Matching the yard and product portfolio of Damen Shipyards

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DAMEN

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

Matching the yard and product portfolio of Damen Shipyards

By

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Performed at

Damen Shipyards Gorinchem

This thesis (SDPO.17.011.m) is classified as confidential in accordance with the general conditions for projects performed by the TU Delft.

19/06/2017

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Preface

This thesis research was undertaken as part of the completion of the master Maritime Technology with specialisation Ship Production at Delft University of Technology. This research is done in cooperation with Damen Shipyards Gorinchem.

The aim of this research is the matching of the yard and product portfolio of Damen. In order to answer the research question, a computerized model is made. The purpose of the computerized model is to make it easy understandable for Damen what the optimal yard portfolio, own capacity and flexible capacity is under different circumstances.

I would like to thank my daily supervisor at Damen ir. J.J.B. Teuben and dr. ir. J.F.J. Pruyn from the TU Delft for their guidance and support throughout the process of writing my thesis. I also would like to thank the Damen Shipyards Group for giving me the opportunity to complete my thesis research as a graduate intern at the Yard Support department in Gorinchem. Finally, I would like to thank my parents for their support throughout my entire study.

Ruben Huygen
Gorinchem, 10th of May 2017

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Summary

Damen Shipyards Group, an international family-owned shipyard group with Dutch roots and headquarters in Gorinchem, started with just one single shipyard in 1927. Today, Damen has grown into a multinational shipbuilding group with more than 9000 employees and clients in over 100 countries. The company delivers up to 180 vessels each year. Damen has around 300 ships in their portfolio that can be built at their own new building yards or at partner yards in the world. Over the years the product portfolio changes, new products are developed and others are removed from the portfolio. Together with the very diverse and changing order intake, it is difficult to match the yard and product portfolio.

Damen wants to have a better match between the yards production capacity and product portfolio. Therefore, Damen wants to research if matching of these portfolios is possible to minimize the costs of underutilization in a recession. At the same time when the economy is booming, Damen wants to be flexible and add additional capacity to their minimal production level if needed to ensure they doesn't miss any opportunities. Given all these aspects, the following main research question can be formulated:

What is the optimal yard portfolio, own capacity and flexible capacity of Damen under different circumstances?

In order to answer the research question, a computerized model is made. Given a product portfolio to be delivered in a year a match can be made with the yard production capacity to minimize the costs. The focus for optimization of the capacity will be on the products build for Damen Gorinchem at own yards in the Gorinchem cluster. Projects at partner yards of the Damen Gorinchem cluster are a flexible layer. When ships cannot be built at own yards, partner yards can build whole ships or hulls. The yards in Table 1 are own Damen yards in the Damen Shipyards Gorinchem newbuilding cluster.

Table 1: Own yards in the Damen Shipyards Gorinchem newbuilding cluster (CNBD)

Yard	Type of yard	Country	Abbreviation
Damen Dredging Equipment	Outfitting yard	The Netherlands	DDE
Damen Shipyards Antalya	Complete shipbuilding	Turkey	DSAn
Damen Shipyards Changde	Complete shipbuilding	China	DSCh
Damen Shipyards Galati	Complete shipbuilding	Romania	DSGa
Damen Shipyards Gorinchem	Outfitting yard	The Netherlands	DSGo
Damen Shipyards Kozle	Complete shipbuilding	Poland	DSKo
Damen Shipyards Singapore	Complete shipbuilding	Singapore	DSSi
Damen Song Cam Shipyard	Outfitting yard	Vietnam	DSCS
Damen Yichang Shipyard	Complete shipbuilding	China	DYS

When looking more into detail, Damen Dredging Equipment, Damen Shipyards Gorinchem and Damen Song Cam only do the outfitting of ships at this moment. The hulls for Damen Shipyards Gorinchem and Damen Song Cam are being built most of the time at partner yards that are not included in the own Damen Shipyards Gorinchem newbuilding cluster yards. Damen Dredging Equipment gets it cutter suction dredgers hulls most of the time from own yards, for example Damen Shipyards Kozle.

The shipbuilding labour hour capacity of the yard in hours will be matched with the needed capacity in hours to build several ships per year. Using the wage rates the most cost optimal matching of hours is

possible. Ships have to be transported from the supply region to the demand region. To find the optimal yard portfolio, the combination of the summation of the total labour cost at the yard and the transport cost needs to be the cheapest as possible.

The output of the model is the optimal allocation of ships over the selected Damen yards in different situations. Based on this calculation, the board can decide which decisions it will make. Using this optimization, the Damen core yards, together with their minimal production level and flexible capacity, under different circumstances can be identified after changing the yard specific input variables in the way the user wants. A case plan is worked out, the idea of the case plan is to get insights in the changing usage of capacity when yard parameters and input of vessels are changed. With the insights gathered during the case plan, conclusions can be drawn.

The following yards can be closed or can be made a partner yard:

- DSSi (Damen Shipyards Singapore)
- DSCh (Damen Shipyards Changde)

Closing these two yards will reduce the understaffing losses of all the Damen yards. When closing these two yards, Damen will be still able to build all vessels at own yards, even when the demand is very high.

When Damen wants to sell DSSi in the future, there are two options:

- The work will shift to DSGo if Damen is able to buy cheap hulls at partner yards and transport them to the outfitting yard.
- The work will shift to DSGo if investments are made and more attention is paid to pre-outfitting and modular outfitting.

Damen Shipyards Changde is the most inefficient yard of the whole yard portfolio of Damen. It can be closed if the yards in Galati and Yichang are made more efficient. The work done at the yard in Changde can then be moved to these yards.

The following seven yards are part of the core portfolio of Damen:

- DDE (Damen Dredging Equipment)
- DSAn (Damen Shipyards Antalya)
- DSGa (Damen Shipyards Galati)
- DSGo (Damen Shipyards Gorinchem)
- DSKo (Damen Shipyards Kozle)
- DSCS (Damen Song Cam Shipyard)
- DYS (Damen Yichang Shipyard)

List of abbreviations

AHTS	Anchor Handling Tug Supplier
ALUC	Alu Cat
ASD	Azimuth Stern Drive
ATD	Azimuth Tractor Drive
ATV	Aids Tender Vessel
BA	Barge
BACL	Barge Clinker
BACR	Barge Crane
BAHA	Barge Hatch
BB	Bunker Barge
BLV	Buoy Laying Vessel
BMV	Buoy Maintenance Vessel
BTV	Buoy Tender Vessel
CF	Combi Freighter
CFE	Container Feeder
CNBD	Damen Commercial New Build Division
CRBA	Crane Barge
CSD	Cutter Suction Dredger
DDE	Damen Dredging Equipment
DLB	Diesel Lighter Barge
DSAn	Damen Shipyards Antalya
DSCh	Damen Shipyards Changde
DSCS	Damen Song Cam Shipyard
DSD	Deep Suction Dredger
DSGa	Damen Shipyards Galati
DSGo	Damen Shipyards Gorinchem
DSHa	Damen Shipyards Hardinxveld
DSKo	Damen Shipyards Kozle
DSNS	Damen Schelde Naval Shipbuilding
DSSi	Damen Shipyards Singapore
DTC	Damen Technical Cooperation
DYS	Damen Yichang Shipyard
F	Budgeted fixed costs per year at a yard
FCS	Fast Crew Supplier
FDO	Floating Dock
FE	Ferry
FF	Fast Ferry
FISV	Fishery Inspection Survey Vessel
FRP	Fast Ro-Pax
FRV	Fishery Research Vessel
FYS	Fast Yacht Support
GHD	Grab Hopper Dredger
GRG	Generalized Reduced Gradient
HD	Hopper Dredger
HLV	Heavy Lift Vessel
HSV	Hydrographic Survey Vessel
HVAC	Heating, Ventilation and Air-conditioning
IC	Interceptor
L	Direct labour production cost
LMLB	Liquid Mixed Lighter Barge

LP	Linear Programming
MFDD	Modular Floating Drydock
MIC	Mini Cat
MPP	Multi-Purpose Pontoon
MPPT	Multi-Purpose Pusher Tug
MPV	Multi-Purpose Vessel
MUC	Multi Cat
N	Nominal capacity
NCV	Nuclear Cargo Vessel
OCA	Offshore Carrier
OPV	Offshore Patrol Vessel
OSV	Offshore Support Vessel
P	Cost to build hulls and complete ships for Damen at partner yards
PBU	Push buster
PLBA	Pipe Laying Barge
PSV	Platform Supply Vessel
PUB	Pushbuster
PUC	Pushy Cat
PUT	Pusher Tug
R	Real used capacity
RPA	RoPax
RTU	Rotor Tug
RV	Research Vessel
SAR	Search and Rescue
SBA	Stan Barge
SBU	Shoalbuster
SFE	Stan Ferry
SFI	Stan Fisher
SLA	Stan Lander
SLAU	Stan Launch
SPA	Stan Patrol
SPI	Stan Pilot
SPO	Stan Pontoon
SRA	Stan Ranger
SSV	Safety Standby Vessel
ST	Salvage Tug
STA	Stan Tanker
STE	Stan Tender
STU	Stan Tug
SUBA	Submersible Barge
SWATH	Small Waterplane Area Twin Hull
TC	Transport cost
TSHD	Trailing Suction Hopper Dredger
V	Budgeted variable costs per year at a yard
WBU	Water Bus
WLBA	Water Lighter Barge
WWSS	World Wide Support Ship

1. Introduction

In this chapter the research question is introduced. This research is done for the Yard Support department. The role of this department is to harmonize the yards. It facilitates the portfolio management and does improvement projects. It aims to have uniform building strategies, processes and methods up to the highest possible standard.

An introduction of the Damen Shipyards Group is given in paragraph 1 to introduce the research question. The second paragraph gives some key figures about the sales of Damen in 2015, to get an idea of the complexity of the problem. In the third paragraph a research question is formulated, based on the problem described. In the last paragraph, an overview of the report chapters is given.

1.1 Damen Shipyards Group

Damen Shipyards Group, an international family-owned shipyard group with Dutch roots and headquarters in Gorinchem, started with just one single shipyard in 1927. Today, Damen has grown into a multinational shipbuilding group with more than 9000 employees and clients in over 100 countries. The company delivers up to 180 vessels each year. Damen designs and builds innovative ships, supported by a worldwide network of sales and services including maintenance, repair and conversion facilities. By building a wide variety of standard hulls for stock, Damen can reduce delivery times. Damen can also provide a wide range of marine components, among others: nozzles, rudders and anchor chains. The standardized vessels can be tailor-made to meet specific customer requirements (Damen, 2016).

The product portfolio of Damen has many ship types that are built on yards all around the world. Currently, Damen can build around 300 different unique ships. Take for example the Azimuth Stern Drive Tug. In this product category, Damen has more than 10 types that the customer can buy. The product portfolio changes over the years, dependent on market conditions, new developments, opportunities and innovations in the shipbuilding industry. Shipbuilding is a global industry and Damen focusses on the following new build product groups:

- Tugs
- Workboats
- High Speed Craft
- Offshore
- Ferries
- Pontoons & Barges
- Shipping
- Naval
- Dredging
- Fishing
- Yachts

When looking at the future, Damen is seeking for new opportunities and markets. Take for example, the fast-growing expedition cruise market. An expedition vessel can reach remote destinations safely from Polynesia to the Arctic Northwest Passage (Damen, 2016). This is a new growing niche market where Damen wants to play a major role in selling and developing these kind of ships, resulting in a new product type in their portfolio.

The vessels can be build either at their own yards worldwide or at partner yards around the world close to the delivery station. Today, Damen has newbuilding yards, newbuilding and repair yards and repair and conversion yards. Next to these own yards, there are DTC yards or Damen Technical Cooperation yards. At these local yards, Damen assists in building and delivers everything from the vessel design to a full material package. In Figure 1 the yards of the Damen Shipyards Group are given (Damen, 2016).

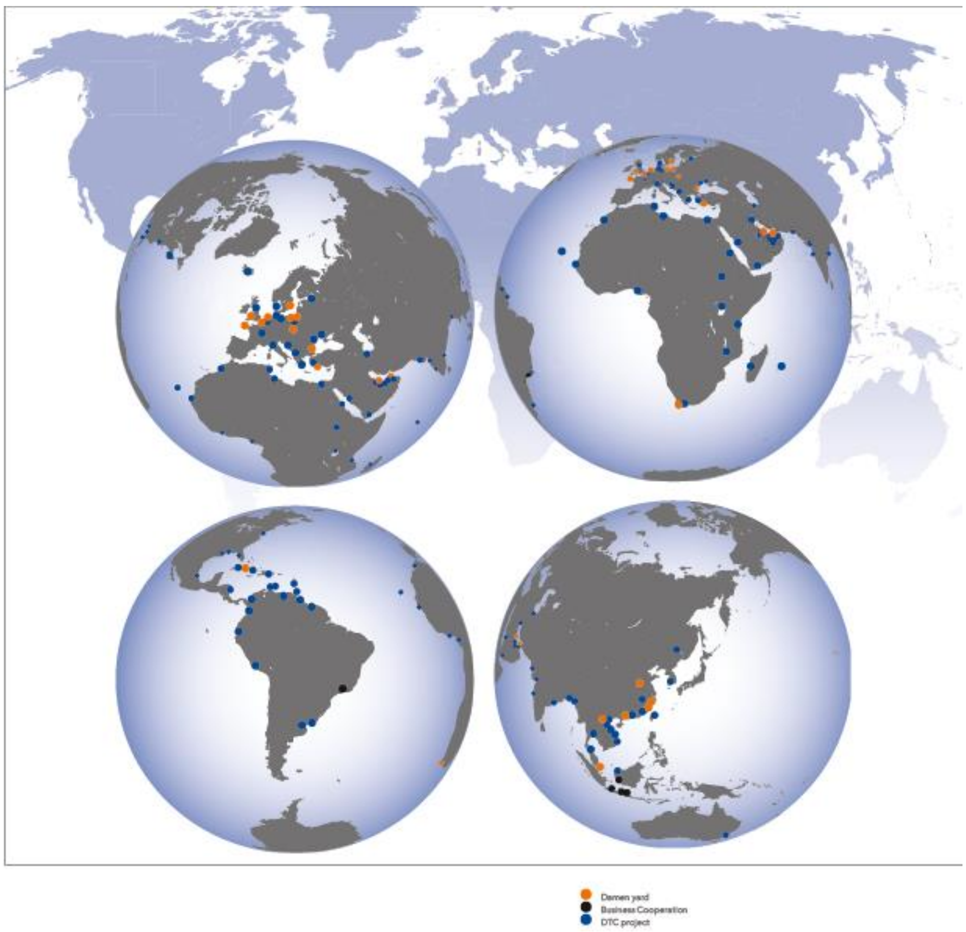

Figure 1: Global Presence Damen (Damen, 2016)

The newbuilding yards of the Damen Shipyards Group can be categorized in the following groups:

- Damen yards
  - Complete ship building yards with different levels of integral building
  - Outfitting yards
- Partner yards
  - Yards that build cascos (steel and/or aluminium hulls)
  - Partner yards that build complete ships
  - DTC yards

1.2 Damen facts and figures

In this paragraph, some facts and figures about the sales of Damen in 2015 are given. Damen Shipyards Group had a total order intake in 2015 of 1.6 billion euros. In the Damen Commercial New Build Division (CNBD), Damen had an order intake of 139 new build vessels with a total contract value of 953 million euros. Information about this Commercial New Build Division of Damen is presented below and is intended to give an idea of the diversity in products sold (Damen, 2016).

Shipbuilding is a global industry and it is all about market cycles. A market trough is followed by a recovery leading to a market peak and followed by a collapse. This cycle is repeated constantly over the years. The demand side is based on expectation; orders of clients are placed based on an estimation of the future demand. Once built, ships remain in service for 25-30 years. Important to notice, there is a time-lag between the ordering of the ship and the delivering of it. This can vary between 1 and 4 years, depending on the size of the order book (Stopford, 2009). As can be seen in Figure 2 the delivered ships, and consequently the order intake, of the entire Damen Shipyards Group varies.

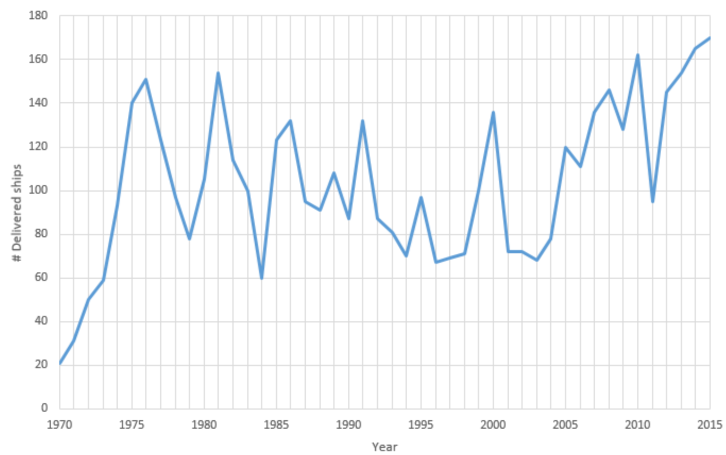

Figure 2: Delivered ships over the past 45 years (1970 – 2015)

Markets change rapidly and new ships are developed and others are removed from the product portfolio. Over the years, more bigger ships are being built instead of small ships as can been seen in Figure 3 when looking at the average length of delivered Damen ships (Damen, 2015).

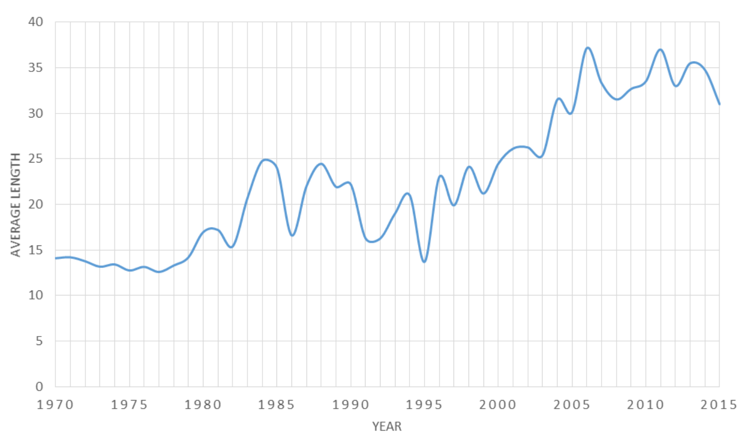

Figure 3: Average length delivered ships over the past 45 years (1970 – 2015)

More information about the changing product portfolio due to market influences and how Damen visualizes this can be found in appendix 1. Currently, new products are being developed for markets such as fish farming. At the same time, the oil market, gas market and alternative energy, such as wind, has a slowdown over the past year. This affects the type of order intake among others in offshore, workboats and high speed craft. In Figure 4 an overview of the order intake of CNBD in 2015 is given per area in the world. The blue bars give an indication of the total contract value relative to each other.

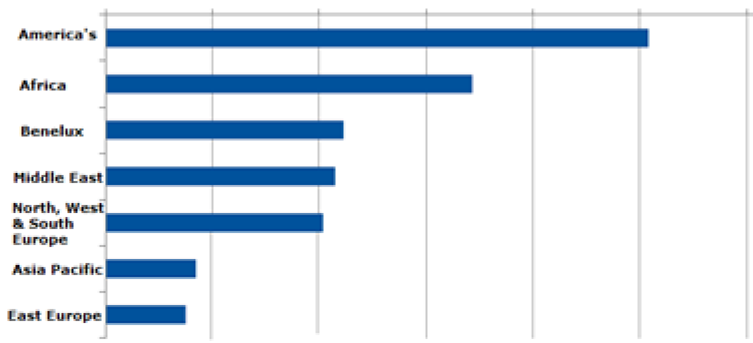

Figure 4: Contract value 2015 per area relative to each other (Damen, 2016)

To get an idea of the order portfolio, in Figure 5 the order intake per market is given relative to each other. Harbour and terminal is the largest one. This market consists of tugs, multi cats, shoal busters, push busters and utility vessels.

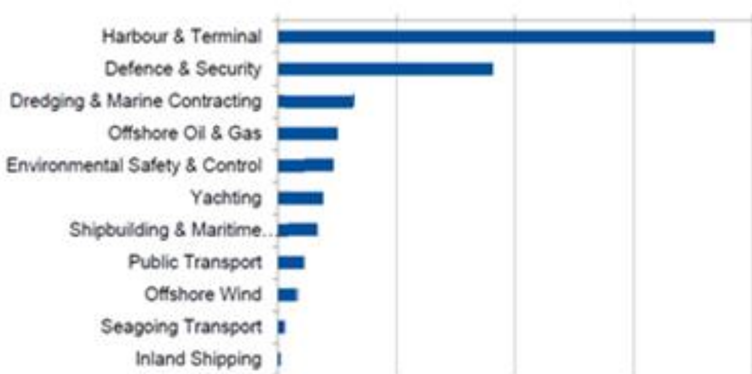

Figure 5: Order intake 2015 per market relative to each other (Damen, 2016)

A more detailed overview of the sales per product can be found in Figure 6, with a description of the product types ID in appendix 2. In this figure the top 10 products of the Damen Commercial New Build Division is given. These 10 ship types are responsible for more than 50% of the order intakes in 2015.

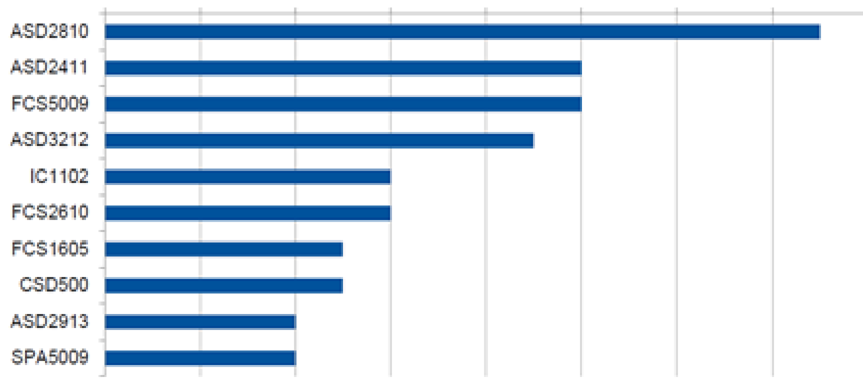

Figure 6: Top 10 product types by product type ID in 2015 relative to each other (Damen, 2016)

It is also interesting to look at the top 10 products by value in Figure 7, with a description of the product types ID in appendix 3. The total contract value of all these products together is responsible for more than 60% of the total contract value in order intake in 2015. Seven products in the top 10 by product ID are also in the top 10 by value.

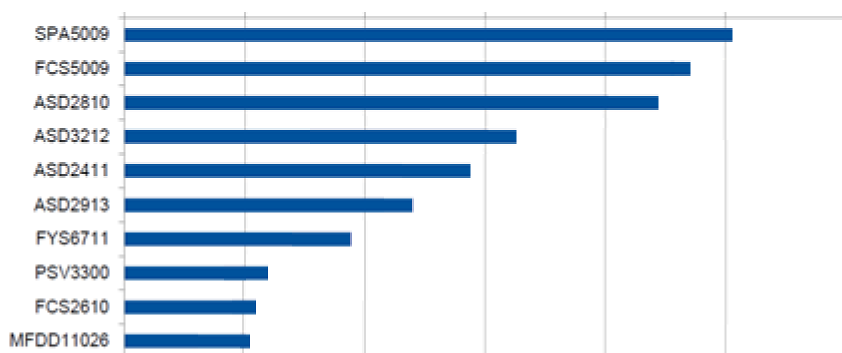

Figure 7: Top 10 products types by value in 2015 relative to each other (Damen, 2016)

Over the years, the order intake and therefore also the deliveries changes, together with an increase of the ship dimensions. For example, the top 10 of deliveries of vessels in the years 2000 and 2015 are quite different as can be seen in Figure 8 (Damen, 2015).

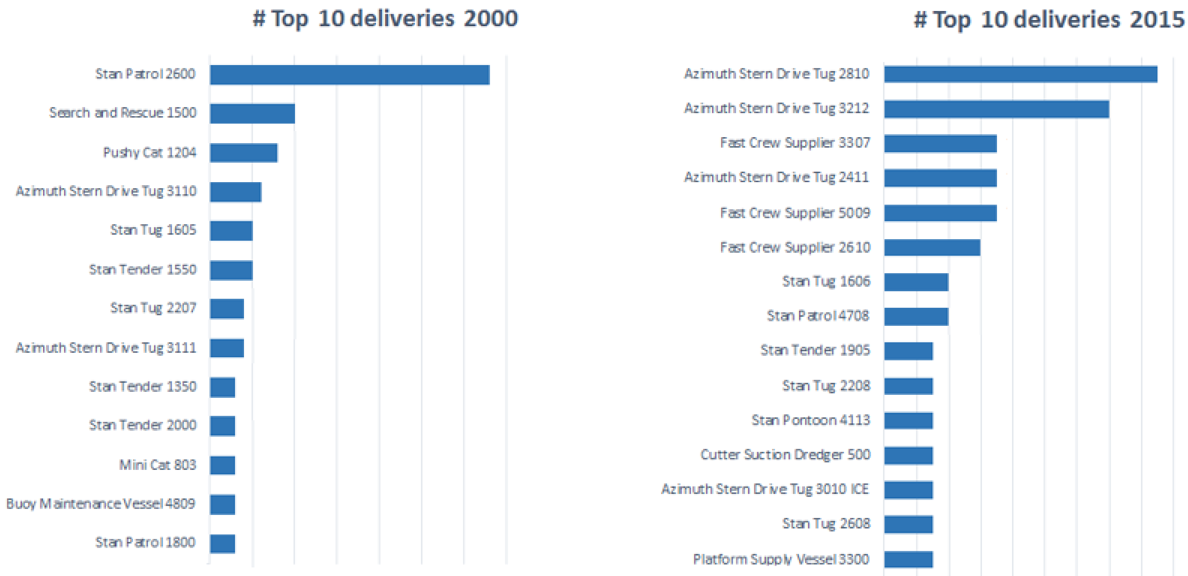

Figure 8: Top 10 deliveries in 2000 and 2015

Shipbuilding is a highly competitive market environment that is very volatile. The yard portfolio of the Damen group also changes over time and yards can be bought or closed. During a recession, the less efficient shipyards are forced out of the business. During the first half of the twentieth century, Europe was the dominant player. In the second half of the century the focus moved to Asia, with Japan as leader followed by South Korea that took over the dominant position at the beginning of the twenty-first century. China is now trying to become the market leader; other smaller Asian countries are also entering the market. Nowadays, European yards are successful in niche markets and high value ships. Asian yards focus mainly on the mass production of large vessels like dry bulk carriers. This market development is important to keep in mind. What is optimal now, can change in a few years and can be completely different (Stopford, 2009).

To summarise, Damen has around 300 ships in their portfolio that can be built at their own new building yards or at partner yards in the world. Over the years the product portfolio changes, new products are developed and others are removed from the portfolio. Together with the very diverse and changing order intake, it is difficult to match the yard and product portfolio.

1.3 Problem analysis

The product and yard portfolio of Damen is very large and changes over time, both in size and composition as discussed before. Ship dimensions increase, new products are developed and others are removed from the product portfolio. Dependent on the economic situation, that is very volatile, the order book of Damen can change fast.

The combination of all these conditions resulted in a matching problem for Damen. Research is needed and the steps to solve the problem will be discussed in this paragraph. First, the problem is analysed and a main research question is given. Secondly the boundaries of this research are set. In the last paragraph, the sub questions are defined.

1.3.1 Main research question

Damen wants to have a better match between the yards' production capacity and product portfolio. Therefore, Damen wants to research if matching of these portfolios is possible to minimize the costs of underutilization in a recession. At the same time when the economy is booming, Damen wants to be flexible and add additional capacity to their minimal production level if needed to ensure they don't miss any opportunities. Given all these aspects, the following main research question can be formulated:

What is the optimal yard portfolio, own capacity and flexible capacity of Damen under different circumstances?

