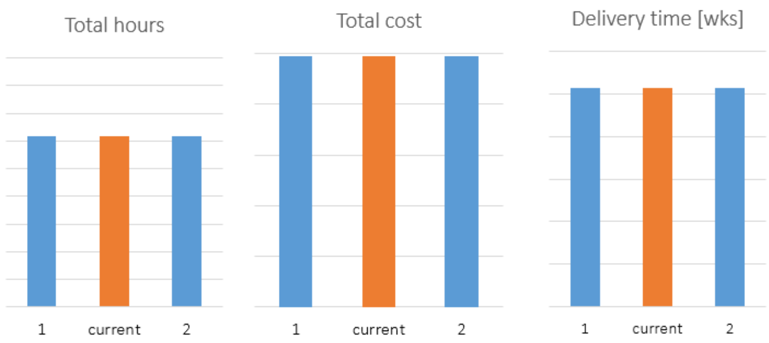

Figure E.9: Results of sensitivity prompt time

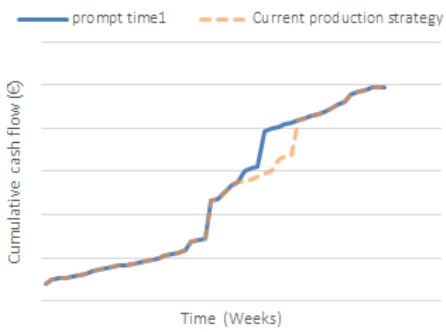

Figure E.10: Cash flow scenario 1 prompt time

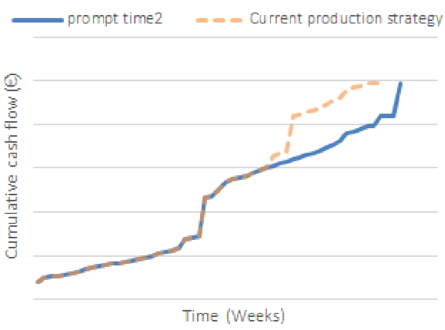

Figure E.11: Cash flow scenario 2 prompt time

E

MAXIMUM PERCENTAGE OF PRE-OUTFITTING

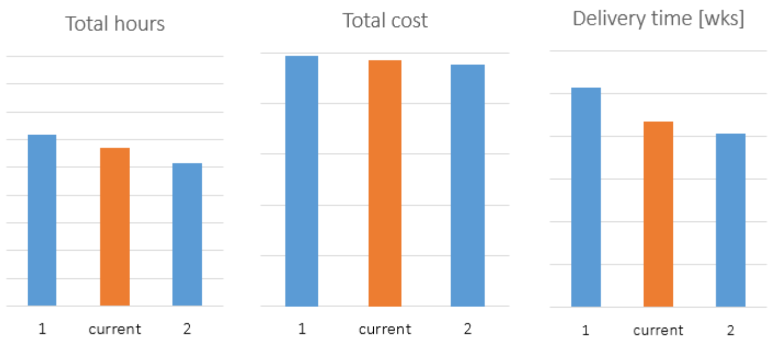

Figure E.12: Results of sensitivity pre-outfitting

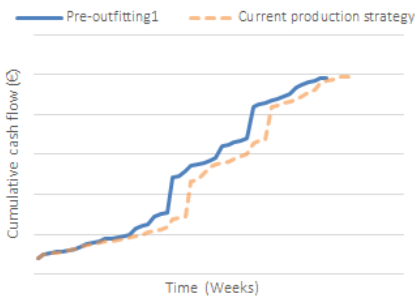

Figure E.13: Cash flow scenario 1 pre-outfitting

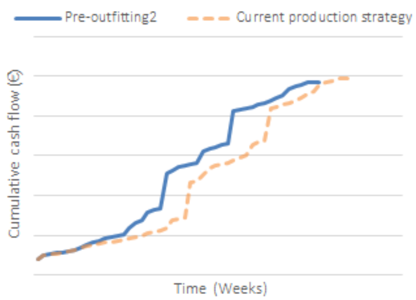

Figure E.14: Cash flow scenario 2 pre-outfitting

F
INTERVIEWS

In the first step of this research the factors that influence product standardisation modularity are determined. This is achieved through a structured assessment in the form of interviews. The interview questions are insprired by the survey questions Asli Sahin-Sariisik, Janis Terpenny, Eileen M. Van Aken & Nihal Orfi (2014)

In order to get an idea of the factors which influence standardisation and modularity it is also important to know and understand the current level of standardization and flexibility within Damen. The results of the interviews therefore not only applied to find potentials for standardisation but also to understand the current situation of how Damen deals with it. The interviews will contribute to the determination of common and unique modules across the product family Tugs.

In total 32 employees from different departments have been interviewed of which a list is presented in Table F.1 The interviews have been performed in a structured way with similar questions for each department of which a list is presented below;

- General questions
  To get to know the department, the department's function and responsibilities and its position within the company.
- Standardisation
  The main topic of the interview is standardisation which is introduced on a general level. What the department believes standardisation stands for, how standardisation is currently being applied within Damen and within the respective department are reflected.
- Opportunities
  The general questions are followed with more specific questions concerning the observations done during the diversity analysis. Potential fields for more standardisation within the production of tugs are being discussed in this phase of the interview.
- Challenges
  With the implementation of standardisation certain challenges arise which automatically follow from the previous topic.
- Communication
  Communication between different departments within the production chain plays

a important role in the implementation of standardisation. Especially in the standardisation of processes. Challenges and opportunities in the communication lines are being discussed here.

- Future trends
  It is helpful to know what the Damen employees expect from future developments on standardisation will be within the company.
- Suggestions
  Finally, advice is asked for further research, which other departments to interview and what strategy to apply.

