Damen yard performance

The performance of Damen shipyards compared to the industry and direct competing shipyards.

Damen Shipyards Gorinchem
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Summary

The goal of this research is to define a performance model with which it is possible to assess the performance of Damen yards compared to competing shipyards in a quantitative way. The assessment is based on freely available information.

The purpose of such a performance analysis is to establish the place of the Damen yards in the global market. This information can help the company to identify its weaknesses and strongpoints. Based on this assessment it is possible to identify improvement possibilities. The aim of these analyses is to stay ahead of the competition and keep the company on track.

The main part of this research can be split up in four parts.

1. Performance model: definition
2. Performance model: data analysis
3. Performance results: Market/Playing field definition
4. Performance results: Damen yard performance

In the first part a theoretical framework with important input parameters is defined, based on a literature research. The result is a set of important parameters which are captured in four areas of interest (left row). These parameters are structured in a performance model based on three structuring methods (right row):

1. Product output
2. Economy & Market
3. Process & Facilities
4. Personnel & Organization

1. Iron triangle (Time, Cost, Quality)
2. Production performance
3. Cost price of a ship

In the second part the availability and quality of the data is investigated to determine how the performance can actually be calculated. The result is a performance model which includes three performance scores:

1. Time -> based on production times.
2. Cost -> based on production costs which are primarily driven by labour costs.
3. Productivity-> which is used to put an extra perspective on the time and cost performance.

The calculated scores are made dimensionless to enable an easy comparison between shipyards and the industry. This makes it also possible to compare direct competitors.

The data for the performance model is primarily retrieved from the Shipping Intelligence Network (SIN) (Clarksons Research, 2017). The investigated time period is 2010 – 2016, because there is detailed internal information at Damen for the Damen yards in this period. This information is used for validation purposes.

In the third part the results are obtained and the market/playing field is defined. It proved that, due to economic influences, it is very hard to compare shipyards on a yearly basis. Therefore the choice is made to compare shipyards based on an average performance score over the entire investigated period 2010 – 2016. Thereby the economic influences are somewhat compensated.

In the fourth part the performance of the Damen yards is compared with the other shipyards in the database. This comparison is made against the industry average and against identified direct competitors. From these comparisons the following conclusions can be drawn:

1. **The time performance is around the industry average.**
2. **The cost performance is around the industry average.**
3. **There is a productivity gap between the Damen yards and the best performing shipyards in the industry.**

The fact that the *time performance* is around the industry average is worrying, while Damen uses a strategic hull stock. This should enable them to deliver vessels significantly faster than the competition. At this moment it turns out that the hull stock isn't an advantage, but a needed resource to keep up with the competition!

The *cost performance* shows that Damen is performing acceptable, but the accompanying *productivity performances* show that a lot of improvement is possible.

- Damen Shipyards Singapore — Increase: 45%
- Damen Shipyards Song Cam Shipyard — Increase: 20%
- Damen Shipyards Galati — Increase: 25%
- Damen Shipyards Changde — Increase: 55%
- Damen Yichang Shipyards — Increase: 30%

The conclusion is that Damen has wage advantages based on the geographical locations of the shipyards, but the productivity performance of the shipyards lacks behind the industry! Extra research is needed to define the exact causes of these performance differences.

For Damen Shipyards Galati and Damen Shipyards Changde a comparison of the available yard resources is made. Based on this comparison it seems that there is a relation between:

- Shipyard lay out
- Available areas
- Available cranes
- Available personnel
- Building strategy

Although there seems to be a relation between these five aspects and the performance, it was not possible to define the exact relationship. Extra research into these aspects is needed to quantify these relations.

Preface

This research into the performance of shipyards is conducted as a graduation project. With this graduation project the master phase of the study Maritime Engineering at the Delft University of Technology is closed. The goal of this research is to quantitatively assess the performance of Damen yards compared to the industry and their direct competitors.

I was able to do this research at Damen Shipyard Gorinchem. They gave me the opportunity to work within the Yard Support group. Inside Yard Support group there is a lot of knowledge and information available with respect to the operation of the shipyards of Damen. Thereby this was a perfect place to execute this research.

I want to thank the people at Damen and especially my colleagues within the Yard Support group. I experienced that Damen is an open company. People are very interested in your work and everybody is prepared to help you, if they can.

My special thanks goes out to Jack Teuben who supervised me from Damen and Jeroen Pruyn who supervised my from the TU Delft. Both putted a lot of effort in supporting and guiding, during this research. This helped me a lot in making decisions and putting different perspectives on my research.

Tom Zevenhoven

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1. Introduction

Outperforming the competition is very important for companies in every sector. By knowing your place with respect to the competition, it becomes possible to understand your place in the market. This knowledge can be used by a company to make the right choices to improve the company. Therefore, it is important for a company to be able to assess its own performance and compare this performance to the performance of its main competitors.

Naturally shipyards also come across this subject. They are operating in a global market and thereby competition between shipyards is intense. Shipyards are competing with each other to deliver the right products to the customer at the right price. At the same time they are experiencing differences which for example are caused by the geographical location of the shipyard. Think of wages, social factors, cultures, political aspects, etc. In such a global market, it is important to understand your own position, compared to the competition.

The background of this subject will be further described in paragraph 1.1. The problem for this subject is stated in paragraph 1.2. In paragraph 1.3 the main research questions will be described and accompanied by sub research questions. The scope of this research and the working method are described in paragraph 1.4 and finally the structure for this report is described in paragraph 1.5.

1.1. Background: Damen Shipyards and its challenges

Damen is an international shipbuilding company. The company is globally active in the industry of commercial new build, ship repair & conversion and lifetime service support. For this means the company owns shipyards and has strong partnerships with other shipyards all over the world. The Damen Group consists of 50 companies worldwide. 22 of these companies are newbuilding shipyards, which emphasizes the importance of this part of the company. Yearly these shipyards deliver 160 – 200 vessels. Damen delivers a wide range of vessels: from tugs to yachts (Damen Shipyards, 2017). Especially the newbuilding market is very important. If customers are kept satisfied in this market, there is a big chance that these customers will also utilize the services of Damen with respect to lifetime service support and ship repair & conversion. So, a good performance in the newbuilding market is important for the existence of the entire company.

Damen is competing in a global market. There is always a high pressure on the company to deliver the demanded ship for a competitive price and with a short delivery time. During economic growth, a fast delivery time will be most important and during a crisis there will be more emphasis on low cost. Despite the state of the economy, a ship should always be in compliance with the demands of the customer. In both scenarios the company with the best performing shipyard will have a competitive advantage.

The performance of a shipyard can be defined in multiple perspectives. For customers, performance is captured in price, service, delivery time, etc. Thereby the ship should meet the expectations of the customer. The shipyard itself will regard profit, quality, lead time, etc. as important performance parameters. With respect to the customer a good performing shipyard will fulfill the demands of the customer and thereby keep the customer satisfied. The shipyard which can keep their customers satisfied is the shipyard that will be selling and producing ships.

It is very hard to outperform competing yards on all points which are concerned with performance. By selecting a strategy and a market, a company can concentrate on certain aspects of the performance and become a market leader in its chosen market. To outperform the competition in the chosen market and to keep outperforming them it is important to know your place in the market. From this knowledge a company can decide how it is performing and where it want to improve. The identification of strongpoints and improvement points can help to stay ahead of the competition. In this way a company is able to adjust its course, keep track of its performance and maintain its existence.

1.2. Problem: challenges in performance assessment

The performance of a company is closely related to the market in which the company is active. A change in performance may lead to a new market position. In the same way can a market change require a company to evaluate its performance. Keeping track of the developments in the market and continuously improving of the performance can help a company to outperform the competition.

There are many methods for the assessment of companies. Mostly these methods are based on a qualitative analysis and only provide a birds eye view on the place of a company with respect to the market. Qualitative analysis also implies that expert knowledge is needed to interpret the results and bring them together in a solution. This is the first drawback. The second drawback is that qualitative analysis is vulnerable to subjectivity and highly dependent on sharp formulation. Even if the analysis is done in an acceptable manner it is very hard to compare the marketplace of companies on such a qualitative basis. Very soon these kind of analysis turn to some kind of rating system which on its turn introduces a new source of subjectivity.

These pitfalls can be avoided by the use of a method based on factual data. By capturing the performance of a company in a value ,it becomes possible to rank companies with respect to each other. In this way companies, and thereby also shipyards, can be compared and differences can be traced back to relevant causes.

Although there are advantages in the use of factual data, the data must be available. Within Damen a culture is being developed in which data regarding production efforts, sales, etc. is captured. The acquisition of data within Damen will thereby be possible for a great extent. The acquisition of data of competing shipyards is a larger challenge. Most companies are not willing to share production information and other data which they are not obliged to publish. This means that the method should be based on factual data which is freely available. Unfortunately, it might turn out that such sources are less reliable than the companies own administration, this needs to be considered when collecting the data.

Assessment of the performance and defining the causes of bad performance can be used to learn and improve. Improvement is a key factor in outperforming competing shipyards and maintain the continuity of the company.

1.3. Research questions

The discussion in paragraph 1.2 leads to the following research questions for this thesis:

Main research question:

''Can the performance level of Damen yards be quantitatively compared to competing yards under the constraint of limited data availability?''

In this question the most important parts are the *comparison* based on performance. The *parameters* which are used to assess the performance and the *availability and quality of information* about competing shipyards. Therefore, the research is divided in four parts based on four sub questions.

Research sub questions:

1. *Which parameters are important if the performance of a shipyard has to be assessed?*
2. *Which required parameters can be obtained and what is their quality?*
3. *How can these parameters be structured in a performance model which captures the relationships and the importance of the parameters?*
4. *What is the performance of Damen yards compared to other shipyards?*

1.4. Research scope and definition of the working method

The first step is to investigate which parameters could help to analyze a company. In essence a shipyard is a company and thereby these parameters should be applicable to a shipyard. There are multiple analysis methods available to assess the performance of a company. Reviewing these methods and investigating the used parameters, will be the starting point for the research. In this way, a theoretical basis will be established.

Answering the second question will help to turn the theoretical basis into a more practical applicable one. Therefore, the available data and the quality of this data need to be assessed. This will help to define which parameters can be used and which parameters are practically not available.

The third question will provide an answer about how a shipyard will be assessed. The combination of the theoretical basis and the practically available data will be used to define a performance model. The structure of this model will be based on existing performance methods and the availability of data. With the defined model it should be possible to define the market/playing field in which the shipyards are participating.

The fourth sub question will provide insight in the actual place of the Damen yards within this playing field. By calculating the performance of the Damen yards and comparing these performances with the industry and direct competitors, it will be possible to define performance gaps. Thereby the place of the Damen yards with respect to the industry and direct competing shipyards can be defined.

The combination of the above given answers will be used to answer the main question. The result will be a performance model with which Damen is able to asses and compare their shipyards performances in a quantitative way. The comparison will be done against a database which includes interesting competing shipyards in the market. The found information can be used for improving purposes.

1.5. Report structure

The report is roughly divided in four parts. Each part is used to answer one of the sub questions. Based on these answers a conclusion is drawn to answer the main question of the research.

I. Model definition

Chapter 2 is a literature review of available performance parameters and performance methods is conducted. These are reviewed to determine which parameters should be included in the model and how these parameters could be structured. Finally a theoretical performance model is defined based on the found parameters and model structures.

II. Data analysis

Chapter 3 defines which shipyards are assessed from Damen and which competing shipyards are included in the database. Besides the actual choice for the shipyards, arguments are given why these shipyards are selected. The available data and the quality of this data will also be investigated. Based on the availability and the quality of the found data the theoretical model is further defined and a practical performance model is defined.

III. Performance results: market/playing field definition

Chapter 4 depicts the overall results of the performance model. Each aspect of the performance model is depicted. In this chapter an overview of the performances of all shipyards can be found. This information is used to define the market/playing field.

IV. Performance results: Damen Yard performance

Chapter 5 zooms in on the shipyards of Damen. Here the question is answered how these shipyards are performing with respect to the rest of the industry and with respect to direct competitors. This comparison is used to establish the place of the Damen yards.

Chapter 6 goes deeper into expansion possibilities of the defined performance model. It contains a comparison of two Damen yards, which investigates the relation between the found performance differences and the yard resources. Furthermore a quick look into investment possibilities is given based on the found performance results for one of the Damen yards.

The final conclusions can be found at the end of the report. These are followed by recommendations for further research.

2. Performance model: definition

To be able to assess and compare shipyards on the performance, a model is needed. The objective of this model is to provide an objective quantitative analysis of the shipyard. This analysis should result in an overall performance score on which shipyards can be compared. The structure of the performance model can be seen in Figure 1.

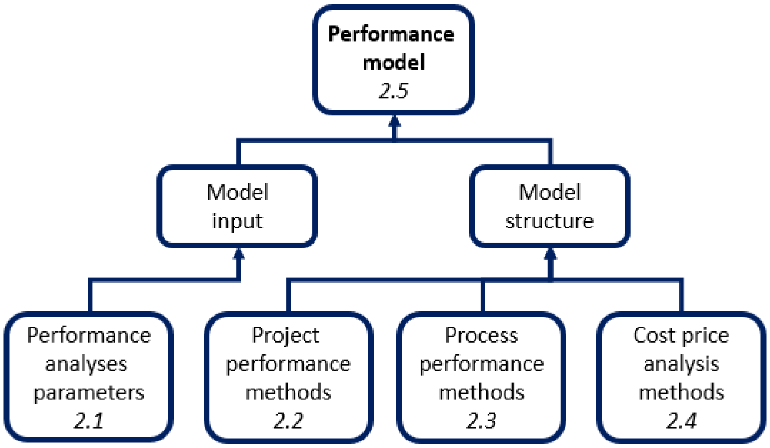


Figure 1: Structured approach of the model definition.

There are two types of input needed and the result is the definition of a new performance model:

Model input

The first step is to investigate which parameters are important for the performance assessment of a company. For this purpose, a literature review is conducted. In paragraph 2.1 different analyses methods and parameters are reviewed to decide which of these parameters are of importance for the performance of a company. These parameters are then projected on a shipyard to define usable parameter groups. In this way, the model input in Figure 1 is defined.

Model structure

The next step is to look at methods, which are used in companies, to control the production process. These can be used to define the model structure (right side of Figure 1). Three theories are selected which can help to assess the performance of a company. A shipyard is merely working on a project basis, so project control is an important subject. The use of project management is reviewed in paragraph 2.2. The theory of production performance within a company, based on the theoretical model of (Veeke, Ottjes, & Lodewijks, 2008), is reviewed in paragraph 2.3. In paragraph 2.4 the cost price of a ship is taken as a basis for the production performance. These three methods are examined and the theory projected on a shipyard to define a model structure.

Performance model

The combination of the found input and the found structures is used to define a new hybrid theoretical performance model. This model is described in paragraph 2.5. Parts from different structures are combined to form a model which is specifically applicable to shipyards. This model is used to compare shipyards.

2.1. Performance analysis parameters

The first step is to define how the performance of a company can be analyzed and assessed. This information can be used to define the model input. There are multiple methods available in literature. A review of these methods will give insight in the importance of different input parameters. Assessment of companies can be done in a qualitative and quantitative way. The aim of this research is to define a quantitative assessment method. Therefore, the focus will be on factual data and quantitative objective analyses.

In general, a company assessment can be split up in three parts:

1. External analysis
2. Internal analysis
3. Combining two analyses and formulation of the results

For this reason, the model input will be split up in internal and external parameters and the combination will provide the needed set of model input for Figure 1.

2.1.1. External analysis parameters in literature

The aim of an external analysis is to define the market and map the important aspects of the market. The purpose of this market definition is to explore the market and find possibilities to penetrate the market. In Appendix A: Analysis models, some commonly used external analysis methods can be found:

- *Porters five forces model* (Grundy, 2006)
- *PEST analysis* (Free-mangement-ebooks, 2013)
- *Blue Ocean Strategy* (Chan Kim & Mauborgne, 2005)
- *Boston Consulting Group Matrix (BCG Matrix)* (Martin, 2017)

Out of these four analysis methods important aspects come forward. They can be sorted in four groups:

1. **Existing products in the market**

   The goal of this point is to define which products are already available in the market. How do these products fulfill the demands of the market? Are there gaps which pose an opportunity for new products? Is it easy to replace products or introduce better alternatives? These questions are used in the methods of *Porter* and *Blue ocean strategy* to assess the current products in the market and search for opportunities.
   From identified opportunities new products can be introduced. The place of these products in the product portfolio of a company defines the importance of this product to the company. A product can have little or no profit, but a company can still emphasize on this product because it wants to enter a new market or increase its market share. These considerations are addressed in the *BCG matrix* method.

2. **Stakeholders in the market**
   Besides the product it is also important to know the important primary stakeholders in the market. For example the bargaining power of suppliers or customers can be of great importance.

If for certain basic materials only one supplier is available, this can have large effects on the price of these materials.

Other important stakeholders are employees. How are the social regulations? What kind of employees are needed? What do they cost? What do they demand in terms of holidays, working hours etc.

Political and legal stakeholders can't be forgotten. What are the rules and regulations? What is the influence of governments on the market or even on the company? Are there important laws which intervene with daily company business.

These factors are addressed in *PEST analysis* and *Porters five forces model*.

3. **Direct competitors**

   The influence of direct competitors can't be forgotten. This part of the market assessment can be found in all models in some way. Sometimes directly by identifying them and sometimes by identifying their products and the consequences of the existence of these products.

4. **Environment**

   The economy has a big influence on a company. Economic growth or downfall determines a great deal of the sales. Relative differences in economy also influence a company. Think of differences in currencies, employee wages, material costs etc. All these factors can benefit or harm a company.

   The actual environment in terms of nature is also becoming more important. A 'green' image can help a company to increase their market share. Nowadays this should be taken into account. Especially *PEST analysis* addresses these factors very well.

A summary of important external analysis aspects and the analysis methods in which they are used can be found in Table 1. In this table, the data type (subjective or objective) and the model in which the parameter is found is depicted. In paragraph 2.1.4 will be discussed which of these parameters can be used for the analysis of a shipyard.

Table 1: Important external analysis points.

External analysis points	Availability data type	Porter's five forces	Pest Analysis	Blue Ocean Strategy	BCG Matrix
Product	Objective	X		X	X
Market (Purchase & Selling)	Objective	X		X	X
Competitors	Subjective	X		X	
Shareholders	Subjective	X			
Politics & Legislation	Subjective		X		
Economy	Objective		X		
Social & Cultural aspects	Subjective		X		
Technology	Subjective		X		

2.1.2. Internal analysis parameters in literature

The second step is an internal analysis. The aim of such an analysis is to define the company and map the important processes. Purpose of this company exploration is to identify the capabilities and find possibilities for the company. In Appendix A: Analysis models, some commonly used internal analysis methods can be found:

- *Balanced Scorecard (BSC)*
  (Kaplan & Norton, The balanced scorecard: translating strategy into action, 1996), (Kaplan & Norton, Putting the balanced scorecard to work, 1993), (Kaplan & Norton, The balanced scorecard - measures that drive performance, 1992)
- *MOST analysis* (Strategy consulting Ltd, 2017), (Free-Management-ebooks, 2017)
- *CATWOE analysis* (Pandey, 2011), (Visee, 2017)
- *Five times why* (Serrat, 2009)
- *McKinsey 7s model* (Waterman, Thomas, Peters, & Phillips, 1980)
- *Value chain analysis* (Kaplinsky, 2010)
- *VRIO analysis* (Free-management-ebooks, 2017), (Barney & William, 2008)

Out of these seven analysis methods important aspects come forward. They can be sorted in five groups:

1. **Company goal**
   This specifies the most important goal of the company at the moment. Does it want to make as much profit as possible, sustain its market share, increase its market share, entirely leave a market etc. Usually these goals are the result of the external market analysis. The definition of a company goal is explicitly mentioned in the *BSC*, *MOST analysis* and *McKinsey 7s model*.
2. **Strategy, mission and vision**
   Then a company can decide upon its current state in the market and where it wants to go. The next step is to transform this into is a strategy, which contains a plan to reach the company goals. The strategy is accompanied with a mission and vision for the company. The establishments of these aspects is visible in some way in all of the methods.
3. **Processes**
   The organization of processes is very important for the performance of a company. Organizing processes in a logic order helps to improve the performance. Examples of mapping these processes can be found in *value chain analysis.* Alignment of the processes with the established strategy is part of *McKinsey's 7s model* and the actual improvement of processes is the aim of the *five times why analysis*. The process aspect comes back in a lot of the analyses and this indicates the importance of this point.
4. **Employees**
   A company generally can't work without employees. So the organization and use of employees has a big influence on the performance of a company. The amount of employees, but also the skill of the employees is important. Especially in *value chain analysis* and *McKinsey's 7s model* employees and skill of employees has an important place.
   In some companies employees and their skill/knowledge make the difference with respect to the competition this is pointed out by *VRIO-analysis*. *VRIO-analysis* is used to focus on the key resources within a company.

5. **Key resources**
   This are the resources which make a company different from its competitors in the market. These are especially emphasized *by VRIO-analysis, value chain analysis* and *CATWOE analysis*. The aim is to identify the resources which can give a company the competitive edge. This can be skill and knowledge from employees, but also the availability of certain production facilities. Even the location of the company with respect to suppliers, customers, infrastructure etc. can be of competitive importance.

A summary of important internal analysis parameters and the analysis methods in which they are used can be found in Table 2. The type of data is also depicted (subjective or objective). In paragraph 2.1.4 will be discussed which of these parameters can be used for the analysis of a shipyard.

Table 2: Important internal analysis points.

Internal analysis points	Availability data type	Balanced Score Card	MOST analysis	Catwoe analysis	Five times why	Mc Kinsey's 7's	Value Chain Analysis	VRIO Analysis
Strategy	Subjective	X	X			X		
Mission	Subjective	X	X					
Objectives	Subjective	X	X					
Tactics	Subjective	X	X					
Process & Facilities	Objective	X		X	X	X	X	X
Organizational structure	Objective					X	X	
Personnel & Education	Objective					X	X	X

2.1.3. Combining external and internal analysis parameters

To have a better understanding usually the external and internal analysis are combined. The combination of both assessments makes it possible to define a performance. Popular methods are (Appendix A: Analysis models):

- *SWOT matrix* (Pickton & Wright, 1998)
- *Benchmarking* (HaskoningDHV UK LTD Maritime & Waterways, 2016)
- *Internal Factor Evaluation (IFE) vs External Factor Evaluation (EFE)* (David, 2007)

Evaluation of the external and internal analysis serves two purposes:

1. **Comparison**
   If a company can define the market and its place in this market, it becomes possible to compare its performance against other companies. This can be done with *benchmarking.* The idea is to establish scores on multiple aspects and compare these with the scores of other companies. In this way, a company can identify its strengths and improvement points. This is the basic idea behind benchmarking.