To answer the research question, a computerized model will be made. Given a product portfolio to be delivered in a year a match can be made with the yard production capacity to minimize the costs.

1.3.2 Boundary conditions

The above described research question is very broad, to keep it manageable within the given time, boundaries need to be set. The boundary conditions that are described in this paragraph are as follows:

- Selection of the investigation area
- Yard capacity and efficiency
- Used data
- Geography

Selection of the investigation area

The focus of this report is the commercial newbuilding cluster of Damen Gorinchem (CNBD). This means that among others DOP pumps, booster stations, components, ship repair and conversion are not considered. Additionally, for example yachts and naval vessels are also not considered because these are two niche markets outside the Gorinchem cluster, both with their own specific yard. Yachts are built at Amels and naval vessels at Damen Schelde Naval Shipbuilding. Cascos for yachts and naval vessels are built at Damen Gorinchem yards, how this is considered will be discussed in the relevant chapter.

Yard capacity and efficiency

A very important boundary condition is the way this research is looking at the problem. Every yard has its own production efficiency and capacity. There are a lot of possibilities to look at the capacity of a yard, in this research yard capacity in man hours is used. The available man hours' capacity per year is matched to the hours needed to build several ships or parts of a ship, for example only the outfitting or hull. When comparing the capacity of yards, hours need to be normalized. A production hour in China is not equal to an hour in the Netherlands. Therefore, an efficiency factor needs to be developed and used for comparison and ranking the yards, this will be discussed in the relevant chapter.

Used data

Data will be analysed from 2000 until the end of 2015 for the product portfolio. In this way, a clear peak and trough of the market can be seen over these years with its corresponding influence on the product deliveries.

Geography

Damen has yards all around the world. However, the demand and supply is not always at the same location. Therefore, transportation costs need to be considered. In this research, the world is divided in groups. This is done to not completely dismiss transportation costs as a driver to build at a certain location.

1.3.3 Secondary questions

With the main research question clear and the boundaries set, it is now possible to identify the secondary questions that need to be solved in order to answer the main question. To define the optimal yard portfolio, own capacity and flexible capacity of Damen under different circumstances the following subjects need to be clear first:

1. What are the flexible layers of the Damen Gorinchem cluster?
2. What are the yards and products of the Damen newbuilding cluster?
3. How to match the man hours at the yard to the product hours?
4. Which optimisation techniques are suited to deal with the problem?

1.4 Report overview

In chapter 2 the flexible layers of Damen and the shipbuilding process will be discussed. The next chapter gives information about the yard and product portfolio of Damen Shipyards. In chapter 4 the method of matching yard and product data is discussed. Chapter 5 gives an overview of the transport cost when transporting for example a ship from the yard to the client. To match the yard and product a computerized model is made and discussed in chapter 6. This computerized model is validated and verified in chapter 7. Results are presented in chapter 8. Conclusions and recommendations are given in chapter 9 and 10.

2. Flexibility

Flexibility will enable Damen to minimize the costs of underutilization in a recession. At the same time when the economy is booming, Damen can respond to customer orders quickly by adding additional workers' capacity at their own yards or subcontract work to partners. Flexibility means different things to different people. It is all about the ability to adapt or change. But, there are many ways to characterize such an ability. What the flexible layers of Damen are will be discussed in this chapter.

Before discussing the flexible layers of Damen in detail, the shipbuilding process need to be clear. The production process will be given in paragraph 1. In paragraph 2, the focus will be on the flexible layers.

After reading this chapter, the following sub question will be solved:

- *What are the flexible layers of the Damen Gorinchem cluster?*

2.1 Production process

There are six phases in the ship building process that are listed below (Hengst, 1999):

1. Design and engineering
2. Pre-fabrication
3. Sub assembly of
    - Panels
    - Sections
    - Blocks
4. Hull assembly
5. Finishing
6. Trials

The time between the start and finishing of production are of importance for this research. Before the production can start there is also contract signing, design and engineering. This is not further discussed in detail; the focus is on the ship building production process at the yard.

In Figure 9 the total building process of a ship in time can be seen from left to right. Starting with the cutting of plates and profiles in the pre-fabrication on the far left and ending with the commissioning and delivery of the vessel on the right. This figure illustrates the material flow during the different phases of the production process; the hull production (blue), outfitting activities (orange) and the workshop activities (grey). The bar on the left shows the amount of materials relative to each other entering the different production phases.

The amount of outfitting increases during the building process when looking at the orange area in the figure. This peak can be lowered by doing more work in the workshops. In the workshop small components, pipes and electrical components are assembled into modules in the dark grey layer. Afterwards, these modules are painted in the painting workshop and installed during the production process. Doing more work in the workshop will lower the work done in the final outfitting and reduce the amount of work that needs to be performed on board.

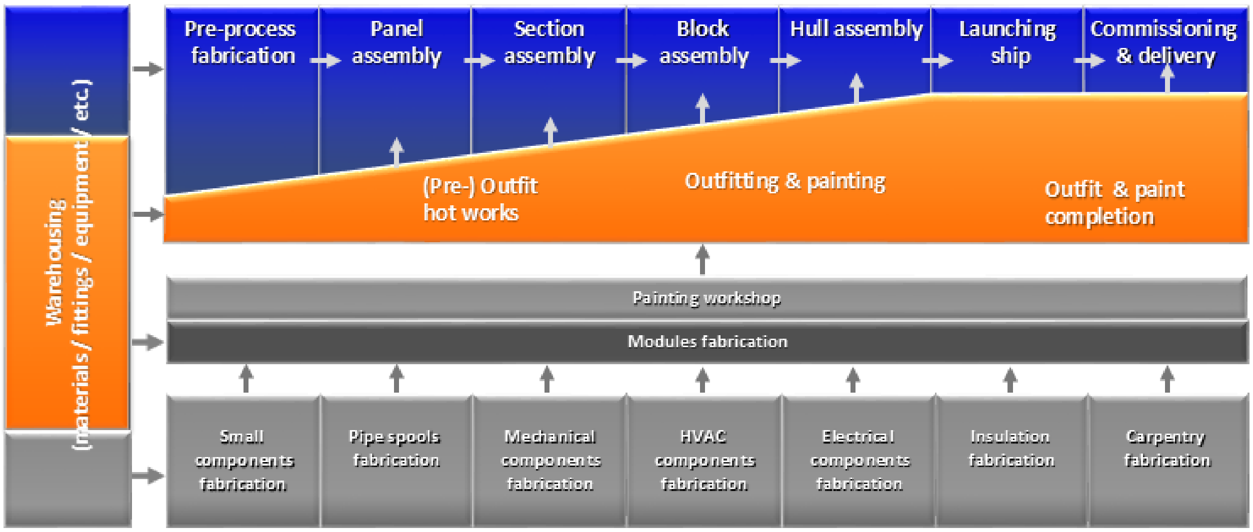

Figure 9: Blueprint production (Yard Support, 2014)

The complete ship building process can thus be divided into three groups as can been seen in Figure 9 that will be further explained in detail below (Yard Support, 2014):

- Hull production (blue area)
- Outfitting and painting (orange area)
- Workshops (grey area)

Hull production

Hull production is the production of the complete steel, aluminium or composite structure of a ship including the superstructure. In Figure 9, it is the process in blue until the launching of the ship. The work included in the hull production is divided into the following steps:

1. Plate and profile processing (pre-process)
2. Panel assembly
3. Section building
4. Block erection
5. Hull erection

Outfitting and painting

Outfitting means the positioning and mounting of items in (partially) painted and (partially) finished compartments. Examples of items that are outfitted are: floors, pumps, electrical systems, carpentry, insulation, furniture, small items (e.g. printers and lamps), cables, etc. Outfitting work can be performed during the whole hull production phase, even after the launching of the ship (see Figure 9). In the section building phase, pre-outfitting activities can be performed such as the placement of foundations and piping. The construction of sections is open and most of the time a section is built upside down, this provides better working conditions and easier supply of equipment and better reachability for cranes. Sections are attached to each other to form bigger blocks. Blocks are most of the time closed and not build upside time, this makes is more difficult to install equipment and perform outfitting activities. In the final phase, blocks are attached to each other to form the hull, the remaining outfitting activities can take place and the final painting is done. The working conditions are worse compared to the block and section phase, e.g. bad accessibility, welding over their head, etc.

Workshops

Workshops produce and paint components and modules to be outfitted on the ship. The following workshops can be defined on a shipyard as can be seen in Figure 9 (grey area):

- Small components workshop (e.g. stairs, mooring items, …)
- Piping workshop
- Mechanical components workshop (e.g. flanges, …)
- Heating, Ventilation and Air-conditioning (HVAC) workshop
- Electrical workshop (e.g. switchboards, desks including all equipment, …)
- Insulation workshop
- Carpentry workshop (e.g. wall panels, furniture, ceiling panels, …)
- Painting workshop (e.g. painting of sections, pipe spools and small components)

2.2 Flexible layers

What is the ideal flexible layer for the Damen organization? It is all about finding the right balance between the core capacity and flexible capacity (Bargon, 2014). Three different layers of flexibility are defined that are relevant for this research to define the ideal flexible layer. These layers are based on interviews with employees at Damen and analysing cost control reports of different Damen ships. The following flexible layers are identified:

1. Employees
    a. Temporary workers
    b. Working overtime
2. Subcontractors
    a. Hull building
    b. Outfitting
3. Partner yards
    a. Casco building
    b. Complete ship building

In Figure 10 an example is given how these flexible layers can be presented. The orange line represents the ships that are built by own Damen employees at Damen yards at minimal capacity. This capacity can easily be scaled up by adding additional workers, working overtime and subcontract work (dark blue line). Additional workers are temporary workers that are hired to do a part of the job to be able to deliver the ships that are ordered. Man hours cannot be scaled up infinite at a yard, when this is not possible anymore a yard can subcontract parts of the job like the building of sections. If this is not enough, partner yards (dark grey line) can build a casco or whole ship when the man hour capacity at own yards is maximal used. The different layers will be explained more into detail below.

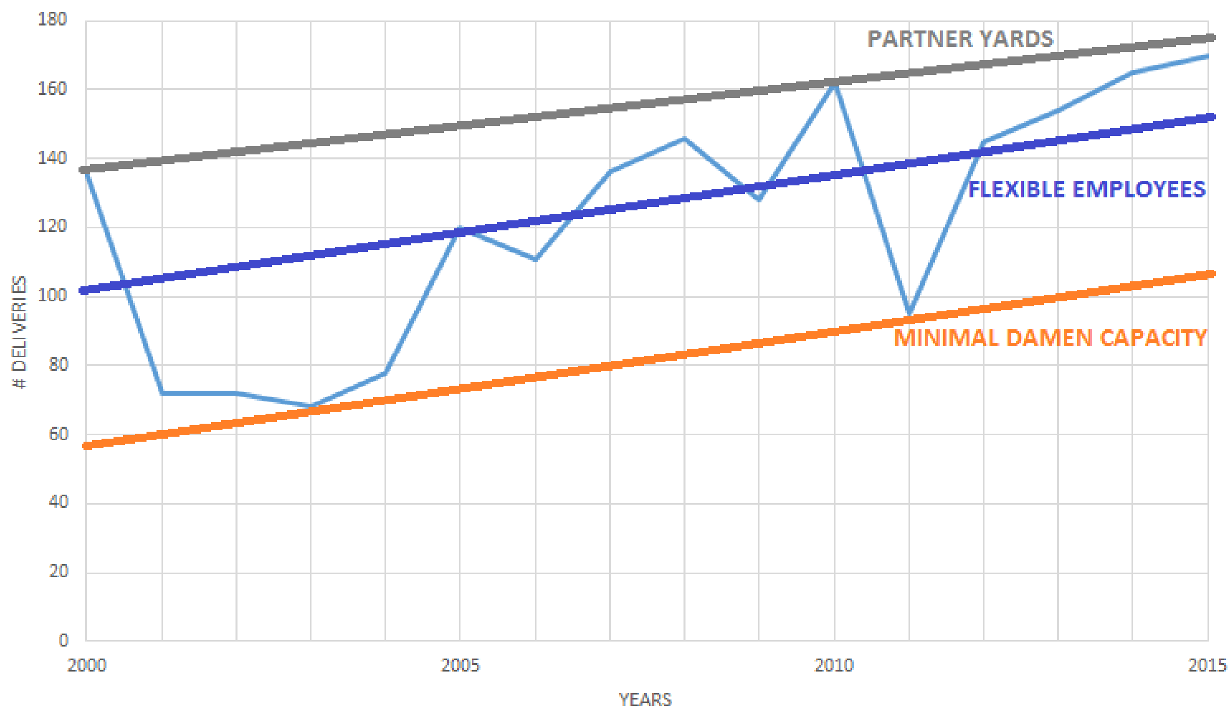

Figure 10: Flexible layers of Damen

A part of the flexibility is the flexible deployment of workers: employees and subcontractors.

Employees

A division is made between own employees and external employees. Own employees can work overtime. On average, an additional flexible layer of 20% can be added on yearly basis to the own capacity by working overtime (Wallace, 2016). This flexible layer of overtime is more expensive than the normal working hours.

Temporary workers are external employees that are hired and added to the core capacity to do a part of the work if needed. This additional capacity can be easily increased when more workers are needed and decreased when there is not much work. In this research, a division is made between temporary workers and subcontractors. Temporary workers are different from subcontractors because temporary workers do the same work as the own core employees at a yard. Subcontractors do a specific job that is not done at the yard, for example the hull building for outfitting yards.

Subcontractors

A subcontractor is a person or company that does a part of the job for the prime contractor. Subcontracted work is a flexible layer, because it is not own capacity. Which work and how many work is done by subcontractors is different for every yard. Some yards have only a core capacity that does all the work, other yards subcontract a lot of their work. For example, subcontractors can build sections or blocks but can also do a part of the outfitting job, like painting or the installation of carpentry.

The employees that can work at a yard cannot be scaled up infinitely, ships or steel hull can be outsourced to partner yards. When the hull is outsourced to a partner yard, the flexible layers will look as presented in Figure 11.

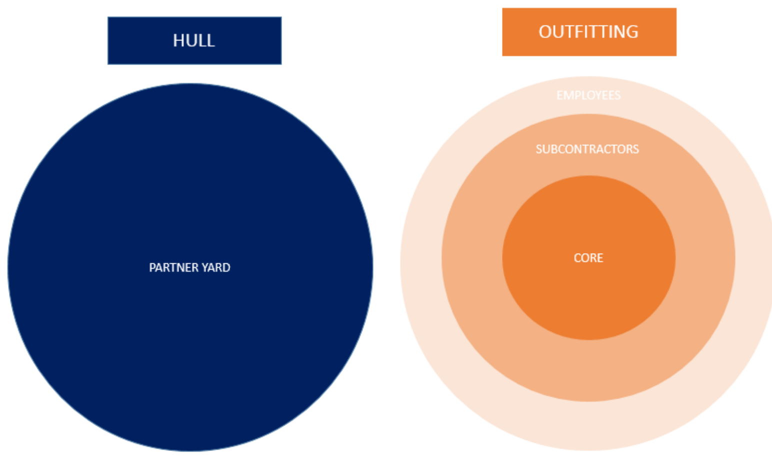

Figure 11: Partner yard that builds the hull

Partner yards

Projects at partner yards of Damen is a flexible layer. When ships cannot be built at own Damen yards, partner yards can build whole ships or steel hulls. Which yards are partner yards and how much of the ships they have delivered in history will be discussed in the next chapter.

2.3 Conclusion

This chapter has given insight in the production process of shipbuilding and flexible layers are identified. This has answered the first secondary question:

- *What are the flexible layers of the Damen Gorinchem cluster?*

The following flexible layers of Damen are defined that are relevant for this research based on interviews with employees at Damen and analysing cost control reports of different Damen ships:

1. Employees
    a. Temporary workers
    b. Working overtime
2. Subcontractors
    a. Hull building
    b. Outfitting
3. Partner yards
    a. Casco building
    b. Complete ship building

3. Yard and product selection

Damen Shipyards Group builds all kinds of vessels. The product portfolio of Damen has many ship types that are built on yards all around the world. Currently, Damen can build around 300 different unique ships. In this research, the capacity of the yard in hours will be matched with the needed capacity in hours to build several ships. Every yard has its own portfolio of ships that they can build. In this research, only the newbuilding yards in the Gorinchem newbuilding cluster are investigated as discussed in the introduction. In this chapter, a further investigation is done of these yards and products. The structure in this chapter is as follows:

- General Damen Shipyards Group structure
- Damen commercial Gorinchem cluster
- Product groups

After reading this chapter the following secondary questions is answered:

- *What are the yards and products of the Damen newbuilding cluster?*

3.1 General Damen Shipyards Group description

There are different types of yards in the Damen Shipyards Group: newbuilding yards, repair yards and conversion yards. In this research, only the newbuilding projects for the Damen commercial Gorinchem cluster (CNBD) are investigated. Yards in the Gorinchem cluster can also build ships for other yards in the Damen Shipyards Group. These yards outside the Gorinchem newbuilding cluster have their own unique product portfolio: Damen Shipyards Hardinxveld (DSHa) is specialized in building shoalbusters and multi cats, Amels is specialised in building yachts and Damen Schelde Naval Shipbuilding (DSNS) in building naval vessels. Complete ships and hulls for these yards can be built on a CNBD yard. A schematic overview of this process can be found in Figure 12.

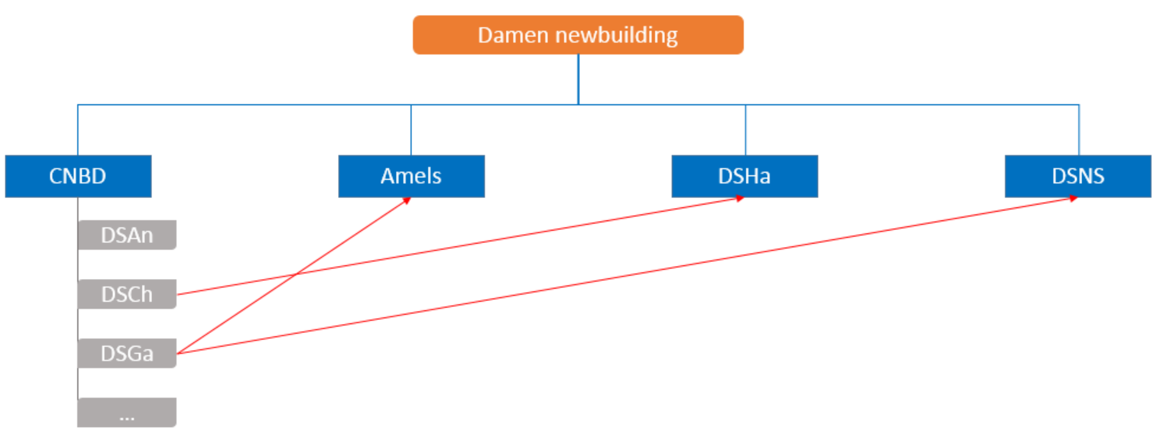

Figure 12: Damen newbuilding yard structure

3.2 Damen commercial Gorinchem cluster

Newbuilding yards in the Gorinchem cluster can be categorized in the following groups as discussed in the introduction:

- Damen yards
  - Complete shipbuilding yards with different levels of integral building
  - Outfitting yards
- Partner yards
  - Yards that build cascos (steel hulls)
  - Partner yards that build complete ships
  - DTC yards

Over the past 15 years, more than 1800 ships for Gorinchem are delivered that where build at different newbuilding yards. The number of projects for Gorinchem between 2011 and 2015 are investigated in detail. In Figure 13, the delivered projects over these years can be found divided into three groups (Damen, 2015):

- Projects at Damen Gorinchem yards (blue area, on average 47% of total)
- Projects for Damen Gorinchem at partner yards (orange area, on average 32% of total)
- DTC projects at DTC yards (grey area, on average 21% of total)

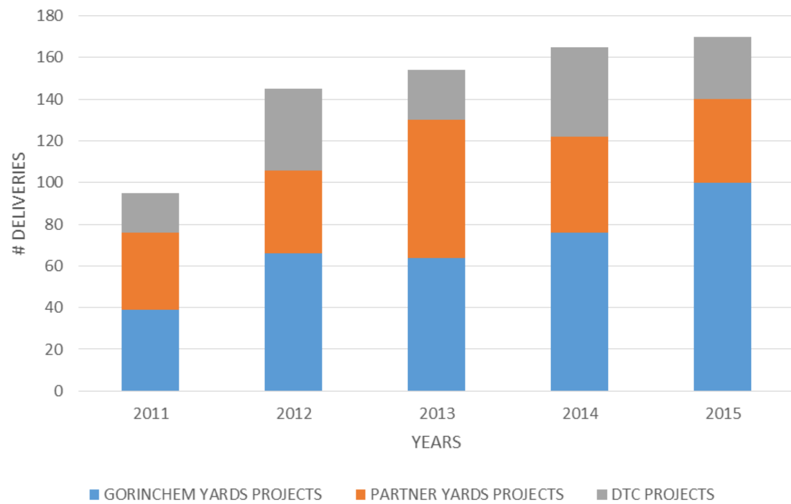

Figure 13: Delivered ships between 2011 – 2015

DTC yards or Damen Technical Cooperation yards can build all sort of vessels of the Damen product portfolio for themselves. Damen helps building those vessels locally, most of the time in Africa or America, at the chosen preferred yard of the customer. Damen delivers everything from the vessel design to a full material package. If required, Damen can provide building assistance and can help with improving the yard facilities. DTC projects are projects where the chance is very low that they will ever been built at own Damen yards. There are several driving factors for customers to use the DTC option (Damen Shipyards Group, 2015):

- Geographic inaccessible locations, e.g. inland lakes
- Political reasons such as import restrictions in the USA
- Increasing need to stimulate the own economy, employment and the own shipbuilding industry

A DTC yard can also build vessels that are not for themselves but instead they build it for the Damen Gorinchem cluster, for that kind of projects they are a partner yard. The reason for this can be among others; the yard can build at a low-cost price and the quality is according to the Damen standard. In the past, efficient DTC yards evolved to Damen yards, examples are Damen Shipyards Changde and Damen Shipyards Kozle. A list of partner yards, DTC yards and a combination of both is given in appendix 4.

To summarize, DTC projects and ships that are not build for Damen Gorinchem (e.g. projects for Amels, DSHa and DSNS) are excluded for further research. The focus for optimization of the capacity will be on the products build for Damen Gorinchem at own yards in the Gorinchem cluster. Projects at partner yards of the Damen Gorinchem cluster are a flexible layer. When ships cannot be built at own yards, partner yards can build whole ships or hulls. The yards in Table 1 are own Damen yards in the Damen Shipyards Gorinchem newbuilding cluster (see appendix 5 and 6 for more detailed information).

Table 2: Own yards in the Damen Shipyards Gorinchem newbuilding cluster (CNBD)

Yard	Type of yard	Country	Abbreviation
Damen Dredging Equipment	Outfitting yard	The Netherlands	DDE
Damen Shipyards Antalya	Complete shipbuilding	Turkey	DSAn
Damen Shipyards Changde	Complete shipbuilding	China	DSCh
Damen Shipyards Galati	Complete shipbuilding	Romania	DSGa
Damen Shipyards Gorinchem	Outfitting yard	The Netherlands	DSGo
Damen Shipyards Kozle	Complete shipbuilding	Poland	DSKo
Damen Shipyards Singapore	Complete shipbuilding	Singapore	DSSi
Damen Song Cam Shipyard	Outfitting yard	Vietnam	DSCS
Damen Yichang Shipyard	Complete shipbuilding	China	DYS

When looking more into detail, Damen Dredging Equipment, Damen Shipyards Gorinchem and Damen Song Cam only do the outfitting of ships at this moment. The hulls for Damen Shipyards Gorinchem and Damen Song Cam are being built most of the time at partner yards that are not included in the own Damen Shipyards Gorinchem newbuilding cluster yards. Damen Dredging Equipment gets it cutter suction dredgers hulls most of the time from own yards, for example Damen Shipyards Kozle. The global presence of all these nine yards can be found in Figure 14.

Figure 14: Global presence of the nine own Damen yards in the Gorinchem newbuilding cluster

3.3 Product groups

The product portfolio of Damen is very large and changes over the years, dependent on market conditions, new developments, opportunities and innovations in the shipbuilding industry. All the delivered ships between 2000 – 2015 are grouped in product groups that represent a large group of ships (Damen, 2015). Product groups are defined based on the following criteria and can be found in appendix 7:

- Own Damen product group classification
- Interviews and discussions with Damen employees
- Every unique ship in a group can be built at a yard where the group is linked to
- Man hour per lightweight ton ratio is comparable (reason will be explained in the next chapter)
- Product clusters need to reflect the whole product portfolio of the Damen Shipyards Group
- Classification needs to be user friendly and easy understandable for further usage in the research

Every product group has a representative dummy ship. In total 24 dummy ships or product groups are defined. Using these product groups, previously selected yards can be linked to dummy ships which they have previously build in history and a clear overview can be presented of the ship types that a yard can build. With the yards selected and the products clustered in groups, yards and product groups can be linked to each other as can be seen in Table 3. These links between the yards and product groups is based on historical data and interviews with employees at Damen. These links are not fixed and can be changed in the future if Damen wants to build a new ship type at a yard where it is not done before.

Table 3: Product groups with corresponding dummy ships that a yard can build

	DDE	DSAn	DSCh	DSGa	DSGo	DSKo	DSSi	DSCS	DYS
ASD2810			X	X	X			X	X
STU1606			X		X			X	X
STU2608			X	X	X			X	X
CF11000				X					X
CSD500	X		X	X		X			X
HD750			X	X		X			X
FCS1605		X			X		X		
FCS3307		X			X		X		
FCS5009		X			X			X	
FF4212				X			X		
OPV2400				X					
MUC1908			X		X	X		X	
PSV3300				X					
RV6613				X					
SAR1906		X			X				
SBU2609			X			X		X	
SLAU804			X						
SPA2606		X			X		X		
SPA4708		X			X	X		X	
SPI1505		X			X				
SPO7524				X					X
STE1905			X		X	X			
IC1102		X							
COMPOSITE		X							

3.4 Conclusion

This chapter has given insight in the yards and products that will be further investigated in this research. The following secondary question is answered after reading this chapter:

- *What are the yards and products of the Damen newbuilding cluster?*

The yards in the newbuilding cluster of Damen are:

- Damen Dredging Equipment
- Damen Shipyards Antalya
- Damen Shipyards Changde
- Damen Shipyards Galati
- Damen Shipyards Gorinchem
- Damen Shipyards Kozle
- Damen Shipyards Singapore
- Damen Song Cam Shipyard
- Damen Yichang Shipyard

All the delivered ships between 2000 – 2015 are grouped in product groups that represent a large group of ships. Every product group has a representative dummy ship. In total 24 dummy ships or product groups are defined. Using these product groups, the previously selected yards can be linked to dummy ships which they have previously build in history (see Table 3 in the previous paragraph for a complete overview). These links between the yards and product groups is based on historical data and interviews with employees at Damen. These links are not fixed and can be changed in the future if Damen wants to build a new ship type at a yard where it is not done before. For further research, the data is used as it is now without future possible changes.

4. Matching yard and product data

Damen wants to have a better match between the yard and product portfolio. The shipbuilding labour hour capacity of the yard in hours will be matched with the needed capacity in hours to build several ships per year. The division of the yard capacity at every yard is different, a total yard capacity in hours is calculated using the own Damen core capacity as it is now and subcontracted capacity. By doing this, all the yards can be compared on the same production depth.