This is the general structure of the interview questions. The themes covered differ between the departments. Product portfolio, product variety and customer service are discussed with the sales, services, business analysis and design and proposal departments. Building strategy details and the development of standard modules are handled with yard support and engineering. And finally supply chain management related topics are touched on with the interviews within the Excellerate group.

Table F.1: Interviewed employees from Damen Shipyards

	Interviewee	Function	Department	Date
1	Andre de bie	Design & Proposal Engineer (PG)	Tugs	29/03/2016
2	Coen Boudesteijn	Product Director Tugs	Tugs	13/04/2016
3	Dirk Degroote	Manager Design & Proposal	Tugs	22/03/2016
4	Leo de jong	Design & Proposal Engineer (PG)	Tugs	24/03/2016
5	Bas Damman	Assistent Project Manager Yard Support	Yard Support	28/04/2016
6	Jack Teuben	Project Manager (PG)	Yard Support	21/04/2016
7	Martin de Bruijn	Managing Director Workboats	Damen Workboats	02/05/2016
8	Joost van der Weiden	Assistant Project Manager	Tugs PM	05/04/2016
9	Will Veltman	Project Manager	Tugs PM	03/05/2016
10	Ernst Jan Goslinga	Technical Manager Engineering	Engineering Tugs	31/03/2016
11	Jeffrey Jacobs	Technical Manager Engineering	Engineering Tugs	01/04/2016
12	Joris van Tienen	Manager Engineering Tugs	Engineering Tugs	01/04/2016
13	Jos Verschuren	Project Manager Excellerate	Excellerate	29/04/2016
14	Frank Jan Mutsters	Project Manager Excellerate	Excellerate	03/05/2016
15	Koen Burgers	Program Manager Excellerate	Excellerate	01/04/2016
16	Laura bohlander	Planner	Management Projects	08/06/2016
17	Casper Visser	Business Analyst	Operations Support	07/05/2016
18	Koen Huethorst	Business Analyst	Product Group Support	15/09/2016
19	Martijn de Munnik	Project Engineer Services	Maintenance Planning	22/03/2016
20	Robert Jan van Houten	Project Manager Services	Maintenance Planning	22/03/2016
21	Richard Nugteren	General Manager	Cargo Vessels	29/03/2016
22	Erik Hertel	Manager Production (PG)	Damen Technical Cooperation PM	05/04/2016
23	Roland Briene	Sales Director Asia Pacific	Sales Area Asia Pacific	23/03/2016
24	Solco Reijnders	Sales Manager	Sales Area Americas	17/03/2016
25	Jaap Gelling	Managing Director High Speed Craft	Damen High Speed Craft	26/04/2016
26	Brian Mewis	Design \& Proposal Engineer (PG)	Damen High Speed Craft (BU)	09/05/2016
27	Toyah Kilver	Product Portfolio Manager	Damen High Speed Craft (BU)	23/03/2016
28	Jan-Peter Dragt	Product Portfolio Manager	Damen High Speed Craft (BU)	23/03/2016
29	Cees van Dijk	Supply Chain Manager Propulsion	Supply Chain Management	04/08/2016
30	Arno de Wit	Project Manager Mechanical Engineering	Engineering HSC/Fe	01/04/2016
31	Roald Bastiaansen	Mechanical Engineer	Engineering HSC/Fe	28/04/2016
32	Willem Haverkamp	Assistant Project Manager Eng. M	Engineering HSC/Fe	04/03/2016

G
Scientific paper

The benefits of implementing standardisation methods in the production of tugs

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Recently the buying power of customers has increased as a result of globalisation forcing manufacturers including shipbuilders to produce products with wider variety at lower delivery times. This research aims to optimise the traditional production strategy applied at Damen shipyards for the production of standard tugs. Three levels of standardisation have been investigated to reduce variety and increase commonality based on the platform-based product development strategy to reduce lead times and production cost. Level 1 main assembly, including the product portfolio configuration and main assembly activities such as; the production of standard sections on stock. Level 2 sub-assembly, which includes shifting outfitting activities from being performed on board to the workshop where standard and modular outfitting units are produced which fit different systems and components and are interchangeable between different ship types. Level 3 components, standardising within and between ship types to achieve a purchase advantage, increase in-house knowledge and improve service and quality. The effect of changing the production strategy to assemble-to-order instead of make-to-stock has also been investigated. A significant stock value reduction of 56% is achieved by changing to the latter production strategy. With the implementation of the three standardisation levels production time, cost and required manhours can be reduced by 36%, 11% and 24%.

Keywords: Shipbuilding; Standardisation; Platform-based product design; Production strategies; Modular outfitting; Production cost; Lead times

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1. INTRODUCTION

Damen Shipyards Group is one of the leaders in the shipbuilding world. The shipbuilding company delivers annually over 160 vessels of different types from 32 shipyards worldwide and keeping more than 200 hulls in stock, to guarantee quick delivery times, [3]. The different ship types they produce include workboats, offshore vessels, high speed crafts, ferries, yachts, pontoons and barges, dredging vessels and naval yachts. One of Damen's fundamental corporate values is the focus on standardisation. The modular building concept has already been applied for decades and still is unique in the ship building industry. Damen has developed a standard range in each of the niche markets they operate.

Although these vessels are based on a standard design, they can be equipped with a large range of options to meet specific customer requirements. When zooming in on an individual scale these standard vessels contain minor deviations such as length, width, machinery and other installations which in the end have a significant impact on the production time and cost.