2. **Learning and improvement**
   The two analyses give an overview of the market and the company itself. The combination of the two can help to identify the aspects on which the company is performing good and aspects on which it can improve itself. This identification of strengths and weaknesses is the basis of the *SWOT matrix*. In this matrix, the internal identified strengths and weaknesses are coupled to external identified opportunities and treats in the market. Eventually tuning the internal and external aspects will help a company to develop itself.

2.1.4. Defining the model input parameters

The more information is included, the more detailed the analysis will be. Although the level of detail is important, it is hard to make an objective quantitative analysis for most of the available analysis parameters mentioned in paragraph 2.1.1 and 2.1.2. A lot of the mentioned analysis parameters are based on a qualitative analysis or on subjectively assigned scores. Thereby these methods are suited to give an overview of a company, but they all rely on subjective input. The use of subjective measures has three important disadvantages (Jahedi & Mendez, 2013; Jahedi & Mendez, 2013):

1. Subjective measures have been shown to suffer from many systematic biases related to order, scale and halo-effects, physiological factors, macroeconomic fluctuations, etc.
2. Subjective measures have been shown to be uncorrelated with independent, objective measures.
3. Subjective measures are difficult to interpret and aggregate because of the ordinal scales in which they are often expressed.

The result is a loss of information and the need of expert knowledge for the interpretation of the analysis results. The informational value of correct objective data is in general higher than that of subjective data. The use of subjective data can be a helpful in addition to the objective data and it can certainly be used to provide more context. Nevertheless, to achieve a more objective comparison, a company analysis should be based on factual data. The use of factual data has four important advantages compared to the use of subjective data:

1. Less room for interpretation -> Less room for debates/arguments.
2. Data can be immediately inserted in the analysis -> faster analysis.
3. Repeating results and consequences which can logically be traced back to causes.
4. No expert knowledge needed to use the analysis.

The combination of the important internal and external analysis parameters (Table 1 and Table 2) and the availability of objective data result in a selection of the parameters. The left out external parameters are depicted in Table 3 and the expelled internal parameters are depicted in Table 4.

Table 3: Expelled external parameters.

External analysis point	Reason for expelling
Competitors	Parameter is an output for the intended performance comparison
Shareholders	Extremely difficult to couple this parameter to meaningful factual data.
Politic & legislation	Extremely difficult to couple this parameter to meaningful factual data.
Social & cultural aspects	Partly captured in the personnel and organizational parameter. Other parts are difficult to capture in a meaningful way.
Technology	The level of technology is hard to define in an objective number.

Table 4: Expelled internal parameters.

Internal analysis point	Reason for expelling
Strategy	The strategy level is above the market analysis level and thereby less meaningful in this research. Very hard to find objective data.
Mission	The mission level is above the market analysis level and thereby less meaningful in this research. Very hard to find objective data.
Objectives	Objectives are difficult to capture with objective data. There mostly qualitatively defined
Tactics	Tactics are difficult to capture in objective data. They generally are used to define guidelines for the day to day work.

After the removal of these nine parameters, six usable analysis parameters are left:

- Product
- Market (selling & purchase)
- Economy
- Process & Facilities
- Organizational structure
- Personnel & Education

The identified analysis parameters can be rearranged in four groups. The purpose of this rearrangement is to combine the analysis parameters, which are highly related to each other. For instance the personnel resources are highly related to the type of organizational structure of a company. The rearrangement of the analysis points into the four groups is further specified in Table 5. The six analysis parameters are combined in four groups.

Table 5: Rearrangement of the identified analysis parameters.

		Product	Market (selling & purchase)	Economy	Process & Facilities	Organizational structure	Personnel & Education
Product output	**1**	X					
Economy & Market	**2**		X	X			
Process & Facilities	**3**				X		
Personnel & Organization	**4**					X	X

In this way, the model input is defined and the result is four analysis parameter groups or areas of interest:

1. Product output
2. Economy & Market
3. Process & Facilities
4. Personnel & Organization

These four areas of interest will be used in the paragraphs 2.2 - 2.4 as input and output for the model structure. Finally, these areas of interest will also become the input and output of the performance model which will be defined in paragraph 2.5.

2.2. Project performance (time, cost & quality)

The defined model parameters need to be integrated in a structure to use them for a performance assessment. One method of integration is using a project management structured method. This is the first model structure in Figure 1.

The construction of a ship can be seen as a project. A project should have the following aspects (Maylor, 1.1. Basic definitions, 1996):

- Temporary (Specified start and end date)
- Unique (Each project is different)
- Multiple resources/skills involved
- Integrating (Requires interlinking of resources)
- Mission focused (Delivers a benefit)
- Social construction (combination of people and organizations)
- Change (impact on people who deliver and receive it)

The construction of ships (at Damen) meets all these requirements and thereby, it seems convenient to assess the construction of a ship based on a project performance assessment. On a shipyard, multiple ships are build. The combined performance of all the projects on a shipyard can be seen as the total performance of the shipyard in a certain period.

There are multiple methods available in literature for the assessment of a project's management and its performance. The most common method is the iron triangle perspective (Maylor, 4.2. Managing strategic choices, 1996). In this assessment, a project is rated based on the assumption that there are three important aspects for every project:

- Time
- Cost
- Quality

Based on the iron triangle, the focus of a project can only lie on two of the three aspects and compromises must be made on the aspect which is the least important for the project. The iron triangle can be seen in Figure 2.

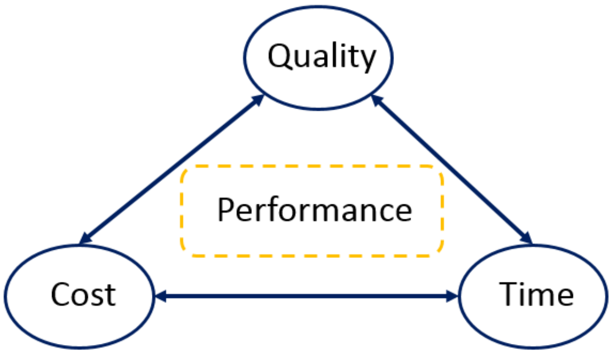


Figure 2: Iron triangle.

Quality

The first aspect in this triangle is the quality of the project (Project management institute, 2013). In general the term quality is used to define the specifications of the project and thereby some overlap is created between quality and scope. The difference between the scope and the quality is mainly made in the level of detail. The scope describes the absolute minimum demands which has to be achieved in a project. The quality also specifies the way in which these demands has to be achieved. For example, a wall should be painted. This is a demand and it is in het scope of the project. The way in which the paint is finished is part of the quality aspect. For instance the color, the roughness, the thickness of the painting layer etc. All these kinds of demands are captured in the quality aspect.

It is very hard to make an assessment of the delivered quality of ships. The assumption is made that the quality of a ship is sufficient, if a ship is delivered. Thereby the quality of a sold vessel is always in compliance with the demands of the customer and the theoretical effectiveness of a shipyard is one.

Time

The second aspect is the timespan of the project (Project management institute, 2013). Every project has a deadline which has to be met. The partition of the project in different tasks helps with the specification of the schedule. The schedule is needed to ensure that the project is finished on time. The timespan for a project is generally influenced by a pre-defined delivery date, which is defined together with a customer. To satisfy the customer this delivery date has to be met. This makes time a very important aspect.

For a shipyard, the time aspect can be captured with the production time. The duration of the construction of a ship is highly dependent on the size and the complexity of the ship and therefore, these need to be taken into account.

Cost

The last aspect is cost (Project management institute, 2013). The cost of a project can be defined in multiple ways, but usually it is based on the use of resources. Initial work breakdown structures of a project are made and these are used to define tasks. By assigning resources to these tasks it becomes possible to assign costs to the tasks, because the costs of resources are known. By adding all the costs of the tasks together it is possible to define the cost of a project.

The cost aspect can best be captured in a cost price. For the establishment of such a number the output of a shipyard and the used resources are needed.

Performance

The quality, time and costs of each task can be pre-defined. During the project the progress of each task can be monitored based on these three aspects. In this way the progress of the entire project can be monitored. The established progress can be compared with the planned progress. In this way a theoretical performance can be determined on each of the three aspects. For example, a project can be on track regarding costs and quality, but at the same time be behind schedule (time). In such a situation interference is needed and a choice has to be made to speed up the process at the sacrifice of more cost or the loss of quality. Or on the other hand a delay in delivery could be accepted. In this way, the performance of a project can be determined.

The performance of a shipyard can be assessed based on the three aspects of the iron triangle. The three aspects of the iron triangle can be captured for each ship with the four parameter groups defined in paragraph 2.1:

1. Product output
2. Economy & Market
3. Process & Facilities
4. Personnel & Organization

The four parameters groups can be found at the bottom of Figure 3. In the same figure the Quality, Cost & Time group (performance) is the result of the iron triangle.

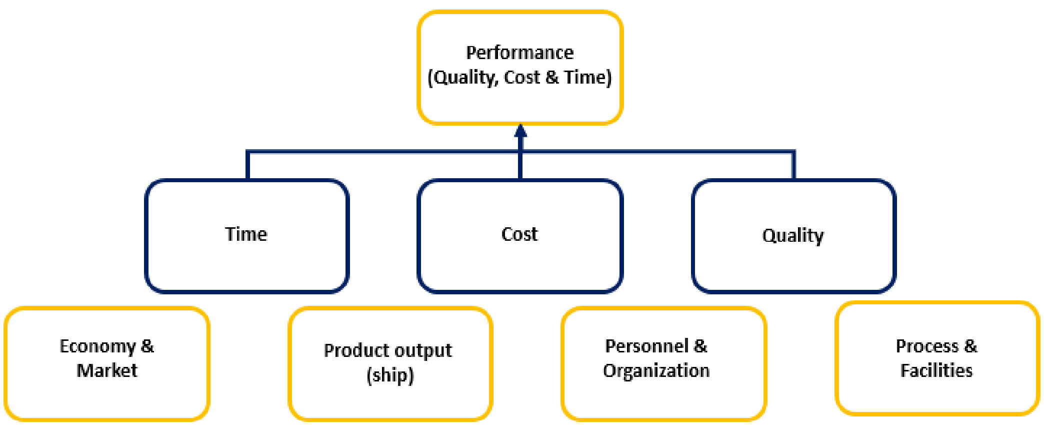


Figure 3: Iron triangle applied to the performance of a shipyard.

The quality, time and cost aspect can be combined to a performance. The iron triangle shows that the performance can be based on these three aspects. The biggest advantage of this method is that it provides a relation between these three important aspects. The accompanying disadvantage is that it can't directly be used for the performance of a shipyard, while it only captures the high over relations. The model doesn't provide detailed methods for each of the three aspects. For the actual calculation of the performance on these aspects, research into other performance methods is needed. A more detailed definition of this performance aspect will be given in paragraph 2.5 and chapter 3 in which the final performance model is specified and described.

2.3. Theoretical production performance

Another way, in which the parameters of the performance model can be structured, is by the use of production performance methods, see Figure 1. There are theoretical methods which assess the production performance. The goal of production performance is to monitor the performance over time and to identify improvement points. To say something about the performance of a shipyard, it is important to give a definition to the word performance.

In paragraph 2.3.1 the theory of production performance accordingly to (Veeke, Ottjes, & Lodewijks, 2008) is described. Thereafter, in paragraph 2.3.2, the theory is coupled to the four defined areas of interest from paragraph 2.1 and thereby coupled to a shipyard.

2.3.1. The theoretical production performance model by Veeke

The most common expressions to measure the performance of a system are: effectiveness, productivity and efficiency. These three parameters can be expressed as in equations (1), (2) and (3) respectively (Veeke, Ottjes, & Lodewijks, 2008).

$$Effectivenes_{theoretical} = \frac{R_{expected}}{R_{intended}} \tag{1}$$

$$Productivity_{theoretical} = \frac{R_{intended}}{S_{expected}} \tag{2}$$

$$Efficiency_{theoretical} = \frac{S_{actual}}{(1 - S_{standard})} = \frac{P_{actual}}{P_{standard}} \tag{3}$$

The used parameters in these equations are two types of results, three types of sacrifices/costs and two types of productivities. The used results are:

- $R_{intended}$ -> Intended results.
  This is the result which is what one wants to reach when a certain mean is used.
- $R_{expected}$ -> Theoretical expected results.
  This is the result which is theoretically expected upfront when a certain mean is used.

The types of sacrifices/costs are:

- S_{actual} -> Actual sacrifices/costs.
  This is the actual incurred sacrifice when a certain mean is used (this can thus differ from the expected sacrifice)
- $S_{expected}$ -> Theoretical expected sacrifices/costs.
  This is the sacrifice which is theoretically expected upfront when certain mean is used.
- $S_{standard}$ -> Standard sacrifices/costs.
  This is the standard expected sacrifice in a certain period. This can be seen as the sacrifice needed for the ‘normal’ production level under ‘normal predictable’ circumstances.

The types of productivities are:

- P_{actual} -> Actual productivity.
  The actual productivity which is achieved.
- $P_{standard}$ -> Standard productivity.
  This is the standard expected productivity in a certain period. This can be seen as the productivity during a 'normal' production under 'normal predictable' circumstances.

Effectiveness

The first parameter is effectiveness, see equation (1). The defined effectiveness is initially based on a mass production process. The goal, for such a process, is to reach an effectiveness of 1. In that case the expected result is similar to the intended result. In mass production, the effectiveness can be used as some sort of quality standard for the production process. The closer the effectiveness is to one, the higher the quality of the production process. Thereby effectiveness can be used as some sort of quality measure.

The effectiveness of a shipyard is a special case. Generally, a ship is built to order and a client can accept or reject the vessel. Thereby the effectiveness of a shipyard is one or zero. Usually the demands of the customer are always met. Thereby, a ship is almost always sold. Based on this fact the effectiveness of a shipyard is per definition one, assuming that the ship meets the clients demands.

Productivity

Productivity is the second parameter. It is defined by equation (2). It captures the relation between the intended result and the expected sacrifice or cost. In this equation, the used numbers are theoretically expected values. These theoretical values are mostly used on a strategic and tactical level. On an operational level (day to day basis) it is also possible to define the productivity as the ratio between the actual result and the actual sacrifice/cost. Productivity can be defined for:

- Person/workforce
- Means/assets
- Combination of people and means

Efficiency

The last parameter is the efficiency. The efficiency of a process can be defined with equation (3). The first way to reach efficiency is to take the ratio of the sacrifices/costs (S_{actual} and $S_{standard}$). A second way is to take the ratio of the productivities (P_{actual} and $P_{standard}$), see equation (3). To use the second ratio it is important to define the two productivity parameters, equation (4) and (5).

$$P_{standard} = \frac{R_{standard}}{S_{standard}} \tag{4}$$

$$P_{actual} = \frac{R_{actual}}{S_{actual}} \tag{5}$$

In these equations the results are divided by the sacrifices/costs and so these parameters can be seen as productivities. Again the ratio of the standard values is merely used on a strategic and tactical level and the actual values come from the operational level (day to day basis). If the actual and the standard productivity are compared there are two options:

1. Assume that the sacrifices/costs are the same. This means that the actual cost is the same as the upfront determined standard cost. If the actual productivity is now divided by the standard productivity the result is the actual effectiveness.
2. Assume that the results are the same. This means that the actual result is the same as the upfront determined standard result. In this case the same division will result in an efficiency. This is a ratio between the sacrifices/costs (efforts).

Performance

The three defined expressions can be used to define a theoretical performance. In this way there are three ways in which the results and the sacrifices/costs can be coupled. Different sources use different definitions, but by using the defined relations all of them can be compared. The relations can be captured, see Figure 4.

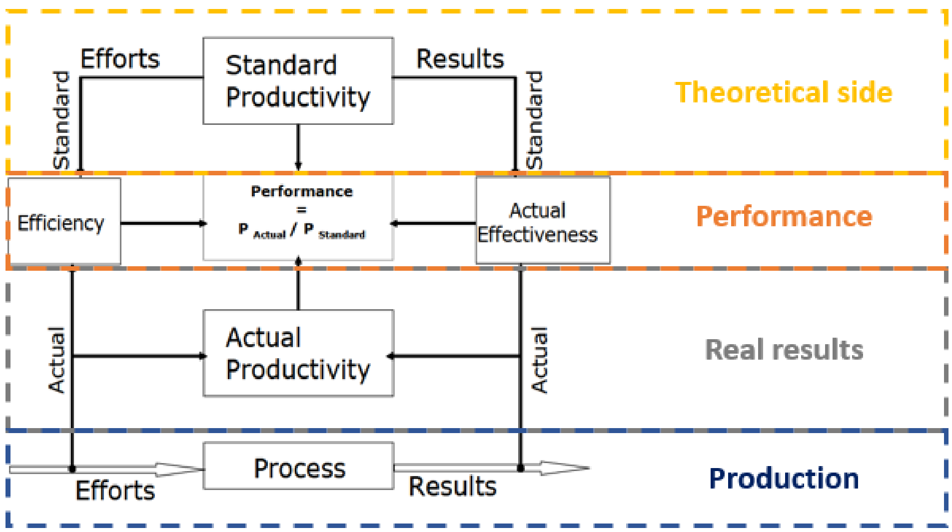


Figure 4: The coherence between the concepts of productivity, effectiveness and efficiency.

In this figure the production process is showed at the lower bottom of the figure. The upper half of the figure displays the standard productivity which is defined by theoretical set budgets (strategic and tactical level). The lower half of the figure displays the actual accomplished productivity of the company (operational level). The comparison of the actual and theoretical productivities is the theoretical performance of the company. Thereby the performance can be determined with equation (6).

$$Performance = Effectiveness_{actual} * Efficiency \quad (6)$$

2.3.2. The theoretical production performance model by Veeke applied to a shipyard

The described structure in paragraph 2.3.1. can be used to calculate the theoretical performance of a shipyard. The relation between sacrifices/costs (efforts), results and the shipyard process is graphically depicted in Figure 5. Figure 5 is based on Figure 4. In this figure the four parameter groups, which are established in paragraph 2.1, are incorporated at the bottom of the figure in the production process.

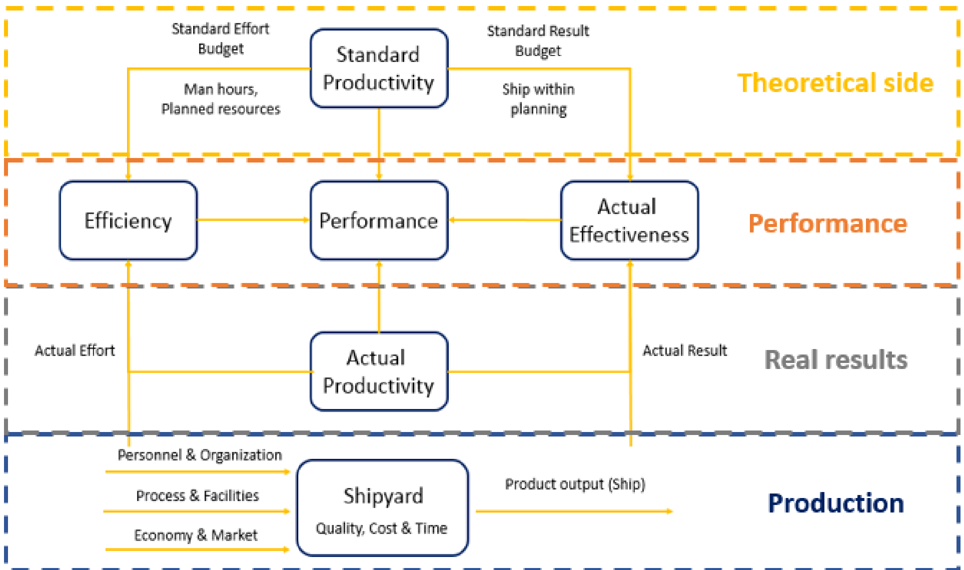


Figure 5: Theoretical performance framework for a shipyard based on H. Veeke.

This scheme can be split up in two parts, on which data is needed:

1. Theoretical side: Theoretical planned data like budgets, milestone planning etc.
2. Real results: Actual production data.

The actual effectiveness of a shipyard will per definition be one. The theoretical output should be a ship and the delivered product is a ship. As long as the customer accepts the ship, the intended result is reached.

Theoretical side

The calculation of the standard productivity is based on theoretical available data and budgets. In theory, a project planning is made for each ship. This planning is constructed from a work breakdown structure in which tasks are defined. A time span, needed resources and end result are assigned to each task. The result is a planning for the entire project, budgets for production and a desired end product. Generally, this information is not published by shipyards. Therefore, it is very hard to establish a theoretical basis for the production performance. This will be further treated in chapter 3, which goes into further detail about the available data.

Real results

For the calculation of the actual productivity, ideally data should be available regarding all the aspects of the production. In practice, this is not the case, but from published data it is possible to find information about the actual production of a shipyard. The actual production data can be divided across the defined parameter groups from paragraph 2.1.

Performance

The left side of Figure 5 compares the actual effort with the theoretical planned effort and it will give a theoretical efficiency. On the right side of this figure the actual result is compared with the intended result and this provides the theoretical effectiveness. The effectiveness of a shipyard is per definition one, see paragraph 2.3.1. The combination of efficiency and effectiveness results in a theoretical performance. Despite the fact that this model very nicely couples the performance with the effectiveness and the efficiency, there is no time factor present in this process performance method. This is a large drawback compared to the described iron triangle model in paragraph 2.2. This should be taken into account in the model definition in paragraph 2.5.

It is already made clear that it's very hard to retrieve the theoretical information about the production. Therefore, the focus will be on the actual production processes. The lack of theoretical information makes it impossible to calculate the theoretical performances. Though it is possible to compare the actual production information of one shipyard with the actual production information of another shipyard. In this way shipyards can be compared. A second possibility is to define a reference value based on an industry average or best practice. Comparing the actual production information of a shipyard to such a reference can be used to rank shipyards. An example of the new structure can be seen in Figure 6. In this figure, the theoretical side of Figure 5 is replaced by an average shipyard. This can be an industry average or a specific shipyard of interest.