Still, a yard in China cannot be directly compared to a yard in the Netherlands. Every yard needs another number of hours to build the same type of vessel. There is a difference in culture, facilities, motivation, process efficiency, etc. To match yards and products on the same level every yards' capacity is normalized based on the norm yard and norm hours to build a ship are defined. The norm yard is the yard that needs the minimal number of hours to build ships. Yards are compared between each other based on the registration of hours for several ship types. The actual total labour hour capacity at a yard is divided by an efficiency, higher or equal to 1, to get a norm capacity. This efficiency is calculated by using the difference between the number of hours needed to build ships at the different Damen yards. Using these registration of hours, per ship an hour norm can also be defined. The norm hours to build a ship is the number of hours at the norm yard. Using these norm hours for ships and the normalized capacity of the yards, yards and products can be matched on the same level.

The main research question is to find an optimal yard portfolio. To be able to find an optimum, wage rates for all the yards are defined. Using the wage rates the most cost optimal matching of hours is possible. To calculate the actual wage costs, the used norm hour capacity at a yard is again multiplied with the previous calculated efficiency to define the real used actual number of hours. Ships must be transported from the supply region to the demand region. To find the optimal yard portfolio, the combination of the summation of the total actual labour cost at the yard and the transport cost needs to be the cheapest as possible.

The data that is required are the normalized capacity of the yard portfolio, the norm hours needed to build the whole product portfolio of Damen, yard efficiency, the hour tariff at every yard and the transport costs. Transport costs will be discussed in the next chapter. The structure of this chapter is as follows:

- Yard capacity
- Division of labour hours
- Yard efficiency
- Norm labour hours to build a ship
- Hour tariff

After reading this chapter, the following secondary question will be answered:

- *How to match the man hours at the yard to the product hours?*

4.1 Yard capacity

The shipbuilding labour hour capacity of the yard consists of a core capacity and flexible capacity as previously discussed in chapter 2, one of the flexible layers of Damen is the outsourcing of work. Subcontractors perform project activities that are not done by own Damen employees. For example, the difference between the carpentry workshop at DSGa and DSCh. In Galati all the carpentry is subcontracted, the workers at the yard in Changde makes everything themselves. To take this difference into account, an additional fictive layer of subcontracted hours is considered additional to the own Damen nominal capacity to include the carpentry hours. In this way, comparison between yards is possible on the same production level.

In Figure 15, an example is given of the outfitting capacity at a yard. In the first case, the yard has a core capacity that does all the outfitting work in the process. The other yard has a small core capacity and the other work is subcontracted. To compare yards on the same level, the subcontracted hours are added to the core capacity.

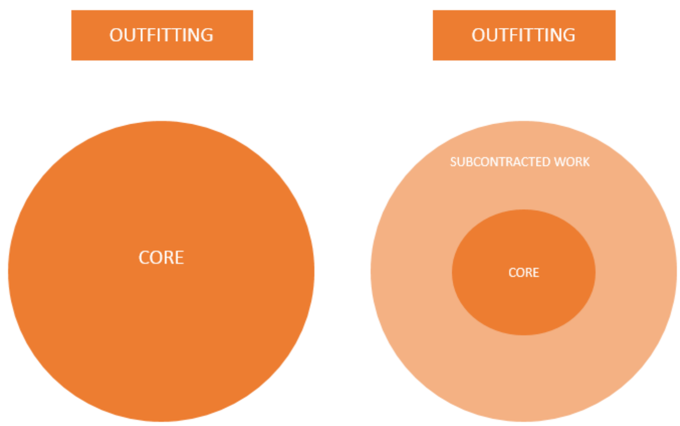

Figure 15: Yard with only own outfitting capacity (left) and yard with own and subcontracted capacity (right)

An overview of the subcontracted work that is completely done by co-makers at the nine yards is given in Table 4.

Table 4: Overview subcontracted work done by co-makers at own Damen yards

Yard	Hull	Construction	Piping	HVAC	Electrical	Insulation	Carpentry	Painting
DDE	X		X		X			
DSAn		X			X			X
DSCh								
DSGa				X	X	X	X	X
DSGo	X		X	X	X			X
DSKo		X	X		X	X	X	
DSSi		X	X		X	X	X	X
DSCS	X							
DYS		X					X	X

To estimate the total subcontracted capacity at a yard, the percentage of the work done by subcontractors per ship type at the yard is investigated using the hour registration of different ships at a yard. Using this information of used subcontracted hours for several ship types at a yard, an estimation of the total hours made by subcontractors per year at a yard can be done. Adding the subcontracted capacity to the own Damen core capacity as it is now, the total yard capacity can be calculated. The estimated subcontracted capacity at a yard varies between 0 and 30% of the total yard capacity. The exact numbers can be found in appendix 12 (Visser, 2015a). For outfitting only yards (DDE, DSGo and DSCS), the total yard capacity is only estimated for the outfitting part. No additional hull man hour capacity is added. The hull related part to build a ship is considered as a cost price that the yard needs to pay to the hull manufacturer.

In this total capacity, there is a flexible layer of projects done for other Damen yards outside the Gorinchem cluster as discussed in chapter 3. These are projects for among others: Amels or Damen Shipyards Hardinxveld. This layer of used capacity varies every year. There is no fixed percentage of the capacity used for Gorinchem projects, therefore a range per yard is defined using data from the past. An overview is given in appendix 12 and Table 5 how much of the total capacity on average can be minimal and maximal used for Gorinchem projects (Wallace, 2017).

Table 5: Capacity used for Damen Gorinchem projects

YARD NAME	MINIMAL % USED	MAXIMAL % USED
Damen Dredging Equipment	5%	25%
Damen Shipyards Antalya	100%	100%
Damen Shipyards Changde	95%	100%
Damen Shipyards Galati	60%	80%
Damen Shipyards Gorinchem	100%	100%
Damen Shipyards Kozle	0%	100%
Damen Shipyards Singapore	100%	100%
Damen Song Cam Shipyard	100%	100%
Damen Yichang Shipyard	100%	100%

4.2 Division of labour hours

The hours needed to build a ship are divided in two big groups: production hull hours and outfitting hours. This division in two groups is done because of the following two reasons:

- As described earlier in this report, three different types of yards exist: hull yards, outfitting yards and complete ship building yards with different levels of integral building. Using this division into two groups, a direct link is created between the ship hours and yard types.
- Detailed hour registration of labour hours during the production process is not available and not uniform over all the yards. To minimize the uncertainty, the hours are divided into two groups instead of many uncertain variables.

Workshop hours, as discussed in chapter 2, in the production process are distributed over the hull and outfitting group. The consequences of this simplification are minimal because the workshops are now responsible for less than 10% of the total labour hours to build a ship at the yards of Damen (Damen Contracting & Yard Support, 2016f). The criteria that is used to define in which group the workshop hours are made, if data or information is available, is as follows: working hours are considered in the outfitting group at the moment when two blocks are assembled to one compartment. The hours made before assembling two blocks to one compartment are considered in the hull group. At a hull yard, in general, the hull is produced and most of the time a lot of hot works and some pre-outfitting is already done. Like for example foundations that are welded to the primary structure. Installing a foundation for machinery is hot work and should be done in the section building phase and the hours are considered in the hull group. Installing and connecting the machinery itself will be outfitting work. Outfitting consist of the instalment of equipment, insulation, carpentry, machinery, painting, etc. A visual representation of this breakdown can be found in appendix 8.

The hours in the two groups, hull and outfitting, are defined based on information from cost control reports of the contracting department at Damen Shipyards Gorinchem. Using these cost control reports of previous build vessels, it is possible to get an indication of the labour hours' division in the two groups.

4.3 Yard efficiency

When the total labour hours' capacity is known, the next step is to compare the efficiency of every yard given their input. A yard in China cannot be directly compared to a yard in the Netherlands. There is a difference in culture, facilities, motivation, process efficiency, etc. A method is needed to compare the performance of yards by using efficiency (in 't Veld, 2002). The formula of efficiency is written as follows:

$$Efficiency = \frac{norm\ input}{real\ input}$$

Yards are compared between each other based on the registration of hours for several ship types. To compare yards on the same level, own Damen workers and needed subcontractors are considered in these hour registration. Using this number of hours needed to build a specific ship, the norm can be defined and yards can be compared between each other.

In this research, the inverse of efficiency will be used. The norm yard has an efficiency of 1 and is the yard where the efficiency is the highest. The input at this yard is the norm input. All the other yards need a higher real input than the norm input, they will get a real normalized efficiency factor higher or equal than 1. When calculating the normalized efficiencies, yards can be compared to each other on the same level and one hour in China can be equalised to one hour in the Netherlands. The total actual yard capacity at a yard is then divided by the calculated efficiency to define the norm capacity. The exact efficiency factors to normalize the yard capacity can be found in appendix 12 (Wallace, 2017).

Shipbuilding is a process involving hundreds of thousand items and parts of machinery, equipment, prefabricated parts, etc. The yard efficiency can be further increased by looking more into detail at the outfitting process and the consequences of the phase when a certain activity is performed. Outfitting of a ship can be done partly during the section phase, yet most of it is done in the block phase and final phase when the hull is erected. Outfitting can also be done after launching of the vessel. All of this can be improved doing more pre-outfitting in earlier phases of the production process and using larger modules, that are pre-assembled in the workshop.

The phase in which an activity is performed influences the duration and required man-hours for an activity. A lot of hours can be saved in the outfitting of a ship by moving activities to an earlier stage. For example, the outfitting of pipes in the engine room. Pipes can be installed in an open section that is built upside down, with good accessibility or the same work can be performed during the final phase when the hull is already completed. A third option that also reduces the lead time is the usage of skids for the piping equipment. These three situations will be explained in detail below:

Situation 1:

Pipes can be installed after completion of the hull, this is worse compared to the other two situations, that will be explained below, due to for example the following facts: workers need to weld over their head and it is difficult to move and place the pipes on the ceiling. More time is needed to fit the pipes on the ceiling of the roof.

Situation 2:

An efficient way to do pre-outfitting is already starting with it in the section building phase, man hours and lead time will be reduced to build a ship. The construction is open, easy accessible and most of the time built upside down (see Figure 16). Consequently, it will take less time and man hours to fit for examples pipes on the ceiling of the engine room compared to the first situation. Important to notice, pipes can already be fitted in sections and blocks but everything that goes over borders cannot be done in the pre-outfitting phase, e.g. connections of pipes and finishing of the painting.

Figure 16: Pre-outfitting work on an open upside down section (Hoekstra, 2014)

Situation 3:

When applying modular outfitting, the outfitting work that is traditionally performed on sections, blocks and after the hull is completed is now partly shifted to the workshops earlier in the building process of a ship (see Figure 17). All these modules that are completed in the workshop can now be constructed simultaneously in the process when building the hull. A module can contain a single piece of equipment that can easily be mounted on board of a ship or can be a complex assembly of equipment or piping that is pre-assembled in the workshop and after completion and testing, installed on board as one big unit. Some advantages of modular outfitting in an earlier stage are listed below (Reiff, 2016):

- Outfitting hours will be reduced.
- Employees can work in comfortable working positions.
- Equipment and systems can be tested and painted in the workshop before being installed.
- Fewer items need to be installed.
- At first, the development of modular units and doing more pre-outfitting require an investment in design, engineering and job preparation. Afterwards, these costs can be reduced because it only needs to be done once in the right way.

Figure 17: Floor skids after construction in workshop (Reiff, 2016)

When standard outfitting modules will be produced in workshops and more pre-outfitting is done, there will be a partially shift to earlier phases in the production process and an overall man hour reduction of 20% is possible when looking at the current situation off all the Damen yards (Reiff, 2016). The yard efficiency as described in the first part of this paragraph will change. This is due to an increased efficiency of the work. Contrary, workshop hours in the hull building phase are increased due to the shift of man hours from the outfitting phase to the section and block production phase. But, this will lead to a significant reduction of work during the final outfitting phase. There is an increase of work in the hull building phase of 10% and a decrease of man hours in the outfitting phase of 50% as can be seen in Figure 18 (Reiff, 2016). A reduction of the lead time and man hours has the consequence that the utilization of the yards can be increased and more projects per yard can be executed. Less shipyards are necessary for the same output!

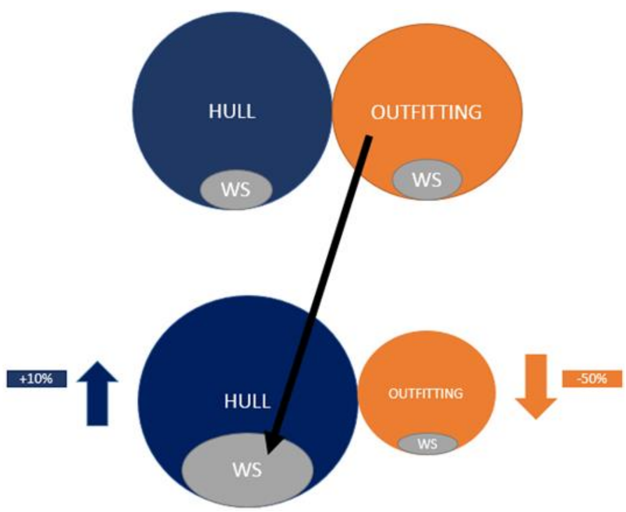

Figure 18: Shift of labour hours when applying modular outfitting (WS = workshop)

4.4 Norm labour hours to build a ship

Per ship an hour norm is defined for the hull and outfitting as discussed in paragraph 4.2. The norm hours to build a ship is the number of hours at the norm yard. The norm yard is the yard that needs the minimal number of hours to build ships as discussed in paragraph 4.3. In Table 6 an example is given of the research method to define the hour norm to build ships. DSGa is the norm yard, other yards need more man hours. When DSGa has not build ships in a certain product group before, the hours are used at another yard that needs the minimal number of hours for these ship types. These hours are than normalized, labour hours are determined that are needed if the ship is built at the norm yard, using the previous calculated efficiencies. The hours at a yard can be different for the same ship type at the same yard, the deviation between the maximum and minimum registered hours is around 10 to 20% of the total labour man hours. In appendix 9 some examples are given of outfitting hours of Damen vessels at Damen Shipyards Gorinchem. An average hour norm is used in this research.

Table 6: Hour norm definition for a selection of ships and yards

Ship type	Product Group	DSCh	DSGa	DSKo	DYS
ASD2810	ASD2810	X	*		X
ASD2913	ASD2810	X	*		X
ASD3010ICE	ASD2810	X	*		X
SBU2609	SBU2609	X		*	
SBU2709	SBU2609	X		*	
X = Product Group Previously build at yard			* = Minimum hours to build ship		

The hour norm for several ships in a product group are defined based on data of the contracting department of Damen, the other unknown norm hours are estimated based on the lightweight of the vessel. Lightweight is the weight of the vessel as it is built without the total weight of the cargo it can carry. This method can be used because the product groups are defined based on the criteria that the man hour per lightweight ton ratio is comparable. The maximum deviation in the man hour per lightweight ton ratio per product group is smaller than 10%. Using this man hour per lightweight ton ratio, the corresponding hull and outfitting hours per ship type are calculated based on the percentage of the total hours used for the hull and outfitting. These percentages are based on the available ship data from the contracting department. The information that is not known about the lightweight of several vessels is estimated using trend lines. Two examples of the trend line method to estimate the lightweight are given in appendix 10.

However, for ASD tugs the man hour per lightweight ton ratio can be used. For dredgers, this is not a good simplification. Cutter suction dredgers become heavier when they increase in length, but the hours needed are not equally increasing when only looking at the lightweight to hour ratio. One of the reasons is that dredgers have heavier components when they are larger, but the work needed to install them is almost equal when the components are smaller. In this case, for all the cutter suction dredgers the hour norm is defined based on data from official Damen sources. The two examples, cutter suction dredgers and ASD tugs, are given in appendix 11. With the normalized yard capacity as discussed in the previous paragraph and all the needed ship labour hours determined as the norm, products and yards can now be matched on the same level.

4.5 Hour tariff

The competiveness of a shipyard does not only depend on how efficiently it assembles the ship. Wage rates and the exchange rate play also a major role to find an optimal yard portfolio when matching hours. When building a ship, costs need to be paid. Ship prices are volatile over the years. The focus of this research is matching the yard and product hours. Among other materials costs, external services like ship classification and additional risk and profit margins are excluded.

Labour cost have a major impact on the competiveness of shipbuilding yards. The focus of this research when looking at the production cost of a ship are the direct needed man labour hours in production. To calculate the actual wage costs, the used norm hour capacity at a yard is again multiplied with the previous calculated efficiency to define the real used actual number of hours. These real used actual number of hours is than multiplied with the direct labour hour tariff. For example, the percentage of direct man hours needed when looking at the production cost of an ASD2810 tug are approximately 30% of the total cost price of a ship (see Figure 19).

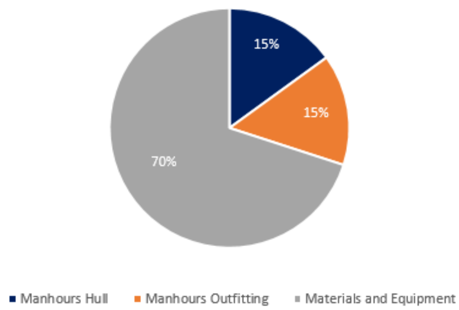

Figure 19: Total costs of an ASD2810 (Reiff, 2016)

The cost of employees working on a project are charged per hour of work. Labour costs vary enormously from one yard to another. To compare hourly wage costs, the labour costs are converted to a common currency: the euro. But, the hourly payment can be very sensitive to the exchange rate of the local currency against the euro. In this research, a fixed exchange rate is considered. To calculate the hour tariff, the company costs per year (excluding the projects materials) are divided by all the budgeted direct man-hours per year (Damen Contracting & Yard Support, 2015). The exact hour tariff can be found in appendix 12 (Visser, 2015a).

The calculation of the hour tariff is based on the following equation:

$$Hour\ tariff = \frac{V + F}{N}$$

With:

V = Budgeted variable costs per year at a yard
F = Budgeted fixed costs per year at a yard (generally do not change when production volume changes)
N = Nominal capacity or the expected average number of direct man hours per year used at a yard for all the projects in the coming years based on the estimated output in these years (Koetzier & Brouwers, 2010). This nominal capacity includes the direct blue collar employees (e.g. welders, outfitters) and direct white collar employees (e.g. project managers, job preparation) and hired direct personnel. Hired personnel is a flexible layer as discussed in chapter 2, but not all the hired personnel must be or is added to the nominal capacity. It is based on management decisions how many of the hired personnel is considered in the nominal capacity to calculate the hour tariff. The rest is still a flexible layer that can easily be increased or decreased dependent on the market and has no effect on the hour tariff.

The possible subcontractors at a yard as earlier discussed in paragraph 4.2 are not included in the calculation of the hour tariff. Subcontractors are invoiced to the project and are added separately to the available capacity as previously discussed.

For further usage in this research a fixed part and a variable part will be used as two separate values in the cost minimization based on the previously discussed hour tariff calculation. The costs that are included in the fixed part are:

- Depreciation costs (e.g. machines, buildings, …)
- Rent of building
- Utilities (gas, water, electricity)
- Internal office costs like project management, general management, human resource management, engineering, finance, job preparation, purchase, etc.

The fixed cost price will always need to be fully paid, independently if the yard builds one or 25 vessels. If the yard is set off, the fixed cost price will be zero and no ships can be assigned to this yard. Part of the costs of the hour rate are moved to the fixed cost price. The fixed cost price at a yard is approximately 30% of the hour rate and is calculated as follows (Damen Contracting & Yard Support, 2015):

$$F = 0.30 \cdot Hour\ tariff\ \cdot N$$

With:

F = Budgeted fixed costs per year at a yard
N = Nominal capacity

Generally, the fixed cost price at a yard does not change, however there is a limit to this. Office personnel that are required for 10 vessels cannot do all activities that are required to produce 15 vessels. A range can be defined to which the fixed cost price will not change when production changes as can be seen in Figure 20. The fixed cost price is thus constant in a certain production capacity range and can become higher or lower in the long-term dependent on the production growth or decline (Koetzier & Brouwers, 2010).

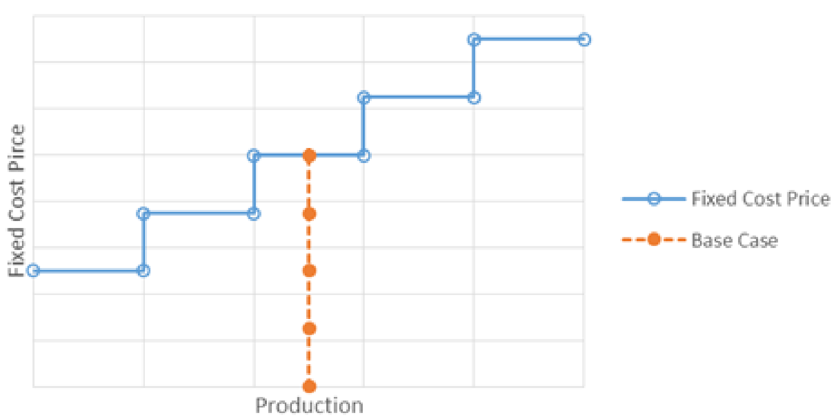

Figure 20: Fixed cost price in relation to the production capacity

The other 70% of the hour tariff is variable and can be used to calculate the direct labour cost of the workers on the production floor as follows:

$$L = 0.70 \cdot Hour\ tariff\ \cdot R$$

With:

L = Direct labour production cost
R = Real used actual capacity: used norm hour capacity at the yard multiplied with the corresponding previous calculated yard efficiency

4.6 Conclusion

Damen wants to have a better match between the yard and product portfolio. To match these two portfolios, data needs to be selected. After reading this chapter the following sub question is solved:

- *How to match the man hours at the yard to the product hours?*

The data that is required to match yards and products are the norm hours needed to build the whole product portfolio of Damen and the normalized capacity of the yard portfolio. The shipbuilding labour hour capacity of the yard in hours can be matched with the needed capacity in hours to build several ships per year on the same level.

The main research question is to find an optimal yard portfolio. To be able to find an optimum, wage rates for all the yards are defined. Using the wage rates the most cost optimal matching of hours is possible. To calculate the actual wage costs, the used norm hour capacity at a yard is translated to the real used actual number of hours. These real used actual number of hours is than multiplied with the direct labour hour tariff and so the labour cost can be calculated. Ships must be transported from the supply region to the demand region. To find the optimal yard portfolio, the combination of the summation of the total labour cost at the yard and the transport cost needs to be the cheapest as possible. In the next chapter, the transport cost will be discussed.

5. Transport

Supply and demand is not always at the same location. Ships must be transported from the supply region to the demand region. To find the optimal yard portfolio, the combination of the summation of the total labour cost at the yard and the transport cost needs to be the cheapest as possible. Transport costs will be discussed in this chapter.

Supply and demand is not at the same location. Asia and Europe are the two main supply markets for Damen ships as discussed in chapter 3, but the demand is all over the world. Dependent on the building and delivery location, a transport cost will need to be paid. Damen divides the world in seven big sales areas:

- Benelux
- Americas
- Middle East
- Africa
- Asia Pacific
- North, West & South Europe
- East & South East Europe

Based on the selected yard locations (= supply) and sales areas (= demand), the world can be divided in groups. In Figure 21 the blue circles with a “D” in it are the demand or sales locations. The orange circles with a “S” in it are the supply countries where there are Damen yards.

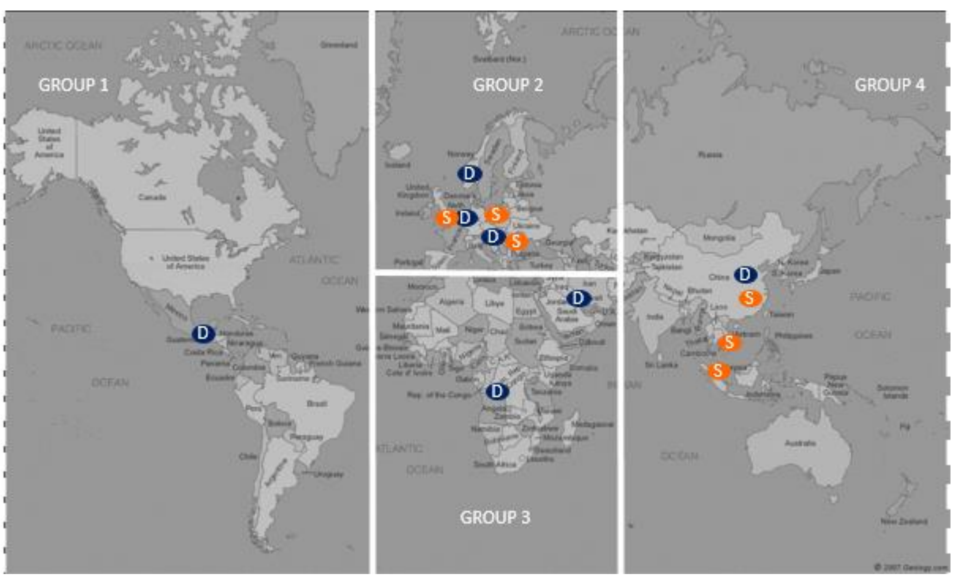

Figure 21: Division of the world based on location Damen yards and sales areas (D = demand, S = supply)

When combining the own Damen yard locations and sales areas, the seven Damen sales areas and two supply market areas are grouped into four regions. It is assumed that the transportation costs within these larger groups are minimal and are not influencing optimization decisions where to build a ship.

The following groups are made:

- Group 1: America
- Group 2: Europe
- Group 3: Africa and Middle East
- Group 4: Asia

The reasons to divide the world in four regions is because transport costs are very uncertain. Additionally, the height of the transport cost is also small compared to the total labour cost when building a ship, it is only used as a barrier to build at a certain location. To minimize the uncertainty, one cost price is assumed for a larger region to avoid many uncertain variables. Thirdly, Asia and Europe are the two main supply markets for Damen ships and the distance between the yards in these two regions is minimal. For Asia and Europe, the transport cost prices in and to other regions in the world are determined and can be found in appendix 12. The total transport costs in this research are around 10 to 15% of the total costs. Therefore, even if it is very unpredictable it can still be used a barrier to build at a certain location.

An average transport cost is defined based on the experience of Damen employees. Cost are estimated based on the supply and demand region, used transportation method and weight of the vessel (Slijkoord, 2016). Transport costs are dependent on a lot of variables like the demand, supply, exact location of the delivery location, time, …. For example, when transporting a ship from Asia to West Africa this can be cheaper than transporting it to East Africa because in the east there is among others piracy and less trade. But, because the transport cost is so uncertain and small in the total cost price, Africa is not divided into two regions and a general cost is assumed.

6. Model description

Using the available information, the needed hours to build a ship can be matched to the available capacity at a yard. A method needs to be selected that can calculate the most optimal yard capacity. This cannot be done manually anymore because the problem is too large, a computerized model needs to be made. In paragraph 1, a discussion is given about optimization methods using a computer. To obtain the optimal yard portfolio and capacity of Damen under different circumstances a cost price function will be minimized and discussed in paragraph 2. Combining the study about optimization methods and the cost price function, a computerized model is made and a description is given in paragraph 3.

After reading this chapter, the following sub question will be solved:

- *Which optimisation techniques are suited to deal with the problem?*

6.1 Optimization

Given a product portfolio to be delivered in a year a match is made with the yard production capacity to minimize the costs, using the methods of operations research. Using this method, the objective function, in this case a cost price function, can be minimized by finding the best allocation of ships to the different yards. An optimal solution is a feasible solution were the cost price is the smallest one possible.