Additionally, over the years a trend has developed in which the customers buying power has significantly increased as a result of globalisation forcing many manufacturers including shipyards to produce an increasingly wide variety of products with shorter delivery times, [2].

Previously, one product could answer most needs, and engineering methods and tools focused primarily on design, development, and deployment of a single product. Todays market is much more fragmented, and niche markets can no longer be ignored, [14]. With this trend, the traditional approach towards product development will increase costs and throughput times notably.

With the rapid growth of Damen Shipyards, the wide variety of products they offer and the increased customer buying power, a closer look has been taken at the efficiency and advantages of their traditional production strategy.

Inspired by highly efficient production processes such as line production and platform-based product development a high level of standardization seems to be achievable whilst maintaining sufficient diversity within a product portfolio. Different ship types can have interchangeable standardised platforms besides the well-known levels of luxury and add-ons which are additional options. Within the numerous product portfolios that Damen boasts, it should be possible to achieve similar benefits for production, leading to overall cost reductions.

This research is an evaluation of the possibility to increase the efficiency of production by implementing the aspects of line production and the platform-based product development strategy on the Damen Product Group Tugs. Therefore the main question of this research is:

"Which levels of standardization provide Damen Shipyards with the most advantages?"

In this research multiple levels of platform integration with different degrees of standardisarion will be defined and their effect on the costs and efficiencies of production will be investigated. The focus of this research will be on the relation between three major elements; the number of equal elements, the effect of these elements on production time and cost and the flexibility of final products.

Within this paper the following topics are covered; in section 2 the theoretical background is found, Section 3 explains the current production strategy applied at Damen Shipyard. Section 4 elaborates on the three standardisation levels to be implemented. Section 5 describes the mathematical model applied to calculate the production cost and time. The results and conclusion are found in Sections 6 and 7.

2. THEORY

Currently, the majority of the manufacturing industries strive to maximize profits by finding ways to reduce development and manufacturing costs while simultaneously satisfying diverse customer demands by keeping their product portfolios diverse. This section provides background information on how product variety and volume influence the applied production process and the platform-based product development method to reduce manufacturing costs while maintaining product variety.

2.1. Production processes

It is important to get an insight in how product variety and volume influence the applied production process. Low-volume operations processes often have a high variety of products and services, and high-volume operations processes often have a narrow variety of products and services. Thus there is a trend running from low volume and high variety in job shop production to high volume and low variety with continuous flow production, on which operations can be positioned as presented in Figure 1. Complex one-off shipbuilding is an example of low-volume and non standard production which will be different per project also known as the job shop production process. On the the other hand refining and transportation of oil is done in high-volumes with a standard configuration of materials and ingredients which is produced according to the continuous flow production process, [19].

Damen's standard vessels are produced in small series

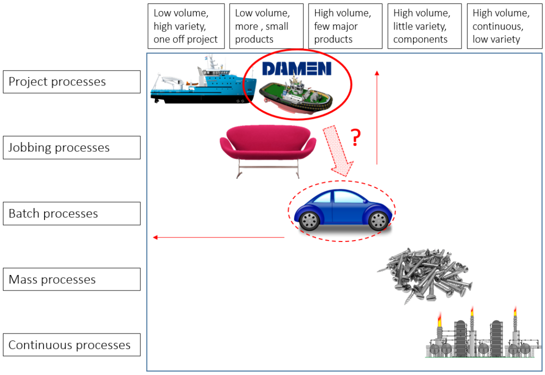

FIGURE 1. Process types for various volume and variety characteristics of the process

between three and ten vessels per year. The position of Damen products in the production process matrix is shown in Figure 1. Because of higher standardisation levels during production and the serial character it is positioned slightly to the right of the one-off shipbuilding example. However the production process in which Damen's vessels are being produced is job shop. Damen aims to optimize its production process towards line flow to reduce cost and time. This shift of production process has already successfully been performed in the automotive and aviation industries. Two main changes which are necessary to make this shift possible are an increase in the size of series production and a decrease in product variety.

When looking at the shipbuilding industry, most yards apply the project or job processes. Varying requirements of the customer, thousands of components and long throughput times require good planning, preparation and communication between the different stakeholders. However, this process can still be improved by implementing characteristics of the other processes. To speed up the shipbuilding process and reduce production cost one should aim to reduce variety and increase the batch size. This does not necessarily mean that the batch size of the end product should be increased but that the variety in equipment, components or even sections could be reduced. This will lead to larger series, the possibility to apply batch processes on a smaller scale and therewith reduce throughput times due to higher production efficiencies.

2.2. Customer Order Decoupling Point

Another factor which concerns manufacturing and supply chain operations is the Customer Order Decoupling Point (CODP). The CODP is the point in the material flow of manufacturing where the product is tied to a specific customer order [12]. The CODP contributes to the alignment between operations in a firm and the market requirements and is used as a reference point for deciding which manufacturing operations and supply chains to use. The main manufacturing strategies include make-to-stock, assemble-to-order, make-to-order, and engineer-to-order, each with a different position of the CODP, illustrated in Figure 2. It can be seen in the

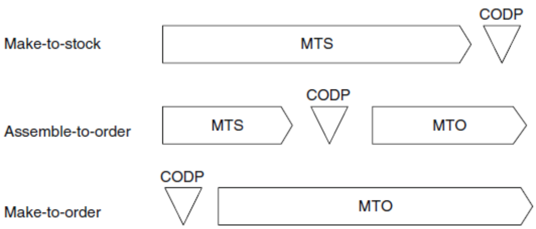

FIGURE 2. Customer Order Decoupling Point, [12]

figure that the CODP can be positioned at different stages of the production. When make-to-stock is applied the COPD is positioned more towards the customer or downstream where finished goods are delivered from stock. In assemble-to-order the CODP divides the manufacturing operations into forecast-driven operations and order-driven operations. Forcast-driven operations are upstream of the CODP and customer order-driven operations are downstream of the CODP. In make-to-order and engineer to order the CODP is positioned at the start of the supply chain, where production starts after an order is placed.