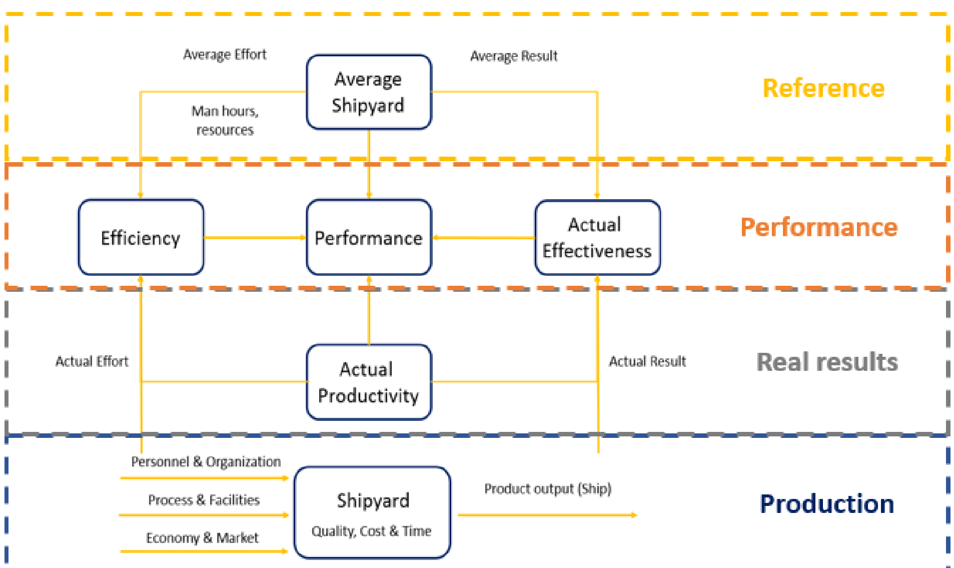


Figure 6: Theoretical performance framework for a shipyard based on H. Veeke for the comparison of shipyards.

The advantage of this method is that it gives detailed relations for the assessment of the efficiency (Cost) and effectiveness (Quality). The accompanying disadvantage is that this model doesn't includes a time parameter.

A further detailed explanation of the use of the process performance structure will be given in paragraph 2.5 and chapter 3 in which the final performance model is specified and described.

2.4. Cost price performance

The last model structure is based on the cost price of a ship, see Figure 1. Investigating the cost price of a ship, on a high level, will help identify important cost drivers. If the cost drivers are managed properly, the performance of a company can be improved. The larger the influence of a parameter on the cost price of a ship, the more important it will be to include this parameter in the performance analysis. Firstly, the cost build-up from a ship is investigated. The total cost price of a ship can be split up in three major parts, see Figure 7:

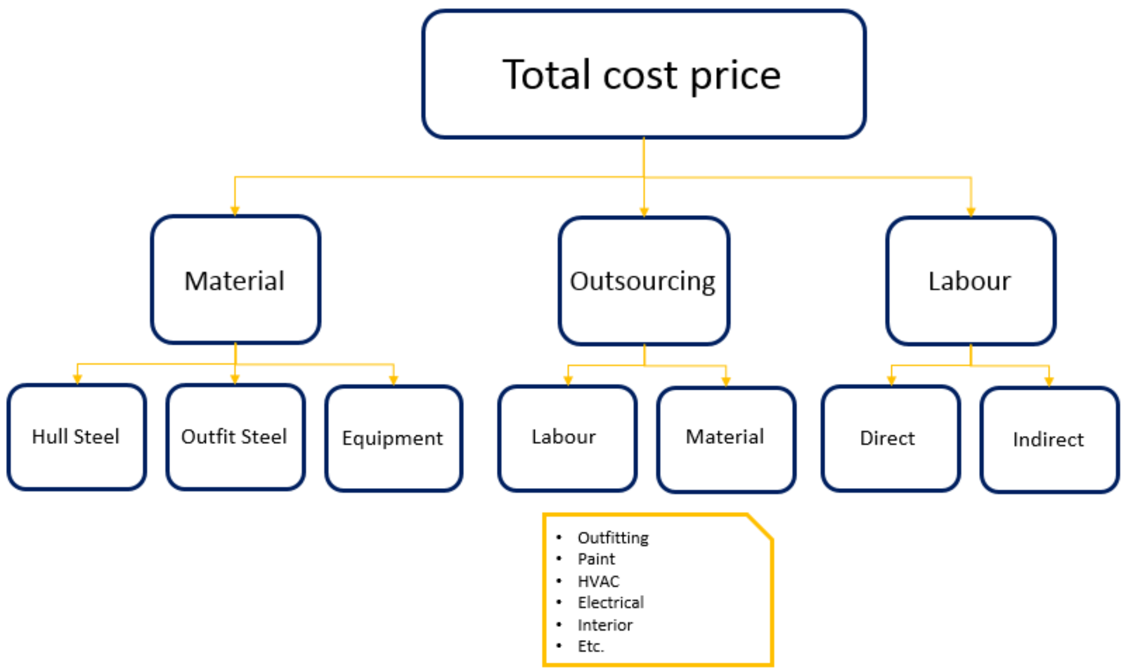


Figure 7: Cost price buildup for a ship.

According to the buildup of the cost price in Figure 7. The three major cost drivers are reviewed in paragraphs:

- 2.4.1: Material
- 2.4.2: Outsourced activities
- 2.4.3: Labour

The advantage of this method is that it gives detailed relations for the assessment of the cost parameter. The disadvantage is that it can only be used for the cost aspect of the model.

2.4.1. Material costs

The first cost driver is the price of material. Material costs differ around the world. A company can perform very well with respect to production, but it can still be outperformed by a competitor due to the differences in material costs. These material costs mainly consists of:

Equipment

A large part of the cost price of a ship is determined by the equipment, which needs to be placed aboard. This includes important aspects like:

- Engine
- Mooring gear
- Specialized equipment
  - Dredging
  - Towing
  - Research
  - Etc.
- Etc.

The amount of equipment is dependent on the type of ship and of course on the demands of the customer.

Hull steel and outfitting steel

Besides the equipment aboard, a ship is mainly build from metal. In most cases it's build from steel. A large part of the material cost is thereby based on the amount of steel, which is needed to construct the hull and for the final outfitting. This makes steel the second important source of material.

2.4.2. Cost of outsourced activities

The second important group of cost are outsourced activities. Ships are becoming more sophisticated. The systems aboard are more detailed and more expert knowledge is needed to assemble and install these systems. The result is that a lot of shipyards are outsourcing the development and installation of these systems to third parties. This kind of outsourcing is especially applicable to:

- HVAC systems
- Electrical systems
- Painting
- Interior
- Specialized equipment (radar, dredging systems etc.)
- Etc.

The extend of outsourcing differs per shipyard. Some shipyards still do the entire process themselves, others only assemble pre-fabricated parts or only build the hull. There are also differences in contract terms between the shipyards and the third parties. A system can be bought including installation, but it is also possible that the contract is based on the actual amount of hours which is used. Depending on the building strategy of a shipyard, outsourcing can be an important cost driver.

2.4.3. Labour costs

The final group of costs is determined by the labour costs. In general, the labour costs are used to cover all the expenses on a shipyard. The total cost price of labour is a combination of the productivity of the employees and the rate of the employees.

Cost of employees

The cost of the employees is determined accordingly to the integral costing principle (Heezen A. , 2012)**.** This kind of cost price calculation is based on the assumption that all the costs, constant and variable, are assigned to the product. To make this possible a 'normal production level' is determined. Using this production level, the costs are divided across the products. A simple example of this calculation can be seen in equation (7).

$$Cost\ price = \frac{C + V_n}{N} \qquad (7)$$

The total constant costs (C) and the variable cost at normal production level (V_n) are divided by the normal production level (N). This results in a cost price which is able to cover the constant and variable made costs.

In this type of cost price calculation a coverage for variable and constant costs is taken into account. This means that besides the costs of direct labour also a coverage for the following costs is obtained:

- Facilities (Shipyard ground, buildings, machines etc.)
- Indirect labour (Overhead, etc.)
- Financial costs (Cost of capital etc.)
- Etc.

This also means that the costs of labour are associated with the largest part of the shipyards costs. Besides the impact on the cost price of a ship, these costs are also the costs on which a shipyard has the most influence. These costs have a very strong relation with the production performance of the shipyard.

Productivity

The definition of productivity is already depicted in equation (2). The productivity defines the relation between the output and the resources, which are necessary to establish this output. The combination of the productivity of the resources and rate of these resources can be used to define the cost of the output. In the maritime industry it is common to define the costs per output instead of output per cost. To come to this cost definition, the definition of productivity provided by (Veeke, Ottjes, & Lodewijks, 2008) is inversed! This is an important aspect to keep in mind.

Although it is very interesting to know the cost of the output, the shipyard has more influence on the productivity than on the rate. Therefore, the productivity is a very interesting parameter which gives extra information about the cost of labour for a shipyard.

Total cost of labour

The cost of labour for a ship is thus a combination of the man hour price and the productivity. The used man hour price is not only based on the costs of direct labour, but there are also other types of cost incorporated. Therefore the relation between this integral man hour price and the defined areas of interest from paragraph 2.1 can be made. Together with the productivity this will determine the labour cost for a ship. The total labour cost of a ship are captured in Figure 8.

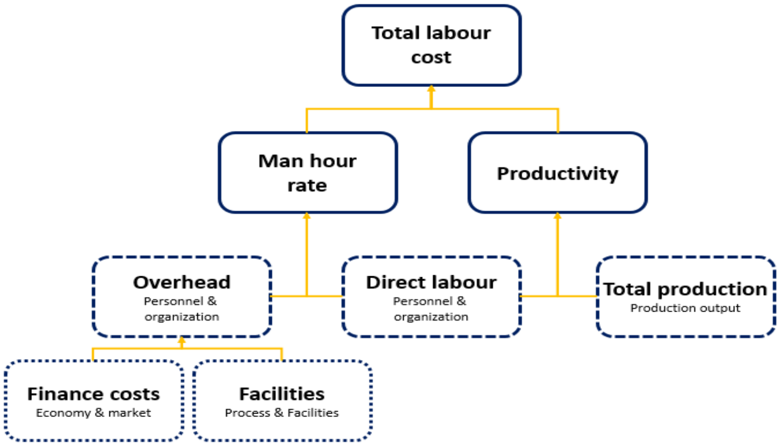


Figure 8: Total labour cost of a ship.

The conclusion is that the total cost of labour have a strong relation with the cost price and thereby with the performance. One of the important parameters behind the labour cost is productivity. A further detailed explanation of the use of labour cost will be given in paragraph 2.5 and chapter 3, in which the final performance model is specified and described.

2.5. Definition of the performance model

Each of the described performance methods, in the paragraphs 2.2 - 2.4, have strongpoints and have flaws. However, together they can be combined to deliver a performance model for a quantitative analysis. A complete assessment can be made, if the identified four areas of interest from paragraph 2.1 are included in this new performance model. The new performance model can be used for comparing shipyards with each other and the industry. This is further described in the last part of this paragraph.

Performance

The initial goal is to define an overall performance. This performance will initially be based on the theory of the iron triangle as described in paragraph 2.2. The iron triangle is favored with respect to the production performance model from paragraph 2.3, because it includes a factor for time. This is an very important parameter which can't be left out. Thereby the core of the performance model is based on the three aspects of the iron triangle:

- Cost
- Time
- Quality

The result is the performance model layout as depicted in Figure 9. The three aspects of the iron triangle will be individually described. Furthermore, the productivity is identified as an important aspect, but this is a part of the cost aspect. Therefore it is depicted with a bold letter type in a closed box in Figure 9.

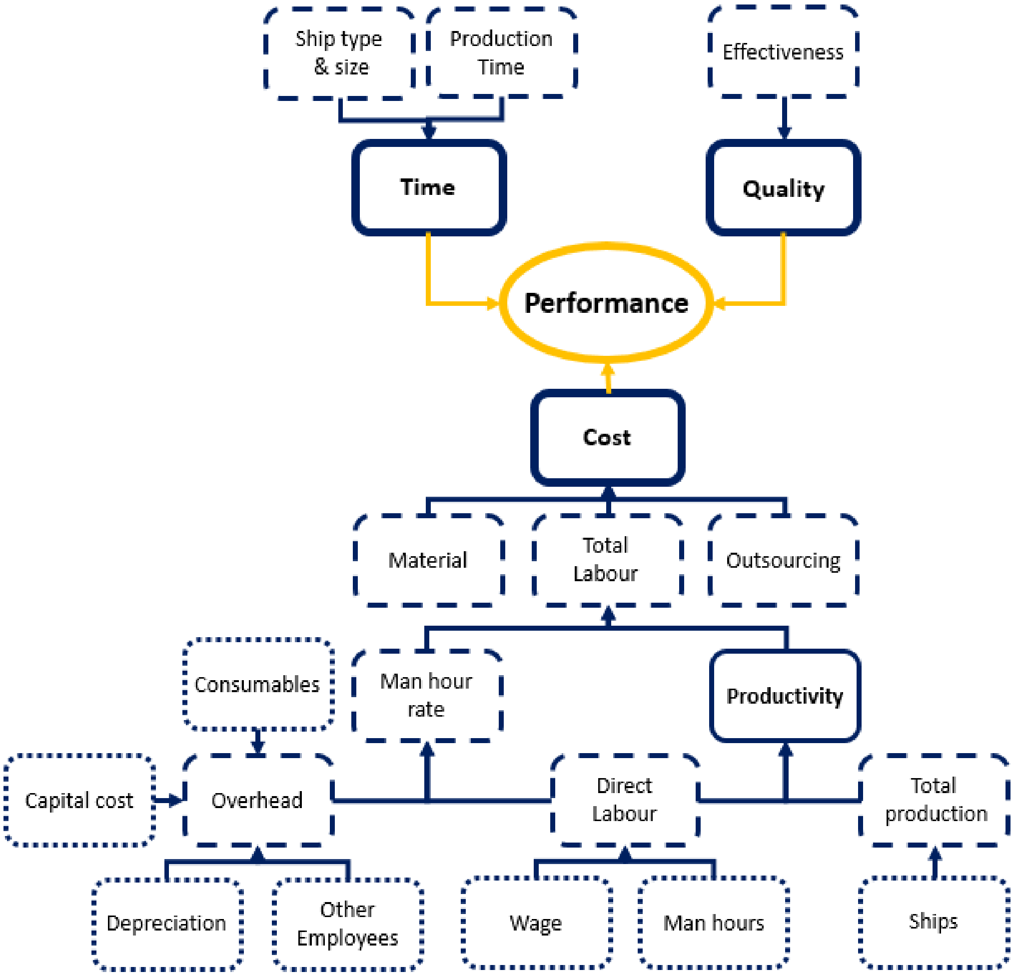


Figure 9: Performance model lay-out.

Cost

The cost assessment is based on the process performance model (paragraph 2.3) and the found relations in the cost price of a ship (paragraph 2.4). The cost needed for the production output are based on:

- Material costs
- Outsourcing costs
- Labour costs
    - Man hour rate
    - Productivity

A combination of these resources and the cost of these resources is used to determine how much money is spent during the production.

To assess a shipyard based on the calculated costs, a comparison between the costs of shipyards is made. This comparison can be defined as some sort of cost efficiency of the shipyard. In this efficiency the performance model of Veeke comes forward (paragraph 2.3).

The cost performance can be further putted in perspective by evaluating the differences in productivity between shipyards. If a difference in cost performance is found, the origin of this difference can be in the man hour rate or in the productivity. Generally, the man hour rate is very difficult to influence. A shipyard has much more influence on the productivity. Thereby, the differences in productivity give a different perspective on the performance.

Time

In the described performance methods in paragraphs 2.2 - 2.4, there isn't a really evident structure to incorporate a time factor into the performance model. Nevertheless, a time factor is included because based on the iron triangle it is an important parameter. The simplest way to incorporate a time parameter is looking at the production time.

A production time per ship is calculated. The production times can be compared between shipyards in the industry. It is important to include the size and the ship type in such a comparison, while these aspects influence the production time. The differences in production time give information about the time performance of a shipyard. The difference between the production times of shipyards can be seen as some sort of time efficiency. In this efficiency the performance model of Veeke comes forward again (paragraph 2.3).

Quality

The quality assessment is based on the effectiveness of the shipyard. The definition of the effectiveness is based on the theory of Veeke (paragraph 2.3). For a shipyard the effectiveness is assumed to be one. Nevertheless, quality is an important aspect and is therefore mentioned in the model.

Comparing shipyards performance

The cost, time and quality score can be combined to one performance score. The final result is an overall score for the shipyard. On the basis of this overall score it is possible to compare different shipyards with each other. It is also possible to rank shipyards with respect to each other and the industry. In essence the defined model in Figure 9 is filled for every shipyard. Thereafter the performance scores can be compared between shipyards as depicted in Figure 10.

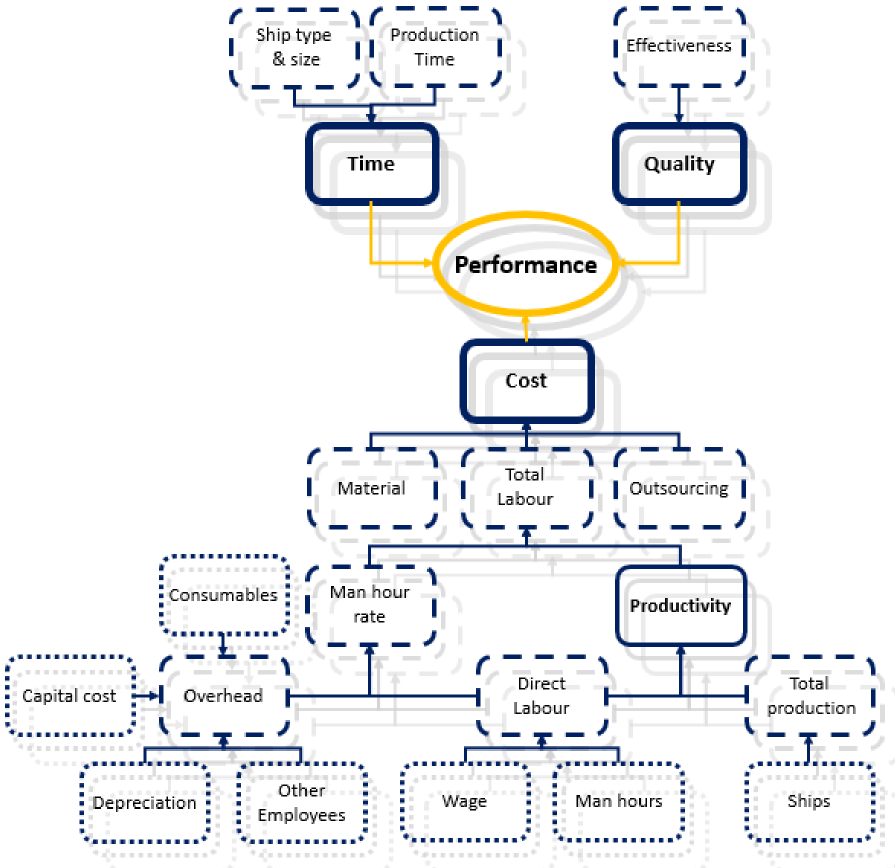


Figure 10: Comparing performance scores of shipyards.

In this figure the performance model can be seen. In the background the same model is seen in shadow. The idea is that the model can be filled for each shipyard and that the performance scores can be compared between shipyards. This gives insight in how a shipyard performs with respect to another shipyard. It is also possible to compare a shipyard with the industry. These kind of comparisons are based on the theory of Veeke (see paragraph 2.3.) and give information about the following parameters:

- Efficiencies by comparing
    - Performance
    - Time
    - Cost (Total cost, Direct labour, Overhead)
- Effectiveness can be calculated by comparing:
    - Quality (for shipyards this will initially always be one)

In this way a theoretical model is defined. The next step is to investigate which of the needed data is available and what the quality of the available data is. This is done in chapter 3. Based on the data analysis it will become possible to further define the performance calculations.

3. Performance model: data analysis

In this chapter the defined performance model from chapter 2 will be explained in more detail. The exact calculation methods for the different performance scores will be explained. For these calculations the availability and the quality of the data need to be assessed. The availability and the quality of the data will to some extend determine the way in which the performance scores are calculated.

The most important part of the data is regarding the shipyards. Therefore a number of shipyards is selected for the performance assessment. Five shipyards from Damen are selected and based on the selected shipyards from Damen, eighteen competing shipyards are selected. The available data with respect to these shipyards is the starting point for the assessment of the data, see paragraph 3.1.

The available data needs to be coupled to the defined performance model from chapter 2. This is done for each of the defined scores:

- Cost score — paragraph 3.2
    - Productivity score — paragraph 3.2
- Time score — paragraph 3.3
- Quality score — paragraph 3.4
- Overall performance — paragraph 3.5

All the performance scores are calculated as a dimensionless number. This is a relative number with respect to a reference. This reference is the 100% benchmark. The use of dimensionless performance scores enables an easy comparison. Due to the definition of the scores, a score below 100% means that a shipyard performs better than the reference. A score above 100% means that a shipyard performs worse than the reference.

3.1. Shipyard data

To make the performance assessment for the shipyards of Damen, a database is needed. In this database competing shipyards are included, which operate in the same markets as Damen. In this way the found results can be used to sketch the playing field in which Damen is participating.

To make such a database, a number of shipyards across the globe is selected. The included competing shipyards will be used to establish a reference, which is seen as the industry average. Damen yards and other arbitrary shipyards can be compared against this reference database. Initially the goal is to position the shipyards from Damen with respect to the competing shipyards. An overview of the locations of the incorporated shipyards can be seen in Figure 11.

Figure 11: Overview of all included shipyards in the analysis.

The blue points on the map represent the selected Damen yards. The basis for selection of the Damen yards is described in paragraph 3.1.1.

The orange points are the incorporated competing shipyards. Based on the selected Damen yards a selection profile is established and this profile is used to select the competing shipyards. These shipyards are described in paragraph 3.1.2.