The following solver parameters need to be defined to solve the matching problem of Damen:

- Objective function: The function that is being minimized is the cost price. This depends on the chosen optimization approach and will be described later.
- Decision Variables: Deliveries per yard, the different vessels that a yard can build will be the changing cells while searching for the best solution.
- Constraints
    - Maximal available hours at a yard:

      $$Used\ model\ capacity_{i,c} \leq Maximal\ capacity\ reality_{i,c}$$

      With:

      i = Yards (1 to n)
      c = 1 to 3: hull, outfitting and flexible layer
      Capacity = available labour hours

    - Decision variables (=deliveries) need to be positive and integers

      $$Deliveries_{i,u} \in \mathbb{N}$$

      With:

      i = Yards (1 to n)
      u = every unique ship that needs to be delivered (1 to z)

    - Input deliveries need to be equal to the total deliveries at all the yards together:

$$Input = \sum_{i=1}^{n} Output_i$$

With:

i = Yards (1 to n)

- Yards can only be filled with ships if they are active

- Solving method: non-linear or linear programming. Which one is the best for this cost optimization problem will be answered after analysing what the difference is between both and setting up the cost price function. Firstly, both solving methods will be discussed and afterwards the cost price function is given.

6.1.1 Nonlinear programming

When all the mathematical functions in the model are linear, linear programming can be used. When the objective function is nonlinear. An algorithm that deals with non-linearity needs to be selected to solve the problem. A nonlinear programming algorithm needs to be selected that can distinguish between a local and global maximum. It is important that the local optimum found is also a global maximum or overall optimal solution in the search space (see Figure 22).

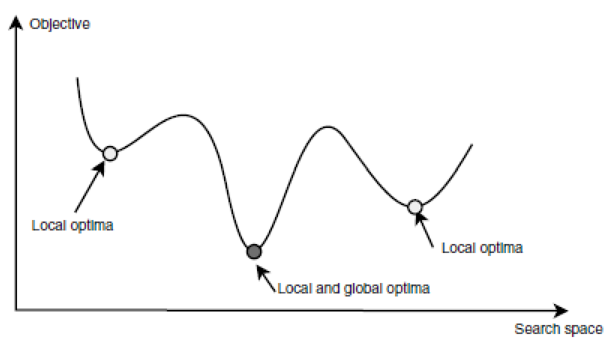

Figure 22: Local and global optimum in a search space (Talbi, 2009)

A method needs to be found which can work with complex functions and functions with a lot of many local optimums when the problem is nonlinear. It needs to be able to evaluate a lot of trial solutions that are not in the same neighbourhood to keep from getting trapped at a local optimum. A genetic algorithm is well suited for dealing with these kinds of problems. On the other hand, a genetic algorithm has also some shortcomings:

- It can take much longer than a linear solving method to find a final solution
- A genetic algorithm is a random process, with random trial solutions. Running it again on the same model can yield to a different final solution.
- The best solution found is most of the time not the optimal one, although it may be very close.

A genetic algorithm can be compared to an intelligent search engine, trying out a lot of different random possible solutions. It has a good performance to find a near-global optimum. However, it almost never reaches the exact global optimal solution. To improve this, another algorithm can be used that searches around its neighbourhood after the genetic algorithm has found its near-global optimum. A hybrid method is created.

A local search algorithm, that searches local around the solution found by the genetic algorithm will be used. A hill climbing procedure is selected, this algorithm starts at the final solution and climbs the hill until it reaches the peak or a boundary constraint and reports this solution. It is important that the climbing procedure is started after running the genetic algorithm. A local search algorithm is not able to detect whether there is a taller hill somewhere else (Hillier & Lieberman, 2015).

6.1.2 Linear programming

As described above, it can take much longer to solve a non-linear problem compared to a linear programming dependent on the required solution. When all the mathematical functions in the model are linear, linear programming can be used. The problem is than an example of the resource-allocation problem that can be solved using integer linear programming (ILP). The simplex method, a general procedure for solving linear programming problems, can be used to find the optimal solution. It is an efficient method that can solve huge problems using a computer in a small amount of time (Hillier & Lieberman, 2015).

6.2 Cost price function

To obtain the optimal yard portfolio and capacity of Damen under different circumstances. The cost price function needs to be minimized. The total cost price function consists of five parts. The summation of these five parts needs to be as minimal as possible and are described below in detail:

- Total fixed cost price:

  Every own Damen yard has a fixed cost price (e.g. overhead costs). If yards are part of the active portfolio of the model, these costs will need to be paid. Other yards that are not in the active yard portfolio have a fixed cost that is equal to zero. Damen wants to be able to manually select the active yards, e.g. political reasons to keep a yard open or close one. Therefore, the user decides which yards can be turned on or off. The total fixed cost price is calculated as follows:

$$\sum_{i=1}^{n} F_i = \sum_{i=1}^{n} 0.30 \cdot Hour\ tariff_i \cdot N_i \cdot X_i$$

With:

Hour tariff = the company costs per year (excluding the projects materials) divided by all the budgeted direct man-hours per year (see chapter 4)
F = Budgeted fixed costs per year at a yard
N = Nominal capacity
X = Binary for all i dependent on user input (0 = OFF, 1 = ON)
i = Own Damen yards (1 to n)

- Direct labour cost:

When the yard is set active by the user, ships can be assigned to the yard. To calculate the actual wage costs, the used norm hour capacity at a yard is again multiplied with the previous calculated efficiency in chapter 4 to define the real used actual number of hours. These real used actual number of hours is than multiplied with the direct labour hour tariff as can been seen in the equation below:

$$\sum_{i=1}^{n} L_i = \sum_{i=1}^{n} 0.70 \cdot Hour\ tariff_i\ \cdot R_i$$

With:

L = Direct labour production cost
Hour tariff = the company costs per year (excluding the projects materials) divided by all the budgeted direct man-hours per year (see chapter 4)
R = Real used actual capacity: used norm hour capacity at the yard multiplied with the corresponding previous calculated yard efficiency
i = Own Damen yards (1 to n)

- Cost price flexible layer:

The flexible layer of employees has another hour tariff than the own Damen employees. Because the only non-linearity in this research is the additional flexible layer, the problem can be made linear by adding a fictive yard to the existing Damen yard to save computation time. This fictive yard has an additional capacity above the existing yard and is more expensive compared to the existing yard. In this research, the rate of the flexible layer is set at 50% more than the direct labour hour tariff at the yard. This is based on data from all the Damen yards and cost price calculations of the hour tariff of flexible workers (Visser, 2016b), (Inhuren, 2017). The fictive yard will only be used when the existing yard is fully used and no other cheaper option is possible.

$$\sum_{i=1}^{n} Flexible_i = \sum_{i=1}^{n} Flexible\ Hour\ tariff_i\ \cdot Flexible\ used\ capacity_i$$

With:

Flexible = Direct labour production cost of the flexible layer
Flexible Hour tariff = The rate of the flexible layer is set at 50% more than the direct labour hour tariff at the yard.
Flexible used capacity = Real used actual flexible capacity: used flexible norm hour capacity at the yard multiplied with the corresponding previous calculated yard efficiency in chapter 4
i = Own Damen yards (1 to n)

- Partner yards:

Hull and outfitting can be on different yards (e.g. Damen Shipyards Gorinchem, Damen Dredging Equipment and Damen Song Cam Shipyard). DDE does only the outfitting of cutter suction dredgers. These hulls will be built in Kozle and transported to DDE. DSGo and DSCS get their hulls from partner yards in their corresponding area. Partner yards can build hulls that are outfitted at a Damen yard or partner yards can build complete ships. The cost price of the labour done at partner yards is as follows:

$$\sum_{j=1}^{m} P_j = \sum_{j=1}^{m} Hour\ tariff_j \cdot R_j$$

With:

P = Cost to build hulls and complete ships for Damen at partner yards
Hour tariff = hour tariff at the partner yard
R = Real used actual capacity: used norm hour capacity at the yard multiplied with a yard efficiency
j = Partner yards (1 to m)

- Transport cost:

The demand and supply of vessels is not always in the same area. Therefore, transportation costs between defined groups need to be considered. These are transport costs between the hull yard and outfitting yard, if there is no complete shipbuilding at a yard, and between the yard and the final delivery location.

$$\sum_{u=1}^{z} TC_u = \sum_{u=1}^{z} (TC_{Hull,u} \cdot X_u + TC_{client,u})$$

With:

TC = Transport cost
Hull = transport cost of the hull to outfitting yard
X = Binary for all u dependent if complete ship is built at the same yard or not (0 = complete ship is built at the same yard, 1 = hull and outfitting yard are different)
Client = transport cost from the yard to the final delivery location
u = every unique ship that needs to be delivered (1 to z)

6.3 Computerized model

A model is made that matches the available capacity of the yard to the needed man hours to build several ships per year in the most cost optimal way. Linear programming is used because all the mathematical functions in the model are made linear. The following four steps are required to find an optimum to solve the main research question:

1. Define which ships will be delivered in a year with corresponding delivery location.
2. To keep the research manageable within the given time, simplifications are needed in such way that does not affect the accuracy of the model. Average dummy ships are defined that are representative for a larger group of input ships. In total, 24 dummy vessels are defined that corresponds with the previous discussed product groups in chapter 3. A model calculates the lightweight of a dummy vessel based on the input in a product group, using this lightweight the norm hours for hull and outfitting are calculated. This simplification has minimal consequences, because the total needed building hours and total delivered ships in a product group are not changed compared to the situation when every unique ship type is used in further calculations.
3. The user can specify which yards will be turned on and what the yard specific parameters are. The user has a lot of decision power because the management can make decisions based on for example political reasons that cannot be included in a computerized model. The model can help the user when he isn't able anymore to match yards and products manually with a given set of input variables.
4. Match the input of the yard parameters and product portfolio and calculate the best solution to minimize the cost price of labour and transport cost.

The purpose of the model is to make it easy understandable what happens when the user changes the input of delivered vessels and input variables of the yard. The model is developed so that the user can give a list of ships as input and change yard specific input variables that are discussed in chapter 4. The user can change the following yard parameters:

- Yards can be turned on or off by the user, if the yard is active in the model a fixed cost price need to be paid and ships can be assigned to this yard.
- Hour tariff
- Change the efficiency factor for hull and outfitting
- Change the total labour capacity available per year
- Add additional employees above the own capacity. This flexible layer is more expensive than the layer of own Damen capacity.
- Add an increased process efficiency for every yard, e.g. more pre-outfitting and modular outfitting. In this way, the needed man hours can be reduced. Consequently, when more pre-outfitting is needed the fixed cost price will increase a little. This is because among others more engineering and job preparation is needed.
- Change the needed capacity for projects outside Gorinchem

Partner yards have no restrictions in hours to build the hulls. There is only a restriction in outfitting hours when the yards are built at a Damen outfitting yard, for example DDE or DSCS. An additional transport cost to transport the hulls to the outfitting yard is also considered. The hull yards are simulated as a "ghost" source with only a cost price for man hours in these cases. If Damen intends to buy new yards in the future, only selected parameters need to be defined and the yard can be included in the model.

Besides the own Damen yards and partner yards to build hulls, two partner yards in the main supply areas of Damen, Asia and Europe, are added to the model that can build complete ships for Damen. The reason for this is that if the demand is very high, the model can still find an optimum. Partner yards are a flexible layer and have only an hour tariff and transport cost and no boundary condition on their capacity.

The output of the model is the optimal allocation of ships over the yards in different situations. The most optimal distribution of the ships over all the yards is the one with the lowest cost price. Based on this calculation, the board can decide which decisions it will make. The user can interpret these results and draw conclusions. Using this optimization, the Damen core yards, together with their minimal production level and flexible capacity, under different circumstances can be identified after changing the yard specific input variables in the way the user wants. A flowchart of the process steps is given in Figure 23.

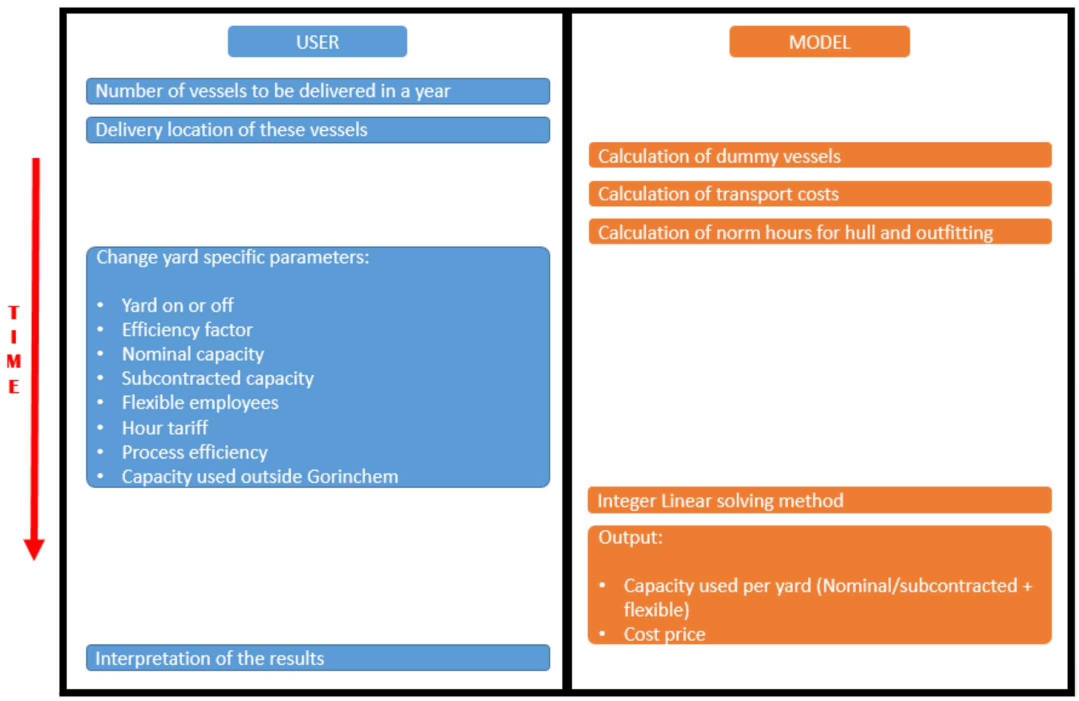

Figure 23: Flowchart of the process steps in time done by the user and model

6.4 Conclusion

The problem can be solved using the methods of operations research. Using this method, the objective function, in this case a cost price function, can be minimized by finding the best allocation of ships to the different yards. Linear programming is used because all the mathematical functions in the model are made linear. A program is selected with the following criteria:

- Can work with a linear algorithm, e.g. Simplex LP (linear) method.
- Ease of use, a manager or other employee at Damen needs to be able to use the program and change variables.
- Needs to be able to work with variables and constraints.

Using the Add-in Solver (a product of Frontline Systems, Inc.) in Microsoft Office Excel, an optimal value for the cost price function subject to constraints can be found by changing variable cells. Microsoft Office Excel 2013 has three solving methods used for solving optimization problems:

1. Simplex Method: used for solving linear problems
2. GRG Nonlinear: uses the hill climbing procedure to solve nonlinear problems
3. Evolutionary Solver: uses genetic algorithm to find its solution. Spreadsheet functions such as the IF-function, in the case of working overtime can be used with this solver.

The advantage of a spreadsheet software is the ease with which it can be used interactively by anyone to see what happens to the best solution when changes are made to the input variables. It is also possible to formulate the research question in a spreadsheet; the Solver can work up to 200 decision variables and can place on up to 100 cells a constraint. Additionally, to these 100 cells, it is possible to place upper and lower bounds and integer constraints on the decision variables (Frontline Systems, 2017). Another advantage is that both the linear programming option and the hybrid method are available in Excel. In this research, the simplex method will be used because all the mathematical functions are made linear.

7. Validation and verification

To ensure that the model can correctly be used for the intended application, verification and validation is needed. A model is an idealized rather than an exact representation of the real problem, there cannot be a guarantee that the best solution for the model will be the best possible solution in real life. There are many uncertainties associated with real problems that cannot be modelled, e.g. political reasons (Hillier & Lieberman, 2015). Tests and evaluations need to be done until there is sufficient confidence that the model can be considered valid for the intended application. This chapter is organised as follows:

- Validation
- Verification
- Historical data

7.1 Validation

Tests and evaluations are conducted to make sure that the model can be considered valid for the intended application. Validation is conducted concurrently with the development of the model and after the model has been developed. The basic approach for deciding whether the model and assumptions are valid or not is interviewing model users at Damen and third parties. A third party has a thorough understanding of the purpose of the model without being a part of both the simulation team and intended model users (Sargent, 2010).

Data is collected from official Damen sources and interviews with experienced employees. The following aspects need to be considered about the data that is used:

- Yard capacity

The total capacity consists of the subcontracted capacity and Damen core capacity. The subcontracted hours at all the Damen yards are estimated to be able to compare yards on the same production level. The own Damen core capacity is based on data from the official Damen database. To estimate the total subcontracted capacity at a yard, the percentage of the work done by subcontractors per ship type at the yard is investigated using the hour registration of different ships at a yard. The estimated subcontracted capacity at a yard varies between 0 and 30% of the total yard capacity. If this estimation turns out to be wrong, e.g. too high or too low, this has no consequences for the interpretation of the results. The model can still give a good indication which yards need to be in the core portfolio of Damen because this will be the yards that will used more, when looking at the used percentage of the capacity, than the less preferred yards. The model can thus still give the user insight in the system of interconnected vessels of all the Damen yards and partner yards that are used in the model. Also, the biggest part of the total capacity is the own Damen core capacity as it is now. The own Damen core capacity is based on the database of Damen.

In this total capacity, there is a flexible layer of projects done for other Damen yards outside the Gorinchem cluster as discussed in chapter 4. These are projects for among others: Amels or Damen Shipyards Hardinxveld. This layer of used capacity varies every year. There is no fixed percentage of the capacity used for Gorinchem projects. The consequences of these uncertainties have no effect on the intended results of this research. The core yards can still be selected, even if the there is a part of the capacity used for projects outside Gorinchem.

- Yard efficiency

Yards are compared between each other based on the registration of hours for several ship types. To compare yards on the same level, own Damen workers and needed subcontractors are considered in these hour registration. Using this number of hours needed to build a specific ship, the norm can be defined and yards can be compared between each other. The total actual yard capacity at a yard is then divided by the calculated efficiency to define the norm capacity.

The efficiencies can differ per ship type at a yard. The used yard efficiency in this research doesn't take this difference into account. The reason for this is the available data. If the data is available on a more detailed level than it is now, different efficiencies can be used to improve the level of detail and an investigation can be done what the consequences are when a new type is built at a yard that is never been done before. Based on this, efficiencies can be given to ship types that can be built at a yard but are not build before there. For now, fixed links are used between the yards and products based on historical data and interviews with employees at Damen. Product groups that are not build before in history at a specific yard cannot be assigned to this yard. The used efficiency on a less detailed level in this research has no consequences for the interpretation of the results. The model can still give the user insight in the system of interconnected vessels of all the Damen yards and partner yards that are used. Additionally, working with this lower level of detail of yard efficiency reduces the effect of the incomplete data on the ship specific level.

- Division of labour hours

The hours needed to build a ship are divided in two big groups: production hull hours and outfitting hours. This division in two groups is done because of the following two reasons as described earlier in this report:

- Three different types of yards exist: hull yards, outfitting yards and complete ship building yards with different levels of integral building. Using this division into two groups, a direct link is created between the ship hours and yard types.
- Detailed hour registration of labour hours during the production process is not available and not uniform over all the yards. To minimize the uncertainty, the hours are divided into two groups instead of many uncertain variables.

Workshop hours, as discussed in chapter 2, in the production process are distributed over the hull and outfitting group. The consequences of this simplification are minimal because the workshops are now responsible for less than 10% of the total labour hours to build a ship at the yards of Damen (Damen Contracting & Yard Support, 2016f). The hours in the two groups, hull and outfitting, are defined based on information from cost control reports of the contracting department at Damen Shipyards Gorinchem. Using these cost control reports of previous build vessels, it is possible to get an indication of the labour hours' division in the two groups. The hours at a yard can be different for the same ship type at the same yard, the deviation between the maximum and minimum registered hours is around 10 to 20% of the total labour man hours. An average hour norm is used in this research.

The consequences of these simplifications have no effect on the intended results of this research. The order of magnitude of all the labour hours is the most important to get an idea of the communicating vessels of all the Damen yards and partner yards.

- Transport costs

Transport costs are very uncertain and are around 10% of the total labour cost price of a ship. Therefore, even if it is very unpredictable it can still be used a barrier to build at a certain location. An average transport cost is defined based on the experience of Damen employees. Cost are estimated based on the supply and demand region, used transportation method and weight of the vessel (Slijkoord, 2016). Transport costs are dependent on a lot of variables like the demand, supply, exact location of the delivery location and time.

A technique that is used to check the transport data is parameter variability or sensitivity analysis. The values of the transport costs will be changed to determine the effect upon the model's behaviour and output. One of the purposes of a sensitivity analysis is to determine the effect on the best solution if the estimated values turn out to be wrong. This analysis can be used for the identification of these parameters that need to be estimated more carefully before applying the model. A great strength of a spreadsheet is the ease with which it can be used interactively by almost anyone to perform various kinds of sensitivity analysis. The user only needs to make a change of some value and click on the solve button again. You can immediately find out what happens (Hillier & Lieberman, 2015).

Individual changes in the model are made by changing the spreadsheet and re-solve it. Different scenarios are worked out, transport costs are varied between the lowest cost price, an average cost price and the highest cost price. The other input data is kept constant. As can be seen in Table 7, there are some changes in the used capacity at the Damen yards when the transport cost is high. The highest transport cost is when ships are transported to America as can been seen in appendix 12.

Table 7: Used capacity when varying the transport cost

	Lowest	Average	Highest
DDE	0%	0%	0%
DSAn	100%	99%	98%
DSCh	15%	15%	15%
DSGa	41%	41%	38%
DSGo	0%	0%	0%
DSKo	52%	52%	0%
DSSi	39%	39%	40%
DSCS	5%	5%	14%
DYS	98%	99%	96%

When the transport cost is high, the difference of the transport cost between both supply regions, Asia and Europe, is also very small. It is thus not only about the height of the transport cost, but another important factor is the difference between the transport costs from both Asia to other regions and from Europe to other regions. For example, when the transport cost is zero or the difference between the transport costs is very small, only the hour tariff and efficiency is of importance and a shift can be seen to cheaper yards. This can clearly be seen in Table 7, DSCS is now building ships that were previously build at DSKo. When the difference between the transport cost is very high, this difference will be a significant part of the total cost price and there will be a shift to the more expensive yards closer located to the end consumer.

To demonstrate this, another example is given in Table 8. Five yards are selected to show the effects of the difference of the transport cost. When there is no difference in transport cost or the transport cost is zero, the yard in Yichang is fully used. When there are some transportation costs, this used capacity declines with 10%. When the transport cost is a significant part of the total cost price, it is cheaper to build at more expensive yards closer to the end customer as can been seen in the table: the yard in Gorinchem is now used for the first time. This can be explained by the fact that the difference in transport cost is very large now. This difference is now a significant part in the decision making process when matching the yards and products of Damen.

Table 8: Varying used capacity at yard when transport cost difference changes between Europe and Asia

	Transport cost = 0€	Average difference	Difference x2	Difference x4
DSGo	0%	0%	0%	**53%**
DSKo	0%	98%	98%	98%
DSSi	28%	28%	28%	0%
DSCS	15%	9%	9%	0%
DYS	**99%**	88%	88%	**15%**

Therefore, for further research an average transport cost is used. This average transport cost takes a difference into account between the two supply regions, without being a significant part of the total labour cost. The cost price difference in this research is on average around 10% of the total cost price at the cheapest Damen yard. The transport cost is thus a barrier to build at a certain location, but it is not a significant part of the total cost price.

7.2 Verification

Model verification is used to ensure that the model implementation is correct. The software used in this research is the Add-in Solver in Microsoft Office Excel. To verify the model, a structured walk through the model programming is done. Firstly, it is manually checked if all the cells in the spreadsheet are linked correct to each other to make sure no mathematical errors are made. Secondly, a thorough investigation is done of the Add-in Solver. In Figure 24, the solver parameters can be seen that needs to be selected in the spreadsheet.

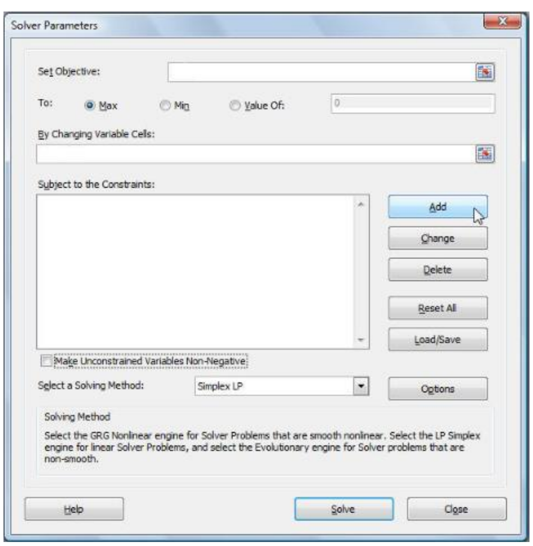

Figure 24: Parameters Add-in Solver

After adding all these parameters, the problem can be solved. To be sure that the model behaves correct, the following results are checked manually using historical data and extreme input scenarios:

- Yards can only be filled with ships if they are active
- Ships linked to yards need to be correct
- Maximal used yard capacity cannot be higher than the set constraint
- Variables need to be non-negative
- Variables need to be integers
- Input of ships need to be equal to the output

7.3 Historical data

A technique to test the validity and verify the model at the same time is the usage of historical data to reconstruct the past. The data from the past 5 years (2011 – 2015) will be put in the model, year by year. It indicates whether the model has shortcomings and requires modifications. By doing this, it is possible to check if the model behaves correct. The nine yards in the portfolio can only become active in the year that Damen has bought them, an overview is given in Table 9.

Table 9: Overview of the historical year when a yard is bought by Damen

YARD NAME	**YEAR BOUGHT BY DAMEN**
Damen Dredging Equipment	1988
Damen Shipyards Antalya (Steel/Aluminium)	2015
Damen Shipyards Changde	2002
Damen Shipyards Galati	1999
Damen Shipyards Gorinchem	1978
Damen Shipyards Kozle	2006
Damen Shipyards Singapore	2000
Damen Song Cam Shipyard	2014
Damen Yichang Shipyard	1998

Using historical data, the results were checked manually on the following points:

- Yards can only be filled with ships if they are active
- Ships linked to yards need to be correct
- Number of ships as input need to be equal to the output
- Maximal yard capacity cannot be higher than the set constraint
- Total norm hours per year in history need to be equal to the modelled output norm hours per year
- Variables need to be non-negative and integers

7.4 Conclusion

In this chapter, the model is validated and verified using different input scenarios. Several tests are done with extreme and historical input scenarios to see if the model behaves correct.

8. Results

In this chapter, results will be presented. Based on historical data presented in paragraph 1, Damen can reduce costs and optimize their yard portfolio. A case plan is worked out to define the core yards of Damen to minimize the costs. The idea of the case plan is to get insights in the changing usage of capacity when yard parameters and input of vessels are changed. In the second paragraph the case plan will be discussed in detail. In the next five paragraphs, different scenarios will be worked out:

- Average case, increase and decrease input portfolio
- Average base case, but increase and decrease workboats or high speed crafts
- Changing yard efficiencies
- Changing flexible layers
- Combinations

8.1 Historical data

Using historical data, it can be determined how well the model best solution found would have performed if it were used. Comparing the best solution to what happened indicates whether the model calculates an improvement or not. The historical usage is calculated based on the number of ships delivered in a year at a yard multiplied with the norm hours corresponding to the ship types. Using the total available norm hour capacity at a yard, a percentage of the used capacity can be calculated. The model calculates a clear potential improvement in the costs. On average, over the years a reduction of 10% of the cost price is possible. This is because there is a shift to the cheapest and most efficient yards. This shows that Damen can do it better. This can be seen in Table 10. History was thus not optimal, but there can be among others political reasons to build at a certain yard and the model doesn't consider this.