2.3. Series effect and learning curve

When a certain activity is repeated several times, less time is needed to perform this activity and the performance will become better at it. This process of learning can be illustrated with learning curves. Learning curves show the amount of work needed to be performed to produce a certain number of units. As number of repeated units produced increases, it can be seen that the amount of work required to complete them reduces. The learning rate is a percentage which states how much time of the first unit is needed to complete the double amount of units, [9].

2.4. Platform-based product development

To reduce development and manufacturing cost while keeping product portfolios diverse enough to satisfy the customer the platform-based product development method can be applied, [18]. This method is based on the production of modular platforms which have the same interfaces and are therefore interchangeable between different product types. It supports the manufacturer to create a family of products which share common platforms with identical components, modules or equipment, [4]. Applying a platform product strategy can lead to multiple advantages including a reduction in overall production costs and development time, [5].

Examples from different industries which have already successfully applied line processes and platform designs for their products are the automotive industry [16, 17, 22], aircraft industry [7, 8, 18] and software developers, [13].

It should be taken into account that these industries differ greatly from the shipbuilding industry in several aspects such as series size, decision ownership and in customer requirement volatility, [14]. To successfully implement the product platform approach, this high degree of product customisation should not be affected or customers should be convinced that the benefits outweigh the decreased customisation potential. It is therefore a great challenge to find the optimal ratio between reducing variety and offering customization within shipbuilding.

2.5. Production and modularity at Damen

Damen shipyards builds complete (standard) vessels with a make-to-stock strategy based on market predictions and can therefore deliver vessels to its customers faster than its competitors. Damen's standard vessels are produced in small series ranging from one to ten vessels per year. Damen Shipyards is aware that the efficiency of their traditional production strategy needs a closer look and has recently been focusing on improving efficiency and decreasing production time and cost. Several projects and pilots have been launched to make their production process more efficient and industrial. Two of these initiatives include the integrated building strategy (bottom hat principle) and Design for production (D4P), [20]. The integrated production strategy is based on producing sections upside down in order to perform hotworks underhand, rather than uncomfortably overhand, after which the section is turned and placed into position. D4P is based on taking production strategies into account during the design phase to make production easier. Excellerate is another program which focuses on optimisation and standardisation of the production process at Damen. The main goal of Excellerate is to bring working with standards to the next level in a multinational environment thereby realising shorter lead times and reduced production cost, [2] . These standards are achieved by creating a Damen Standard Product Approach which includes clear and standard process structures, systems, solutions captured in handbooks and parts captured in the a catalog.

Decision moments

On the longer term Damen wants to continue improving the efficiency of their building strategy with the aim to reduce production time with 50%. This will affect the current production strategy applied. Currently, one month prior to the start of steel cutting it is decided which ship type will be produced, this is the release date of the Unrestricted Action List (UAL). After the UAL release date, long lead items such as propulsion sets are ordered. As a result of reduced lead times the order moment of long lead items in order to be delivered on time during production will have to take place before the UAL release date, creating a contrasting situation. This problem can be solved by taking long lead items on stock. After the UAL release date stock will be replenished and production can continue without having to wait for the delivery of long lead items, as presented in Figure 3.

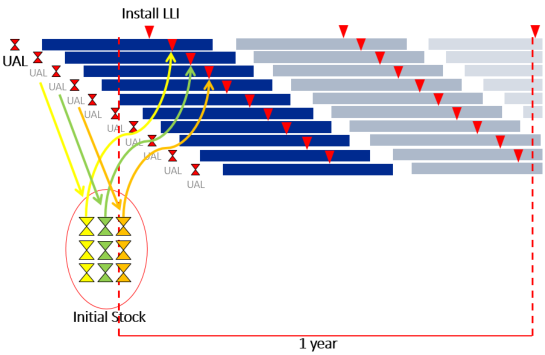

FIGURE 3. Production planning including standard platforms

2.6. Production Strategy

The production strategy of the ASD2810 build at Damen Galati is used as a base case for this research and represents the production for a single vessel. The building strategy for this vessel has already been evaluated and used in previous research [11], and has been applied in this research to find the factors which determine the production cost and time and evaluate the impact of different levels of standardisation on them.

Total Cost

Production costs determine to a great extent the profit that can be made. The further costs can be reduced the more profit can be made. Therefore it is import to know which parameters determine the cost and how high they are linked. The piechart in Figure 4 shows the different items which together form the total production cost for a vessel. The major expense groups are machinery and equipment, shipbuilding, construction materials, joinery and general items.

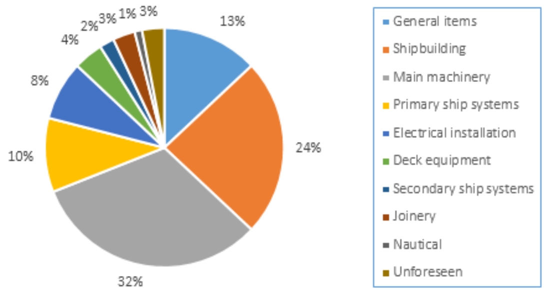

FIGURE 4. Cost division current building strategy [11]

Production phases

The Work Breakdown Structure presented in Figure 5 shows the three main phases for hull production consisting of a section phase (the bottom row), a block phase (the middle row) and an assembly phase in which the blocks are assembled into two zones (top row) which are finally attached to form the complete hull. Workshop activities can be performed parallel to these three phases and trials are performed when production is completed. This framework forms the base for scheduling smaller activities and to determine throughput times and production costs of outfitting activities.