The data for all the shipyards is retrieved from the Shipping Intelligence Network (SIN). This database is sustained by Clarksons (Clarksons Research, 2017). A validation of this data is done in paragraph 3.6.

3.1.1. Damen shipyards

The first step is to select shipyards within Damen. The focus will be on shipyards which are owned by Damen. A description of these shipyards can be found in Appendix B: Damen shipyards yard description (Huygen, 2017). From these nine shipyards, five shipyards are chosen to analyze:

- Damen Shipyards Singapore (DSSi)
- Damen Song Cam Shipyard (DSCS)
- Damen Shipyards Galati (DSGa)
- Damen Shipyards Changde (DSCh)
- Damen Yichang Shipyards (DYS)

These five shipyards are selected for the following four reasons:

1. There is recent detailed information available with respect to the shipyards.
    a. Damen Singapore (Visser, 2015)
    b. Damen Song Cam Shipyard (Damen Song Cam, 2016)
    c. Damen Galati (Damen Galati, 2016)
    d. Damen Changde (Huethorst K. , Yard Description - Damen Shipyards Changde, 2013)
    e. Damen Yichang (Damen Yichang, 2016)
2. Newbuilding is main activity on these shipyards.
3. These shipyards have a mixed product portfolio.
4. These shipyards are representative for the entire newbuilding process of the Damen group.

Recent information

The first and main advantage of these shipyards is that there is a lot of information available. This information can be used to assess the amount of available facilities and resources at the shipyard. At the same time this information can be used to validate the information, which is freely available on the internet. This can give more insight in the quality of the information sources, see paragraph 3.6.

The most detailed information within Damen traces back till 2010. Therefore the choice is made to assess the period *2010 – 2016*. In this way seven entire years can be evaluated. By using data from this period, the calculated performance scores will reflect recent achievements of the shipyards. Thereby, the evaluation of a longer period helps to compensate for economic fluctuations.

The validation of the SIN database is further described in paragraph 3.6. The sources for the information about the Damen yards can be seen in Table 6.

Table 6: Information sources regarding overall performance Damen yards.

Company	Produced vessels	Production times	Personnel numbers	Period
Damen Changde	SIN database \ Damen info	SIN database \ Damen info	SIN database \ Damen info	2010-2016
Damen Galati	SIN database \ Damen info	SIN database \ Damen info	SIN database \ Damen info	2010-2016
Damen Singapore	SIN database \ Damen info	SIN database \ Damen info	SIN database \ Damen info	2010-2016
Damen Song Cam – Bien Ken	SIN database \ Damen info	SIN database \ Damen info	SIN database \ Damen info	2010-2016
Damen Yichang	SIN database \ Damen info	SIN database \ Damen info	SIN database \ Damen info	2010-2016

Focus on newbuilding

The second reason, for the selection of Damen yards, is that this research is focused on newbuilding activities. Parts of the Damen group are focused on services and repairs. This part of the company is not analyzed and therefore these shipyards are not incorporated in the research.

Mixed product portfolio

The third point is that these shipyards build an acceptable part of the product portfolio. The shipyards aren't specialized in one ship type, but they are used to build several types of ships. This mix of ships makes these shipyards interesting to analyze.

Entire production process

The last point is that these shipyards are focused on building the entire ship on the shipyard. Some shipyards of Damen specialize in the construction of hulls or the outfitting and commissioning of already constructed hulls. The focus of this research will be on shipyards which do the entire production process themselves, like Damen Changde, Damen Galati and Damen Yichang.

The previous four points are applicable to Damen Galati, Damen Yichang and Damen Changde. Damen Song Cam Shipyard and Damen Singapore have a slightly different profile. These two shipyards are included to provide insight in the results of comparing different types of shipyards with one model. Damen Song Cam Shipyard is an outfitting and commissioning yard and Damen Singapore is specialized in smaller fast vessels. The performance of these shipyards with respect to the more traditional shipyard profile is interesting for Damen and for the usability of the model. The results can be found in chapter 4 and chapter 5.

3.1.2. Competing shipyards

Based on the selected Damen yards a choice can be made about the competing shipyards to analyze. These competing shipyards will be used to establish a database on which references can be established for comparison of shipyards. The competing shipyards are selected to match the profile of Damen Galati, Damen Changde and Damen Yichang. This choice is made for the following five reasons:

1. Enable a fair comparison with respect to product output (Level playing field).
2. Direct competitors are active in the same market.
3. Direct competitors will have a similar product portfolio and shipyard profile (otherwise they are active in other markets).
4. Differences between shipyards, which have the same profile, can help to identify learning and improvement opportunities.
5. Important influential factors on a shipyard's overall performance can be established.

For these reasons the competing shipyards are selected based on three criteria:

1. *Product portfolio*
   Shipyards should have a similar product portfolio as Damen Galati, Damen Changde and Damen Yichang.
2. *Production process*
   Shipyards should preferably produce the entire ship (or at least the larger part of it).
3. *Vessel size*
   Shipyards should build similar vessel sizes (smaller workboats, Tugs, PSV, etc.)

If a shipyard fits these three criteria it can be analyzed and used for the database. To make the database as varied as possible, the shipyards should differ on other aspects. Acceptable and interesting differences are:

- Locations in the world.
- Total output of the shipyard.
- Available facilities on the shipyard.

These differences can help to identify which variables are important in the overall performance of a shipyard. Based on these criteria eighteen shipyards are selected. These are found in the SIN (Clarksons Research, 2017). The selection can be seen in Table 7.

Table 7: Analyzed competing shipyards.

	Company	Country		Company	Country
1	**Sanmar**	Turkey	10	Keppel Singmarine	Singapore
2	**Kleven Verft**	Norway	11	Fujian Southeast	China
3	**North American SB**	United States of America	12	Nam Cheong Dockyard	Malaysia
4	**Havyard Leirvik**	Norway	13	ABG SY	India
5	**Cheoy Lee Shipyards**	United States of America	14	Wuchang SB Group	China
6	**Batamec Shipyard**	Indonesia	15	CSSC Guijiang	China
7	**Ulstein Ulsteinvik**	Norway	16	Guang Zhou Huangpu	China
8	**Jiangsu Zhenjiang**	China	17	DMHI	Romania
9	**Muhibbah Marine**	Malaysia	18	FSG	Germany

The sources of information, regarding the competing shipyards, can be seen in Table 8. The shipyard is mentioned in the first column. The second column depicts the source from which a list with delivered ships is retrieved. The source for the production times can be seen in column three. The source for the personnel numbers is shown in column four. Finally the period for which information is available is depicted in column five. The investigated period is 2010 – 2016, but for some shipyards there is no information available for the entire period. Causes for this lack of data can be: Temporarily closure of the shipyard, missing data, etc.

Table 8: Information sources regarding overall performance.

Company	Produced vessels	Production times	Personnel numbers	Period
Sanmar	SIN database	SIN database	Estimation by LinkedIn	2010, 2012-2016
Kleven Verft	SIN database	SIN database	SIN database	2010-2016
North American SB	SIN database	SIN database	Estimation by LinkedIn	2010-2016
Havyard Leirvik	SIN database	SIN database	SIN database	2010-2016
Wuchang SB Group	SIN database	SIN database	SIN database	2010-2016
Batamec Shipyard	SIN database	SIN database	SIN database	2010-2015
Ulstein Ulsteinvik	SIN database	SIN database	SIN database	2010-2016
Jiangsu Zhenjiang	SIN database	SIN database	SIN database	2010-2016
Muhibbah Marine	SIN database	SIN database	SIN database	2010-2015
Keppel Singmarine	SIN database	SIN database	Estimation by LinkedIn	2010-2016
Fujian Southeast	SIN database	SIN database	SIN database	2010-2016
Nam Cheong Dockyard	SIN database	SIN database	SIN database	2010-2014, 2016
ABG SY	SIN database	SIN database	SIN database	2010-2015
Cheoy Lee Shipyards	SIN database	SIN database	Company website	2010-2016
CSSC Guijiang	SIN database	SIN database	SIN database	2010-2015
Guang Zhou Huangpu	SIN database	SIN database	SIN database	2010-2013
DMHI	SIN database	SIN database	SIN database	2010-2016
FSG	SIN database	SIN database	SIN database	2010-2016

The most important sources are:

- SIN database
- Websites
    - Company sites
    - Social media
    - publications

The usage of the SIN database is described in detail in Appendix C: Clarksons Shipping Intelligence Network (SIN). The information in the SIN database is regarded as acceptable, see paragraph 3.6. The information from the internet sources should always be checked for:

- date (is the information recent?)
- credibility (is the information in line with expectation?)

If the information of a source doesn't meet the criteria above a good solution is to use cross reference. Instead of using one source, the information can be cross checked from multiple sources to establish a better insight in the credibility of the information.

There are three shipyards for which it wasn't possible to find exact personnel numbers. These shipyards are:

- Sanmar Ltd.
- North American SB
- Keppel Singmarine

In Table 8 it can be seen that the personnel numbers are estimated based on the company profile which is found on LinkedIn (LinkedIn, 2017). There were no other sources available to cross check this information. Therefore these shipyards are not used in the calculation of industry references in paragraph 3.2 and 3.3. The result is that the industry reference lines will be based on fifteen shipyards, instead of eighteen shipyards.

The uncertainty of the personnel numbers affects the certainty of the cost scores of these shipyards. Therefore the cost scores from these three shipyards should be used with extra caution. Although the time score is not affected, it is important to indicate these shipyards in all the results in chapter 4 and chapter 5.

3.2. Cost

The first score is the cost score. This aspect is highlighted in Figure 12.

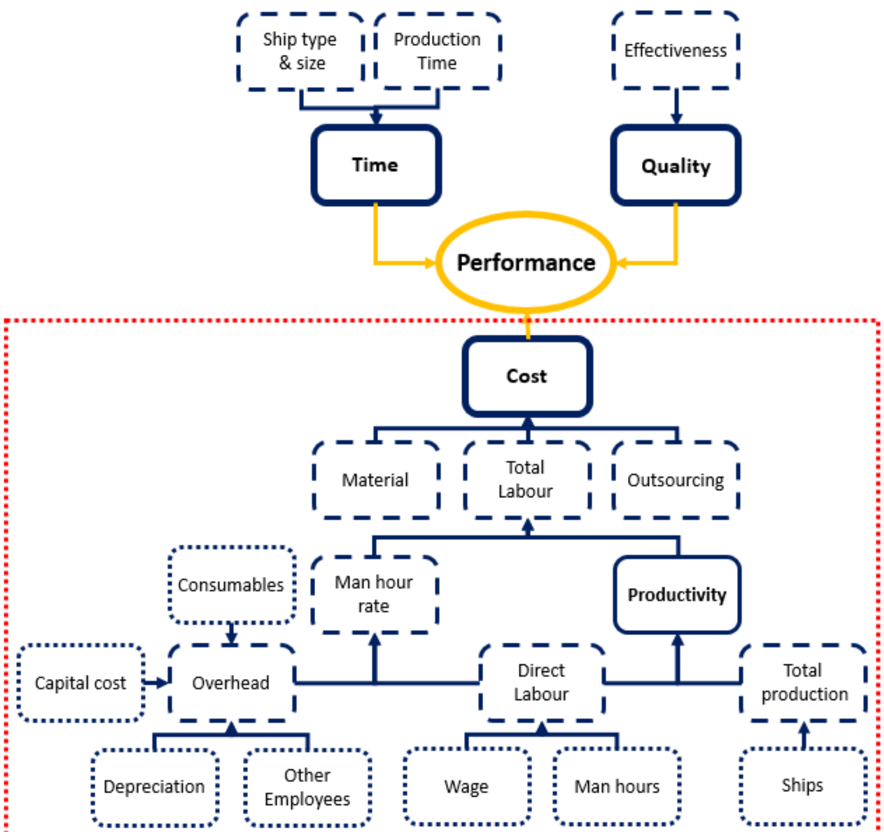


Figure 12: Cost aspect of the performance model.

The goal of the cost aspect is to establish a dimensionless cost score. The first step is to calculate a cost price, which couples the output of a shipyard to the cost of used resources. This cost price can be made dimensionless with an industry reference price. The average cost price of the industry is taken as the reference value, though an arbitrary value within the range would also have functioned. The cost score will give an indication of the cost performance with respect to the industry average.

There are three main contributors to the cost aspect:

1. *Material cost* Paragraph 3.2.1
2. *Outsourced cost* Paragraph 3.2.2
3. *Total Labour cost* paragraph 3.2.3
    - Total production
        - Ships
    - Direct labour (Blue collar, project management, etc.)
        - Man hours
        - wages
    - Overhead
        - Consumables (electricity, welding material, etc.)
        - Capital costs (pre-financing, etc.)
        - Depreciation (buildings, large equipment, etc.)
        - Other employees (General employees, white collar, etc.)

Together they form the dimensionless cost score, see paragraph 3.2.4. An important part of the cost score is determined by the productivity of a shipyard. Therefore, an extra perspective to the cost score is provided by the calculation of a productivity score. This score can be found in 3.2.5.

3.2.1. Material cost

The first cost driver is the price of material. Material costs differ around the world. A company can perform very well with respect to production, but it can still be outperformed by a competitor due to the differences in material costs. These material costs mainly consists of:

- Equipment
- Hull steel & Outfitting steel

Equipment

The prices for large equipment are mainly driven by the suppliers. This is a result of the fact that for most equipment there is a limited amount of suppliers. The prices of these suppliers are similar and therefore, the equipment prices for shipyards will be similar. There can be differences in purchase conditions for different shipyards. Large shipyards can purchase larger quantities and this may result in better purchase conditions. It is very hard to asses if a shipyard has such an advantage. Even if this information is known the exact advantage is hard to estimate. Therefore the assumption is made that, in general, all companies will have similar costs for equipment.

Hull steel and outfitting steel

The prices for hull steel and outfitting steel will mainly be driven by the world wide steel price. The development of the steel price is based on a worldwide database (The Steel Index, 2017). There are steel price indexes available for a number of continents:

- USA
- North Europe
- South Europe
- Turkey (Central Europe)
- Chinese Export
- Chinese Export to EU/USA
- Chinese Export to Asia
- Chinese Export

For all these continents there is information available for multiple products:

- Hot Rolled Coil (HRC)
- Cold Reduced Coil (CRC)
- Hot Dipped Galvanized Coil (HDG)
- Plate
- Rebar

First of all the trends are regarded per continent. These trends can be seen in Appendix D: Regional trends in steel prices From these trends it becomes clear that different products in the same region follow the same price trend.

In absolute terms the price for Cold Rolled Plate would be the best index, but most information is available for Hot Rolled Coil. The relative difference between locations is of greater importance than the absolute price level. Therefore, the HRC prices are used to make comparisons between continents.

The prices are taken in the period from 2010 to 2016. Every quarter the price of HRC is registered. With these four prices per year it is possible to calculate an average steel price per year. This price is calculated for:

- North Europe
- South Europe
- USA
- Turkey (Central Europe)

Using the same method an average steel price is calculated for China. Prices are initially calculated in RMB per ton and with the exchange rate converted to Euro per ton. The calculations can be found in Appendix E: Continental steel prices 2010-2016. The results can be seen in Table 9.

Table 9: HRC prices in euro per ton across the globe.

Continent	China	North EU	South EU	Turkey (Central EU)	USA
2010	€ 516.70	€ 497.50	€ 486.25	€ 458.75	€ 486.25
2011	€ 594.36	€ 495.00	€ 487.50	€ 468.75	€ 545.00
2012	€ 503.35	€ 460.00	€ 442.50	€ 443.75	€ 496.25
2013	€ 451.14	€ 408.75	€ 405.00	€ 402.50	€ 487.50
2014	€ 438.83	€ 380.00	€ 375.00	€ 396.25	€ 498.75
2015	€ 336.40	€ 330.00	€ 302.50	€ 313.75	€ 396.25
2016	€ 397.26	€ 425.00	€ 388.75	€ 491.25	€ 515.00

From this analysis it becomes clear that the differences in steel prices across the globe are very small. The maximum absolute difference between different parts of the world is approximately €100,-/ton. Regarding the absolute prices this results in a bandwidth of approximately 15% - 20% compared to the average world price.

In the total cost price of a ship the fluctuation of the raw steel price plays a relatively small role. In Figure 13 the relation of the raw steel price is displayed with respect to the total cost price.

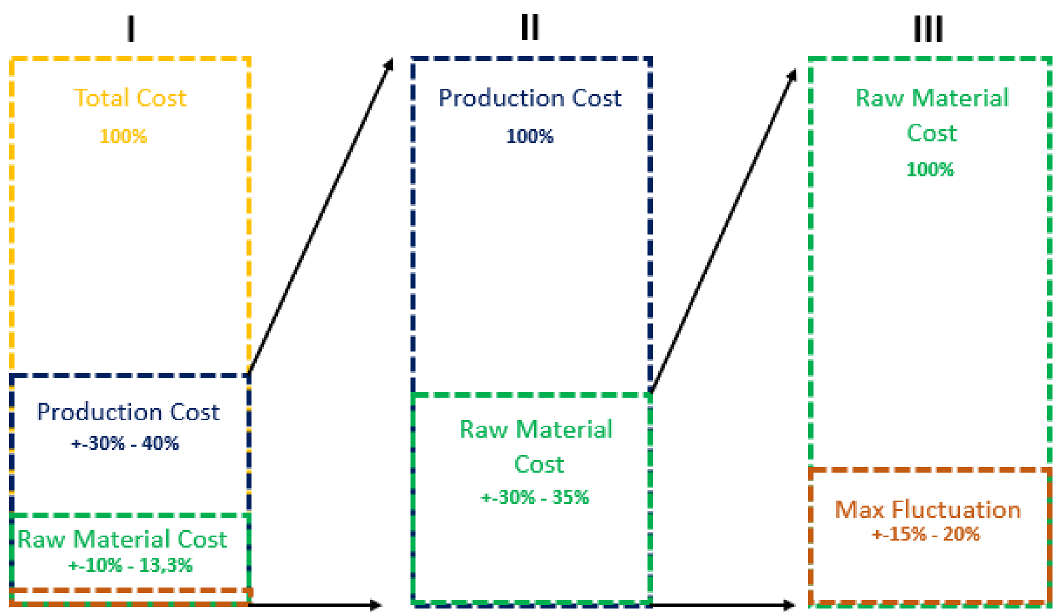


Figure 13: Fluctuation of the raw steel price of a ship with respect to the total cost price.

I. Total cost price

In the total cost price of a ship approximately 30% - 40% is determined by the actual production. This can be concluded from Damen IDK sheets, see Appendix F: The influence of material prizes in the total cost price of a ship (Man, 2017). The other part is determined by other costs like engines, equipment, etc.

II. Production cost

The production cost consist of the construction of the hull, the outfitting of the hull and placing of equipment. These cost include the purchase of raw material and the cost of processing these materials. These costs can therefore roughly be split in raw material costs and labor costs. This calculation is done for multiple ship types within the Damen product portfolio. The result is that approximately 30% - 35% of the costs on a shipyard are raw steel costs.

III. Material cost (raw steel)

The fluctuations in steel prices around the world are approximately 15% - 20%. This means that in the total cost price of a ship the fluctuations in the steel price are 2% - 2,7% of the total cost price. So the fluctuations in steel prices have a relative small influence on the total cost price of a ship, compared to other factors like labour. Therefore the choice is made not to include steel price fluctuations. A more detailed explanation of the calculations can be found in Appendix F: The influence of material prizes in the total cost price of a ship.

3.2.2. Cost of outsourced activities

The extend of outsourcing differs per shipyard. Some shipyards still do the entire production process themselves, others only assemble pre-fabricated parts or only build the hull. Despite the extremes in the industry, in general the part of the work which is outsourced will regard specialized systems for which expert knowledge is needed. Examples are:

- HVAC systems
- Electrical systems
- Painting
- Interior
- Specialized equipment (radar, dredging systems etc.)
- Etc.

So generally, this will be a small portion of the entire cost price of the ship. Especially for the selected shipyards, for which one of the selection criteria was that they perform the entire building process themselves, the amount of outsourcing will be small. Thereby, one way or another expenses have to be made to get this work done. Or the shipyard uses own resources (man hours, machine hours, etc.) or the shipyard pays a contract price for this work.

The biggest challenge lies in the fact that it is very hard to establish which part of a shipyards workforce is used for this work or what kind of contracts are made between a shipyard and the outsourcing party. There are many differences in contract terms between the shipyards and the third parties. A system can be bought including installation, but it is also possible that the contract is based on the actual amount of hours which is used. It is very difficult to deduce what these costs are and how they can be related to the output of a shipyard.

With a detailed research it might be possible to establish this kind of data for the included Damen yards, but it is very difficult to establish this data for the competing shipyards. Rough estimations could be made, but this would take a lot of effort and time and the result would be very uncertain. Due to the uncertainty in this information and the fact that the amount of outsourcing is in general only accounting for a small portion of the entire cost price, the choice is made not to include this as a research parameter.

This decision will influence the results, when an included shipyard uses outsourcing in an extreme way (for instance by buying complete hulls).

These shipyards are expected to become outliers in the results. Thereby, they will presumably stand out in the results and if this happens, extra investigation in the cause has to be executed. The results of these influences are further described in chapter 4 and chapter 5 in which the results of the performance model are described. Especially paragraph 5.2 includes interesting results with respect to this subject. in this paragraph the performance results of DSCS are described. This shipyards uses outsourcing in an extreme way, while it only outfits already made hulls.

3.2.3. Total labour cost

Due to the choice of not including the material cost and cost of outsourcing, the entire cost score will be based on the total cost of labour. Instead of looking at an absolute cost price, a cost price per output will be regarded. The use of such a price per output is more conventional in shipbuilding industry. To get to this cost price per output the following aspects will be discussed:

- Total production
- Direct labour cost
- Overhead cost

Total production

The total production needs to be captured in a number. There are multiple parameters available:

- Deadweight tonnage
- Gross tonnage
- Compensated gross tonnage
- Lightweight
- Number of ships
- Vessel type
- Revenue

Each of the parameters are reviewed from different perspectives, to see how they cope with the information. An overview of the parameters and the perspectives can be seen in Table 10. Five perspectives are used:

1. **Production output**
   Is it possible to quantify the production output in a physical way? In other words how many material is processed on a shipyard?
2. **Ship type**
   is it possible to determine which kind of ships is build based on the chosen parameter? Is the parameter able of depicting differences in ship types?
3. **Data available**
   Is the parameter readily available? Is it for example mandatory registered by class?
4. **Data approachable**
   If the parameter isn't registered, is it then possible to estimate the parameter in a sensible way?
5. **Basic parameter**
   With this the complexity of the parameter is assessed. The more straightforward the definition of the parameter, the simpler the parameter can be used and understood.