Table 10: Yard capacity model compared to historical yard capacity (no flexible layer used in model)

	2011		2012		2013		2014		2015	
Yard	Model	History	Model	History	Model	History	Model	History	Model	History
DDE	0%	26%	0%	5%	0%	12%	0%	9%	0%	20%
DSAn									99%	0%
DSCh	2%	49%	0%	73%	0%	89%	9%	65%	20%	89%
DSGa	18%	28%	33%	33%	51%	51%	70%	59%	99%	72%
DSGo	11%	29%	31%	57%	25%	75%	2%	75%	0%	62%
DSKo	3%	20%	51%	14%	64%	31%	93%	25%	76%	50%
DSSi	27%	17%	92%	82%	93%	72%	82%	69%	56%	119%
DSCS							6%	7%	3%	21%
DYS	83%	35%	66%	40%	41%	0%	10%	0%	7%	0%

Reasons for this shift are:

- There is a shift to DYS, because it is cheaper than for example DSCh and at the same time it has a better efficiency.
- There is a shift from fast crew suppliers build at Gorinchem to DSSi, because DSSi is cheaper.
- The steel and aluminum part of Antalya can build a lot of the ships that are also build in Singapore. Antalya is cheaper and more efficient; a clear shift can be seen in 2015.
- The capacity used at the different yards is strongly dependent on the delivered product portfolio.

A more thorough investigation of the core yards is given in the next paragraphs based on the results of historical data. Damen can do it better, with fewer yards and optimal usage of their selected core yards. The selection process of the Damen core yards and their flexible layers will be presented below.

8.2 Case plan

As a case study, a selection of input scenario's is worked out. A list of different scenarios with a high and low demand of Damen vessels will be used. Based on the previous analysis of historical data, Damen can do it better. To define a better yard portfolio for Damen, the input list of ships and yard specific parameters like efficiencies and flexible layers will be systematically changed to get a better understanding when yards are used. Transport costs are kept constant for all the different scenarios. The flexible layer of subcontractors is added to the own capacity as discussed in chapter 4, partner yards in Asia and Europe can be used anytime in every step. A step-by-step plan is developed to define the consequences and shifts of capacity when yard parameters and the ship input list are changed. The steps that are done are described below:

1) Average case, increase and decrease input portfolio

   Based on the ships built at the Gorinchem cluster yards between 2011 – 2015 an average input portfolio is developed. This input list of vessels is decreased and increased to define the capacity used at the nine yards and partner yards with a varying input list. Yard parameters, as discussed in chapter 6, are kept constant. The values of the yard parameters in the model are equal to the values as it is now, without future improvements or changes.

2) Average base case, but increase and decrease workboats or high speed crafts

   Using this average base case as input, every unique business unit will be increased or decreased. This is done to simulate a changing economy when the demand is increasing or decreasing of a specific business unit. This is useful for a better understanding what the consequences are when there is a shift in the production portfolio of Damen.

3) Changing yard efficiencies

   Every yard has a yard specific efficiency. The norm yard has a normalized efficiency of 1 and can built a ship with the least number of hours. All the other yards need more man hours, these yards have a normalized efficiency that is higher than 1. Damen is investing in increasing the efficiency at their yards by looking at the shipbuilding process of their yards. Based on previous research, a man hour reduction of 20% is possible. Using the model and different input scenarios with an increasing and decreasing demand, the possibilities and shift to more efficient yards can be calculated.

4) Adding flexible layers

   Different flexible layers are defined in chapter 2. In this step additional employees are added to the man hour capacity at a yard. This flexible layer is more expensive than the own employees direct labour hour tariff (hour tariff excluding the fixed costs) at the yard. The direct labour hour tariff for the flexible layer is 50% more than the direct labour hour tariff of the own core capacity as described in appendix 12.

5) Combinations

   The final step is to combine the previous steps and vary the flexible layers, efficiency, input list, yards are set off, etc. Several combinations are calculated using the model to define the most optimal yard portfolio of Damen under different circumstances.

8.3 Average case, increase and decrease input portfolio

With the model validated and verified, an average case is worked out. Based on the historical data between 2011 - 2015, an average product portfolio is determined of the following dummy ships:

- 16 ASD2810
- 9 STU1606
- 3 STU2608
- 5 CSD500
- 5 FCS1605
- 9 FCS3307
- 2 FCS5009
- 1 FF4212
- 2 MUC1908
- 2 PSV3300
- 1 SLAU804
- 2 SPA2606
- 2 SPA4708
- 2 STE1905

This average product portfolio is used as the base case for further investigation. Damen has one yard that can build composite vessels that is also located in Antalya. Because it is the only composite yard in the whole Damen portfolio, it is also the preferred one. Composite ships go directly to this yard and are not further discussed in this chapter. This chapter wants to show the communicating vessels of the whole Damen yard portfolio when changing input variables. In total, 61 vessels are used as a base case. This base case of delivered ships will be increased and decreased as can be seen in Table 11. In the last column, a percentage is given of the total norm hours in a scenario divided by the total norm hour capacity available at the yards of Damen. A detailed overview can be found in appendix 15.

Table 11: Overview of the increasing and decreasing input portfolio

Increase/decrease	# Vessels	% Total/available
- 75%	17	17%
- 50%	34	26%
- 25%	50	41%
BASE	61	47%
+ 25%	78	64%
+ 50%	95	73%
+ 75%	111	88%
+ 100%	122	95%
+ 150%	156	121%

In Table 12 and Figure 25, the capacity used at the different Damen yards can be seen when the input portfolio is changed. The yard parameters are kept constant (= default values) and no capacity is used for projects outside Gorinchem. Partner yards are only used in the last three cases. The percentage of norm hours used at these partner yards is smaller than 2%.

Table 12: Capacity used at a yard in the average case, increase and decrease input portfolio

Average case, increase and decrease input portfolio									
YARD	**-75.0%**	**-50.0%**	**-25.0%**	**BASE**	**25.0%**	**50.0%**	**75.0%**	**100.0%**	**150.0%**
DDE	0%	0%	0%	0%	0%	0%	0%	0%	0%
DSAn-Steel/Al	83%	90%	91%	99%	99%	99%	98%	98%	98%
DSCh	8%	8%	15%	15%	23%	23%	94%	94%	100%
DSGa	17%	21%	37%	41%	70%	86%	100%	100%	100%
DSGo	0%	0%	0%	0%	0%	0%	18%	18%	23%
DSKo	26%	26%	52%	52%	78%	78%	78%	78%	92%
DSSi	0%	0%	27%	39%	66%	94%	95%	95%	95%
DSCS	0%	3%	5%	5%	8%	8%	32%	32%	97%
DYS	29%	59%	78%	99%	98%	99%	98%	98%	100%

Which yards are used is among others a combination of labour costs, efficiency, transport costs and the type of input portfolio. When looking at the table above, the yards that are already fully used in the base case are Damen Shipyards Antalya and Damen Yichang Shipyard. These yards have a good cost price and efficiency balance compared to other yards. For example, DSAn builds the same type of vessels as Damen Shipyards Singapore but DSSi is more expensive and less efficient than DSAn. Damen Shipyards Changde is a yard that is not so expensive. But, compared to other yards it is a very inefficient yard that needs a lot more hours to build ships.

Even when the demand is very high, the most expensive yards, Damen Dredging Equipment and Damen Shipyards Gorinchem are not used for more than 25% of their capacity even if the percentage of the total divided by the available capacity is more than 120%. This can be explained by the fact that partner yards build hulls for DSGo and Damen Song Cam Shipyard. This capacity is not included in the own capacity at described earlier in this report.

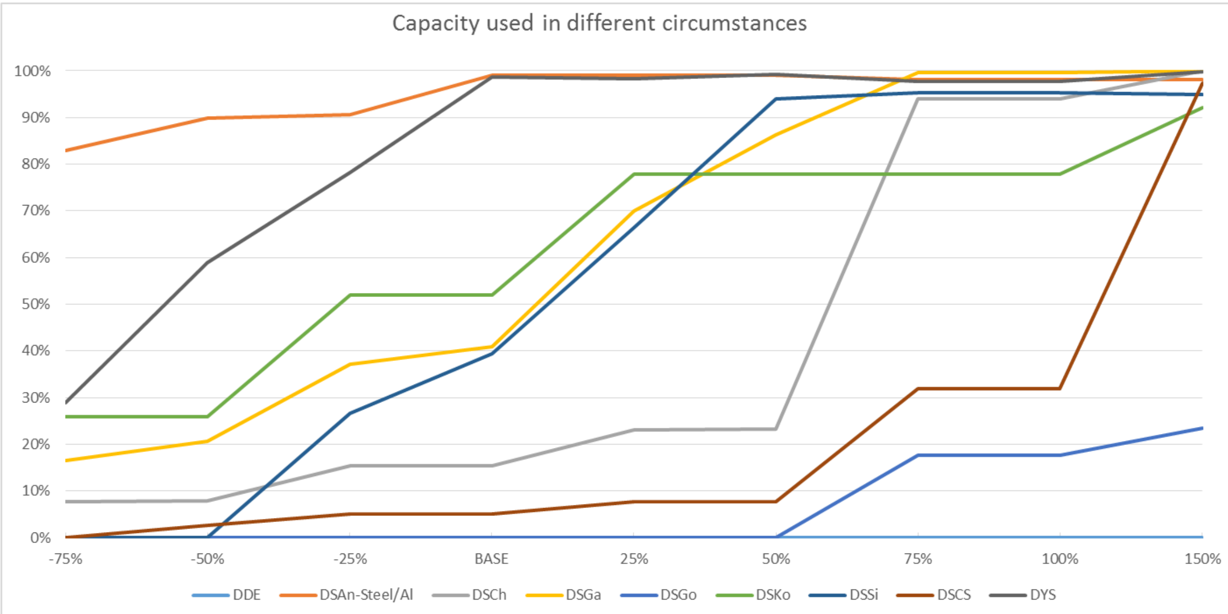

Figure 25: Average case, increase and decrease input portfolio

In the figure above, it can clearly be seen that two yards are fully used in the base case: Damen Shipyards Antalya and Damen Yichang Shipyard. Other yards are maximal used for 50%. Damen Dredging Equipment is never being used, but this can be explained by the fact that the focus of the Gorinchem cluster in the previous years was not on the dredging vessels and that the yard is expensive compared to other yards. The capacity used to build vessels for Damen Gorinchem at Damen Dredging Equipment was maximal 25% in history as discussed in appendix 12 and chapter 4. Damen Song Cam Shipyard is only fully used when the demand is very high, therefore it is one of the least preferred yards to build vessels together with Damen Shipyards Gorinchem that is very expensive compared to other yards.

8.4 Average case, increase and decrease workboats/high speed crafts

Two different scenarios are worked out for the increase and decrease of business units: workboats and high speed crafts. More information about the business units can be found in appendix 14. Using the base case as discussed in the previous paragraph, only the corresponding vessels in a business unit are increased or decreased.

Firstly, a decrease and increase of the demand of workboat vessels is calculated. In Table 13 an overview is given of the delivered number of vessels and total norm labour hours. In the last column, a percentage is given of the total norm hours in a scenario divided by the total norm hour capacity available at the yards of Damen. The demand of the following dummy vessels is changed with an increasing and decreasing percentage, the other dummy vessels are kept the same as in the average base scenario:

- ASD2810
- STU1606
- STU2608
- CSD500
- MUC1908
- SLAU804

Table 13: Average base case with an increasing and decreasing demand in the workboats business unit

Increase/decrease	# Vessels	% Total/available
- 75%	34	31%
- 50%	45	37%
- 25%	53	41%
BASE	61	47%
+ 25%	70	54%
+ 50%	81	60%
+ 75%	89	64%
+ 100%	97	70%
+ 150%	117	83%

In Figure 26, the capacity used at the different Damen yards can be seen when the input portfolio of workboat vessels is changed. The yard parameters are kept constant (= default values) and no capacity is used for projects outside Gorinchem.

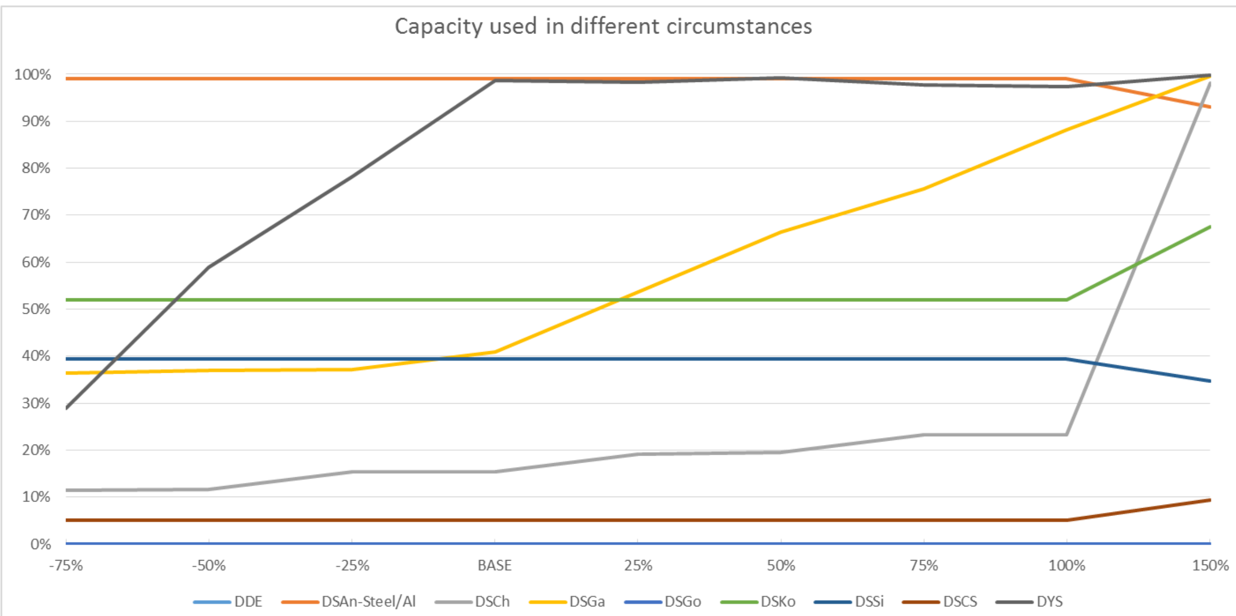

Figure 26: Increasing and decreasing the demand in the workboats business unit

In the figure above, the preferred yard to build workboats is Damen Yichang Shipyard. This yard is the only yard that is completely full with workboat vessels in the base case. The second yard on the list is Damen Shipyards Galati, followed by Damen Shipyards Kozle and Damen Shipyards Changde.

Secondly, a decrease and increase of the demand of high speed craft vessels is calculated. In Table 14 an overview is given of the delivered number of vessels and total norm labour hours. In the last column, a percentage is given of the total norm hours in a scenario divided by the total norm hour capacity available at the yards of Damen. The demand of the following dummy vessels is changed with an increasing and decreasing percentage, the other dummy vessels are kept the same as in the average base scenario:

- FCS1605
- FCS3307

- FCS5009
- FF4212
- SPA206
- SPA4708
- STE1905

Table 14: Average base case with an increasing and decreasing demand in the high speed craft business unit

Increase/decrease	# Vessels	% Total/available
- 75%	45	41%
- 50%	51	44%
- 25%	58	47%
BASE	61	47%
+ 25%	68	50%
+ 50%	74	53%
+ 75%	81	56%
+ 100%	84	56%
+ 150%	97	62%

In Figure 27, the capacity used at the different Damen yards can be seen when the input portfolio of high speed craft vessels is changed. The yard parameters are kept constant (= default values) and no capacity is used for projects outside Gorinchem.

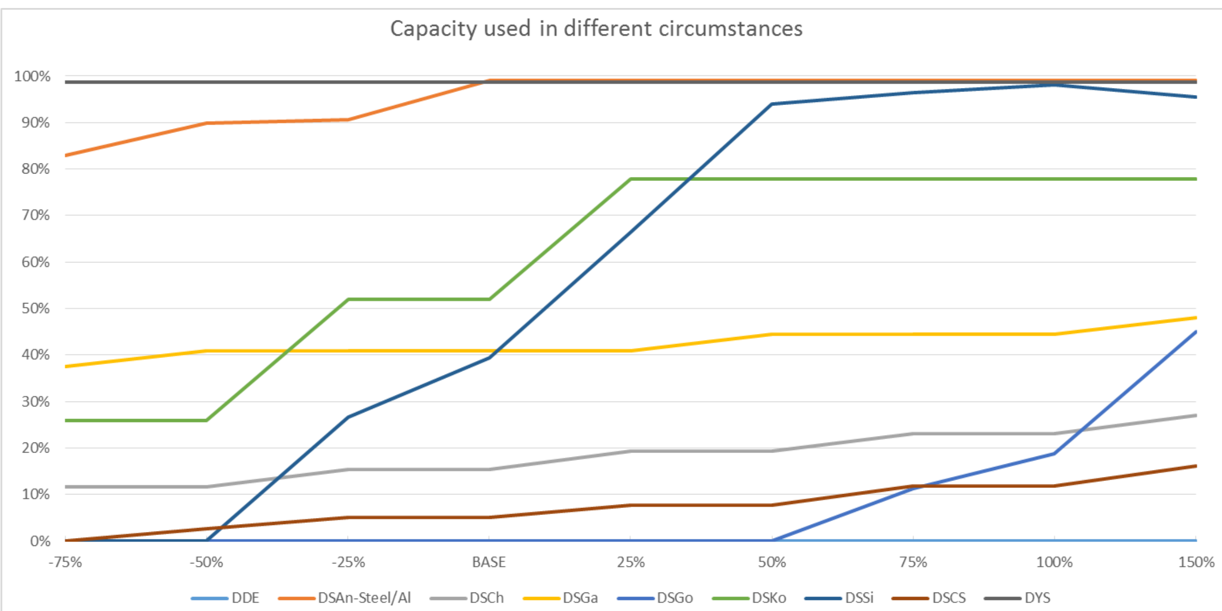

Figure 27: Increasing and decreasing the demand in the high speed craft business unit

When focusing on the high-speed craft scenario, the steel and aluminium yard in Antalya is in all scenarios almost fully used. Therefore, it is the preferable yard for building high speed crafts. Damen Shipyards Gorinchem is only used when the demand is very high. When the demand is increased with more than 75%, DSGo is used for the first time. This is because the yards in Antalya and Singapore are now fully used and several ship types can now only be built at DSGo. In the next paragraphs the yard parameters, for example yard efficiencies and flexible layers, will be changed and determined what the consequences are.

8.5 Changing yard efficiencies

To get a better insight in the effects of a changing yard efficiency on the distribution of ships over all the yards, yard efficiencies are changed. A detailed overview of the used capacity per yard can be found in appendix 15. The following tests are done:

- Every yard, +20% process efficiency
- Business unit high speed craft increasing and decreasing, process efficiency DSGo +20%
- Every yard, yard efficiency = 1
- Damen Song Cam Shipyard, +20% process efficiency
- Damen Shipyards Galati, +20% process efficiency
- Damen Yichang Shipyard, +20% process efficiency

The same vessel input is used as described in paragraph 8.3 (average case, increase and decrease of the demand). The second case is an exception, only the high speed craft business unit is increased and decreased, the other business units are kept constant. After investigation of the results of the previously described scenarios, the following conclusions can be drawn when comparing the different tests to the base case:

1) Every yard, +20% process efficiency:

When increasing the process efficiency with 20%, there is a shift of the work done in the outfitting phase to the workshops in the hull building phase. More work is now done in the hull building phase and lesser hours are needed in the outfitting phase and total building process of a ship. The following observations are done:

- The capacity used at Damen Shipyards Kozle and Damen Shipyards Gorinchem is increased compared to the average case.
- The capacity used at Damen Shipyards Changde and Damen Song Cam Shipyard is decreased compared to the average case
- The capacity used at Damen Shipyards Singapore is less than 5% in all scenarios. This is a significant reduction compared to the average base case. In the average base case two scenarios were around 30% and one scenario was almost 100%.

The reason for the increasing usage of DSGo is that complete hulls are built at partner yards that have a cheaper hour tariff than for example DSSi. Therefore, with the increasing work done at partner hull yards it has now become interesting to outfit ships at DSGo. The work previously done at DSSi is now shifted to DSGo. The most preferred yards as described in the previous paragraphs can now build more ships because less hours are needed compared to the base case. The capacity of the least preferred yards, like DSCh is therefore further decreased because these yards are still very inefficient and more expensive compared to other yards.

2) Business unit high speed craft increasing and decreasing, process efficiency DSGo +20%

A clear shift can be seen from Damen Shipyards Singapore to Damen Shipyards Gorinchem compared to the average case when the business unit high speed craft was increased and decreased. The work done at DSSi is now completely shifted to the DSGo yard. The reason for the increasing usage of DSGo is that complete hulls are built at partner yards that have a cheaper hour tariff than DSSi. Therefore, with the increasing work done at partner hull yards it has now become interesting to outfit ships at DSGo. The capacity at DSSi is in six of the nine scenarios 0%. The other three scenarios are not higher than 6%. In the average case, the used capacity at DSSi was in four of the nine scenarios almost 100%. The capacity used at other yards is not significantly changed.

3) Every yard, yard efficiency = 1

When the yard efficiency is equal to 1, the actual hours are equal to the norm hours. Only the transport cost and direct labour hour tariff is now of importance. Consequently the capacity used at the yards is decreased and when the demand is high, lesser ships are assigned to partner yards because the own Damen yards have still enough capacity.

The cheapest yards are used more compared to the previous base case when also the yard efficiency was considered. This can clearly be seen when looking into detail at the used capacity in Changde, a lot more vessels are assigned to this yard now. Contrary, the used capacity at Damen Shipyards Galati is decreased because most of the yards in Asia are cheaper. Additionally, Damen Shipyards Gorinchem, Damen Shipyards Singapore and Damen Song Cam Shipyard are one of the most expensive yards in the portfolio when comparing it to yards that build the same type of vessels. These yards are less used compared to the average base case, because the cheapest yards can now build more vessels with the same amount of man hours.

With the insights of the previous cases, the focus of the next cases is the increasing of the process efficiency at the three yards with the highest man hour capacity (around 1 million man hours and more): Damen Shipyards Galati, Damen Yichang Shipyard, Damen Song Cam Shipyard and Damen Shipyards Changde.

4) Damen Song Cam Shipyard, +20% process efficiency

Damen Song Cam Shipyard is officially opened in 2014. In previous scenarios, the capacity used at DSCS was in most cases less than 30%. In this test, the consequences of an increase in the process efficiency of DSCS is investigated. When increasing the process efficiency with 20%, there is a shift of the work done in the outfitting phase to the workshops in the hull building phase. More work is now done in the hull building phase and lesser hours are needed in the outfitting phase and total building process of a ship. The hulls of DSCS are built at a partner yard, the following shifts in capacity can be seen:

- A clear shift can be seen from Damen Shipyards Changde to DSCS. The capacity used at DSCh is not higher than 40% when the process efficiency at DSCS is increased with 20%. In the average case, the capacity at DSCh was in three cases almost 100%.
- The capacity used at DSCS is decreased a little, but more ships are being built at the yard. This is because the needed outfitting hours are significantly decreased when more attention is paid to the shipbuilding process.

Currently, Damen Song Cam Shipyard is exclusively an outfitting yard with partner yard Song Cam as a main hull supplier. In the future, the yard will combine the production of 50 hulls and the outfitting of another 80 vessels per year. Consequently, the understaffing losses can be decreased and the used capacity at the yard can be increased when Damen can build complete vessels at DSCS.

5) Damen Shipyards Galati, +20% process efficiency

The needed man hours at DSGa are decreased with 20% because the shipbuilding process is improved. A clear shift can be seen from DYS to DSGa in the base scenario. Compared to the average case, the used capacity at DYS is decreased with 60%. When the demand is higher, the used capacity at DYS is still 100%. There is a shift from Damen Shipyards Changde to DSGa when the demand is high. The used capacity is decreased with 50%. When the demand is more than 150%, the used capacity at DSCh is still 100%. In other cases, the capacity is significantly reduced compared to the average base case. The reason for all these shifts is that DSGa needs less hours to build ships together with a competitive hour tariff. Compared to the average base case with an increasing and decreasing input portfolio, a cost price reduction between 5 and 10% is possible.

6) Damen Yichang Shipyard, +20% process efficiency

More ships can now be built at DYS, because 20% less hours are needed to build a ship. The capacity in most cases is still around 100%. Because DYS can build more vessels in an efficient way at a very low cost price lesser ships are built at Damen Shipyards Changde, Damen Shipyards Kozle and Damen Song Cam Shipyard. Compared to the average base case with an increasing and decreasing input portfolio, a cost price reduction between 5 and 10% is possible.

7) Damen Shipyards Changde, +20% process efficiency

The capacity used at DSCh is almost the same as the average case, at the same time more ships are built at DSCh because 20% less hours are needed to build a ship. Contrary, when the demand is low there are no significant shifts to the DSCh yard because the yard is still very inefficient compared to other Damen yards.

8.6 Changing the flexible layers

An important part of the main research question is the determination of the flexible layers of the different Damen yards. Different flexible layers are defined in chapter 2. In this step additional employees are added to the man hour capacity at a yard. A flexible layer is more expensive than the own core capacity. The direct labour hour tariff for the flexible layer is 50% more than the direct labour hour tariff of the own core capacity as described in chapter 6. The following tests are done, results can be found in appendix 15:

- Flexible layer DSGa (+50%), DYS (+50%), DSAn (+50%), DSCh (+50%), DSKo (+50%), DSSi (+50%) and DSCS (+50%)
- Flexible layer DSGa (+50%), DYS (+50%), DSAn (+50%), DSCh (+50%), DSKo (+50%), DSSi (+50%) and DSCS (+50%). Partner hull hour tariff of DSCS is now 9 euro instead of 10 euro.
- Flexible layer DYS (+50%) and DSAn (+50%)

The same vessel input is used as described in paragraph 8.3 (average case, increase and decrease of the demand). The second case is an exception, in this case the consequences of a changing hour tariff at the partner yard of DSCS was investigated together with the effects of a flexible layer. After investigation of the results of the previously described scenarios, the following conclusions can be drawn:

1) Flexible layer DSGa (+50%), DYS (+50%), DSAn (+50%), DSCh (+50%), DSKo (+50%), DSSi (+50%) and DSCS (+50%)

The first step is to see if the flexible capacity is used at the Damen yards, even if this flexible layer is 50% more expensive than the hour tariff at the yard. It can clearly be seen that the yards that also performed well in the average base case are the ones where the flexible layer is used in more than one scenario: Damen Shipyards Antalya and Damen Yichang Shipyard. This is because even with the higher hour tariff, the yards are still cheaper in combination with a high efficiency compared to other yards in the Damen portfolio, for example Damen Shipyards Singapore and Damen Song Cam Shipyards. The flexible layer of Damen Shipyards Galati and Damen Shipyards Changde is only used when the demand is higher than 150% because other cheaper yards are now fully used. The other yards in the Damen portfolio don't use their flexible layer in any of the scenarios because other cheaper yards have still enough capacity to build all the vessels.

2) Flexible layer DSGa (+50%), DYS (+50%), DSAn (+50%), DSCh (+50%), DSKo (+50%), DSSi (+50%) and DSCS (+50%). Partner hull hour tariff of DSCS is now 9 euro instead of 10 euro.

Because the hulls for Damen Song Cam Shipyard are built at a partner yard, the hour tariff is changed together with a flexible layer of 50% for every yard to calculate the effects of changing this variable. This is done to see if there are significant changes if the hour tariff can be made cheaper at the partner yard of DSCS. The most interesting shift can be seen from Damen Shipyards Kozle to DSCS. DSKo is only used in the scenario when the demand is 150% higher than the base case because DSCS is fully used and it is more expensive to use the flexible layer of DSCS that to build at DSKo. In other scenarios, the used capacity is 0%. This is because it has now become interesting to pay the higher transport cost from the DSCS yard to the client because the hull hour tariff is made cheaper at the partner yard.