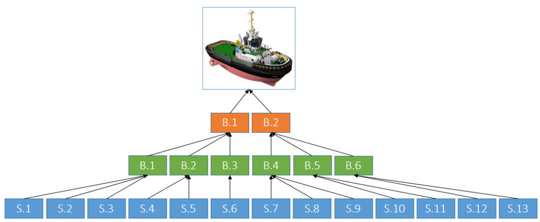

FIGURE 5. Work Breakdown Structure showing production phases

Activities

Thousands of activities are carried out during production. However only a few activities determine the length, required work and cost of production. Activities and equipment with a price tag equal or more than

1% of the total project costs are assigned to an activity in outfitting or installation. Activities with long durations and labour requirements are also selected and where necessary, they are grouped into larger activities with the help of value stream maps and planning of the Damen Galati yard. In total 25 activities are selected. Activities can take place in multiple phases, for example the activity "Hot works" is split in "Hot works Engine Room (ER)" and "Hot works Accommodation and Wheel House (ACC + WH)".

Activity cost

Production costs strongly influence the operating income that can be generated by production, therefore it is necessary to determine the building strategy variables that influence the production costs.

The costs have been split into shipbuilding costs for the three phases, outfitting costs for the selected activities, individual costs including large equipment and general costs which covers start-up costs and trial costs, [11]. Instant cost are paid at the start of an activity and linear cost are paid weekly during the progress of that activity. General costs include buy-in costs for steel, start-up costs and fixed weekly costs including rent, electricity and project management costs.

Linking variables

The production strategy variables are linked to each other to form 13 sections, which are assembled to 6 blocks and finally into 2 zones which will together form the hull which requires outfitting and painting activities in the final phase.

Required manhours and durations are linked with equations taken from previous research and literate, [11, 10] to the production variables and activities. Next, the production variables are linked to cost. These calculations are used to determine the final production cost, cashflow, duration, required labour. This theoretical model will be used as a base to develop a computerised mathematical model which simulates the current production strategy and determine the effect of different standardisation levels.

3. STANDARDISATION LEVELS

Platform-based product development, the learning curve and the creation of standard templates can be applied in their own way within different phases of the production process to finally achieve higher efficiencies in production and reduce costs.

This section discusses the implementation of the before mentioned methods on three different levels of the production process of tugs. The potential savings described in this section will be used to calculate the impact on production time and cost.

3.1. Level 1 Main assembly

The first and highest level of standardisation is on a main assembly level including the standardisation of the product portfolio and main assembly blocks of the vessel. The Damen Shipyard's product portfolio for tugs has been analysed to develop a more compact portfolio with reduction in variety of 40%. The development of a more compact product portfolio leads to less variation and greater volumes of the end products. This will contribute to a faster production process such as the batch process and will lead to shorter throughput times and lower production costs. Additionally, especially the wheelhouse and deckhouse sections have the potential to be produced in even higher volumes when they are produced as standard sections which can be placed on multiple ship types. Also, with less variation is is easier to change the production strategy from a make-to-stock to an assemble-to-order strategy with the production of standard sections on stock rather than complete hulls.

3.2. Level 2 Sub assembly

The second level of standardisation goes more into detail and includes standardisation and modularisation of outfitting based on the platform-based product development method. Making outfitting modular means that outfitting activities are no longer performed during section or block assembly and final outfitting but in the workshop. Hotworks, piping activities, the production of skids for (large) equipment and floor frames will be pre-produced and tested in the workshop and assembled as one module in one go on board. These assemblies produced in the workshop can be placed on board of different ship types within the product family. The outfitting modules should be developed to fit different types and sizes of equipment, pipes or systems. Modular outfitting requires a high level of detailed measuring and pre-engineering for the development of these units [6], but will significantly reduce production time and cost. On the long term these assembly units can cover the total range of system capacity on board of different ship types across multiple product families and quality and experience of maintenance engineers will increase due to a reduction in components [14].

3.3. Level 3 Components

The third level of the pyramid focuses on standardization on a component level within and between different ship types. Literature shows that in shipbuilding and especially for complex ships the value of purchased materials and components is a very important and contributes for a major part to the overall product costs, [15,14]. Damen Shipyards is concerned with this topic and is currently implementing this standardisation level through the Excellerate program. By reducing the variety of component types and standardising them between different vessel types within a product family, engineering work will reduce, purchase advantages can be gained, fewer parts to be stocked in inventory are needed and installation and maintenance time and cost can be reduced [18].

4. MATHEMATICAL MODEL

In order to prove that the implementation of the above presented standardisation levels into the current production strategy and switching to an assembly-to-order strategy will provide Damen with shorter production times, reduced cost and more flexibility a mathematical model is required. This section describes a computerised mathematical model which consists out of two sub-models; the building strategy model and the production strategy model and an excel calculation as presented in Figure 6.

4.1. Approach

The requirements for the model are based on the information gained during the literature study and after analysing the current building strategy. The requirements are for the mathematical mode include:

- The model needs to be able to calculate the effect of implementing the three standardisation levels on production cost and lead times.
- The model needs to be able to calculate the initial stock required when switching to an assembly-to-order strategy in which propulsion sets and sections are held on stock.
- The model needs to be able to give a financial indication of having propulsion sets and sections on stock compared to complete hulls.

The following Figure 6 presents the setup of the mathematical model including the two sub-models (in orange) and the excel calculation (in green) which will be explained in more detail in the following sections.