Table 10: Output parameter overview.

Parameter	Production output	Ship type	Data available	Data approachable	Basic parameter
Deadweight tonnage	X		X		X
Gross tonnage	X		X		X
Compensated gross tonnage	X	X		X	
Lightweight	X			X	X
Number of ships	X				X
Vessel type		X	X		
Revenue	X				

The advantages and disadvantages of all parameters are discussed in Appendix G: Selection of the output parameter.

The choice is made to use lightweight as the output parameter. Lightweight is the most basic parameter which can be used for the output. It gives information about the used amount of material and it can be used for a cost estimation. The steel weight can also be used to formulate the production efficiency of a shipyard. By the use of lightweight a problem rises. If simply the output is measured in tons this is beneficial for shipyards which build large simple ships. One could argue that the complexity of ships is better described in de Compensated Gross Tonnage (CGT) system, but due to the focus of this research the benefit of CGT is lost. The portfolio of the selected shipyards is focused on smaller workboats, see paragraph 3.1. These ship types are not sufficiently represented in the CGT system.

Furthermore, the lightweight isn't mandatory registered. It is however possible to estimate the lightweight, see equation (8). The only drawback is that lightweight doesn't express the exact complexity of a ship. This should be kept in mind when the cost scores are compared!

Generally, the lightweight of a ship is not available, because it is not mandatory to register the lightweight. Therefore, this parameter has to be calculated based on available information. The lightweight of a ship can be estimated with equation(8).

$$Lightweight = Displacement - Deadweight \qquad (8)$$

This estimation is based on the relation between the displacement, deadweight and lightweight of a ship. To use this method the following parameters are needed:

- Displacement
    - Length (L_{ship})
    - Beam (B_{ship})
    - Draught (D_{ship})
    - Block coefficient (C_b)
- Deadweight

Mostly the deadweight and main dimensions of a ship are available, because these are mandatory registered by class. This information can be retrieved from the shipping intelligence network (SIN) and results are depicted in Appendix C: Clarksons Shipping Intelligence Network (SIN) (Clarksons Research, 2017). The block coefficient is harder to retrieve, because this factor is not mandatory registered by class and because it gives a lot of information about the ship which builders/owners would like to keep confident.

Nevertheless, there are ways in which the block coefficient can be estimated and a common way of estimation is with the method of Watson and Gilfillan (Watson, 3.4.4. The Watson an Gilfillan Cb/Fn relationship, 1998). This method uses the Froude number to make an estimation about the block coefficient of a ship. For a large amount of ships the Froude number and the block coefficient are registered. The Froude number can thereby be used to estimate the block coefficient. The Froude number is calculated with equation (9), with V_{ship} representing the ship's design speed.

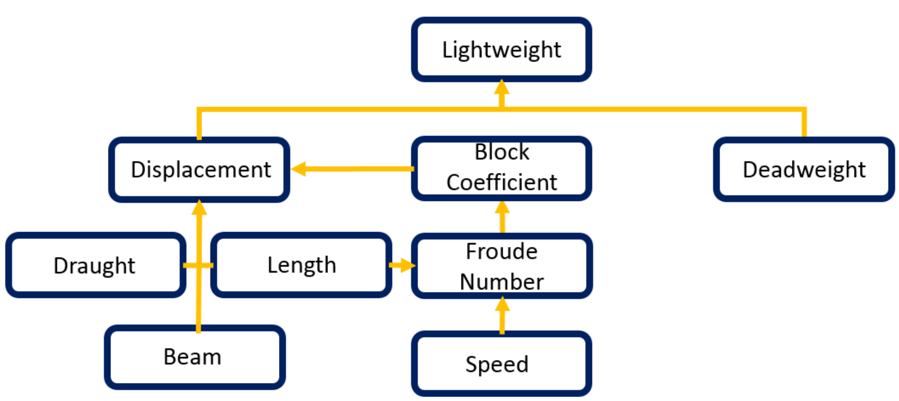
$$F_N = \frac{V_{Ship}}{\sqrt{g * L_{Ship}}} \quad (9)$$

With the Froude number, it is possible to estimate the block coefficient with equation (10). This equation describes the mean line which is fitted through the observed data by Watson and Gilfillan.

$$C_b = 0.7 + \frac{1}{8}\tan^{-1}\frac{(23 - 100F_N)}{4} \quad (10)$$

Watson and Gilfillan found that, with very few exceptions, all data fell in a band of +-0.025 from the calculated mean line. A majority of the points even came much closer. This equation is based on a fit with the database. There is no physical meaning in the use of the inverse tangent function, other than that this function has the best shape to capture the data trend. This function is valid in the Froude number range of approximately 0,1 to 0,4 due to the shape of the tangent function. Most commercially build ship types are within this range. The use of this function implies that for higher or lower Froude numbers the block coefficient won't change very much anymore. Thereby the upper limit of the Block coefficient is approximately 0,87 and the lower limit is approximately 0,5. This is a direct result of the use of the inverse tangent function. For this research the application bandwidth of the tangent function is sufficient, as for the ships build by the investigated Damen yards, the block coefficients vary from 0,55 to 0,85.

In 1991 a validity test was done by adding new data to the line and it still proved to be valid (Watson, 3.4.4. The Watson an Gilfillan Cb/Fn relationship, 1998). Therefore, this method seems suited to estimate the block coefficient. With the known block coefficient, it is possible to calculate the displacement of a



ship. The difference between the displacement and the deadweight is the lightweight of the vessel. An overview of the entire lightweight estimation is depicted in Figure 14.

Figure 14: Process of lightweight estimation.

Although the ship type is not explicitly used in the lightweight calculation, it is implicitly introduced by the use of the Froude number and the block coefficient. These parameters take the shape of the vessel into account and thereby the ship type is partly introduced in the equation.

<u>Direct labour costs</u>

The next step is to define the amount of resources which are used to establish the output. By assigning resources to the output and then assigning costs to the resources it becomes possible to assign costs to the production.

The direct labour costs are caused by employees which directly perform a job which enables the shipyard to build a ship. The work of welders, shipbuilders, etc. can directly be coupled to a ship. The cost of these resources are mainly caused by wages. A good indication of these costs can be retrieved, if the amount of man hours and the cost of these man hours is known.

<u>Amount of employees</u>

To estimate the amount of personnel on a shipyard, information from SIN (Clarksons Research, 2017) and company sources is used. In the SIN there are shipyard profiles available, which contain primary information about the shipyard. For the majority of shipyards the amount of personnel is registered. Extra information or missing information can be retrieved from company sources like the websites, yearly reports and other publications. If only the total amount of personnel can be retrieved the following partition across the employee groups will be used:

- 85% Blue collar
- 15% other employees
    - 10% White collar
    - 5% General office

This partition is based on the average partition on European shipyards. This is the result from a research conducted by the community of European shipyard associations (CESA) (Pruyn, 2017).

<u>Cost of employees</u>

The next step is to estimate the cost of the employees. There are global differences in the cost of employees due to differences in:

- Duration of the workweek
- Wage levels
- Social additional costs for employers
- Taxes
- Extra rewards (vacation money, 13th month, etc.)
- Etc.

First of all the duration of the workweek is different around the world. In Europe, employees normally work eight hours a day during five days. In China a normal workweek consists of eight hours a day during six days. This introduces significant differences. To overcome these differences the choice is made to use monthly wages. The duration of the workweek is taken into account in these monthly wages, because they are based on a standard full time job. The second argument for the use of a monthly wage, is the level on which the performance calculation is done. At this high level it is not necessary to know the exact hours. If the total amount of employees and the monthly wage is known, the cost of direct labour can be calculated.

The wage level is established based on the location of the shipyard. This wage information is in general not published by shipyards, there is however data about global differences in average wages per year. The ILO (International Labour Organization, 2017) registers this information. This database can be used to establish relative wage differences between countries and between different time periods. This relative difference can be used to scale a baseline wage. By establishing a baseline for the monthly wage and combining this with the relative differences in wage per country, a prediction of the monthly wage can be made for each country and each time period included in the ILO database.

There is a difference between the gross monthly wage of an employee and the monthly cost of an employee for the employer. These differences are due to additional costs like social insurance, taxes, extra rewards, etc. In Europe there are already large differences between the gross monthly wage and the monthly costs for the employer (Pruyn, 2017). The exact differences are hard to retrieve, but in general the monthly cost of an employee will be approximately 10% - 40% higher than the gross monthly wage. Initially there will be a constant percentage added to the baseline gross wage for the coverage of the additional employer costs. Differences in additional costs between countries won't be included in the model. By including these additional costs for the baseline, the initial assumption is made that these costs are relatively the same around the world.

The Netherlands is taken to establish a baseline wage in euro per month. This information comes from loonwijzer.nl and is based on employees having 10 years' experience (Loonwijzer.nl, 2017). The information on this site is based on the gross average wages in the Netherlands. These wages are based on a full time workweek. The average gross monthly wages per employee group can be seen in the second column of Table 11.

This wage is the gross monthly wage which is earned. For the employer there are additional costs which have to be added to this wage like:

- Payroll tax
- Public insurance (AOW, ANW, WLZ)
- Extra rewards (vacation money, 13th month, etc.)

These additions are based on the law of the Netherlands (Rijksoverheid, 2017). These costs are different for each profession based on agreements in the sector. A general rule of thumb is that if the gross wage is set at 100%, the costs for the employer will approximately be 130% (Digital Entrepreneur, 2017). This increase should in general be enough to compensate for the additional costs. The monthly cost for the employer can be seen in column three of Table 11.

Table 11: Monthly wages in the Netherlands in March 2017.

Employee group	Monthly wage in Euros	Monthly wage incl. employer charges	Used profession
Blue Collar	€ 2600,-	€ 3380,-	Shipbuilder
White Collar	€ 4000,-	€ 5200,-	Maritime Engineer
Office	€ 2600,-	€ 3380,-	Secretary

The baseline is set for the Netherlands as in 2016. This baseline can now be converted to other countries and other time periods. For this means the database from the International Labour Organization (ILO) is used (International Labour Organization, 2017). The ILO has a database in which the average wage of countries per year for the period 1995-2015 is registered. In this database the relative difference between average wages can be calculated. In this way there is accounted for differences between:

- Countries
- Time periods

In the ILO database, the average wage level of each country is depicted in its own currency. This currency is converted to euros using the exchange rate of March 2017 (XE, 2017). In the calculation this currency rate is used for the entire period 1995-2015. There is no wage information about the period after 2015 in the ILO database. The assumption is made that in 2016 the relative difference between countries will remain the same as in 2015.

Now for each country and each time period the relative difference with the average wage in the Netherlands in 2016 can be calculated. This relative difference can be used to convert the wages for the different employee groups for each country and each time period. The approach can be summarized as follows:

1. The wages for blue collar, white collar and general office in 2016 in the Netherlands are set as baseline.
2. The average wage level is established from the ILO database for countries and time periods
3. This average wage level is converted to euros based on the exchange rate from March 2017.
4. The average wage in 2016 in the Netherlands is used as the 100% level. The relative wage levels of these countries are determined against this level.
5. With this relative wage difference the absolute wage level can be calculated.

In this way the wages can be calculated for different countries in different time periods. The combination of the available personnel and the cost of these resources can be used to establish the cost of direct labour. One last remark is made for countries which aren't included in the database. For these countries similar included countries will be used to calculate the relative differences in wages. Similar countries are selected based on:

- Geographical location (Region)
- Relative income levels
    - High income
    - Middle income
    - Low income

Information about the relative income levels can be retrieved from (Worldbank, 2017).

Overhead costs

The next group of used resources can be found in the overhead. In this group all the costs of the shipyard are gathered which can't directly be related to a certain ship, but which need to be made to keep the shipyard in operation. There are four important contributors to the overhead costs:

1. Other employees
    a. White collar
    b. General office
2. Consumables
3. Capital costs
4. Depreciation

Other employees

The first group are the employees, which aren't directly involved with the production. These employees mostly provide services or jobs which enable the shipyard to produce ships. The amount of other employees can be found using the SIN (Clarksons Research, 2017) and other company sources, if necessary. By using the same assumptions as for the direct employees, it is possible to estimate the costs of these employees. This information can be found in Table 11. In combination with a yearly output in lightweight, it is possible to divide these overhead costs along the production.

Consumables

The second group of overhead costs are consumables. These are goods and services which a shipyard need, to keep all processes running. Most important consumables are:

- Electricity
- Water
- Gasses (Welding, cutting, heating etc.)
- Etc.

The amount of consumables, which is used, is dependent on the output and the size of the shipyard. For example, a large shipyard will consume more electricity than a small shipyard. In the same way will a very productive shipyard use more consumables than a shipyard with less production. In general, will the level of used consumables change proportional to the size and the production rate of the shipyard. Research shows that only a small portion of the production costs is affected by consumables (European Commission, 2014). Approximately 1% - 2,5% of the total manufacturing costs is determined by the cost of electricity and approximately 5% of the total manufacturing is determined by natural gas. The total manufacturing costs are much more influenced by labour costs (20% - 25%) and other costs like material, equipment, etc. (70% - 80%).

The prices of electricity are very fluctuating and region bounded. There are worldwide large differences. Although there are large global differences in electricity costs, the effect on the overall performance will be relatively small, due to the small share of electricity costs in the manufacturing cost (20% - 25%). Natural gas has a slightly bigger share in the manufacturing costs, but the price differences in this market are globally much smaller. Due to the small influence of these consumables on the manufacturing costs, the choice is made to not include these differences in the overall performance calculation.

Capital cost

The third group are capital costs. The largest part of these cost will be caused by pre-financing of material. This means that these costs are highly dominated by interest costs. A shipyard needs to use a part of its own capital or lend extra money to pre-finance material for the construction of the ship. In both cases there are costs of capital. If a shipyard borrows money there will be interest and if it uses its own capital it will demand a return on this capital.

An important measure for the interest rate is the LIBOR interest rate (Global rates, 2017). The LIBOR interest rate is a measure, which gives an indication about the interest rate at which banks are prepared to lend unsecured funds to one another on the London money market. This rate is seen as the most important benchmark in the world for short-term interest rates. Banks use the LIBOR rate to base their interest levels for loans on. There are LIBOR rates available for five currencies:

- American Dollar
- British Pound
- European Euro
- Japanese Yen
- Swiss Franc

Because of this world wide similar calculation of the LIBOR interest rate, there is some sort of global commitment to this rate. It is used all over the world to establish interest rates and it is globally accepted. Thereby, the differences in interest on the global market are very small. Shipyards face approximately the same capital costs and it is very hard or even impossible to outperform the competition on this level. For this reason these costs are not included in the model.

Depreciation cost

The last group is concerned with depreciation costs. These costs are the result of the ownership of expensive property and assets like facilities, buildings, large machinery etc. Every year these will lose a part of their value and this loss of value is captured in the depreciation. For example, a new building facility costs 1 million euro's and it is expected to be used for 50 years. Depending on the tax rules, a shipyard can depreciate the building. If the assumption is made that the loss of value is constant, than the depreciation will be 20.000,- euro per year. These kinds of calculations can be made for every expensive property and asset. The problem is that it is very hard to establish, if it is allowed to depreciate. The next uncertainty is that there are many different rules and methods for the application of depreciation.

Although the initial investment in these properties and assets might seem large, the lifetime is generally also very long. (see example above). Thereby, the yearly depreciation costs are relatively small compared to other costs like the pre-financing of material, the costs of employees, etc. In this respect, the burden of the depreciation is relatively small. Furthermore, it is very hard to make a good estimation about the value of properties and assets. Even if it is possible to make an estimation of the total value, it is still difficult to estimate how long the properties and assets will last and what the exact depreciation will be. The final conclusion is that it is more convenient to leave these costs out of the comparison.

The conclusion is that differences in overhead costs are limited and generally small. For some overhead costs there are distinctive differences, but the effect on the total performance is relatively small. In all cases it takes a lot of effort to establish the differences on a scientific basis. The choice is made to only include differences in indirect labour costs, because these differences are relatively large and they are important in the overall performance of a shipyard. The importance of labour costs is already established in paragraph 2.4. The other overhead costs are left out, because of the small influence on the cost performance and the high amount of effort which is needed to retrieve them.

3.2.4. Cost score

The combination of the total production, the use of personnel and the costs of this personnel gives a euro per lightweight ton cost. This cost is calculated per shipyard per year. To make this cost price dimensionless, it is divided by a reference cost price. The reference cost price is based on the average cost price in the industry. The final cost score can be calculated with equation (11).

$$Cost\ score[-] = \frac{Actual\ cost\ price\ [\frac{€}{Lightweight\ ton}]}{Industry\ average\ cost\ price\ [\frac{€}{Lightweight\ ton}]} \tag{11}$$

The result is a score ranging from zero to a maximum value, which is caused by the shipyard with the highest cost price score. The cost scores are calculated per shipyard per year. This score can be used for the overall performance calculation of a shipyard in a certain year.

3.2.5. Productivity score

Based on the calculated cost score, it is possible to compare shipyards with each other. However, it is very hard to interpret the differences between shipyards. This originates from the fact that the calculated cost score is only based on labour costs. The other influences on the cost score are assumed to be equal for every shipyard and are therefore left out of the comparison. Even if these influences are perfectly equal, the differences in the now calculated cost score don't show the entire picture. An example of the cost score differences between two shipyards, which could come out of the performance model, is shown in Figure 15.

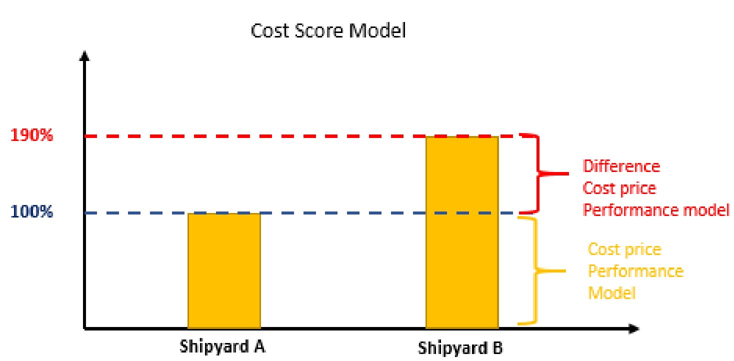


Figure 15: Differences depicted by the cost score in the performance model.

This difference is only based on the input which is used in the performance model. This means that this picture only shows the labour part of the shipyards. In this example the difference in the cost score between *shipyard A* and *shipyard B* is 90%. This implies that *Shipyard A* is 90% more cost efficient than *shipyard B*, but this is not true. In fact it only says something about the difference with respect to the involved employee costs.

The entire picture including for example the material costs is depicted in Figure 16.

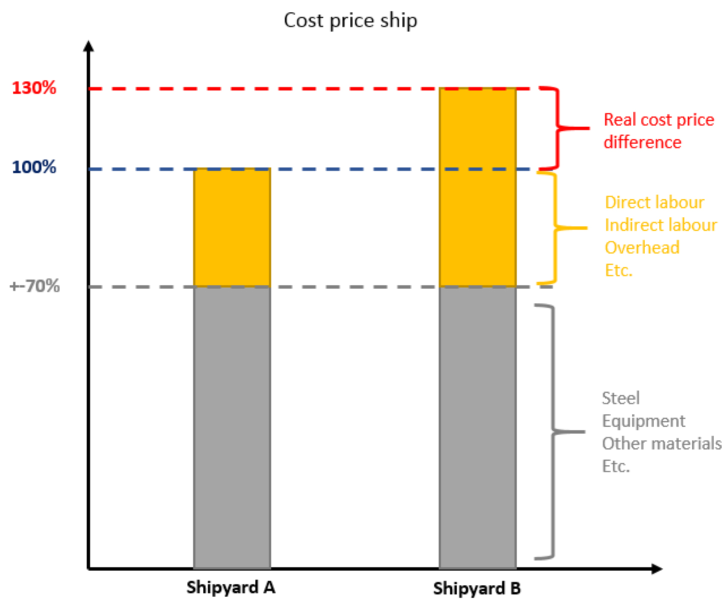


Figure 16: Cost price differences in the real situation.

In this figure also the costs of steel, equipment and other materials is shown. Immediately it becomes clear that the differences shown in Figure 15 seem a lot larger than the actual differences which are shown in Figure 16.

The initial difference of 90% depicted in Figure 15, is in the total picture of Figure 16 only a difference of 30%. For example, 70% of the cost price of a certain ship type is determined by material cost and the other 30% is determined by labour cost. This means that the initial found difference in cost score of 90%, displayed in Figure 15, is in the total picture only a difference in labour part (orange). In the total picture (orange and grey) it becomes approximately three times smaller, see Figure 16.

This example shows that it is possible to assess differences between shipyards based on the cost scores, but that these scores don't depict the entire picture. Therefore, these cost scores can't immediately be used to say something about the exact size of the performance of a shipyard.

It would be very interesting to have a performance number which depicts the entire picture. Therefore, a productivity score is calculated to give more context about the found cost scores. In this way it becomes possible to say something about the productivity of a shipyard compared to the industry. These productivity scores would make it possible to quantify the size of improvement, which is possible at a shipyard. The productivity scores are highly related to the cost scores and therefore they are based on the cost scores. The cost score is build up from the output of the shipyard, the amount of employees and the cost of these employees. Together they form the cost score as explained in paragraph 3.2.4. In essence this cost score could be summarized by equation (12)

$$Cost\ Score = Productivity^{-1} * Employee\ cost \qquad (12)$$

In this equation the three numbers are dimensionless numbers. The defined cost score from paragraph 3.2.4 is a dimensionless number. The relative difference between employee cost for different locations can also be expressed as a dimensionless number, see paragraph 3.2.3. Thereby, it is possible to define the productivity as a dimensionless number. The dimensionless productivity can be calculated with equation (13).

$$Productivity^{-1}\,[-] = \frac{Cost\ Score\,[-]}{Employee\ Cost\,[-]} \tag{13}$$

Actually the defined productivity number is the inverse of the productivity, as defined in paragraph 2.3! This is the result of the fact that in shipbuilding it is common to define cost per output instead of output per cost. An accompanying advantage is that, due to this definition all the performance scores have the same kind of relation with the performance. A better performance will result in a lower relative score (below 100%) and a worse performance will result in a higher relative score (above 100%).