3) Flexible layer DYS (+50%) and DSAn (+50%)

When the demand is low, a decrease of the usage of capacity can be seen at Damen Shipyards Gorinchem and Damen Shipyards Singapore compared to the average base case and increase of the usage of the flexible layer of Damen Shipyards Antalya. If the demand is increasing, the capacity used at DSGo and DSSi is also increasing because the flexible capacity at DSAn is almost fully used. The reason for this shift is that DSAn is still cheaper when combining the hour tariff and efficiency for the flexible layer compared to DSGo and DSSi. An overall reduction of the labour cost price around 1 million euro is possible compared to the average base case. Only when the demand is high (highest three scenarios), the flexible layer of Damen Yichang Shipyard is used. A shift can be seen from DSCS to DYS compared to the average base case. The reason for this is that the flexible layer of DYS is still cheaper than the own core capacity of DSCS.

8.7 Combinations

With the insights gathered from the previous experiments, combinations can be calculated to see what the consequences are when different input parameters are changed. In this paragraph, yards will be closed to reduce understaffing losses and make as optimal as possible usage of the own capacity at Damen yards. The following tests are done based on the insights of the previous paragraphs:

- Flexible layer DYS (+10%), DSAn (+40%) and DSAn has a +20% process efficiency
- Flexible layer DYS (+10%), DSAn (+40%) and DSAn, DSGo and DYS have a +20% process efficiency

- Flexible layer DYS (+10%), DSAn (+40%) and DSAn, DSGo, DYS and DSCS have a +20% process efficiency
- Flexible layer DYS (+10%), DSAn (+40%) and DSGo and DSAn have a +20% process efficiency
- Flexible layer DYS (+10%), DSAn (+40%) and DSGo and DSAn have a +20% process efficiency, close DSSi
- Flexible layer DYS (+10%), DSAn (+40%) and DSCS and DSGa have a +20% process efficiency
- Flexible layer DYS (+10%), DSAn (+40%) and DSCS and DSGa have a +20% process efficiency, close DSCh
- Flexible layer DYS (+10%), DSAn (+40%) and DSCS, DSGa, DSAn and DSGo have a +20% process efficiency, close DSCh and DSSi
- Flexible layer DYS (+10%), DSAn (+40%) and DSCS, DSGa, DSAn and DSGo have a +10% process efficiency, close DSCh and DSSi
- Flexible layer DSAn (+40%), DSGa (+20%), DSGo (+20%), DSKo (+20%), DSCS (+20%), DYS (+20%), close DSCh and DSSi
- Changing the fixed cost price at DSCh
- Changing the hour tariff of the hull yard of DSGo

In all the above scenarios, the total cost price of ships build at partner yards was smaller than 2% of the total cost price in all scenarios. Therefore, the focus will be on the capacity used at the own yards. The shifts of used capacity at certain yards when yard parameters are changed are the same as previously discussed. The focus of the discussion below will be on the possibilities of closing yards, defining own capacity and flexible capacity. All the results and figures are presented in appendix 15.

The following yards can be closed or can be made a partner yard based on the previous cases:

- DSSi (Damen Shipyards Singapore)
- DSCh (Damen Shipyards Changde)

Closing these two yards will reduce the understaffing losses of all the Damen yards. When closing these two yards, Damen will be still able to build all vessels at own yards, even when the demand is very high.

DSSi (Damen Shipyards Singapore)

Using the model, the user can easily change different parameters to see what the consequences are when changing for example the hour tariff of a hull yard. This test is done for the Damen Gorinchem yard. A clear shift can be seen from Damen Shipyards Singapore to Damen Shipyards Gorinchem when the hull hour tariff of DSGo is reduced to 10 euros per hour. The results are presented in appendix 15. When Damen wants to sell DSSi in the future, there are thus two options based on the tests done in this chapter:

- The work will shift to DSGo if Damen is able to buy cheap hulls at partner yards and transport them to the outfitting yard.
- The work will shift to DSGo if investments are made and more attention is paid to pre-outfitting and modular outfitting.

DSCh (Damen Shipyards Changde)

Damen Shipyards Changde is the most inefficient yard of the whole yard portfolio of Damen. It can be closed if the yards in Galati and Yichang are made more efficient. The work done at the yard in Changde can then be moved to these yards. Damen is now investing a lot of money to improve the efficiency in Changde, based on previous results this is not such a good idea. An additional investigation will be done of the estimation of the direct labour cost. If this is estimated too low or too high, this can have effects on the end results.

In this research, the fixed cost price is based on the hour tariff and nominal capacity:

$$F = 0.30 \cdot Hour\ tariff\ \cdot N$$

Using the model, the fixed cost price can easily be changed and a higher or lower percentage can be used. The first test that is done is increasing the percentage from 30% to 50%. There are no significant changes. It can thus be concluded that the height of the fixed cost price in this research is not relevant, only the relative cost price difference is important.

Additional, the fixed cost price of Changde is investigated. Based on the previous discussion, Damen Shipyards Changde is one of the least preferred yards to build ships but it is one of the yards where the investments are high compared to other yards. This additional test is done to check what the consequences are when the fixed cost price isn't estimated correct. For this, an analysis is done of the labour hour tariff all around the world to see if the labour hour tariff in China corresponds with the used labour hour tariff in this research (Zevenhoven, 2017). Using this insight, it can be checked if the used fixed cost price is acceptable for this yard.

The hour tariff in Changde is compared with the hour tariff in Romania and the Netherlands. When these labour hour tariffs are compared relative to each other with the data from the *International Labour Organization*, the relative difference in both cases is almost the same. The hour tariff at Damen Shipyards Changde is thus competitive compared to official data. Therefore, even if the fixed cost price is estimated wrong, too high or too low, the relative difference between the yards is correct and therefore the communicating vessels of the Damen yards can be calculated.

Even with this known information, an additional test is done to show what the consequences are when the yard in Changde has an increasing percentage of the fixed cost price from 30% to 50%. All the other yards are kept the same, the fixed cost price is still calculated with 30% of the hour tariff. In this case, the yard in Changde is almost fully used in every scenario when looking at the base case (see appendix 15). It is thus recommended to get a better insight in the cost price calculation of the hour tariff at every Damen yard to make a more accurate estimation of the fixed cost price and linked with this the direct labour hour tariff. It is better now to let the model decide which yards will be turned on or off because the fixed cost price is now a significant part in the total cost price optimization. When the model can make the decision which yards will be turned on or off it can decide which yards are kept in life and which ones are not interesting when looking at the combination of the fixed cost price and direct labour cost.

The following seven yards are part of the core portfolio of Damen:

- DDE (Damen Dredging Equipment)
- DSAn (Damen Shipyards Antalya)
- DSGa (Damen Shipyards Galati)
- DSGo (Damen Shipyards Gorinchem)
- DSKo (Damen Shipyards Kozle)
- DSCS (Damen Song Cam Shipyard)

- DYS (Damen Yichang Shipyard)

DDE (Damen Dredging Equipment)

Damen Dredging Equipment is the only yard in the portfolio that is never used in any scenario. But, as discussed in appendix 12 and chapter 4. The maximal capacity used for Damen Gorinchem projects at this yard is between 5 and 25% of the total yard capacity. The other capacity is used for own projects. An additional study is needed to analyse the specific used capacity at this yard over the past years to define the optimal capacity and flexible capacity. With the information that is now available, it is not possible to give a fact-based answer for this yard.

DSAn (Damen Shipyards Antalya)

Damen Shipyards Antalya is the preferred yard to build steel and aluminium high speed craft ships. In most of the scenarios it is fully used together with its flexible layer. Damen has one yard that can build composite vessels that is also located in Antalya. Because it is the only composite yard in the whole Damen portfolio, it is also the preferred one.

DSGa (Damen Shipyards Galati)

Damen Shipyards Galati is one of the biggest yards of Damen that can build a wide variety of vessels with a high efficiency and competitive hour tariff. The capacity of DSGa is also used for projects outside the Gorinchem cluster. This can vary between 20 and 40% of the total capacity.

DSGo (Damen Shipyards Gorinchem)

Damen Shipyards Gorinchem is the headquarters of the Damen Shipyards Group. DSGo is one of the most expensive yards in the Damen yard portfolio and the capacity is never fully used. Closing this yard is not an option because DSGo is used for marketing reasons when clients visit the headquarters of Damen. A better idea would be to reduce the capacity and build lesser vessels at this yard and use this yard for prototype building and investigation of possible innovations at Damen ships with the engineering and research department so close by.

DSKo (Damen Shipyards Kozle)

Damen Shipyards Kozle is one of the yards that is also used for projects outside the Gorinchem cluster. The used capacity for Gorinchem projects can vary between 0 and 100%. Therefore, it is not a good idea to close the yard. An additional study can be done to analyse the specific used capacity at this yard over the past years to define the optimal capacity and flexible capacity.

DSCS (Damen Song Cam Shipyard)

Currently, Damen Song Cam Shipyard is exclusively an outfitting yard with partner yard Song Cam as a main hull supplier. The understaffing losses can be decreased and the used capacity at the yard can be increased when Damen can build complete vessels at DSCS. When Damen is building complete vessels at this yard, the yard capacity as it is now can be totally used.

DYS (Damen Yichang Shipyard)

Damen Shipyards Yichang is one of the cheapest yards of Damen. Also its efficiency compared to other yards in the same area is not so bad. Therefore, it is not such a good idea to close this yard.

The flexible capacity used at the yards of Damen depends on the input list of ships and yard parameters. But, after the calculation of several cases the next three insights can be given:

- A flexible capacity at DSAn can be added to the total capacity. Because this additional capacity is used in a lot of scenarios in every case, it can be interesting to enlarge the production site in Antalya on the long term.
- When the demand is high, it is interesting to add a flexible capacity at DYS.
- There is no need to add additional flexible capacity above the own total capacity at other Damen yards. In most cases, the own capacity is not fully used at these yards even when the demand is very high.

The idea of this chapter was to give insight in the possibilities of the model and give an overview of the changes when certain parameters are variated. A user manual of the computerized model can be found in appendix 16. The idea is that the user can specify its own yard parameters and input list and define which capacity is the best possibility for his problem.

9. Conclusion

Damen wants to have a better match between the yards production capacity and product portfolio. Therefore, Damen wants to research if matching of these portfolios is possible to minimize the costs of underutilization in a recession. At the same time when the economy is booming, Damen wants to be flexible and add additional capacity to their minimal production level if needed to ensure they doesn't miss any opportunities. Given all these aspects, the following main research question can be formulated:

What is the optimal yard portfolio, own capacity and flexible capacity of Damen under different circumstances?

In order to answer the research question, a computerized model is made. Given a product portfolio to be delivered in a year a match can be made with the yard production capacity to minimize the costs. The shipbuilding labour hour capacity of the yard in hours will be matched with the needed capacity in hours to build several ships per year. Using the wage rates the most cost optimal matching of hours is possible. Ships have to be transported from the supply region to the demand region. To find the optimal yard portfolio, the combination of the summation of the total labour cost at the yard and the transport cost needs to be the cheapest as possible. Linear programming is used because the mathematical function of the cost price in the model are made linear.

The purpose of the model is to make it easy understandable what happens when the user changes the input of delivered vessels and input variables of the yard. The user can change the following yard parameters:

- Yards can be turned on or off by the user, if the yard is active in the model a fixed cost price need to be paid and ships can be assigned to this yard.
- Hour tariff
- Change the efficiency factor for hull and outfitting
- Change the total labour capacity available per year
- Add additional employees above the own capacity. This flexible layer is more expensive than the layer of own Damen capacity.
- Add an increased process efficiency for every yard, e.g. more pre-outfitting. In this way, the needed man hours can be reduced. Consequently, when more pre-outfitting is needed the fixed cost price will increase a little. This is because among others more engineering and job preparation is needed.
- Change the needed capacity for projects outside Gorinchem

The output of the model is the optimal allocation of ships over the selected Damen yards in different situations. Based on this calculation, the board can decide which decisions it will make. Using this optimization, the Damen core yards, together with their minimal production level and flexible capacity, under different circumstances can be identified after changing the yard specific input variables in the way the user wants. A case plan is worked out, the idea of the case plan is to get insights in the changing usage of capacity when yard parameters and input of vessels are changed. With the insights gathered during the case plan, conclusions can be drawn.

The following yards can be closed or can be made a partner yard:

- DSSi (Damen Shipyards Singapore)
- DSCh (Damen Shipyards Changde)

Closing these two yards will reduce the understaffing losses of all the Damen yards. When closing these two yards, Damen will be still able to build all vessels at own yards, even when the demand is very high.

When Damen wants to sell DSSi in the future, there are two options:

- The work will shift to DSGo if Damen is able to buy cheap hulls at partner yards and transport them to the outfitting yard.
- The work will shift to DSGo if investments are made and more attention is paid to pre-outfitting and modular outfitting.

Damen Shipyards Changde is the most inefficient yard of the whole yard portfolio of Damen. It can be closed if the yards in Galati and Yichang are made more efficient. The work done at the yard in Changde can then be moved to these yards.

The following seven yards are part of the core portfolio of Damen:

- DDE (Damen Dredging Equipment)
- DSAn (Damen Shipyards Antalya)
- DSGa (Damen Shipyards Galati)
- DSGo (Damen Shipyards Gorinchem)
- DSKo (Damen Shipyards Kozle)
- DSCS (Damen Song Cam Shipyard)
- DYS (Damen Yichang Shipyard)

Damen Dredging Equipment is the only yard in the portfolio that is never used in any scenario. The maximal capacity used for Damen Gorinchem projects at this yard is between 5 and 25% of the total yard capacity. The other capacity is used for own projects. An additional study is needed to analyse the specific used capacity at this yard over the past years to define the optimal capacity and flexible capacity. With the information that is now available, it is not possible to give a fact-based answer for this yard.

Damen Shipyards Antalya is the preferred yard to build steel and aluminium high speed craft ships. In most of the scenarios it is fully used together with its flexible layer. Damen has one yard that can build composite vessels that is also located in Antalya. Because it is the only composite yard in the whole Damen portfolio, it is also the preferred one.

Damen Shipyards Galati is one of the biggest yards of Damen that can build a wide variety of vessels with a high efficiency and competitive hour tariff. The capacity of DSGa is also used for projects outside the Gorinchem cluster. This can vary between 20 and 40% of the total capacity.

Damen Shipyards Gorinchem is the headquarters of the Damen Shipyards Group. DSGo is one of the most expensive yards in the Damen yard portfolio and the capacity is never fully used. Closing this yard is not an option because DSGo is used for marketing reasons when clients visit the headquarters of Damen. A better idea would be to reduce the capacity and build lesser vessels at this yard and use this yard for prototype building and investigation of possible innovations at Damen ships with the engineering and research department so close by.

Damen Shipyards Kozle is one of the yards that is also used for projects outside the Gorinchem cluster. The used capacity for Gorinchem projects can vary between 0 and 100%. Therefore, it is not a good idea to close the yard. An additional study can be done to analyse the specific used capacity at this yard over the past years to define the optimal capacity and flexible capacity.

Currently, Damen Song Cam Shipyard is exclusively an outfitting yard with partner yard Song Cam as a main hull supplier. The understaffing losses can be decreased and the used capacity at the yard can be increased when Damen can build complete vessels at DSCS. When Damen is building complete vessels at this yard, the yard capacity as it is now can be totally used.

Damen Shipyards Yichang is one of the cheapest yards of Damen. Also its efficiency compared to other yards in the same area is not so bad. Therefore, it is not such a good idea to close this yard.

The flexible capacity used at the yards of Damen depends on the input list of ships and yard parameters. But, after the calculation of several cases the next three insights can be given:

- A flexible capacity at DSAn can be added to the total capacity. Because this additional capacity is used in a lot of scenarios in every case, it can be interesting to enlarge the production site in Antalya on the long term.
- When the demand is high, it is interesting to add a flexible capacity at DYS.
- There is no need to add additional flexible capacity above the own total capacity at other Damen yards. In most cases, the own capacity is not fully used at these yards even when the demand is very high.

10. Recommendations and remarks

In this research assumptions are made and a focus is set on the specific domain of matching hours. In this chapter, some recommendations and remarks are given about the results presented in this report.

The main recommendation for Damen is to get their data structured, register hours on a more detailed and uniform level and get a better insight in the hour tariff calculation for every Damen yard. During the process a lot of data was needed and most of the time this was very chaotic or incomplete.

Next to this main recommendation, the following remarks and recommendations are given:

- This research focuses on the matching of labour hours and optimization of the labour costs at a yard on a very high level. But, there are more costs in the shipbuilding process that are not considered in this research e.g. materials costs, transport of these materials, etc. For further research, if data is available, it would be recommended to include all the building costs to get an optimization on a more detailed level.
- Ship building hours are constant. No delays or rework is considered, which is usually not the case in reality.
- Lead time/waiting time and financing is not taken into account (discussed more into detail below)
- This research is done for the nine yards of the newbuilding cluster. The research method used in this report can also be used for other yards in the Damen Group when the data is known.

Aspects that are not considered are the building period of a vessel, financial indicators and cash flow. As stated in the introduction, this research focuses on the problem of matching hours without taken into account the building period or ship financing. In further research, it would be interesting to take this into account. For a little bit more understanding of ship financing, a small overview is presented below. This overview has no intention to be detailed or complete, it only wants to show the bigger picture of ship financing.

The ship owner that buys a new ship at a yard will prefer to spread and delay the payments as much as possible. Contrary, the yard would prefer to get paid the full amount in advance. Both yard and ship owner need to borrow money for financing and both will prefer to do this as late as possible in order to avoid large interest payments.

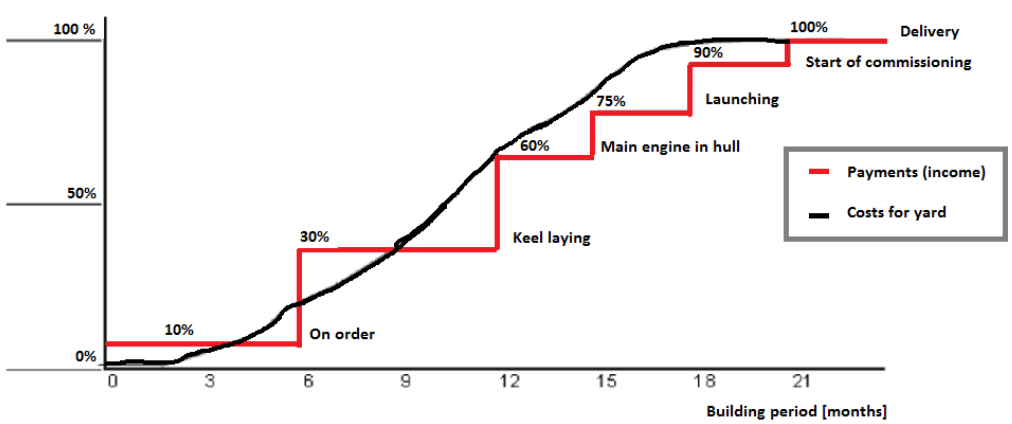

Figure 28: Costs versus income at a yard (Pruyn, 2014)

The costs for the yard are high at the start of the project, when expensive equipment like main engines need to be ordered. The discrepancy between the cost of the yard and the ship owners' payment can be seen in Figure 28 where the costs versus income for the yard is presented in a fair case. As can be seen in the figure, the yard will need to lend money in order to finance the project (Pruyn, 2014).

In this research, the time between the keel laying and delivery was considered and simplified to an amount of hours without considering a long or a short lead time. Varying the lead time due to an increase in the process efficiency will also have a consequence on ship financing that is not considered because it was outside the scope of this research.

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Glossary

Blue collar employees: Employees that to physical work at the work floor (e.g. welders, outfitters).

Capacity used outside Gorinchem: Labour hours that are used for projects that are not for the Gorinchem cluster. This can be among others: ships for Amels, Damen Shipyards Hardinxveld or Damen Schelde Naval Shipbuilding.

Co-makers (see also subcontractor): A contractor that performs activities for Damen. This outsourced work hours are not considered in the nominal yard capacity. In practice, the costs are invoiced to the project. In this research, the co-makers labour hours are added to the nominal capacity to be able to compare yards on the same production depth.

DTC yard: With Damen Technical Cooperation the costumer can build all sort of vessels of the Damen product portfolio locally at the chosen preferred yard.

Dummy ship: Representative ship for a large group of vessels.

Effectivity: Real output/norm output.

Efficiency: Norm input/real input, producing a certain number of goods with the minimal number of hours needed. When comparing yards, efficiency is used to normalize the hours and compare yards on the same level.

Fixed cost price: A cost that does generally not change when production volume changes, however there is a limit to this. Fixed costs include deprecation costs, rent and internal office cost. Fixed costs are part of the hour tariff.

Gorinchem cluster: Yards in the Commercial New Build Division, Damen Shipyards Antalya (DSAn), Damen Dredging Equipment (DDE), Damen Shipyards Changde (DSCh), Damen Shipyards Galati (DSGa), Damen Shipyards Gorinchem (DSGo), Damen Shipyards Kozle (DSKo), Damen Shipyards Singapore (DSSi), Damen Song Cam Shipyards (DSCS), Damen Yichang Shipyard (DYS).

Hour tariff: Labour cost per hour, the company costs per year (excluding the project materials) are divided by the nominal capacity.

Lightweight: Lightweight is the weight of the vessel as it is built without the total weight of the cargo it can carry.

Nominal capacity: Expected average number of direct man hours per year used at a yard for all the projects in the coming years, based on the estimated output in these years. The nominal capacity includes own Damen employees and hired personnel and is used to calculate the hour tariff.

Norm ship hours: Minimal needed labour work hours, divided in the production of the hull and outfitting, to build a certain ship type at the yard that needs the minimal amount of man hours.

Normalized capacity: To compare yards on the same level, normalized capacity is used. Using this normalized capacity of labour man hours, one work hour in China is equal to one work hour in the Netherlands.

Partner yard: When ships cannot be built for Gorinchem at a Gorinchem cluster yard, partner yards can build whole ships or steels and aluminium hulls.

Process efficiency: The phase in which an activity is performed influences the duration and required man hours for an activity. A lot of hours can be saved in the production process of a ship by moving activities to an earlier stage to increase the process efficiency.

Productivity: Productivity is the ratio of output to input.

Subcontractors: A subcontractor is a person or company that does a part of the job for the prime contractor. A subcontractor is paid for a fixed price do to the work. In this research, the subcontracted labour hours are added to the nominal capacity to be able to compare yards on the same production depth.

White collar employees: Employees that do office jobs like project managing and job preparation.

Workshops: Workshops produce and paint components and modules to be outfitted on the ship.

Appendix 1: Product Portfolio Management

In this appendix, product portfolio management (PPM) is explained. Does Damen has the right vessels for tomorrow? How does the Damen portfolio changes? The importance of product portfolio management is explained in paragraph 1. In the next paragraph the product life cycle and the growth-matrix are discussed together with an example.

Goals of Product Portfolio Management

Today's new product projects decide tomorrow's market profile of a firm. Product portfolio management is the process were new projects are evaluated and existing project may be killed. It is important that resources are allocated to projects that can maximize the value of the portfolio via profitability, acceptable risk, etc. At the same time, find the best balance between the resources available and the resources demands. A desired balance of projects via a number of parameters, for example short term versus long term and across various markets needs to be achieved.

The importance of a good product portfolio management is that companies can avoid projects that have not a high value to the business or their portfolio has a poor balance in project types and prioritizing. As a result a company may have too many wrong low value projects, maldistribution of the resources and projects take too long to go to the market (Stage-Gate, 2016).

Product life cycle and growth matrix

It is all about doing the right projects and having a portfolio that is properly balanced. A product can be considered as a question mark, a star, a cash cow or a dog that corresponds with the life cycle of a product (see Figure 29). A production life cycle is an important principle that manufactures need to understand in order to stay in business and make a profit. It explains the growth and decline of revenues and profits associated with a product (Mr. Dashboard , 2016).

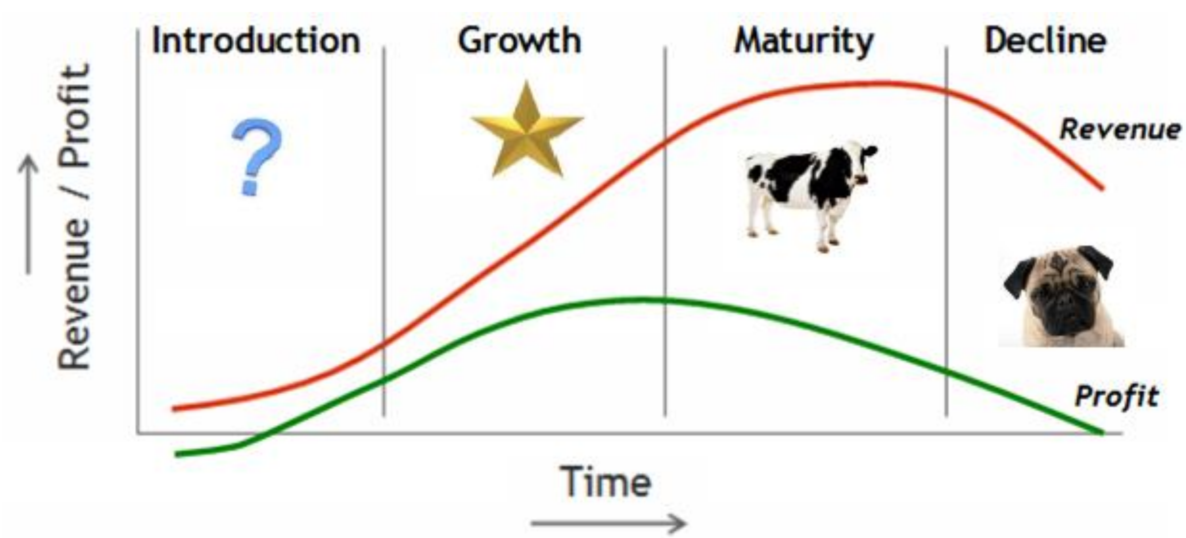


Figure 29: Product life cycle (Mr. Dashboard , 2016)

Market introduction (question mark)

A new market has to be created and must be carefully analysed in order to determine whether it is worth the investment. The product is introduced for the first time and a lot advertising and promotional investment is done to introduce the new product to the target market. Generally during this stage, the investments are high and the revenues are rather low due to the low market share. Under the right circumstances it can grow and become a star, but without a growth it can quickly decline and become a dog.

Market growth (star)

The revenues and profit increases, a high growth rate in a high growth market. The target market is familiar with the product and already purchase it. Due to the economies of scale, the overall cost is decreasing and the products profit is increasing. On the other hand, more competitors try to enter the business as they see the market trend.

Market maternity (cash cow)

A cash cow has a high market share in a mature market that is saturated. The revenues starts to decline and also the profit is decreasing. The competition is hard and there is very little market growth. Competitors start to compete more on price level and less through product differentiation. The reason is that most of the competitors can offer the same product. At the same time, due to the strong competition more marketing and sales investments need to be done to keep the market share. The revenue is also used to invest in new product developments and market introduction of others.

Market decline (dog)

New products are introduced that replace the old products, both revenues and profits decline. The product is at the end of his life.

Damen uses the Boston Consultancy Matrix or growth-share matrix per product group for their product portfolio management and visualising the moment in the life cycle of their products (see Figure 30) (Damen, 2016). The matrix shows four segments by plotting market growth and market shares, every product is plotted in one of four positions on the matrix. This diagram can be used to decide where to focus time, effort and investment capital (SmartDraw, 2016).

The growth-share matrix has some limitations, for example the definition of the market or the volatility of the market. A unit can dominate in its small niche, but have a very low market share in the overall industry. The framework also assumes that each unit is independent of the others, e.g. a unit that is a “dog” can help other units to gain a competitive advantage. Taken this limitations into account, the Boston Consultancy Matrix can still serve as a simple way to have an overview of the portfolio of a company (ICMBA, 2010).