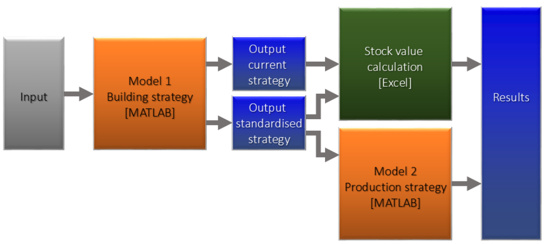

FIGURE 6. Model Setup

- The *building strategy model*, connects the production strategy variables and costs explained in Section 2.6 to calculate the total throughput time, cost and required manhours for the current production of a single vessel. When this is done, the standardisation levels defined in the previous section can be implemented into the same model to calculate the throughput time, cost and required manhours for the standardised building strategy.
- The output of the first model is used as input for the *production strategy model* which calculates the initial stock values for sections and propulsion sets for the yearly production of a complete product portfolio. This is done in five steps.
- The output of the first model is also used for the *stock value calculation* of the current production strategy and the stock cost for an assemble-to-order strategy where sections and propulsion sets are kept on stock.

The results of this calculation model include the total production time, cost and required manhours for a single vessel built with the current and standardised building strategy, the yearly stock costs of the having hulls on stock for the current production strategy, the yearly stock costs of having sections and propulsion sets on stock for an assembly-to-order production strategy and the initial stock values of sections and propulsion sets for a yearly production of tugs.

4.2. Building strategy model

It is good to know how the cost of producing of a vessel are built up when looking at the total production cost. This can be done with a cash flow pattern. A cash flow pattern is strongly related to the sequence of production variables and therefore a scheduling model is required. This model links the variables and places them in the right order. The different variables and order of activities to make this model have been explained in Section 2.6.
The building strategy variables in this model determine the cost and duration of activities and if costs take place instantly or linear through the activity duration. Activity durations and the amount of work done parallel are combined to derive the required labour.
To implement the different standardisation levels, the number of variables, the relation between them and the cost should be easy to change.

In previous research T.J. Hoekstra [11] has developed a mathematical model in the software package MATLAB to calculate the production time and cost of a single vessel produced at different shipyards for various building strategies. In his research the mathematical model optimised the building strategy for each yard. His model has been used in this research as a base for the building strategy model to calculate the production time and cost of a single vessel. However, in this research the the building strategy is fixed and not optimised. The model is used to calculate the total production time, cost and required manhours for two strategies. First, the current building strategy and after that the standardised building strategy. The building strategy is based on the production of an ASD2810 produced at the Damen Galati shipyard (DSGa).

The output delivered by the first model includes the total production cost, total required manhours, delivery time in weeks and the cash flow showing a weekly overview of how costs are divided over time for a single vessel.

4.3. Production strategy model

Now that the throughput time and cost are known, the calculation can be performed to find out whether it is beneficial to switch to an assembly-to-order production strategy and produce sections and have long lead items on stock, as explained in Section 2. The reduced production time calculated in the previous model is used as input for the throughput times in the second model (see Figure 6) in which the required stock for long lead items and sections is calculated for the yearly production of tugs.
This model takes the yearly production of the complete range of tugs into account. Collecting data and calculating the production time and cost for each individual ship type in the portfolio takes too much time and a large amount of this data is not available. To still model this with the available data and within the set time a simplification step is done. The production data of a single vessel provided by the building strategy model is used to model the production of the complete product range. This means that the ASD2810 represents all tug types produced in 2015. Even though the production times and cost for each phase, section, activity and item are the same, the ship types, sections and long lead items are separated by type. For example a series production of five RSD2513 tugs is modeled as a series of five ASD2810's with the same throughput time and cost but its ship type, section types and propulsion set type are defined with specific type numbers. Through this simplification step it is possible to give an indication of the initial stock levels of the different sections and propulsion sets at the start of the year.

In short, this means that each vessel including all sections have the same total throughput time and cost and that the ship, section and propulsion set types are specified by a type number in this model to calculate the required stock levels for a yearly production.

The output of the model gives a daily overview of the vessels in production, the stock levels of the propulsion set and sections and the financial commitment per propulsion type and section. The results provide an overview of the initial stock, intermediate stock levels and whether the initial stock is large enough to cover the yearly production.

4.4. Stock Value calculation

This section presents the impact of switching from a make-to-stock to an assembly-to-order production strategy.
Several assumptions have been made to express and compare the cost of having vessels and sections on stock. Firstly it is assumed that there is a constant stock of one vessel per ship type. This means that when a certain vessel is sold, a new vessel is added to stock, keeping the stock constant to one vessel. The same is done for the sections of the standardised portfolio, a constant stock of one per section type is present at all times.
Secondly, the following equation is applied to calculate the mean yearly stock value assigned to a respective vessel. This equation is also applied to calculate the stock value of sections.

$$Stock\,Value = Vessel\,price * \frac{1}{\#\ vessel\ type\ sold\ per\ year}$$

The vessel price for all vessels is assumed to be the same for each ship type in the portfolio and excluding trial costs and for the sections it is calculated separately excluding trial and assembly cost. The Damen Baseline (which is a prediction of coming sales) for the coming year has been taken as the input for this calculation. This equation has been applied to each vessel type in the baseline for the current portfolio, each vessel type in the baseline for the standardised portfolio and for each section present in the baseline of the standardised portfolio.

4.5. Verification and validation

The simulation model of this research has been validated and verified according to the verification and validation methods described by Robert G. Sargent [21]. The data is verified with sufficient and reliable data sources, the conceptual model is validated by checking the methods applied, the computerised model is verified on mathematical correctness and the results are checked with a sensitivity analysis by adjusting important variables. It is also checked if the activities are linked correctly and if the (intermediate) results correspond to what is expected of the model.