To get a useable productivity number seven steps have to be taken:

1. *Establish the basis*

The calculated cost scores from paragraph 3.2.4 are taken as the basis for the productivity number.

2. *Set a baseline (100%)*

A shipyard of interest is chosen as reference shipyard. The used cost scores are scaled. The chosen reference shipyard is set as baseline (100%), before the dimensionless productivity number is calculated. In this way it is possible to calculate the productivity of shipyard with respect to a specific shipyard of interest. This makes it easy to determine the productivity differences between specific shipyards. For instance between a Damen yard and its direct competitors.

3. *Relative wage differences.*

The defined wage differences from paragraph 3.2.3 are taken as the basis. These wage differences initially have the Netherlands as baseline (100%). The relative wage differences need to be scaled to the right country, which corresponds to the chosen reference shipyard. The relative wage differences and the cost scores need to be based on the same reference shipyard. If for example Damen Shipyards Galati is taken as the reference shipyard, the relative wage differences should use Romania as baseline.

4. *Calculate productivity number.*

If these scaling calculations are done, the productivity numbers with respect to the chosen reference shipyard can be calculated. The calculated productivity differences don't depict the real productivity differences, because they are only based on differences in labour as explained in Figure 15.

5. *Put the productivity number into perspective.*

To get to the real productivity numbers, the relative difference between material cost and labour cost for a ship is needed. This relative difference is largely determined by the ship size and ship type. A big tanker will have a different material vs labour cost division than a small tug. Therefore, it is important to know the content of the product portfolio of a shipyard. Based on this portfolio, a general division between material cost and labour cost can be made for a shipyard. This division can be used to put the calculated productivity numbers, from step 4, in total perspective (Figure 16).

The content of the product portfolios per shipyard can be found in Appendix H: Product portfolio shipyards. The division in material vs labour cost for certain ship types can be found in Appendix I: Cost division ship types. The resulting eight categories, in which the portfolio is divided, can be seen in Figure 17. The dots in this figure are the representative Damen vessels for each category. These are also depicted underneath the figure per ship category.

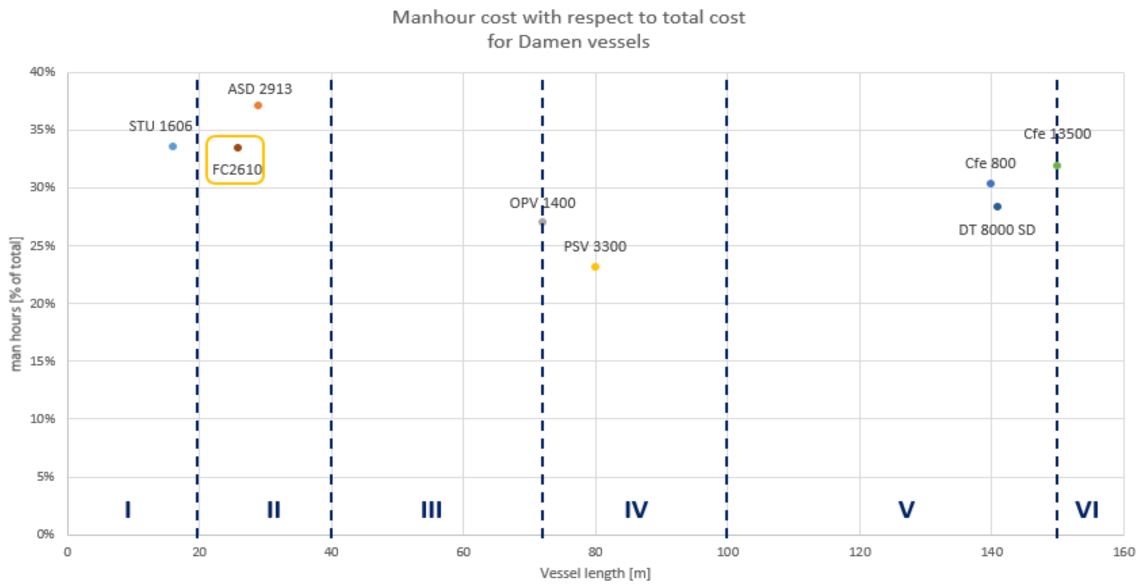


Figure 17: Division in ship categories.

Normal speed ships

I.	Tugs 0 – 20 m.	STU 1606
II.	Tugs 20 – 40 m.	ASD 2913
III.	Vessels 40 – 70 m.	OPV 1400
IV.	Vessels 70 – 100 m.	PSV 3300
V.	Vessels 100 – 150 m.	CFe 800 and DT 8000 SD
VI.	Vessels >150 m.	CFe 13500

Fast ships

VII.	Vessels 0 – 40 m.	FC 2610

Pontoons

VIII.	Pontoons all sizes	CFe 800, DT 8000 SD and CFe 13500

The choice is made to work with categories, because there is too less information for the establishment of a statically correct trend line. Furthermore, due to the selection of the shipyards in paragraph 3.1, the product portfolio of the shipyards can be captured with these eight categories. With this selection it proved to be possible to define the portfolio of all shipyards.

6. *Compare productivity and identify improvement possibilities.*

The resulting dimensionless productivity numbers can be used to assess the differences between the chosen reference shipyard and the other shipyards in the database. Based on these differences an estimation can be made about the improvement possibilities of a shipyard.

7. *Repeat for each shipyard of interest.*

After determining the differences for the reference shipyard, it is possible to scale the results to another reference shipyard. In other words set a new baseline. In this way it is possible to assess the improvement possibilities of multiple shipyards, for instance the shipyards of Damen.

The results for the Damen yards of these productivity calculations can be found in chapter 5.

3.3. Time

The second aspect of the overall performance model is time, see Figure 18. In this aspect, the influence of the production time of a shipyard is taken into account. The time score is the result of comparing the production time of a shipyard for a certain ship to the minimum production time for that ship in the industry. This minimum production time is established by looking at the achieved production times in the industry. If the shipyard is faster than the industries minimum, the time score will be better (<100%). In the same way will a slower production time result in a worse time score (>100%).

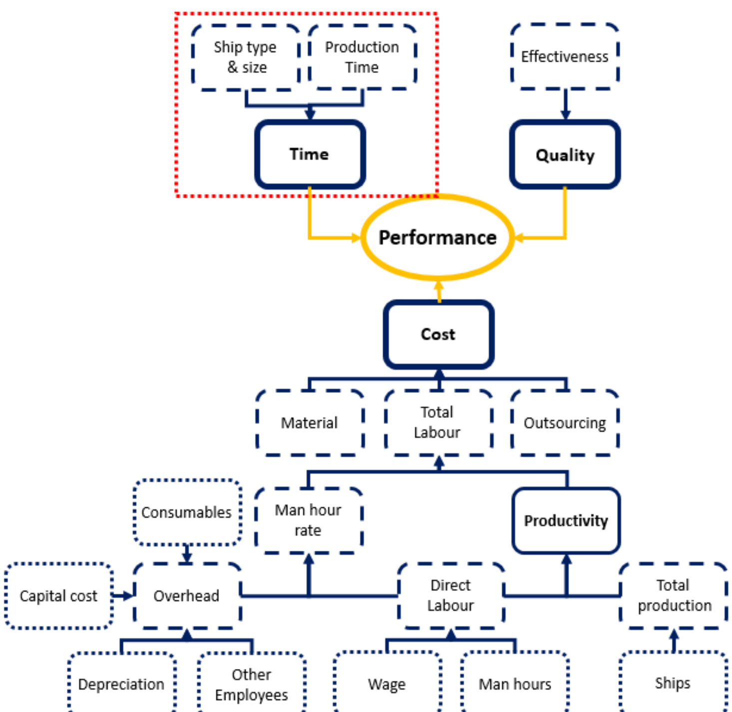


Figure 18: Time aspect of the performance model.

3.3.1. Production time based on delivery date & contract date

For the time score there is data needed with respect to the deliveries of ships per shipyard. The data for these calculations comes from the SIN from (Clarksons Research, 2017). In this database it is possible to retrieve the contract and delivery dates of ships per shipbuilder. The difference between the contract date and the delivery date is defined as the production time. In this way it is possible to calculate a production time for each ship that is delivered by a shipyard.

This production time should be used with caution. In general the contract date and the start of production will be closely after each other. Nevertheless, it is possible that the start of production is delayed or that due to a full order book the start of production is much later than the contract date. Thereby this calculation of the production time can overestimate the actual production time of a ship. The effect of these outliers and how to deal with this problem will be further specified in paragraph 3.3.3. On the contrary one could argue that a customer is only interested in the total delivery time between contract signing and the actual delivery and that a delay in start of production is a sign of bad performance.

3.3.2. Theoretical production time

Of course there is a difference between the production time of a small tugboat and the production time of a large containership. Differences in production time are a measure for the performance of a shipyard, but they are also highly dependent on the ship type and the ship size. A larger ship will have a larger production time than a smaller ship of a similar type on a shipyard with a similar performance. In the same way will a simple ship, like a container ship, have a shorter production time than a similar sized dredger. The dredger is equipped with much more sophisticated systems and thereby the production will take longer.

To be able to asses a shipyard based on a time parameter a reference is established. The production time of an arbitrary shipyard can be benchmarked against this reference and thereby the time performance of the shipyard can be captured.

This reference is based on the production times, which are realized in the industry. Theoretically the production time of a ship is influenced by two main constraints:

1. *The maximum lightweight production*
   A shipyard has a limited amount of resources and thereby it is only able to produce a certain amount of lightweight per day. Depending on this capacity and with the assumption that all resources can be fully used at all times this will give a straight line (see red line in Figure 19)
2. *Equipment per ton lightweight fraction.*
   The second important parameter is the equipment per lightweight fraction. If there is more equipment per ton of lightweight, the production time of a lightweight ton will increase. There is more time needed to complete the outfitting and installation per ton of lightweight (yellow line in Figure 19)

The result of these two theoretical constraints can be seen in Figure 19. The resulting line is the depicted blue line. The three lines aren’t based on real data, so the scale is not correct. This is done to highlight the trend in these lines. Beforehand the expectation is that the delivery times of the ships will follow the trend of the blue curve. At the end of paragraph 3.3.3 this theoretical trend will be coupled to the found data.

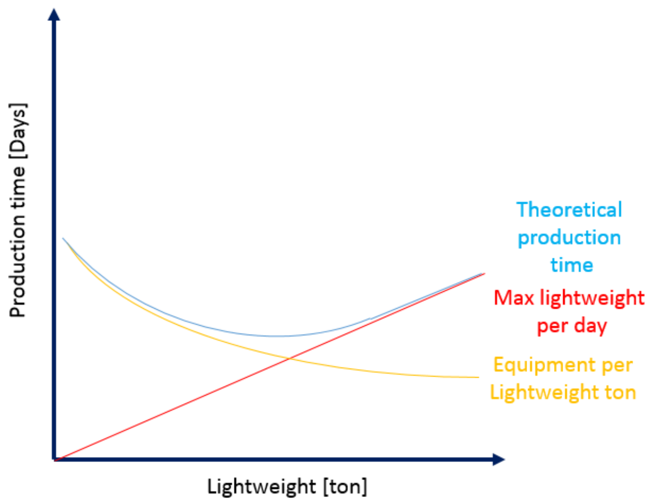


Figure 19: Theoretical dependency of lightweight and production time.

3.3.3. Production times in the industry

The production time and the lightweight of each ship, which is delivered by the included shipyards, is registered. The result is a database of approximately 750 ships, including all kinds of ship types built at different shipyards. The included shipyards in the database can be found in paragraph 3.1. From all these ships the lightweight and the production time is plotted in a graph and this graph can be seen in Figure 20. In this graph the colors denote the ship size categories.

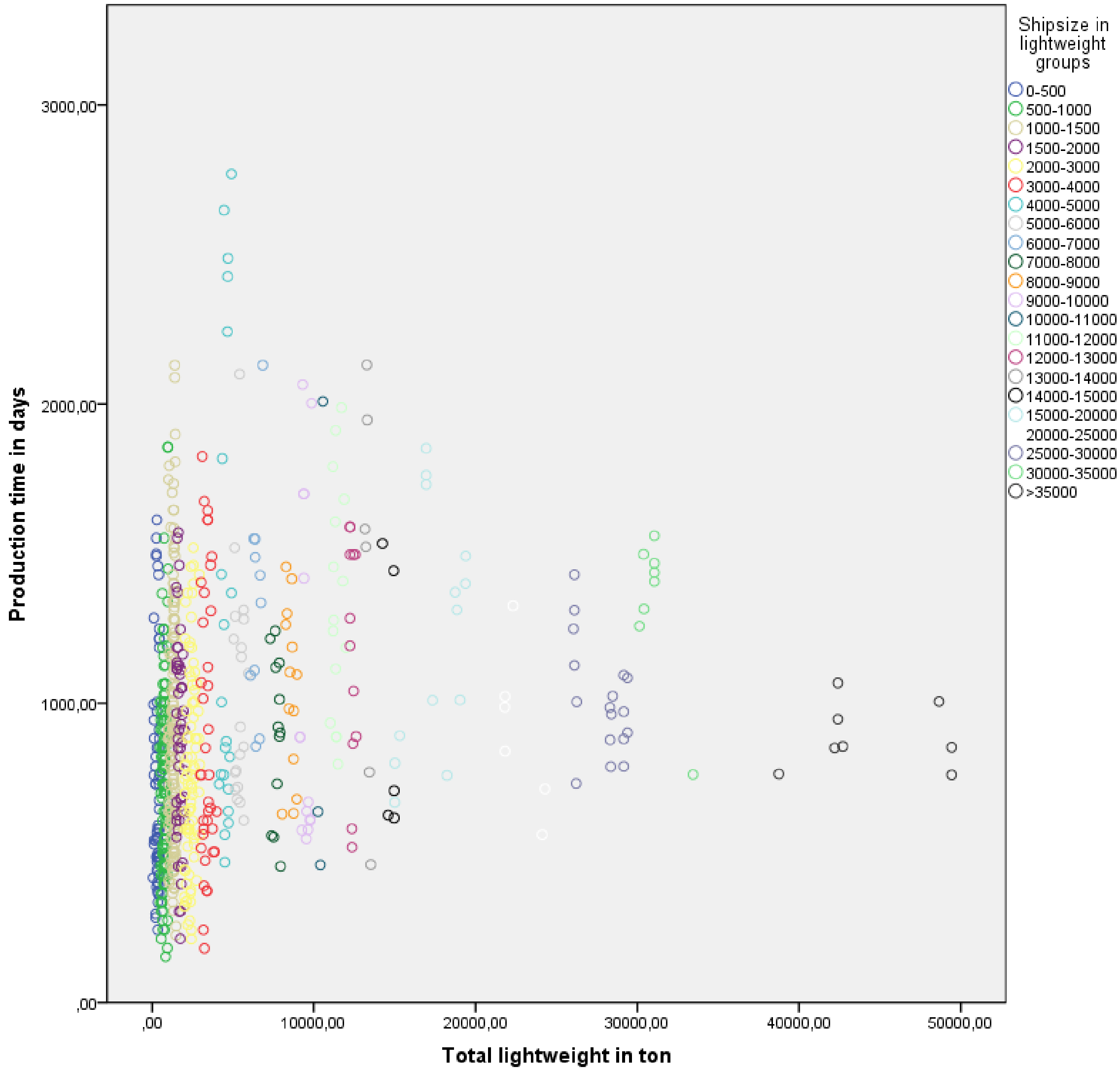


Figure 20: Production time versus the lightweight with respect to the ship size categories.

The spread in the graph is independent of the ship size. All sizes of ships have a spread in the results. It is also visible that the largest part of the ships in the database are smaller than approximately 7000 ton. In the same way a plot can be made for the dependency of the production time and the ship size regarding different ship types. This can be seen in Figure 21.

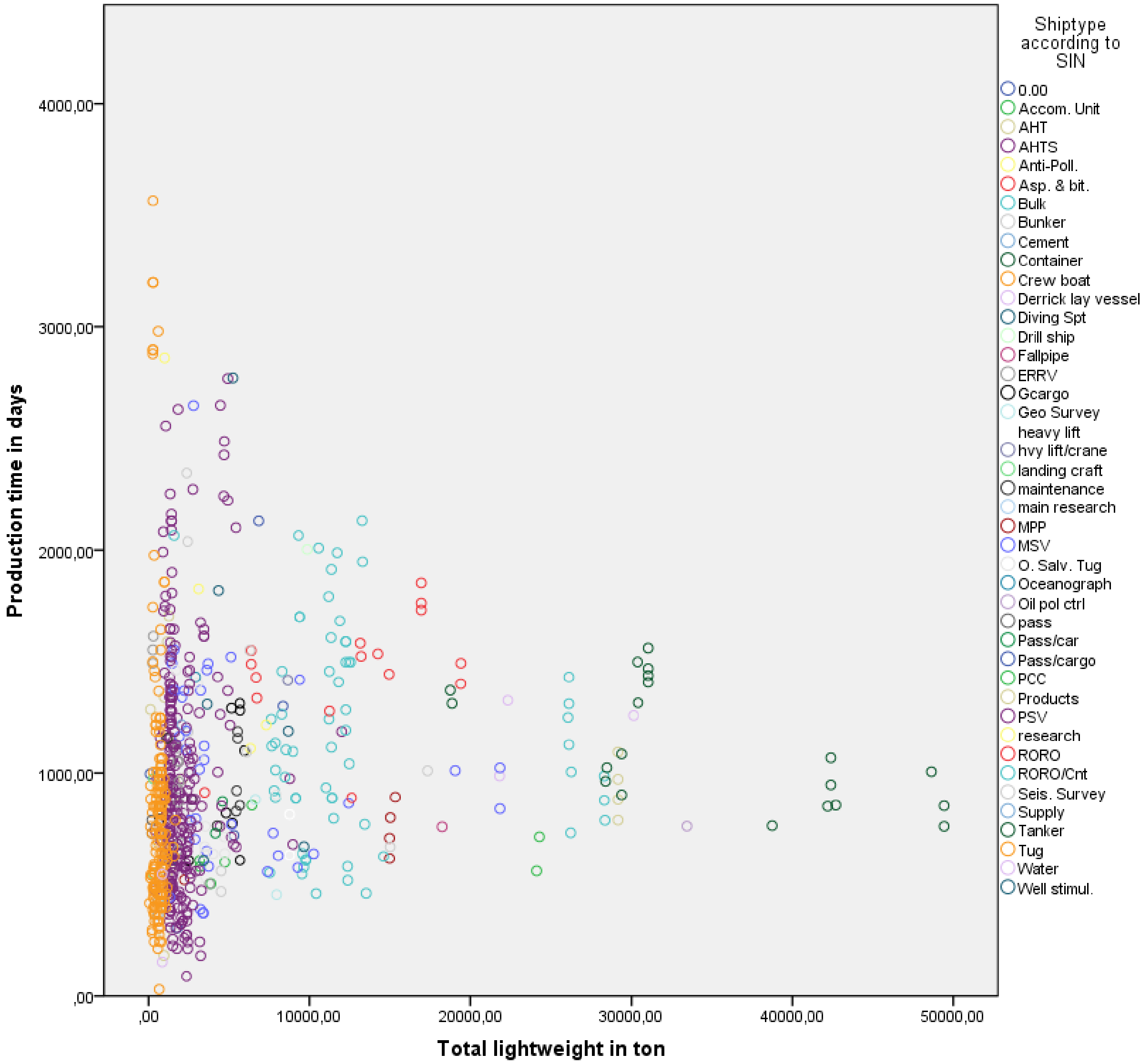


Figure 21: Production time versus lightweight with respect to the ship types.

Again a large spread in the results is observed. From this spread the conclusion is drawn that there is no clear dependency between the production time and the ship type.

Finally the dependency of the production time and the ship size is investigated regarding different shipyards. This graph can be seen in Figure 22.

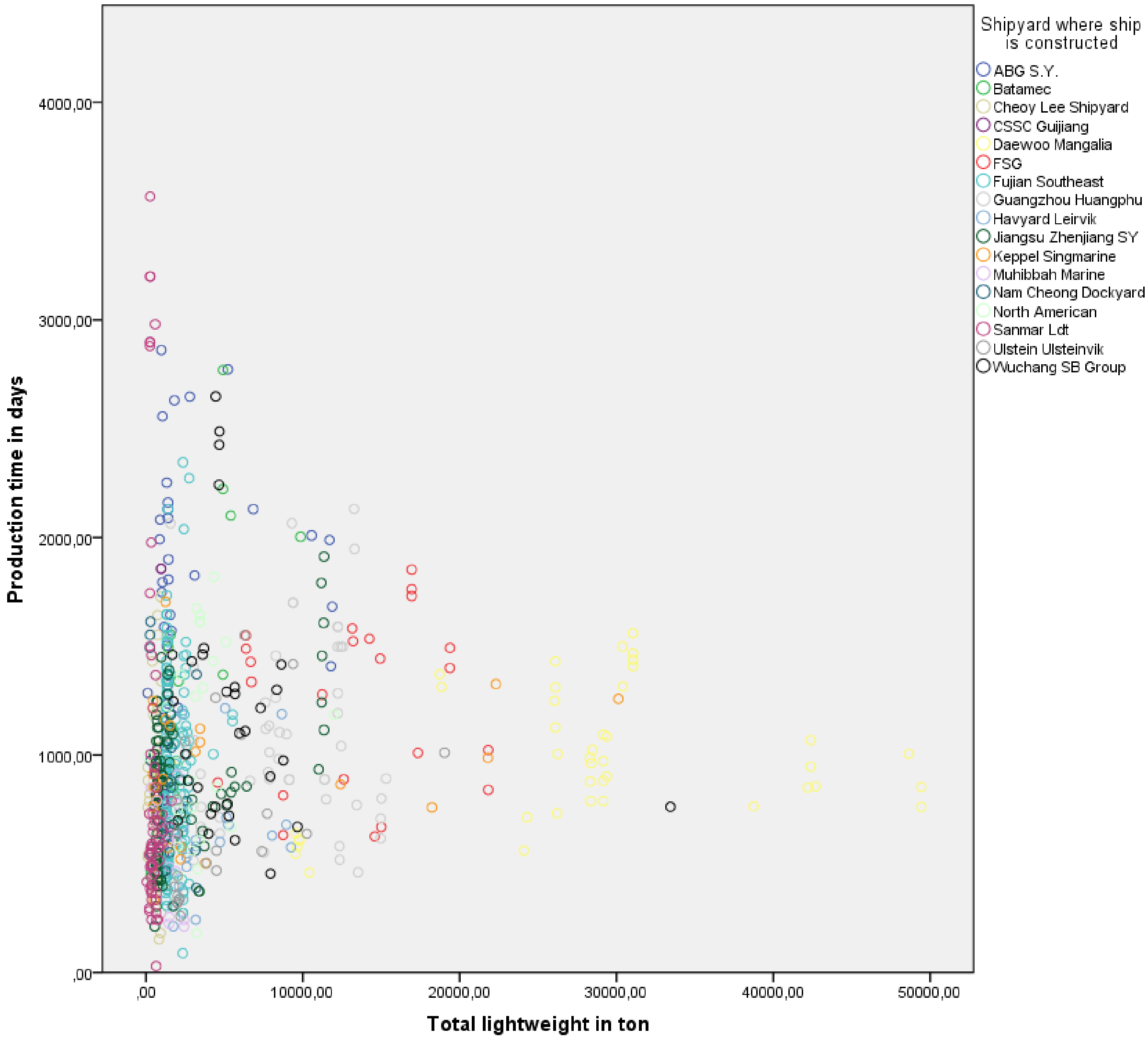


Figure 22: Production time in days per shipyard.