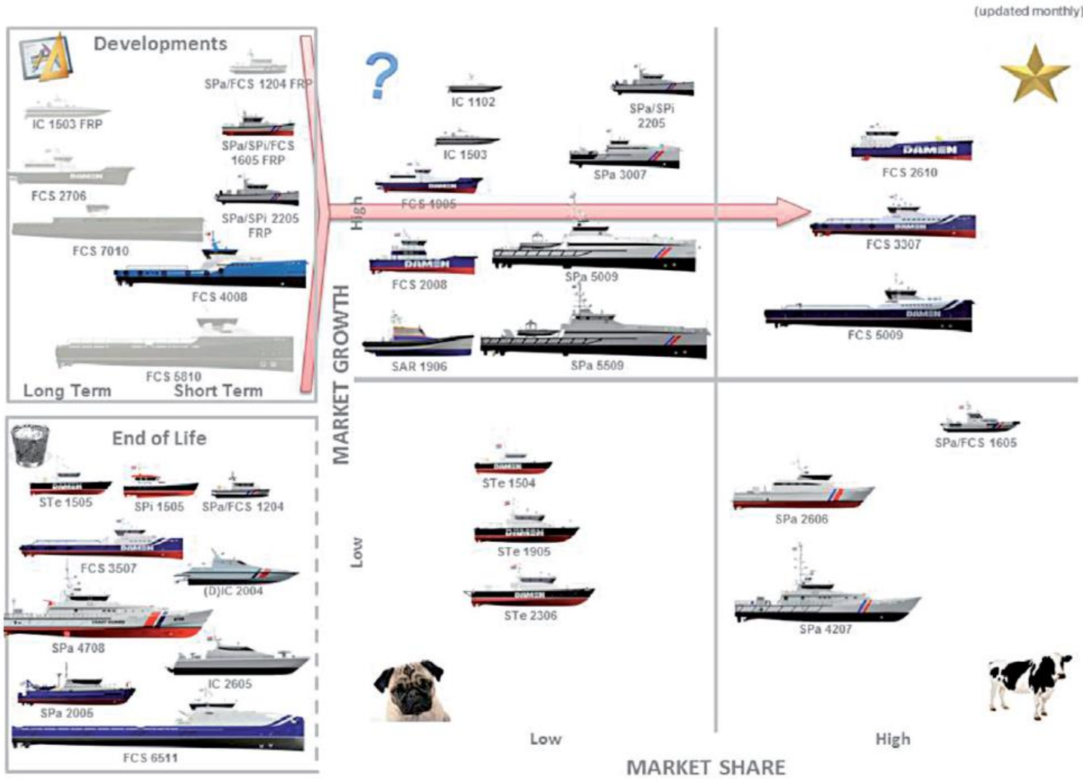
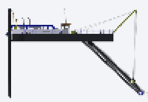


Figure 30: Boston Consultancy Matrix using a part of the Damen product portfolio (Damen, 2016)

Appendix 2: Description products by ID

Product ID	Description					
ASD2810	 ASD TUG 2810	Bollard pull max (tonnes): 60	Length (meter): 28.67	Power total (BKW): 3730	Speed max (kts): 13.4	Beam (m): 10.43
ASD2411	 ASD TUG 2411	Bollard pull max (tonnes): 70	Length (meter): 24.47	Power total (BKW): 4200	Speed max (kts): 13	Beam (m): 11.33
FCS5009	 FAST CREW SUPPLIER 5009	Length (meter): 53.25	Speed max (kts): 30	Deck area (m2): 240	Industrial personnel: 80	Hull construction: Steel
ASD3212	 ASD TUG 3212	Bollard pull max (tonnes): 80	Length (meter): 32.7	Power total (BKW): 5050	Speed max (kts): 14.3	Beam (m): 12.82
IC1102	 INTERCEPTOR 1102	Length (meter): 10.97	Speed max: 55+	Crew: 2	Hull construction: FRP	Propulsion: 2x Stern drives
FCS2610	 FAST CREW SUPPLIER 2610	Length (meter): 25.75	Speed max (kts): 25	Deck area (m2): 90	Industrial personnel: 12	Hull construction: Aluminium

FCS1605	 FAST CREW SUPPLIER 1605	Length (meter): 16.15	Speed max (kts): 30	Deck area (m2): 15	Industrial personnel: 29	Hull construction: Aluminium
CSD500	 CUTTER SUCTION DREDGER 500	Production (m3h): 4000	Dredging depth (m): 14	Total installed power (kW): 1293	Total weight (tonnes): 140	Pipe diameter (mm): 500
ASD2913	 ASD TUG 2913	Bollard pull max (tonnes): 80	Length (meter): 28.9	Power total (BKW): 5050	Speed max (kts): 13.7	Beam (m): 13.23
SPA5009	 STAN PATROL 5009	Length (meter): 50.2	Speed max (kts): 30	Crew: 18-26	Hull construction: Steel	Propulsion: 4x Fixed pitch propellers

Appendix 3: Description products by value

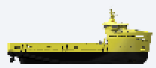
Product ID	Description					
SPA5009	 STAN PATROL 5009	Length (meter) 50.2	Speed max (kts) 30	Crew 18-26	Hull construction Steel	Propulsion 4x Fixed pitch propellers
FCS5009	 FAST CREW SUPPLIER 5009	Length (meter) 53.25	Speed max (kts) 30	Deck area (m2) 240	Industrial personnel 80	Hull construction Steel
ASD2810	 ASD TUG 2810	Bollard pull max (tonnes) 60	Length (meter) 28.67	Power total (BKW) 3730	Speed max (kts) 13.4	Beam (m) 10.43
ASD3212	 ASD TUG 3212	Bollard pull max (tonnes) 80	Length (meter) 32.7	Power total (BKW) 5050	Speed max (kts) 14.3	Beam (m) 12.82
ASD2411	 ASD TUG 2411	Bollard pull max (tonnes) 70	Length (meter) 24.47	Power total (BKW) 4200	Speed max (kts) 13	Beam (m) 11.33
ASD2913	 ASD TUG 2913	Bollard pull max (tonnes) 80	Length (meter) 28.9	Power total (BKW) 5050	Speed max (kts) 13.7	Beam (m) 13.23

FYS6711

SPECIFICATIONS

Length overall	67.15 metres (220 feet)
Beam overall at hull	11.5 metres
Gross Tonnage	1143GT
Naval architecture	DAMEN
Maximum speed	22 knots
Range	4500nm @ 16 knots
Crew accommodation	21
Exterior deck storage (ex heli)	275 m²
Dive area	70 m²
Garage / workshop	70 m²
Helicopter max take-off weight	5.000 kg

PSV3300



PLATFORM SUPPLY VESSEL 3300 CD

Deadweight (tonnes)	Length (meter)	Speed max (kts)	Beam (m)	Deck area (m2)
3500	80	13.5	16.2	720

FCS2610

FAST CREW SUPPLIER 2610

Length (meter)	Speed max (kts)	Deck area (m2)	Industrial personnel	Hull construction
25.75	25	90	12	Aluminium

MFDD11026

MODULAR FLOATING DRYDOCK 11026

Length (m)	Beam (m)	Internal width (m)	Max lifting capacity (tonnes)	Max load (tm)
110	32	26	5000	50

Appendix 4: Partner yards and DTC yards

In this appendix an overview is given of projects at partner yards, yards for DTC projects and a combination of these two.

Selection of partner yards of the Damen Shipyards Gorinchem cluster

- Damen Shipyards Sharjah
- Scheepswerf J. Talsma BV Heeg
- Scheepswerf Made B.V.
- Van Noorloos Cascobouw B.V.
- Wisla Aluminium Sp.z.o.o.

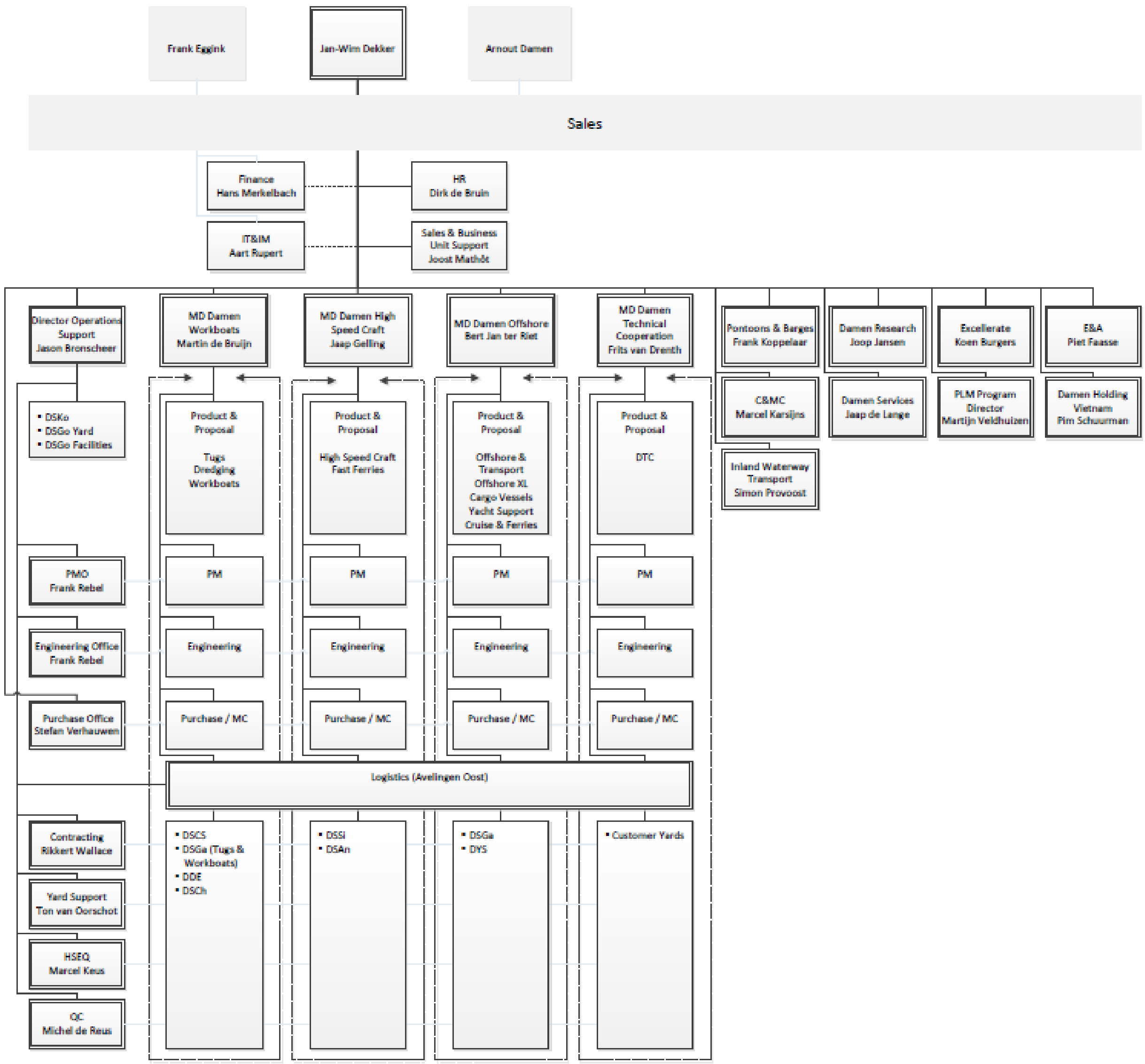
Selection of yards for DTC projects

- Abu Dhabi Shipbuilding Co.
- Astilleros Navales Ecuatorianos
- Bollinger Shipyards Inc.
- Canal Naval Construction Co
- Cantiere Navale Vittoria
- Far Eastern Shipbuilding & Repair center
- KSEW
- Ministria E Mbrojtjes
- Monkey Bay Shipyard
- Nakilat Damen Shipyards Qatar LTD..
- PT. World Wide Equipment South East Asia Batam, Batam Equipment yard
- Secretaria De Marina
- Servicios Portuarios Integrados (SPI) S.A.
- SteadFast Marine
- Wilson Sons

Selection of yards for DTC projects and Damen Shipyards Gorinchem cluster projects

- 189 one member limited liability company
- Albwardy Marine Engineering L.L.C.
- Damen Shipyards Cape Town (PTY) Ltd.
- DAMEX Shipbuilding & Engineering
- Ha Long Shipyard
- Dumas Tanjung Perak Shipyard
- Song Cam Shipyard JSC
- Song Thu Corporation

Appendix 5: Organogram



Appendix 6: Yard description

In this appendix a description of the nine own Damen yards are given. This description includes a general discussion of the yard and the possible products a yard can build based on employee interviews at Damen, available data from IFS and the world wide web. In Table 15 an overview of the dummy ships that a yard can build are given.

Table 15: Dummy ships that a yard can build

	DDE	DSAn	DSCh	DSGa	DSGo	DSKo	DSSi	DSCS	DYS
ASD2810			X	X	X			X	X
STU1606			X		X			X	X
STU2608			X	X	X			X	X
CF11000				X					X
CSD500	X		X	X		X			X
HD750			X	X		X			X
FCS1605		X			X		X		
FCS3307		X			X		X		
FCS5009		X			X			X	
FF4212				X			X		
OPV2400				X					
MUC1908			X		X	X		X	
PSV3300				X					
RV6613				X					
SAR1906		X			X				
SBU2609			X			X		X	
SLAU804			X						
SPA2606		X			X		X		
SPA4708		X			X	X		X	
SPI1505		X			X				
SPO7524				X					X
STE1905			X		X	X			
IC1102		X							
COMPOSITE		X							

China

Damen Shipyards Changde

Damen Changde is located 1200 kilometres upstream from Shanghai on the Yuan river (Huethorst, Yard Description: Damen Shipyards Changde, 2016). Damen Shipyards Changde builds workboats, ASD Tugs, Stan Tugs, Stan Launches, Multi Cats, Shoalbusters and high speed crafts. It has separate hull fabrication and outfitting facilities. Vessels are transported from Changde to Shanghai by barges or towing for delivery and sea trials. All the workers in production are Chinese (Damen, 2016).

Examples of product clusters that can be built at the yard:

- Dredgers

- Multi Cat
- Shoalbuster
- Stan Launch
- Stan Tender
- Tugs: ASD2810, STU1606 and STU2608 cluster

Damen Yichang Shipyard

The yard in Yichang builds combi freighters, pontoons, dredgers, tugs, etc. It is located along the Yangtze river, 1670 kilometres from Shanghai (Visser, Yard Description: Damen Yichang Shipyard, 2016). If the vessel is not too big, it can sail to Shanghai. If this is not the case, the vessel has to be towed by tugs. The outfitting quay is located 30 kilometres far from the shipyard downstream. There is also the possibility to outfit on a quay or in a dry dock in Shanghai. Everybody working at Yichang has the Chinese nationality. There is also a lot subcontracted capacity, e.g. painting. The yard is specialized in building cargo vessels from 8000 to 15 000 deadweight tonnage (Damen, 2016).

Examples of product clusters that can be built at the yard:

- Dredgers
- Pontoons and barges
- Seagoing transport
- Tugs: ASD2810, STU1606 and STU2608 cluster

Poland

Damen Shipyards Kozle

Damen Shipyards Koźle is located in Southern Poland, 500 kilometres upstream on the Oder River (Visser, Yard Description: Damen Shipyards Koźle , 2016). Sometimes some of the vessels or parts of the vessels are delivered by road. The hull and the superstructure are built as separate sections. After mounting the superstructure to the hull, pre outfitting can take place. Koźle is a steel newbuilding yard for inland vessels, cutter suction dredgers and tug and workboat casco's. The majority of the workers in production are Polish, Ukrainian and Moldawian (Damen Shipyards Kozle, 2016).

Examples of product clusters that can be built at the yard:

- Dredgers
- Multi Cat
- Shoalbuster
- Stan Patrol: SPA4708 cluster
- Stan Tender

Romania

Damen Shipyards Galati

Damen Shipyards Galati, the largest yard of the Damen Shipyards Group, can build all sort of vessels, ranging from tugs to dredgers and offshore patrol vessels (Visser, Yard Description: Damen Shipyards Galati, 2016). All the shipyards employees are Romanians. Some work is subcontracted, among others painting, carpentry and electrical works. On average, 24 vessels a year are been built at the yard in Galati (Damen Shipyards Galati, 2016).

Examples of product clusters that can be built at the yard:

- Dredgers
- Ferry
- Offshore Patrol Vessel
- Platform Supply Vessel
- Pontoons & Barges
- Seagoing Transport
- Support Vessel
- Tugs: AHTS130, ASD2810 and STU2608 cluster

Singapore

Damen Shipyards Singapore

Damen Shipyards Singapore builds complete new aluminium vessels up to 55 meters with a maximal weight of 200 tons, the yard does also steel outfitting jobs. (Visser, Yard Description: Damen Shipyards Singapore, 2015). It was founded in 1990 and since 2000 it is a fully owned member of the Damen Shipyards Group. The hull and the superstructure are built as separate sections. The yard prefers to do as much as pre outfitting as possible when the conditions allows this. Between 15 and 25 aluminium vessels are delivered every year. It has also the facilities to do maintenance and reparation on shore or along jetties. The nationalities working in production at the yard are: Singaporean, Malay, Indian, Bangladesh and Chinese (Damen, 2016).

Examples of product clusters that can be built at the yard:

- Fast Crew Supplier: FCS1605 and FCS3307 cluster
- Ferry
- Stan Patrol: SPA2606 cluster

The Netherlands

Damen Dredging Equipment

Damen Dredging Equipment is the Damen yard dedicated to the dredging industry. The yard specializes in the design, manufacture and supply of dredgers. The yard does only the outfitting of cutter suction dredging vessels (Damen Shipyards Group , 2016). Other dredging vessels like the trailing suction hopper dredger cannot reach the yard due to restrictions of the waterway.

Examples of product clusters that can be built at the yard (only outfitting):

- Dredgers: only CSD versions

Damen Shipyards Gorinchem

Damen Shipyards Gorinchem is both the head office of the Damen Shipyards Group and is also a production yard (Visser, Yard Description: Damen Shipyards Gorinchem, 2015). The yard consists of two assembly halls in which ship hulls are being outfitted to complete ships. Damen Shipyards Gorinchem does only outfitting of steel and aluminium ships. Almost all ship types from the Damen portfolio can be outfitted. Besides the outfitting of new ships, also ships can be repaired. Painting, HVAC, piping and the electrical system is subcontracted.

Examples of product clusters that can be built at the yard (only outfitting):

- Fast Crew Supplier
- Multi Cat
- Stan Launch
- Stan Patrol
- Stan Pilot
- Stan Tender
- Search and Rescue Vessel
- Tugs: ASD2810, STU1606 and STU2608 cluster

Turkey

Damen Shipyards Antalya

Damen Shipyards Antalya is the yard for high-tech composite shipbuilding. The yard in Antalya is fully optimized to build ships in composite, e.g. interceptors and stan patrol vessels. Antalya is the only own yard in the Damen portfolio that can build new composite vessels. The maximal yard capacity per year is around 35 vessels (Huethorst, Yard Description: Damen Shipyards Antalya, 2013).

Examples of product clusters that can be built in composite at the yard:

- Interceptors
- Search and Rescue Vessel
- Stan Pilot

Damen Shipyards Antalya can also build vessels in steel and aluminium at another location in the Antalya zone, more specific Fast Crew Suppliers with lengths between 40 to 50 metres. It has a capacity to build around six FCS5009 a year (Damen Shipyards Antalya, 2016).

Vietnam

Damen Song Cam Shipyard

Damen Song Cam Shipyard is the preferred production location for Damen tugs and workboats up to 60 metres long and is officially opened in 2014. (Visser, Yard Description: Damen Song Cam Shipyard, 2016). Currently, the yard is exclusively an outfitting yard with partner yard Song Cam as a main hull supplier.

The initial production capacity is around 40 workboats per year. In the future, the yard will combine the production of 50 hulls and the outfitting of another 80 vessels per year (Damen, 2016).

Examples of product clusters that can be built at the yard (currently only outfitting):

- Fast Crew Supplier: FCS5009
- Multi Cat
- Shoalbuster
- Stan Patrol: SPA4708
- Tugs: *ASD2810*, STU1606 and STU 2608 cluster

Appendix 7: Product groups

Dredgers

CSD500			
Length	38.5	meters	
Beam	7.95	meters	
Including	CZ550, DSD180, HD1600, HD1150, GHD600, HD700, HD750, GHD750, TSHD2500		

HD750			
Length	60.45	meters	
Beam	11	meters	
Including	DSD180, HD1600, HD1150, GHD600, HD700, HD750, GHD750, TSHD2500		

Fast Crew Supplier

FCS1605			
Length	16.15	meters	
Beam	5.40	meters	
Building material	Aluminium		
Including	FCS1605, FCS1405, FCS1204, FCS1905, FCS2008, ALUC1050, ALUC1104, ALUC1405, ALUC1500, ALUC1605, ALUC850, SRA1504, SRA1604		

FCS3307			
Length	33.32	meters	
Beam	7.35	meters	
Building material	Aluminium		
Including	FCS3307, FCS3507, FCS2610		

FCS5009			
Length	53.25	meters	
Beam	10.10	meters	
Building material	Steel		
Including	FCS5009, STE4709		

Ferry

FF4212			
Length	42.20	meters	
Beam	11.60	meters	
Building material	Aluminium		
Including	FF1004, FF1907, FF3007, FF3009, FF3207, FF3209, FF3810, FF4010, FF4108, FF4212, FF4912, SWATH3717, FE2306, FE5012, SFE4010, SFE4012, WBU3412, FRP4512, FRP8521, RPA13022, RPA8017		

Interceptors

IC1102			
Length	10.97	meters	
Beam	2.49	meters	
Building material	Composite		
Including	IC1102, IC1503		

Multi Cat

MUC1908			
Length	19.05	meters	
Beam	8.06	meters	
Including	MUC1005, MUC1205, MUC1506, MUC1908, MUC1908SD, MUC2409, MUC2510, MUC2611, MUC2613, MUC2712, MUC3013, MUC3213		

Offshore Patrol Vessel

OPV2400			
Length	90	meters	
Beam	14.40	meters	
Including	FISV6210, OPV2400, OPV6111, OPV6210, OPV8313, OPV950		

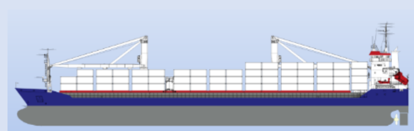
Platform Supply Vessel

PSV3300			
Length	80.10	meters	
Beam	16.20	meters	
Including	PSV3000, PSV3300, PSV4500, PSV7216, OCA7500		

Pontoons and Barges

SPO7524			
Length	74.24	meters	
Beam	23.5	meters	
Including	DLB3009, FDO5019, MPP8522, SPO12032, SPO14040, SPO2116, SPO4015, SPO4018, SPO4111, SPO4113, SPO5211, SPO5213, SPO6316, SPO6511, SPO7524, SPO8916ICE, SPO9127, BA2405, BACL2507, BACR6324, BACR8025, BAHA1507, BB3008, BB3408, CRBA4920, LMLB4315, PLBA10129, SBA3009, SBA4512, SBA4515, SUBA14035, SUBA8522, WLBA2909		

Seagoing transport

CF11000			
Length	145.63	meters	
Beam	18.30	meters	
Including	CF10500, CF11000, CF12000, CF13500, CF6300, CFE800, HLV1800, NCV1600, STA5412, STA5512, STA6312		

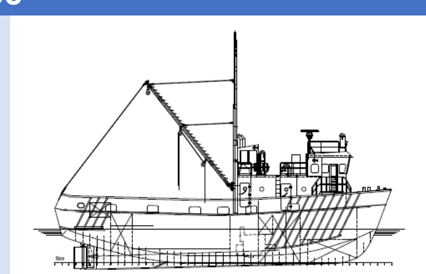
Search and Rescue Vessel

SAR1906			
Length	19.30	meters	
Beam	6.55	meters	
Building material	Aluminium Hull FRP Superstructure		
Including	SAR1500, SAR1600, SAR1906, SAR2700, SAR903		

Shoalbuster

SBU2609			
Length	26.21	meters	
Beam	9.10	meters	
Including	PBU3009, MPPT2510, PUT2110, PUB3511, SBU1907, SBU2208, SBU2308, SBU2508SD, SBU2509, SBU2609, SBU2709, SBU2709ICE, SBU3009, SBU3009SD, SBU3209, SBU3511, SBU3612		

Stan Fisher

SFI2350			
Length	23.99	meters	
Beam	6.50	meters	
Including	SFI2350		

Stan Lander

SLA5612			
Length	57.12	meters	
Beam	12.16	meters	
Including	SLA3408, SLA5612, SLA5915, SLA7112		

Stan Launch

SLAU804			
Length	8.62	meters	
Beam	3.77	meters	
Including	SLAU804, MIC803		

Stan Patrol

SPA2606			
Length	26.50	meters	
Beam	5.90	meters	
Building material	Aluminium		
Including	SPA1204, SPA1505, SPA1605, SPA1800, SPA2005, SPA2400, SPA2505, SPA2600, SPA2606, SPA2706, SPA2707, SPA3007, SPA3407, SPA3507, SAR4100		

SPA4708			
Length	47.00	meters	
Beam	8.11	meters	
Building material	Steel		
Including	SPA4207, SPA4708, SPA5009, SPA5509		

Stan Pilot

SPI1505			
Length	15.4	meters	
Beam	4.9	meters	
Building material	Aluminium		
Including	SPI1505, SPI2205, SPI2706		

Stan Tender

STE1905			
Length	19.15	meters	
Beam	5.30	meters	
Building material	Steel Hull Aluminium Superstructure		
Including	STE1350, STE1400, STE1504, STE1505, STE1550, STE1605, STE1750, STE1905, STE2000, STE2006, STE2306, STE2606, STE4309		

Support Vessel

RV6613			
Length	66.35	meters	
Beam	13.20	meters	
Including	FRV2808, HSV6613, RV3609, RV5312, RV6615, OSV8316, SSV4711, ST4612, ST6014, MPV5212, MPV8116, WWSS8316, ATV4810, BLV8016, BLV8317, BMV4809, BTV5811		

Tugs

AHTS130			
Length	66	meters	
Beam	15.22	meters	
Including	AHTS130, AHTS70, AHTS75		

ASD2810			
Length	28.67	meters	
Beam	10.43	meters	
Including	ASD2009, ASD2310, ASD2310ICE, ASD2411, ASD2509, ASD2810, ASD2810HYBRID, ASD2810ICE, ASD2913, ASD3010, ASD3010ICE, ASD3110, ASD3111, ASD3211, ASD3212, ASD3212ICE, ASD3213, RTU3213, ATD2412, ATD2909		

STU1606			
Length	16.76	meters	
Beam	5.94	meters	
Including	STU1004, STU1205, STU1405, STU1605, STU1606, STU1806, STU1906, STU1907, MIC1003, PUC46, PUC1204		

STU2608			
Length	26.16	meters	
Beam	8.54	meters	
Including	STU2006, STU2207, STU2208, STU2507, STU2608, STU2909, STU3008, STU3011, STU3110, STU3209, STU3509, STU4011, STU4013, STU4511		

Appendix 8: Ship building

In Figure 31, a visual representation of the process of the hull production of an ASD tug is given (Damen Contracting & Yard Support, 2016).

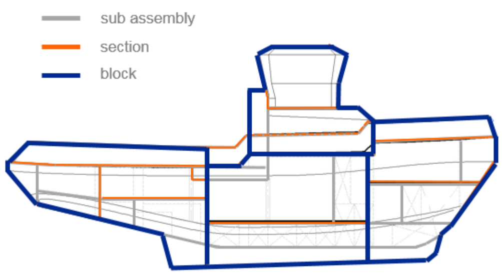


Figure 31: Hull production of an ASD tug (Damen Contracting & Yard Support, 2016)

In Figure 32, a visualization of the outfitting of an ASD tug is given.