5. RESULTS

This section presents the impact of implementing the three standardisation levels into the current production strategy at Damen Shipyards on production cost, lead times and required labour. The following subsections give the results per standardisation level.

5.1. Level 1. Main assembly

The first level of standardisation mainly influences the series size of vessel types, sections and propulsions sets being produced, assembled and ordered on stock. On an activity level it influences the activities involved in the production of sections on stock. Being critical about the configuration of the product portfolio, reducing the variety in offered ship types and increasing the commonalities, such as the development of standard deckhouses and wheelhouses leads to the production of larger series of vessels and its sections. Especially delivery times will reduce due to serial production. The total throughput time of vessel delivery will reduce with 10% when taking the average series size of the yearly production of vessels and sections for the proposed standardised product portfolio. An additional cost reduction of 5% and hour reduction of 2% can be achieved with serial production leading to the third best opportunity for Damen Shipyards. Shifting to an assembly-to-order strategy in which propulsion sets and standard sections are held on stock rather than complete hulls will have a huge impact on Damen's production strategy which is currently make-to-stock. Up to 56% can be saved on stock value cost when keeping standard sections on stock and assemble them when an order comes in.

5.2. Level 2. Sub assembly

On a sub assembly level, the implementation of modular outfitting will affect the order of activities. Outfitting activities which include hotworks and piping will partially be shifted to earlier phases and to the workshop. Work in the workshop is performed faster due to higher efficiencies, better working conditions and equipment can be tested before being installed on board. Other activities will be performed with higher efficiencies because more space and better working conditions are created by moving work to the workshop. The total lead time can be reduced with 28% and the required hours with 20%. Cost will also reduce but with a lower rate of 4%.

5.3. Level 3. Components

On a component level primarily money can be saved by making components standard and interchangeable between different ship types so they can be purchased in larger batches. This will lead to reduced purchasing cost and lower transport cost. Also if the variety between components is reduced the in-house knowledge about the products is increased, leading to better maintenance programs and less investments to train maintenance workers. Standardising components within ship types and between them will provide Damen Shipyards mainly with a drop in costs of 5%.

Total results for standardised production strategy
The results of implementing all three levels of standardisation into the current building strategy for the production of tugs are promising. Production time can be reduced with 36%, production costs with 11% and the required manhours with 24%. The total throughput time can be further reduced to less than 50% of the current lead time by working in two shifts.

5.4. Additional improvement

The total lead time is reduced to less than 50% of the current lead time by working in two shifts. The cash flow pattern for the current (orange) and standardised building strategy (blue) with one shift and the standardised stratgy with two shifts (green) are presented in Figure 7. When comparing the two shift graph to the current single shift graph, it can be seen that both cost and lead time are lower. The total lead time of the two shift standardised building strategy is less than half compared to the lead time of the current single shift strategy with 7% less required labour and at 4% lower cost.
Additionally the vertical solid lines in figure 7 represent the moment the hulls are ready for stock for the respective production strategies and the dotted vertical lines represent the moment sections are ready for stock. When zooming in on the moment that hulls and sections are ready for stock it can be seen that both the completion of sections and hulls is significantly earlier for the two shift standardised strategy than the current strategy.

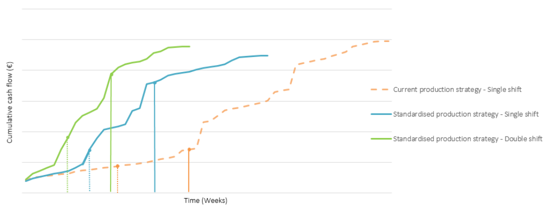

FIGURE 7. Cash flow of doubling shift

5.5. Initial stock

This section elaborated on the effect of storing propulsion sets and producing standard sections on stock. The yearly production of the product portfolio for the year 2015 has been modeled to gain this information. When changing the portfolio into the proposed standardised portfolio with the standardised building strategy with reduced production time and cost, the number of vessels will be reduced to eleven different ship types. As explained in Section 3, the wheelhouse and deckhouse have the most potential to be produced on stock. With the new product portfolio and standardised propulsion sets there will be a stock of nine different propulsion systems, four deckhouse variants and three types of wheelhouses. In the production strategy model the size of the initial stock levels of propulsion sets and sections needed to fulfill yearly production requirements is calculated. The initial stock levels required for the propulsion sets range between 1 and 11. The production of sections to replenish stock is completed before the sections have been removed from stock for assembly. This means that for the production of wheelhouses and deckhouses, no stock is required. Only sections which are needed before the production is completed should be held on stock, like afts.

6. CONCLUSIONS & RECOMMENDATIONS

In this research three levels of standardisation have been defined with the help of standardisation methods and the platform-based product development strategy to increase production efficiency and decrease production cost and throughput times. These standardisation levels have been implemented in the current production strategy applied at Damen shipyards with a computerised model in order to define their impact on the production cost, lead time and required labour. This sections answers the main reseach question in the enumeration below and finished with a discussion and recommentations for further research.

Level 1. Main assembly
The first and highest level of standardisation is on a main assembly level including the standardisation of the product portfolio and main assembly blocks of the vessel. Reducing variety in ship types being offered to the customer and increasing the commonality between them will increase efficiency and reduce production time and cost.