There is a large spread in the results between shipyards for the smaller ship types. There are a lot of ships included in this part of the graph. This is the result of the chosen shipyards, see paragraph 3.1. There are less ships in the larger ship type categories, because of the made selection of shipyards. The available larger ships are mainly built by Daewoo Mangalia. This should be taken into account during the assessment.

The lack of clear dependencies with the ship type and the shipyard result in the choice to use the ship size as predictor for the production time. The production time will be coupled to the ship size and the entire database will be used to establish a baseline. The amount of ships in each ship size category is depicted in the histogram in Figure 23.

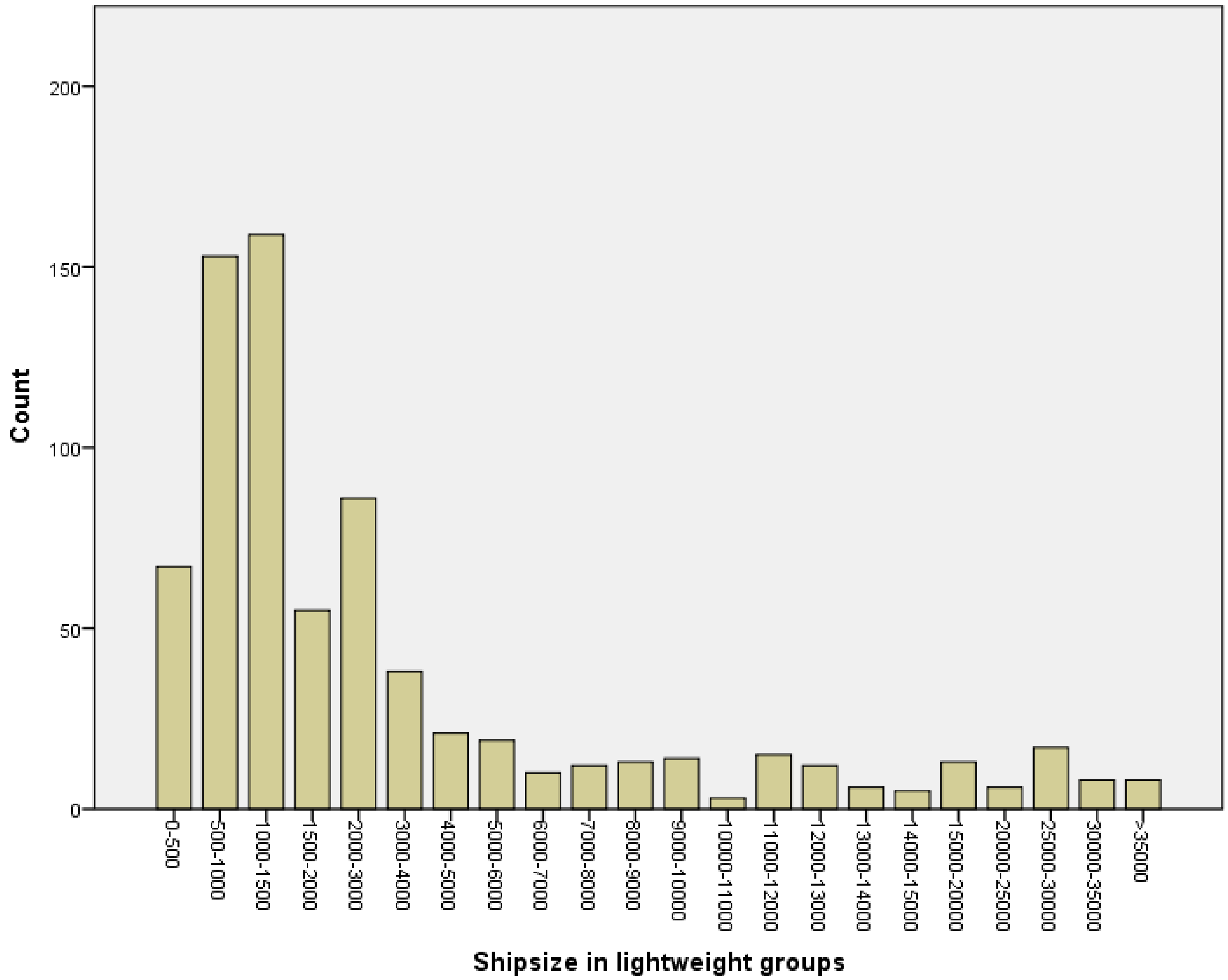


Figure 23: Amount of ships in each ship size category.

Most of the ships are in the smaller size categories. This is expected because the included shipyards are selected based on the builder profile of DSGa, DSCh and DYS. These shipyard mainly builds smaller sized ships (see paragraph 3.1). The observed spread in the production time results can be made more specific with a boxplot per ship size category. This can be seen in Figure 24.

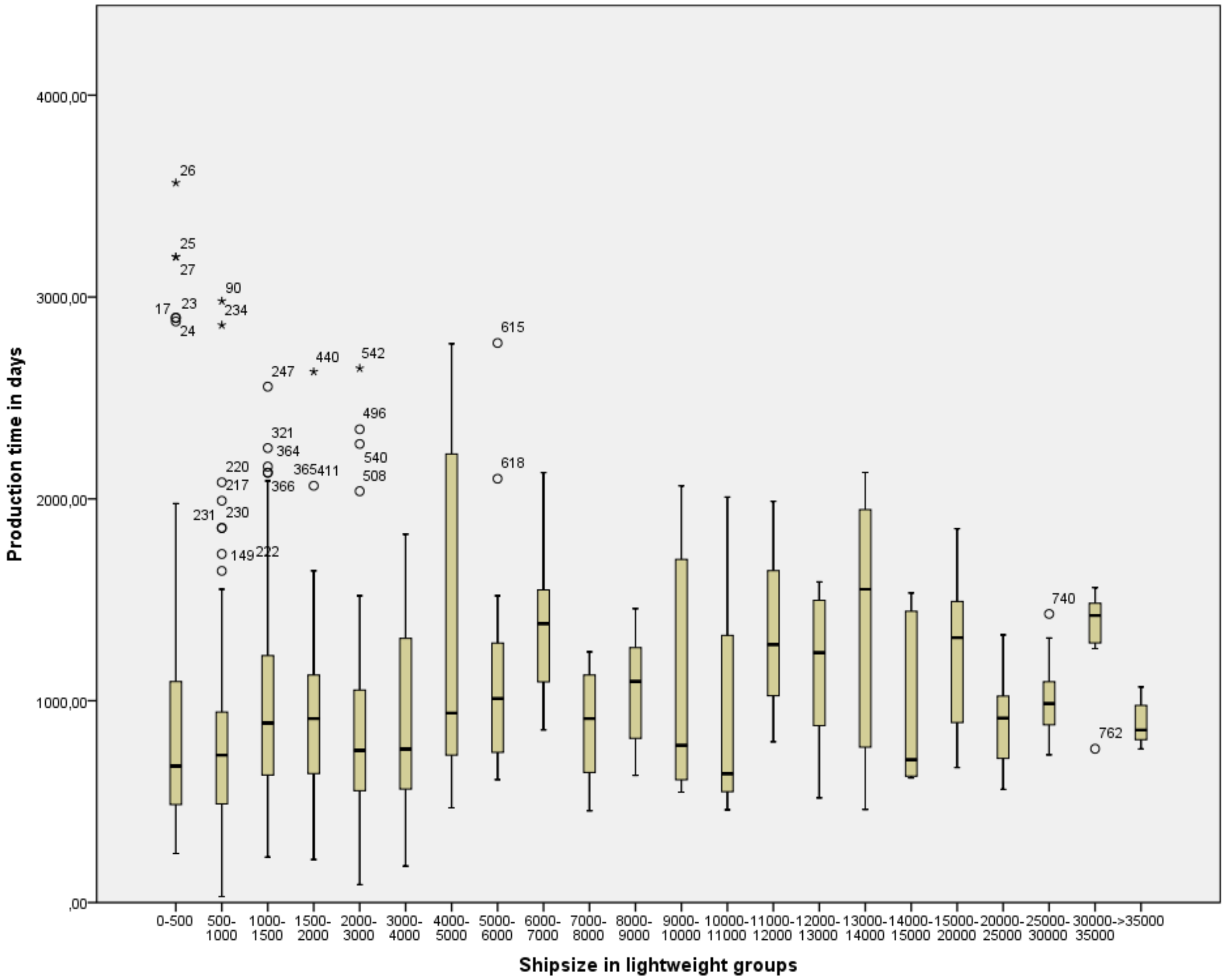


Figure 24: Boxplot with the production times per ship size category with the initial database.

From this boxplot it becomes clear that the largest part of the influential outliers is in the higher production times. Although there is only one outlier on the low side of the boxplots, there are some unrealistic data points. These data points are examined and, if there is a grounded reason, they are taken out of the database. The details can be found in Appendix J: Removed data points from the database After the removal of the outliers from the database a new boxplot is made based on the cleaned data. The result is the boxplot in Figure 25.

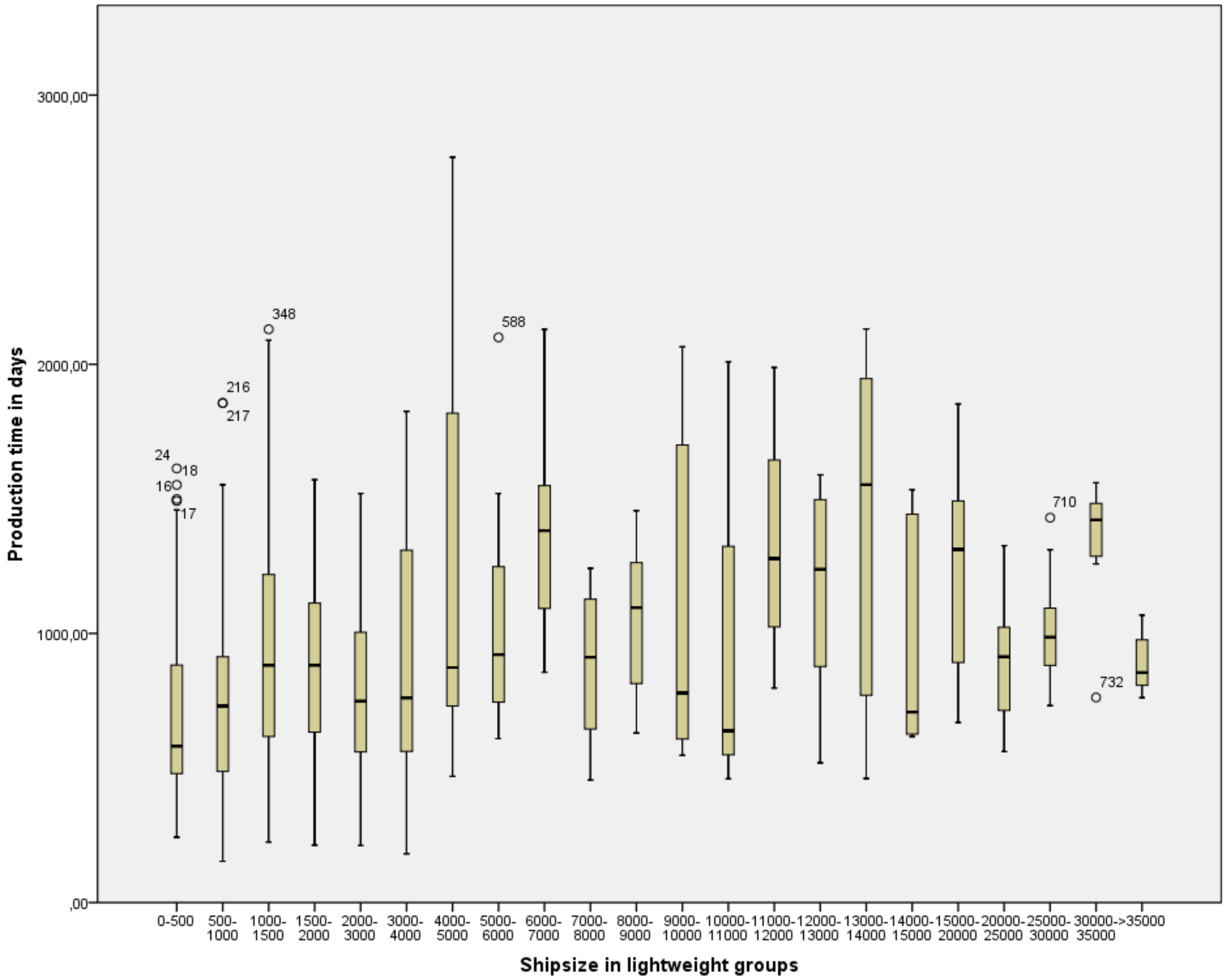


Figure 25: Boxplot with the production times per ship size category with the cleaned database.

The results can roughly be split in two parts. The ship size categories from 0 – 7000 ton and the categories with the larger ships from 7000 ton and larger. There are four notable ship size categories with respect to the spread in the production times:

1. *1000 – 1500 ton*
   For the 1000 – 1500 ton ship size category the explanation for the outlying behavior can be found in the fact that this category has a lot of ships. This means a lot of different shipyards and ship types are within this category. This is an explanation for the spread.
2. *4000 – 5000 ton*
   The explanation for the spread in the 4000 – 5000 ton category is found in the fact that these ships are relatively large and there is a high diversity of ship types in this category ranging from container ships to specialized workboats. This results in a large spread in the production times.

3. *11000 – 12000 ton*
   The ship size category of 11000-12000 ton mainly consists of bulk ships which are ordered and delivered in the period 2005-2011. This was during the economic boom and this can partly explain the long production times. In this period there were large waiting times for the purchase of a ship. This category immediately shows the already indicated danger for overestimation of the production times as mentioned in paragraph 3.3.1.
4. *30000 – 35000 ton*
   The ship size category of 30000-35000 is dominated by a series containerships, which is built by one shipyard for one customer. Probably there are some special specifications which increase the production time. Nevertheless, there is one ship in this category, which is not in the mentioned series. This ship is the visible outlier in Figure 25. Although this ship is an outlier in its category, it fits in the linear trend for the larger ship size categories.

A final remark should be made for the ship size categories above 7000 ton. Due to the focus on the smaller ship types, the amount of ships in the larger categories is small and they tend to come from two shipyards, see Figure 22. The small size of these groups indicate that the statistic results should be used with caution. Due to the timespan of this research it is not achievable to enlarge the database.

The minima whiskers of the boxplot (Figure 25) are used to search for the theoretical expected trend. The choice is made to use the minima of the production times, because maxima are more vulnerable for influences like:

- *Production time calculation*
  The production time is calculated as difference between contract date and delivery date. The build doesn't always start at the contract date. There can be a delay. The result is overestimation of the production time. (A good example is the ship size category of 11000 – 12000 ton). Therefore it is important to compare shipyards using data from the same (short) period
- *Economic factors*
  Due to economic factors a shipyard can make the choice not to fully utilize its resources. The result is that production times can deliberately be increased for a certain ship than expected based on the theory. Other factors might be the effect of a learning curve, if a shipyard builds a certain ship in series. With the small amount of ships in some categories there is also the danger of a strong influence of individual special cases. It is very hard to capture all these influences, but the result of these factors is the large spread.

The mentioned influential factors will generally increase the theoretical expected production time for a ship. Theoretically spoken, it will be impossible to achieve a faster production time than theoretical possible with the available resources. From this point of view the assumption is made that the maximum production times will be more influenced than the minimum production times.

The absolute minima aren't used, because of the limited size of the dataset. Especially for the ship size categories with a small amount of ships there is a chance that the absolute minimum isn't included. Therefore the choice is made to use the minimum whiskers of the boxplot. These are located 1,5 times the inter quartile range from the median. Statistically this value represents a distance which is three times the standard deviation from the median (Hoffmann, 2017). If the size of a category is large enough, this value will be close to the minimum of a ship size category. For categories with less ships, the assumption is made that this value will be close to the real minimum. The minimum whiskers are used to compensate for the spread in the data.

The next step is to fit a trendline through the minima of the whiskers of the boxplot. These whiskers are depicted in Table 12.

Table 12: Minima of the whiskers in the boxplots.

Ship size category	Minima whisker in boxplot	Ship size category	Minima whisker in boxplot
0-500	327,25	**9000-10000**	355,38
500-1000	122,50	**10000-11000**	415,50
1000-1500	219,50	**11000-12000**	644,25
1500-2000	259,50	**12000-13000**	350,50
2000-3000	280,38	**13000-14000**	66,88
3000-4000	275,50	**14000-15000**	503,00
4000-5000	515,50	**15000-20000**	262,00
5000-6000	479,75	**20000-25000**	493,50
6000-7000	670,13	**25000-30000**	723,50
7000-8000	352,13	**30000-35000**	1118,88
8000-9000	391,00	**>35000**	791,38

The data from Table 12 is used to fit a line through the minima of the whiskers for each ship size category. The found trendline can be seen in Figure 26.

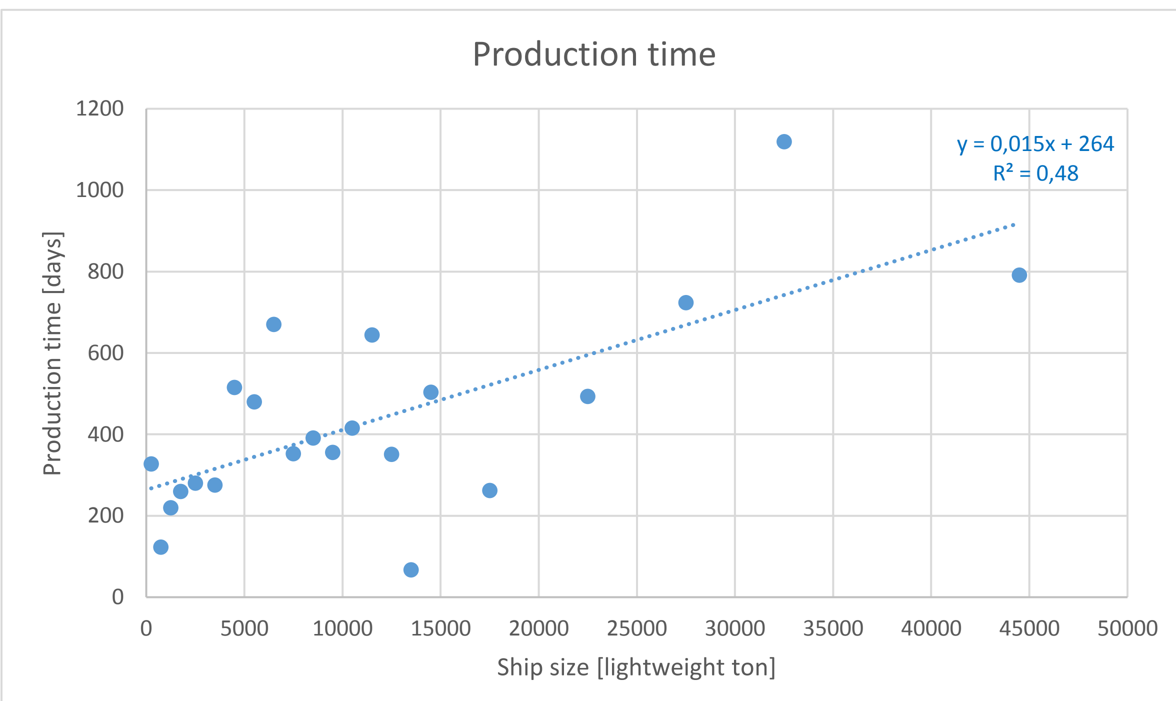


Figure 26: Trend line through the minima of the whiskers of the boxplots.

The found trend line will be used as reference for the time score. This line is seen as the minimum building time for a ship based on the lightweight. The equation of the trend line is shown in equation (14).

$$Production\ time = (0{,}015 * Lightweight) + 264 \quad (14)$$

The expected theoretical initial decrease followed by an increase of the production time isn't captured by this linear trend line. The minimum whiskers in Figure 25 slightly show this trend for the smaller ship size categories, but the trend is broken from ship sizes larger than 7000 ton. Most probably this is due to the limited size of the database. An alternative would be to fit two separate trend lines to the data. One for the categories smaller than 7000 ton and one for the ship size categories larger than 7000 ton. There are two reasons why this theoretical trend isn't applied:

1. Especially the trend line for the larger ship size categories would be affected by the fact that there is a limited amount of data.
2. A jump arises in the coupling of the two trend lines which causes problems in the continuity of the results.

Regarding the available dataset the best solution seems to use a linear trend line through the entire dataset. The found trend line will be used as the reference for assigning a time score to shipyards.