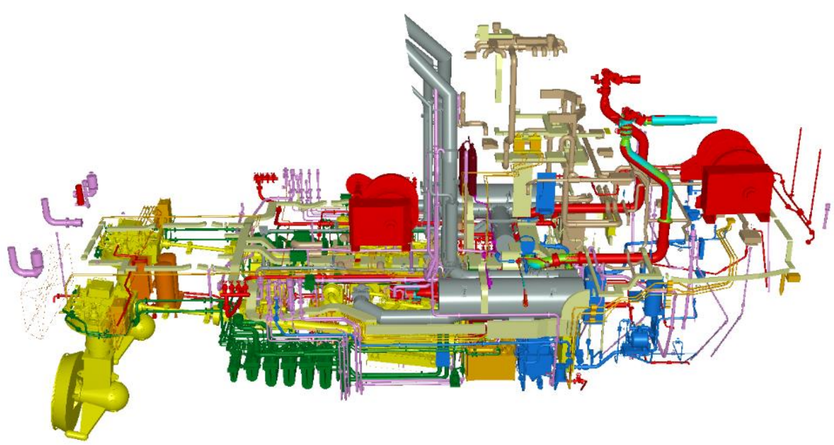


Figure 32: Outfitting of an ASD tug (Damen Contracting & Yard Support, 2016)

Appendix 9: Hour registration at Damen Shipyards Gorinchem

Confidential

Appendix 10: Trend line

Confidential

Appendix 11: Hours per ton

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Appendix 12: Model data

Confidential

Appendix 13: Total norm and actual hours

Confidential

Appendix 14: Damen products

Confidential

Appendix 15: Cases and results

Confidential

Appendix 16: User manual

Confidential

Matching the yard and product portfolio of Damen Shipyards

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Damen Shipyards Group, an international family-owned shipyard group with Dutch roots and headquarters in Gorinchem delivers up to 180 vessels each year. The vessels can be build either at their own yards worldwide or at partner yards around the world close to the delivery station. Damen wants to research if matching of the yard and product portfolio is possible to minimize the costs of underutilization in a recession. At the same time when the economy is booming, Damen wants to be flexible and add additional capacity to their minimal production level if needed to ensure they don't miss any opportunities. Given a product portfolio to be delivered in a year a match can be made with the yard production capacity to minimize the costs using a computerized model. The focus for optimization of the capacity will be on the products build for Damen Gorinchem at own yards in the Gorinchem cluster. The following yards can be closed or can be made a partner yard: Damen Shipyards Singapore and Damen Shipyards Changde. The following seven yards are part of the core portfolio of Damen: Damen Dredging Equipment, Damen Shipyards Antalya, Damen Shipyards Galati, Damen Shipyards Gorinchem, Damen Shipyards Kozle, Damen Song Cam Shipyard and Damen Yichang Shipyard.

Keywords: Damen; Flexible layers; Matching; Operations research; Ship production; Shipbuilding

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1. INTRODUCTION

Damen Shipyards Group, an international family-owned shipyard group with Dutch roots and headquarters in Gorinchem, started with just one single shipyard in 1927. Today, Damen has grown into a multinational shipbuilding group with more than 9000 employees and clients in over 100 countries. The company delivers up to 180 vessels each year. Damen designs and builds innovative ships, supported by a worldwide network of sales and services including maintenance, repair and conversion facilities.

The product portfolio of Damen has many ship types that are built on yards all around the world. Currently, Damen can build around 300 different unique ships. The product portfolio changes over the years, dependent on market conditions, new developments, opportunities and innovations in the shipbuilding industry.

The vessels can be build either at their own yards worldwide or at partner yards around the world close to the delivery station. The newbuilding yards of the Damen Shipyards Group can be categorized in the following groups:

- Damen yards
    - Complete ship building yards with different levels of integral building
    - Outfitting yards
- Partner yards
    - Yards that build cascos (steel and/or aluminium hulls)

- Partner yards that build complete ships
- DTC yards

Shipbuilding is a global industry and it is all about market cycles. A market trough is followed by a recovery leading to a market peak and followed by a collapse. This cycle is repeated constantly over the years. The demand side is based on expectation; orders of clients are placed based on an estimation of the future demand. Once built, ships remain in service for 25-30 years. Important to notice, there is a time-lag between the ordering of the ship and the delivering of it. This can vary between 1 and 4 years, depending on the size of the order book (Stopford, 2009).

Shipbuilding is a highly competitive market environment that is very volatile. The yard portfolio of the Damen group also changes over time and yards can be bought or closed. During a recession, the less efficient shipyards are forced out of the business. This market development is important to keep in mind. What is optimal now, can change in a few years and can be completely different.

To summarise, Damen has around 300 ships in their portfolio that can be built at their own new building yards or at partner yards in the world. Over the years the product portfolio changes, new products are developed and others are removed from the portfolio. Together with the very diverse and changing order intake, it is difficult to match the yard and product portfolio.

Damen wants to have a better match between the yard and product portfolio. Therefore, Damen wants to research if matching of these portfolios is possible to minimize the costs of underutilization in a recession. At the same time when the economy is booming, Damen wants to be flexible and add additional capacity to their minimal production level if needed to ensure they don't miss any opportunities. Given all these aspects, the following main research question can be formulated:

What is the optimal yard portfolio, own capacity and flexible capacity of Damen under different circumstances?

To answer the research question, a computerized model will be made. Given a product portfolio to be delivered in a year a match can be made with the yard production capacity to minimize the costs.

The focus of this research is the commercial newbuilding cluster of Damen Gorinchem (CNBD). The available man hours' capacity per year at the different yards of Damen is matched to the hours needed to build several ships or parts of a ship, for example only the outfitting or hull, at these yards.

In this paper the following topics are covered: in section 2 the theory can be found, section 3 describes the method of matching the product and yard data. In section 4 a model description is given. The results can be found in section 5. In section 6 the conclusion and recommendations are given.

2. THEORY

In this section information is given about the production process, division of labour hours, flexible layers, selection of Damen yards, Damen products and transport.

2.1 Production process

The complete ship building process is given in Figure 1. When reading this figure from left to right, the whole ship building process in time can be seen. Starting with the cutting of plates and profiles in the pre-fabrication on the far left and ending with the commissioning and delivery of the vessel on the right. This figure illustrates the material flow during the different phases of the production process; the hull production (blue), outfitting activities (orange) and the workshop activities (grey). The bar on the left shows the amount of materials relative to each other entering the different production phases.

The amount of outfitting increases during the building process when looking at the orange area in the figure. Outfitting means the positioning and mounting of items in (partially) painted and (partially) finished compartments. Examples of items that are outfitted are: floors, pumps, electrical systems, carpentry, insulation, furniture, small items (e.g. printers and lamps), cables, etc. Outfitting work can be performed during the whole hull production phase, even after the launching of the ship.

This peak of outfitting activities can be lowered by doing more work in the workshops. In the workshop small components, pipes and electrical components are assembled into modules in the dark grey layer. Afterwards, these modules are painted in the painting workshop and installed during the production process. Doing more work in the workshop will lower the work done in the final outfitting and reduce the amount of work that needs to be performed on board.

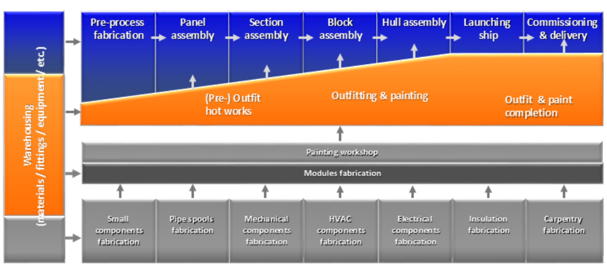

Figure 1: Blueprint production (Yard Support, 2014)

2.2 Flexible layers

What is the ideal flexible layer for the Damen organization? It is all about finding the right balance between the core capacity and flexible capacity (Bargon, 2014). Three different layers of flexibility are defined that are relevant for this research to define the ideal flexible layer. These layers are based on interviews with employees at Damen and analysing cost control reports of different Damen ships. The following flexible layers are identified:

1. Employees
    a. Temporary workers
    b. Working overtime
2. Subcontractors
    a. Hull building
    b. Outfitting
3. Partner yards
    a. Casco building
    b. Complete ship building

A division is made between own employees and external employees. Own employees can work overtime. On average, an additional flexible layer of 20% can be added on yearly basis to the own capacity by working overtime (Wallace, Contracting, 2016). This flexible layer of overtime is more expensive than the normal working hours.

Temporary workers are external employees that are hired and added to the core capacity to do a part of the work if needed. This additional capacity can be easily increased when more workers are needed and decreased when there is not much work. In this research, a division is made between temporary workers and subcontractors. Temporary workers are different from subcontractors because temporary workers do the same work as the own core employees at a yard. Subcontractors do a specific job that is not done at the yard, for example the hull building for outfitting yards.

A subcontractor is a person or company that does a part of the job for the prime contractor. Subcontracted work is a flexible layer, because it is not own capacity. Which work and how many work is done by subcontractors is different for every yard. Some yards have only a core capacity that does all the work, other yards subcontract a lot of their work. For example, subcontractors can build sections or blocks but can also do a part of the outfitting job, like painting or the installation of carpentry.

Projects at partner yards of Damen is a flexible layer. When ships cannot be built at own yards, partner yards can build whole ships or steel hulls. Which yards are partner yards and how much of the ships they have delivered in history will be discussed in the next chapter.

2.3 Yard and product selection

Damen Shipyards Group builds all kinds of vessels. Every yard has its own portfolio of ships that they can build. In this research, only the newbuilding projects for the Damen commercial Gorinchem cluster are investigated.

Over the past 15 years, more than 1800 ships for Gorinchem are delivered that where build at different newbuilding yards. The number of projects for Gorinchem between 2011 and 2015 are investigated in detail. In Figure 2, the delivered projects over these years can be found divided into three groups:

- Projects at Damen Gorinchem yards
- Projects for Damen Gorinchem at partner yards
- DTC projects at DTC yards

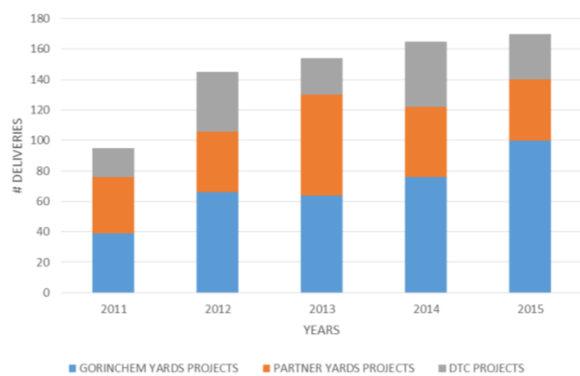

Figure 2: Delivered ships between 2011 – 2015

DTC yards or Damen Technical Cooperation yards can build all sort of vessels of the Damen product portfolio for themselves. Damen helps building those vessels locally, most of the time in Africa or America, at the chosen preferred yard of the customer. Damen delivers everything from the vessel design to a full material package. If required, Damen can provide building assistance and can help with improving the yard facilities. DTC projects are projects where the chance is very low that they will ever been built at own Damen yards. There are several driving factors for customers to use the DTC option (Damen Shipyards Group, 2015):

- Geographic inaccessible locations, e.g. inland lakes
- Political reasons such as import restrictions in the USA
- Increasing need to stimulate the own economy, employment and the own shipbuilding industry

A DTC yard can also build vessels that are not for themselves but instead they build it for the Damen Gorinchem cluster, for that kind of projects they are a partner yard. The reason for this can be among others; the yard can build at a low-cost price and the quality is according to the Damen standard. In the past, efficient DTC yards evolved to Damen yards, examples are Damen Shipyards Changde and Damen Shipyards Kozle.

DTC projects and ships that are not build for Gorinchem are excluded in this research. The focus for optimization of the capacity will be on the products build for Damen Gorinchem at own yards in the Gorinchem cluster. Projects at partner yards of the Damen Gorinchem cluster are a flexible layer. When ships cannot be built at own yards, partner yards can build whole ships or hulls. The following yards are own Damen yards in the Damen Shipyards Gorinchem newbuilding cluster:

- Damen Dredging Equipment (DDE)
- Damen Shipyards Antalya (DSAn)
- Damen Shipyards Changde (DSCh)
- Damen Shipyards Galati (DSGa)
- Damen Shipyards Gorinchem (DSGo)
- Damen Shipyards Kozle (DSKo)
- Damen Shipyards Singapore (DSSi)
- Damen Song Cam Shipyard (DSCS)
- Damen Yichang Shipyard (DYS)

The product portfolio of Damen is very large and changes over the years, dependent on market conditions, new developments, opportunities and innovations in the shipbuilding industry. All the delivered ships between 2000 – 2015 are grouped in product groups that represent a large group of ships. Every product group has a representative dummy ship. In total 24 dummy ships or product groups are defined.

Using these product groups, previously selected yards can be linked to dummy ships which they have previously build in history and a clear overview can be presented of the ship types that a yard can build. These links are not fixed and can be changed in the future if Damen wants to build a new ship type at a yard where it is not done before.

2.4 Transport

Supply and demand is not always at the same location. Ships must be transported from the supply region to the demand region. To find the optimal yard portfolio, the combination of the summation of the total labour cost at the yard and the transport cost needs to be the cheapest as possible. This will be discussed more into detail in the next sections.

When combining the own Damen yard locations and sales areas, the following groups are made:

- Group 1: America
- Group 2: Europe
- Group 3: Africa and Middle East
- Group 4: Asia

It is assumed that the transportation costs within these larger groups are minimal and are not influencing optimization decisions where to build a ship. The reasons to divide the world in four regions is because transport costs are very uncertain. Additionally, the height of the transport cost is also small compared to the total labour cost when building a ship, it is only used as a barrier to build at a certain location. To minimize the uncertainty, one cost price is assumed for a larger region to avoid many uncertain variables. Thirdly, Asia and Europe are the two main supply markets for Damen ships and the distance between the yards in these two regions is minimal. The total transport costs in this research are around 10 to 15% of the total costs. Therefore, even if it is very unpredictable it can still be used a barrier to build at a certain location.

3. MATCHING PRODUCT AND YARD DATA

Damen wants to have a better match between the yard and product portfolio. The shipbuilding labour hour capacity of the yard in hours will be matched with the needed capacity in hours to build several ships per year. The division of the yard capacity at every yard is different, a total yard capacity in hours is calculated using the own Damen core capacity as it is now and subcontracted capacity. By doing this, all the yards can be compared on the same production depth.

Still, a yard in China cannot be directly compared to a yard in the Netherlands. Every yard needs another number of hours to build the same type of vessel. There is a difference in culture, facilities, motivation, process efficiency, etc. To match yards and products on the same level every yards' capacity is normalized based on the norm yard and norm hours to build a ship are defined. The norm yard is the yard that needs the minimal number of hours to build ships. Yards are compared between each other based on the registration of hours for several ship types. The actual total labour hour capacity at a yard is divided by an efficiency (in 't Veld, 2002), higher or equal to 1, to get a norm capacity. This efficiency is calculated by using the difference between the number of hours needed to build ships at the different Damen yards. Using these registration of hours, per ship an hour norm can also be defined. The norm hours to build a ship is the number of hours at the norm yard. Using these norm hours for ships and the normalized capacity of the yards, yards and products can be matched on the same level.

The main research question is to find an optimal yard portfolio. To be able to find an optimum, wage rates for all the yards are defined. Using the wage rates the most cost optimal matching of hours is possible. To calculate the actual wage costs, the used norm hour capacity at a yard is again multiplied with the previous calculated efficiency to define the real used actual number of hours. Ships must be transported from the supply region to the demand region. To find the optimal yard portfolio, the combination of the summation of the total actual labour cost at the yard and the transport cost needs to be the cheapest as possible.

The data that is required are the normalized capacity of the yard portfolio, the norm hours needed to build the whole product portfolio of Damen, yard efficiency, the hour tariff at every yard and the transport costs. Transport costs will be discussed in the next chapter. The structure of this section is as follows:

- Yard capacity
- Division of labour hours
- Yard efficiency
- Norm labour hours to build a ship
- Hour tariff

3.1 Yard capacity

The shipbuilding labour hour capacity of the yard consists of a core capacity and flexible capacity as previously discussed, one of the flexible layers of Damen is the outsourcing of work. Subcontractors perform project activities that are not done by own Damen employees.

For example, the difference between the carpentry workshop at DSGa and DSCh. In Galati all the carpentry is subcontracted, the workers at the yard in Changde makes everything themselves. To take this difference into account, an additional fictive layer of subcontracted hours is considered additional to the own Damen nominal capacity to include the carpentry hours. In this way, comparison between yards is possible on the same production level.

3.2 Division of labour hours

The hours needed to build a ship are divided in two big groups: production hull hours and outfitting hours. This division in two groups is done because of the following two reasons:

- As described earlier in this paper, three different types of yards exist: hull yards, outfitting yards and complete ship building yards with different levels of integral building. Using this division into two groups, a direct link is created between the ship hours and yard types.
- Detailed hour registration of labour hours during the production process is not available and not uniform over all the yards. To minimize the uncertainty, the hours are divided into two groups instead of many uncertain variables.

Workshop hours, as discussed in section 2, in the production process are distributed over the hull and outfitting group. The consequences of this simplification are minimal because the workshops are now responsible for less than 10% of the total labour hours to build a ship at the yards of Damen (Damen Contracting & Yard Support, 2016f). The criteria that is used to define in which group the workshop hours are made, if data or information is available, is as follows: working hours are considered in the outfitting group at the moment when two blocks are assembled to one compartment. The hours made before assembling two blocks to one compartment are considered in the hull group.

3.3 Yard efficiency

When the total labour hours' capacity is known, the next step is to compare the efficiency of every yard given their input. A yard in China cannot be directly compared to a yard in the

Netherlands. There is a difference in culture, facilities, motivation, process efficiency, etc. A method is needed to compare the performance of yards by using efficiency (in 't Veld, 2002). The formula of efficiency is written as follows:

$$Efficiency = \frac{norm\ input}{real\ input}$$

Yards are compared between each other based on the registration of hours for several ship types. To compare yards on the same level, own Damen workers and needed subcontractors are considered in these hour registration. Using this number of hours needed to build a specific ship, the norm can be defined and yards can be compared between each other.

In this research, the inverse of efficiency will be used. The norm yard has an efficiency of 1 and is the yard where the efficiency is the highest. The input at this yard is the norm input. All the other yards need a higher real input than the norm input, they will get a real normalized efficiency factor higher or equal than 1. The total actual yard capacity at a yard is then divided by the calculated efficiency to define the norm capacity.

Shipbuilding is a process involving hundreds of thousand items and parts of machinery, equipment, prefabricated parts, etc. The yard efficiency can be further increased by looking more into detail at the outfitting process and the consequences of the phase when a certain activity is performed. Outfitting of a ship can be done partly during the section phase, yet most of it is done in the block phase and final phase when the hull is erected. Outfitting can also be done after launching of the vessel. All of this can be improved doing more pre-outfitting in earlier phases of the production process and using larger modules, that are pre-assembled in the workshop.

When standard outfitting modules will be produced in workshops and more pre-outfitting is done, there will be a partially shift to earlier phases in the production process and an overall man hour reduction of 20% is possible when looking at the current situation off all the yards (Reiff, 2016). The yard efficiency as described in the first part of this paragraph will change.

A reduction of the lead time and man hours has the consequence that the utilization of the yards can be increased and more projects per yard can be executed. Less shipyards are necessary for the same output!

3.4 Norm labour hours to build a ship

Per ship an hour norm is defined for the hull and outfitting. The norm hours to build a ship is the number of hours at the norm yard. The norm yard is the yard that needs the minimal number of hours to build ships. DSGa is the norm yard, other yards need more man hours. When DSGa has not build ships in a certain product group before, the hours are used at another yard that needs the minimal number of hours for these ship types. These hours are than normalized, labour hours are determined that are needed if the ship is built at the norm yard, using the previous calculated efficiencies. The hours at a yard can be different for the same ship type at the same yard, the deviation between the maximum and minimum registered hours is around 10 to 20% of the total labour man hours.

With the normalized yard capacity as discussed in the previous paragraph and all the needed ship labour hours determined as the norm, products and yards can now be matched on the same level.

3.5 Hour tariff

The competiveness of a shipyard does not only depend on how efficiently it assembles the ship. Labour costs vary enormously from one yard to another. To compare hourly wage costs, the labour costs are converted to a common currency: the euro.

To calculate the hour tariff, the company costs per year (excluding the projects materials) are divided by all the budgeted direct man-hours per year (Damen Contracting & Yard Support, 2015). The calculation of the hour tariff is based on the following equation:

$$Hour\ tariff = \frac{V + F}{N}$$

With:

V = Budgeted variable costs per year at a yard
F = Budgeted fixed costs per year at a yard (generally do not change when production volume changes)
N = Nominal capacity or the expected average number of direct man hours per year used at a yard for all the projects in the coming years based on the estimated output in these years (Koetzier & Brouwers, 2010).

The possible subcontractors at a yard as earlier discussed in section 3.1 are not included in the calculation of the hour tariff. Co-makers are invoiced to the project and are added separately to the available capacity as previously discussed.

4. COMPUTERIZED MODEL

Using the available information, the needed hours to build a ship can be matched to the available capacity at a yard. A method needs to be selected that can calculate the most optimal yard capacity. This cannot be done manually anymore because the problem is too large, a computerized model needs to be made. To obtain the optimal yard portfolio and capacity of Damen under different circumstances a cost price function will be minimized and discussed in the first paragraph. A description of the computerized model is given in paragraph 2. In the last paragraph the model is validated and verified.

4.1 Cost price function

To obtain the optimal yard portfolio and capacity of Damen under different circumstances. The cost price function needs to be minimized. The total cost price function consists of five parts. The summation of these five parts needs to be as minimal as possible:

- Fixed cost price per year
- Direct labour hour costs
- Cost price of the flexible layer
- Partner yards cost price
- Transport cost

4.2 Model description

Given a product portfolio to be delivered in a year a match is made with the yard production capacity to minimize the costs, using the methods of operations research (Hillier & Lieberman, 2015). Using this method, the objective function, in this case a cost price function, can be minimized by finding the best allocation of ships to the different yards. A model is made that matches the available capacity of the yard to the needed man hours to build several ships per year in the most cost optimal way. Linear programming is used because all the mathematical functions in the model are made linear. Using the Add-in Solver (a product of Frontline Systems, Inc.) in Microsoft Office Excel, an optimal value for the cost price function subject to constraints can be found by changing variable cells (Frontline Systems, 2017).

The purpose of the model is to make it easy understandable what happens when the user changes the input of delivered vessels and input variables of the yard. The model is developed so that the user can give a list of ships as input and change yard specific input variables that are discussed in section 3. The user can change the following yard parameters:

- Yards can be turned on or off by the user, if the yard is active in the model a fixed cost price need to be paid and ships can be assigned to this yard.

- Hour tariff
- Change the efficiency factor for hull and outfitting
- Change the total labour capacity available per year
- Add additional employees above the own capacity. This flexible layer is more expensive than the layer of own Damen capacity.
- Add an increased process efficiency for every yard, e.g. more pre-outfitting and modular outfitting. In this way, the needed man hours can be reduced. Consequently, when more pre-outfitting is needed the fixed cost price will increase a little. This is because among others more engineering and job preparation is needed.
- Change the needed capacity for projects outside Gorinchem

The output of the model is the optimal allocation of ships over the yards in different situations. The most optimal distribution of the ships over all the yards is the one with the lowest cost price. Based on this calculation, the board can decide which decisions it will make. The user can interpret these results and draw conclusions. Using this optimization, the Damen core yards, together with their minimal production level and flexible capacity, under different circumstances can be identified after changing the yard specific input variables in the way the user wants.

4.3 Validation and verification

To ensure that the model can correctly be used for the intended application, verification and validation is done. Tests and evaluations are done until there is sufficient confidence that the model can be considered valid for the intended application.

Data is collected from official Damen sources and interviews with experienced employees. The values of the input and internal parameters inside the model are changed to determine the effect upon the model's behaviour and output.

In order to verify the model, a structured walk through the model programming is done. Firstly, it is manually checked if all the cells in the spreadsheet are linked correct to each other to make sure no mathematical errors are made. Secondly, a thorough investigation is done of the Add-in Solver.

5. RESULTS

In this section, the case study method will be explained. Based on the optimization of historical data, Damen can do it better. A case plan is worked out to define the core yards of Damen. The idea of the case plan is to get insights in the changing usage of capacity when yard parameters and input of vessels are changed. The following cases are worked out:

- Average case, increase and decrease input portfolio
- Average base case, but increase and decrease workboats or high speed crafts
- Changing yard efficiencies
- Adding flexible layers
- Combinations

The following yards can be closed or can be made a partner yard based on the previous cases:

- DSSi (Damen Shipyards Singapore)
- DSCh (Damen Shipyards Changde)

Closing these two yards will reduce the understaffing losses of all the Damen yards. When closing these two yards, Damen will be still able to build all vessels at own yards, even when the demand is very high.

The following seven yards are part of the core portfolio of Damen:

- DDE (Damen Dredging Equipment)
- DSAn (Damen Shipyards Antalya)
- DSGa (Damen Shipyards Galati)
- DSGo (Damen Shipyards Gorinchem)
- DSKo (Damen Shipyards Kozle)
- DSCS (Damen Song Cam Shipyard)
- DYS (Damen Yichang Shipyard)

The flexible capacity used at the yards of Damen depends on the input list of ships and yard parameters. But, after the calculation of several cases the next three insights can be given:

- A flexible capacity at DSAn can be added to the total capacity. Because this additional capacity is used in a lot of scenarios in every case, it can be interesting to enlarge the production site in Antalya on the long term.
- When the demand is high, it is interesting to add a flexible capacity at DYS.
- There is no need to add additional flexible capacity above the own total capacity at other Damen yards. In most cases, the own capacity is not fully used at these yards even when the demand is very high.

6. CONCLUSION AND RECOMMENDATIONS

Based on the previous discussed results, Damen can close yards in order to use their capacity in the most cost optimal way. In this research simplifications are made and a focus is set on the specific domain of matching hours. In this section, some recommendations are given about the results presented in this paper. The main recommendation for Damen is to get their data structured, register hours on a more detailed and uniform level and get a better insight in the hour tariff calculation for every Damen yard. During the process a lot of data was needed and most of the time this was very chaotic or incomplete.

During the research process, assumptions are made and this affects the results presented in this paper. The following remarks are given:

- This research focuses on the matching of labour hours and optimization of the labour costs at a yard on a very high level. But, there are more costs in the shipbuilding process that are not considered in this research e.g. materials costs, transport of these materials, etc. For further research, if data is available, it would be recommended to include all the building costs to get an optimization on a more detailed level.
- Ship building hours are constant. No delays or rework is considered, which is usually not the case in reality.
- Lead time/waiting time and financing is not taken into account (discussed more into detail below)
- This research is done for the nine yards of the newbuilding cluster. The research method used in this report can also be used for other yards in the Damen Group when the data is known.

Aspects that are not considered are the building period of a vessel, financial indicators and cash flow. As stated in the introduction, this research focuses on the problem of matching hours without taken into account the building period or ship financing. In further research, it would be interesting to take this into account.

The ship owner that buys a new ship at a yard will prefer to spread and delay the payments as much as possible. Contrary, the yard would prefer to get paid the full amount in advance. Both yard and ship owner need to borrow money for financing and both will prefer to do this as late as possible in order to avoid large interest payments.

The costs for the yard are high at the start of the project, when expensive equipment like main engines need to be ordered. The yard will need to lend money in order to finance the project (Pruyn, 2014).

In this research, the time between the keel laying and delivery was considered and simplified to an amount of hours without considering a long or a short lead time. Varying the lead time due to an increase in the process efficiency will also have a consequence on ship financing that is not considered because it was outside the scope of this research.

ACKNOWLEDGEMENTS

This thesis research was undertaken as part of the completion of the master Maritime Technology with specialisation Ship Production at Delft University of Technology. This research is done in cooperation with Damen Shipyards Gorinchem.

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