1. Being critical about the configuration of the product portfolio, reducing the variety in offered ship types and increasing the commonalities, such as the development of standard deckhouses and wheelhouses leads to the production of larger series of vessels and its sections. Additionally, shifting to an assembly-to-order strategy in which propulsion sets and standard sections are held on stock rather than complete vessels has a huge impact on Damen shipyards's production strategy which is currently make-to-stock. Apart from the 56% financial advantage, this shift will provide Damen Shipyards with multiple other advantages. Firstly, having semi-finished products, like sections on stock instead of complete hulls will save maintenance cos, because they are stored on land rather than in (salt) water. Additionally, due to the short production time, sections will be less affected by material price fluctuations such as steel compared to complete hull production. Finally, producing hulls on stock based on market predictions has a great risk with it. Whereas combining sections from stock to assemble vessels according to customer's wishes has a significantly lower risk.

Level 2. Sub assembly
This level of standardisation is based on the implementation of standard platforms produced in the workshop, which can be placed on multiple ship types and can be used for different categories of equipment. Work can be performed more efficient in the workshop than on board due to better working conditions. Hotworks, piping activities, the production of modules for (large) equipment and floor frames will be pre-produced and tested in the workshop and assembled on board as a whole. This requires a high level of detailed measuring and pre-engineering for the development of these units, but will significantly reduce production time and cost.

2. The implementation of modular outfitting mostly influences the production time and required manhours, reductions of respectively 28% and 20%. The effect of this implementation has potential to be much larger for Damen when developing standardised modular assembly units, skids and frames which can be placed on board of tugs of multiple product families. This promotes serial production and purchase advantages which will lead to further reductions in cost and production time. Also, the implementation of standard modular assembly units does not require large investments nor large changes in the production strategy and can be implemented on a short term.

Level 1. Main assembly

3. As a result of reducing variety in the product portfolio and increasing commonalities between vessels and sections the batch sizes of production will increase. When vessels and sections can be produced in larger series, Damen will benefit from serial production. Delivery times will reduce due to serial production leading to the third best implementation for Damen Shipyards.

Level 3. Components
The third and most detailed level of standardisation is on a component level. Damen is already concerned with this topic and is currently implementing this standardisation level through the Excellerate program. By reducing the variety of component types within and between different vessel types, purchase advantages can be gained and installation and maintenance time and cost can be reduced. Standardising components between multiple ship types and therewith gaining a purchase advantage has great impact on the total

production cost.

4. Standardising components within ship types and between them will reduce the number of suppliers and will provide Damen mainly with a cost advantage (5%). Even though the implementation of this level of standardisation provides Damen with the least advantages, it contributes greatly to the other levels of standardisation and has a lot of potential to increase its impact. When components become standardised, it is easier to develop standard assembly units and the batch size will increase, which will lead to lower development time and cost. Standardising components will also lead to a higher degree of knowledge of the products which helps to do better life cycle asessments leading to better, faster and higher degree service and maintenance programs. Additionally, by sourcing components locally transport time and cost can be saved. Finally, when Damen reduces the number of suppliers and increase standardisation of its components Damen can benefit from closer cooperation with suppliers, for example by including them in the product development phase. This will help Damen to gain more knowledge of their products and maintain its position as as a shipbuilder using high quality state of the art technology.

6.1. Discussion

This section covers the decisions and assumptions made for the simulation model in this research. Firstly, the production strategy for the ASD2810 is chosen as a base case and represents the complete Product Portfolio Tugs which includes a large range of different ship types. It is assumed that the results for this vessel is scalable to other ship types considering throughput times and cost of activities which is in reality not completely true. As already stated in the introduction, it should be kept in mind that this research is an economical feasibility study and does not take detailed design and engineering requirements into account. Secondly, it is assumed that all activities in the simulation model are performed as planned, without delays, rework or other additional costs or delays, which is usually not the case in reality. Additionally, it should be taken into account that the efficiency improvements for performing outfitting activities in the workshop and gains from the purchase advantage will only take place after training of employees. It is expected that the learning effect is noticeable on the longer term and when serial production is taking place and not instantly. This is why three scenarios have been selected with increasing efficiency between the first and third scenario. Finally, the production and storage of sections and propulsion sets have been based on a baseline, which is a prediction of the market demand for the coming year. Demand may increase when the economy will improve, which would result in different numbers for the stock value.

6.2. Recommendations

In this section several recommendations for Damen Shipyards and further research are presented. It is not expected that all levels of standardisation can be implemented simultaneously and within the same time frame. Therefore it is recommended to start or actually continue with the implementation of modular outfitting. The pilot for the ASD2913 has already implemented skids and frames for the engine room produced in the workshop with promising results considering throughput times and cost. The number of skids and frames can be significantly increased and should have a modular design to be interchangeable between different ship types. It is expected that this will have the largest impact on the shortest term. The development of standard modules is associated with standardisation on a component level. This will lead to a substantial decrease in procurement cost due to larger purchase batches.
Another recommendation is to increase the cooperation between the different optimisation pilots and programs running within Damen. Results from interviews show that many initiatives are running to increase efficiency, however independently from each other. Collaboration between the initiatives from different product groups, yard support and Excellerate will lead to the best achievements.

Several observations have been made during this research which are interesting for further research. It has been proven that serial production of sections on stock will decrease the stock value considerable. It would be interesting to investigate how and where the production line of these sections should take place to take maximum advantage of this implementation. Additionally, it has been mentioned that Damen should produce ship types solely at one yard, again to gain from serial production. It would be valuable to investigate the optimal location for production of the respective ship types. Also, standardising compartment arrangement has not been included into this research but would be valuable to take into account in further research and will most likely save engineering time. Finally, it would be meaningful to know to what extent modular outfitting can be implemented on ship types from other business units such as high Speed Craft (HSC) and Offshore and Transport (O&T). This could result in the development of standard modules with the potential to be produced in large series, saving substantial time and money.

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