Due to the selection of the shipyards in paragraph 3.1, the focus strongly lies on shipyards which build smaller workboats. This makes the available data limited in its usability. If more shipyards, ship types and ship sizes are included in the database, the usability of the model would significantly increase. This is further treated in the recommendations.

Another point of attention is the definition of the project duration. Due to the availability of data the choice is made to define the length of a project as the difference between the contract date and delivery date. There is however the possibility that the contract date isn't the same date as the start of the production date. Thereby the length of a project can be overestimated. This topic is further treated in the results (paragraph 4.1) and the recommendation.

3.3.4. Time score

The estimation of the production time is based on the lightweight of a ship. In this way for each ship the theoretical minimum production time can be estimated. This estimated production time is compared with the actual production time. The time score is then defined as in equation (15).

$$Time\ score[-] = \frac{Actual\ production\ time\ [days]}{Estimated\ production\ time\ [days]} \quad (15)$$

The result is a score ranging from zero to a maximum value, which is caused by the project with the longest production time. The time scores are calculated per ship. A time score per year per shipyard can be calculated by averaging the time scores of all the ships in a certain period. The final result is a time score per year.

3.4. Quality

The quality perspective is the final aspect of the performance, see Figure 27. In general the quality of a product is demanded by the market. Thereby, the assumption can be made that, if a product is sold, it's in compliance with the demands of the customer. The effectiveness of a sold product is therefore one.

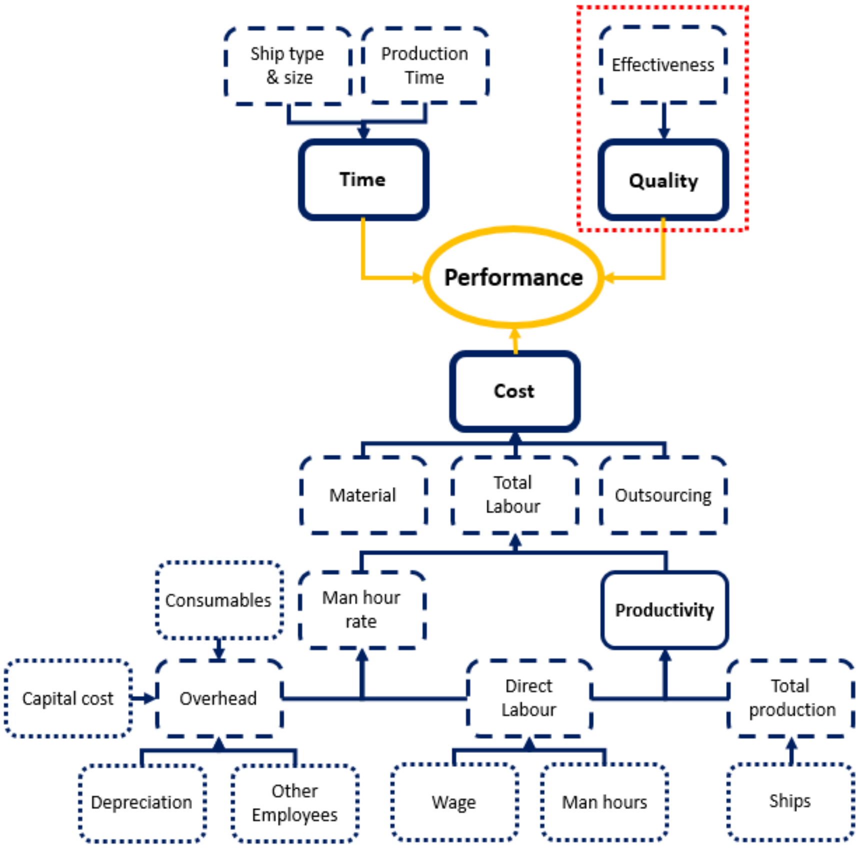


Figure 27: Quality aspect performance model.

A point of discussion could be found in the quality of the used materials. In a mature market there will be multiple solutions and materials available. Usually these products have proven themselves with respect to the quality. The differences in these markets between suppliers are small and the products are in general of the same quality. In an upcoming market it is possible that one solution might result in a better quality then another. This could be the result of differences in quality and lifetime of the product. There can also be a difference in lifetime maintenance cost between products.

All these factors can be taken into account in the quality aspect, but to do so a large database with lifetime records is needed. The general lifetime of a ship is 20 years. This is a long period and it is very hard to capture and retrieve this information for a large amount of ships. Another challenge is that, if this information is available, it will be for ships which are produced approximately 20 years ago. To use this information the shipyards, which built these ships, should still be in operation. From the currently operating shipyards it is very hard, and often even impossible, to assess how well their portfolio performs in operation and how well it will perform in the future. Therefore, the choice is made to assume that a ship meets the expectations, if it is accepted by the customer. The effectiveness of a shipyard is thereby one if a ship is sold. This makes the quality aspect less influential in this model. Nevertheless, one should keep in mind that quality differences exist and that they can play an important role in the choice of a customer for a shipyard.

3.5. Overall performance score

Finally the scores on the three aspects have to be combined to one overall performance score. There are several possibilities to combine these scores. Ideally the scores of different shipyards and different time periods should be comparable. In this way the performance of the shipyards can be assessed with itself and competing shipyards over a time period.

To enable such a comparison there should be compensated for differences in the economy in different time periods. The state of the economy will influence the mutually importance of the three aspects. In an economic boom the delivery time of a product will become more important, while in a recession the price will be the dominating factor.

The compensation for economic influences can be done by scaling the three aspects with the average of the specific year of interest. In this way a dimensionless number with respect to a certain year is gained. With such a scaling it is possible to compare the dimensionless scores across different years. The scaling of the aspects is dependent on the data and therefore the exact scaling will further explained in chapter 4, in which the results are described.

The final step is to combine the three scaled performance aspects into one performance score. This can be done by adding the three aspects together, based on a weighted method. The overall performance score can then be defined as in equation (16).

$$Overall\ performance\ score = A * \ Cost\ score + B * \ Time\ score + C * Quality\ score \qquad (16)$$

The choice is made to make a weighted score. Thereby, the overall performance score is a result of the three scores. The use of the weights makes it possible to assign an importance to each factor. The weights of the three scores are further treated in paragraph 4.3 together with the results. The overall performance score can be used to define the place of a shipyard with respect to the market and its direct competitors.

3.6. Data validation for the deliveries in the SIN database

The SIN database (Clarksons Research, 2017) is the most important data source for this research. In this database global information about shipyards and their deliveries is registered. The defined performance model is very dependent on the quality of the data which is available. Low quality data will result in wrong results. The quality of the data has a serious impact on the usability of the performance model.

To validate the provided data in the SIN database a cross check is made. In this validation the data in the SIN database is compared with the data from Damen for the deliveries of the Damen yards in the period 2010 – 2016. In this way it is possible to check a part of the SIN database. The assumption is made that, if the data is correct for Damen yards, it will also be correct for the other shipyards in the database.

The method is depicted in Figure 28. The idea is that the data in the SIN database (brown line) can be validated with data from the internal Damen database (green line). The Damen database is provided by (Huethorst K. , 2017). This check can only be done for the Damen yards. Therefore, the green line stops at the border between the Damen yards and the competing shipyards.

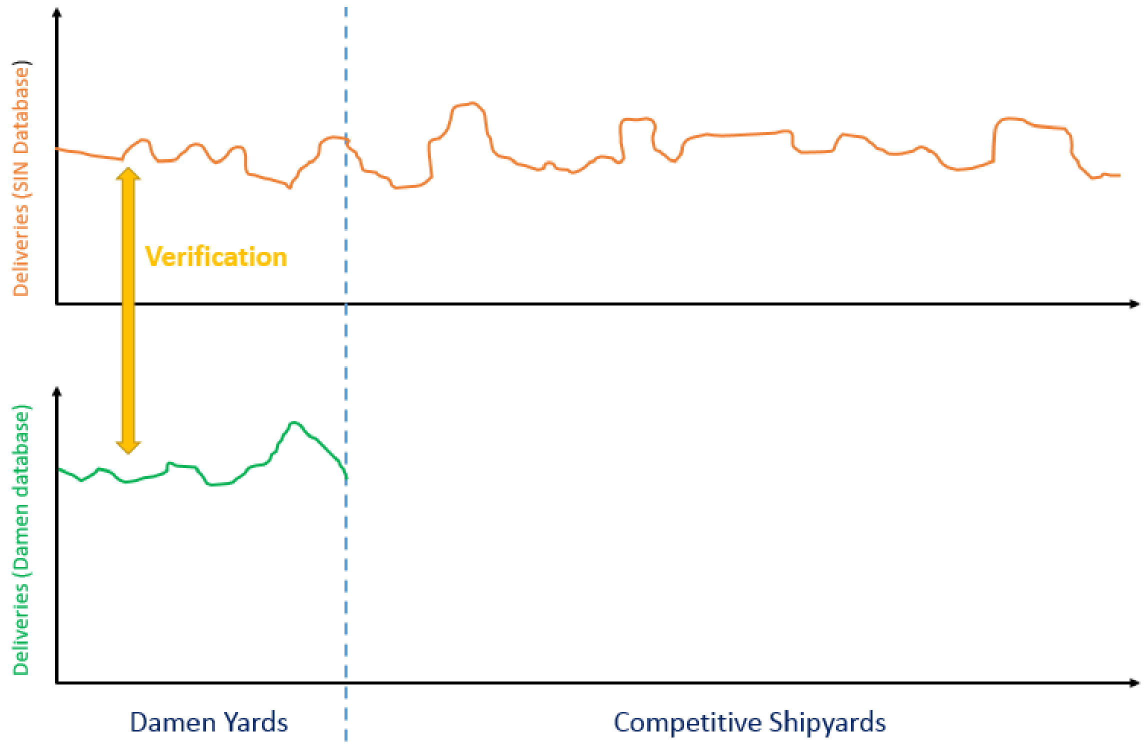


Figure 28: Method for data validation SIN database

In this way a data validation for the five included shipyards from Damen in the SIN database is done for the period 2010 – 2016. The details and results of this validation can be found in Appendix K: SIN database validation. From this validation four differences are discovered, the number in brackets is the paragraph in which they are discussed.:

- Ships are registered in the SIN database on a company level. (3.6.1)
- Unregistered vessel types (3.6.2)
- Vessels < 100 GT are not included (3.6.3)
- Random error (3.6.4)

Finally the information of the SIN database is also compared with the IHS Fairplay database in paragraph 3.6.5. This is done to provide an extra perspective on the SIN database. In paragraph 3.6.6 an overall conclusion about the quality of the SIN database is given.

3.6.1. Company registration for companies with multiple shipyards

The first important difference between the registration in the SIN database and the internal registration of Damen is the shipyard where a vessel is registered as delivered. Damen registers a vessel at the shipyard where it is constructed. In the SIN database a ship is registered as delivered at the shipyard where it is delivered on paper. This results in differences between the two databases. There are for instance ships which are constructed at Damen Shipyards Galati, while the sale and registration of the ship is done by Damen Shipyards Gorinchem. In such a case the ship is registered in the SIN database as delivered by Damen Shipyards Gorinchem, while it is actually constructed at Damen Shipyards Galati.

The overall result is that the SIN database has information about all the deliveries of a company but, if a company has multiple locations, it is possible that a ship is registered at the wrong location. This means that the overall performance of a company isn't influenced, but the individual performance of shipyards within a company can be influenced. Luckily there are not that many large shipbuilding groups. Thereby, this shouldn't be a problem. Nevertheless, if a company consists of multiple shipyards, extra research is needed to check on which location a ship is actually build and the entire company group should be researched to obtain all relevant vessels.

3.6.2. Unregistered vessels

The second difference is found for unregistered vessels. The SIN database is based on registration data from ships. There are however vessels which aren't registered and the two most important groups are:

- hulls
- pontoons

Hulls

There are companies, like Damen, which build hulls upfront. It is possible that these hulls will be put in stock and that they will be used in a later period. Until these hulls are sold, registered and delivered they are not registered in the SIN database. Thereby, they are not available for the performance model. There are very few companies which build a lot of hulls upfront. Furthermore, this problem becomes smaller, if a larger period is investigated. Normally, over time, all the hulls will be sold. Nevertheless, these hulls will be registered as delivered in a later period than the period in which they were actually constructed. As a result, the credit for these deliveries can be in another period than the period in which the hulls are actually made.

Pontoons

Pontoons are mostly not registered, but in general the amount of pontoons that is built on a shipyard is rather small. An exception on this is Damen Yichang Shipyards which only constructed pontoons in the period 2014 – 2016. This is an exception in the regarded shipyard profile. If a shipyard starts producing more pontoons or other none registered vessels, this will stand out in the database as the amount of delivered ships will suddenly drop. In such a case extra investigation is needed to determine why the delivery of ships suddenly decreased. It is therefore important to investigate the yards for multiple years, five at least, but perhaps even more is advisable. Otherwise such a deviation is not noticeable.

3.6.3. Vessels smaller than 100 GT

A third important point is the fact that ships smaller than 100 GT are not registered in the SIN database (English, 2017). For this information extra sources would be needed, like the World Fleet Register (Clarksons Research , 2017). Due to the budget of this research this was not possible.

Although it is possible that a large part of the output of a shipyard is determined by smaller vessels, in general the impact of these vessels on the output will be limited. As said vessels under 100 GT are not included in the SIN database. The impact of these small vessels on this lightweight is small. The performance of the shipyards is based on the amount of lightweight which is delivered. So even if these small vessels account for a large part of the output based on numbers, the relative effect on the absolute delivered lightweight is small. The effect of a missing vessel > 100 GT is much larger compared to ships smaller than 100 GT.

The selected shipyards in paragraph 3.1 are merely involved with the production of ships which are larger than 100 GT. Nevertheless, this is a point of attention when a shipyard is assessed.

3.6.4. Resulting random error in the SIN database

If a company doesn't own multiple shipyards or if it is possible to assign all the delivered ships of a company to the right shipyard, the problem described in paragraph 3.6.1 is overcome. If the unregistered vessels and small vessels are not taken into account, as explained in paragraph 3.6.2 and paragraph 3.6.3 respectively, than there is still a difference between the internal Damen database and the SIN database. However, the found error is random. There is no system discovered in the ships that are missing. All kinds of sizes and types are found in the list of missing vessels. The details of the comparison can be found in Appendix K: SIN database validation. A summary per shipyard of the yearly database errors in the SIN database can be seen in Table 13.

Table 13: Database errors in SIN database with respect to internal Damen database.

Year	Changde	Galati	Yichang	Singapore	Song Cam Shipyard	Average
2010	9%	50%	0%	29%	37%	25%
2011	0%	36%	33%	20%	0%	18%
2012	0%	35%	0%	0%	28%	13%
2013	6%	38%	0%	0%	20%	13%
2014	14%	9%	14%	13%	24%	15%
2015	7%	4%	0%	55%	19%	17%
2016	26%	30%	25%	42%	46%	34%

The depicted error is the resulting random error after the exclusion of unregistered vessels and vessels smaller than 100 GT. From these results it seems that there is a random error of approximately 10% - 30% in the SIN database. Because of the random nature of this error, the assumption is made that this error is in the database for each shipyard. The effect on the performance results will therefore by neglected.

3.6.5. IHS Fairplay database

In a later stage of the research, a part of the IHS Fairplay database was retrieved from the Damen business development department (Vlimmeren, 2017). The errors in the IHS Fairplay Database are similar to those of the SIN database. Unfortunately due to the time frame of this research it was not possible to insert the information from this source in the performance model. However, the IHS Fairplay database is used to provide an extra reference frame to the SIN database. The details of the comparison can be found in Appendix K: SIN database validation.

From the comparison it turned out that the IHS Fairplay database would be a very good completion of the SIN database. In the IHS Fairplay database there are ships registered, which weren't available in the SIN database. for instance:

- More smaller vessels (<100 GT)
- Pontoons & Barges

Despite these extra ships which aren't registered in the SIN database, there are also other vessels registered which would reduce the random error in the SIN database. The conclusion is that the combination of the SIN database and the IHS Fairplay database would result in a more complete database regarding the deliveries of a shipyard.

3.6.6. Conclusion validation SIN database

The overall conclusion is that the SIN database seems an acceptable source for the deliveries. There is a significant difference between the deliveries that are registered by Damen and in the SIN database. Nevertheless, this difference is random and found for all five shipyards from Damen. Thereby, the assumption is made that this random error will exist for all the shipyards in the database. Therefore this error shouldn't influence the comparison of the shipyards, when multiple years are taken into account in the comparison.

Nevertheless, it seemed that the IHS Fairplay database would be a very useful completion on the SIN database. Together with the mentioned World Fleet Register (Clarksons Research , 2017) a more detailed delivery database could be made. The combination of the three databases would provide a more complete image of the deliveries. Furthermore, a cross check between the three databases could be made to validate the deliveries. This would seriously improve the quality of the data and thereby the quality of the results in the performance model. Unfortunately due to the limited time and budget, only the SIN database is used. A first recommendation to improve the data quality is to use the IHS Fairplay database and the World Fleet Register this will be further treated in the recommendation part of the report.

4. Performance results

With the model from chapter 2 and the data from chapter 3, the performances of the different shipyards can be calculated. The three score aspects can be used for the assessment of a shipyard and based on the found scores the overall performance can be established. The general trends in the scores will be evaluated per score. For all the scores yields, that a score below 100% indicates a performance which is better than the reference. So the lower the score, the better the performance. The only exception is a score of 0%. This indicates that there are no deliveries and thereby no performance scores.

The aspects on which a performance score is earned are (Quality, being replaced by effectiveness, which is 1 for shipbuilding):

- Time — paragraph 4.1
- Cost — paragraph 4.2
    - Productivity — paragraph 4.2
- Overall performance — paragraph 4.3

The results for the five selected Damen yards will be explicitly treated in chapter 5.

4.1. Time scores

The time score is calculated as described in paragraph 3.3. There are shipyards which in certain years don't deliver any ships. The time score of these shipyards is thereby zero. If a shipyard doesn't deliver any vessels in a certain year, then this shipyard is not taken into account for the average time score of that year. This means that in some years the yearly average reference score is based on less than fifteen shipyards. The time scores of the competing shipyards can be seen in Figure 29 and the results of the Damen yards can be seen in Figure 31. The exact time scores can be found in Appendix L: Performance model: Time scores.

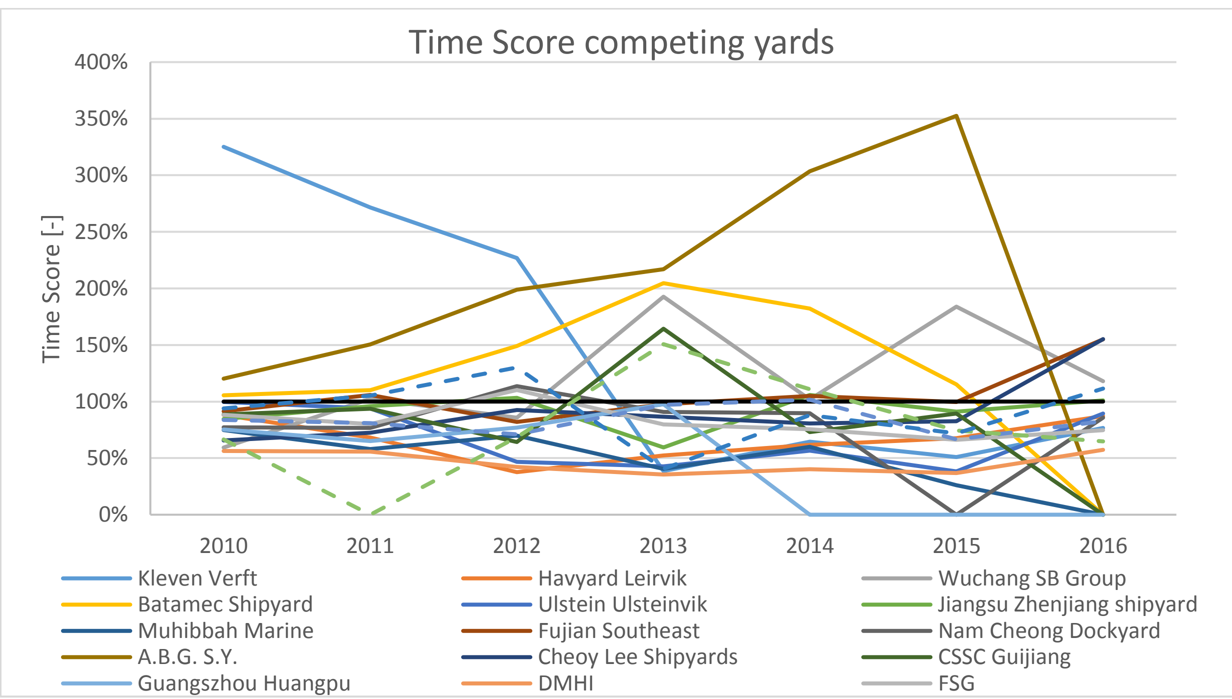


Figure 29: Time scores of the competing shipyards with the average reference time score.

The three dashed lines in Figure 29 are the time scores from the three excluded shipyards (see paragraph 3.1.2):

- Keppel Singmarine
- Sanmar Ltd.
- North American SB

There is a general trend visible in these time scores. Almost all the shipyards tend to have a peak in the period 2010 – 2013. This peak indicates relatively long production times. For some shipyards, this peak is directly in 2010 and for others the peak appears later in this period. This peak is probably a result of the economic boom in the period of 2005 – 2007 (World bank, 2017), as for this model the year of delivery is relevant, not the year of ordering. In this period, the order books of shipyards were packed. Apparently, some shipyards filled their capacity and order book faster than others. This could explain the differences in peak years for different shipyards.

The second period from 2014 – 2016 is affected by the economic crises which started in 2008. The orders suddenly came to a hold. This meant that the order books of shipyards deflated. The production time in the model is calculated as the difference between contract and delivery date. De deflating order book resulted in a shorter time between contract and delivery. Therefore, the production times decreased in this period. Both trends are visible for the individual shipyards, but also in the industry average line (black line).

The influence of the economy makes it impossible to compare different years with each other. This is already mentioned in paragraph 3.5. These influences in combination with the definition of the production time (paragraph 3.3) results in peaks in the time performance. Ideally there should be compensated for the influence of the economy. This could be done by calculating a production time reference line per year, instead of a reference line for the entire period (2010 – 2016). To establish such a set of reference lines, the database should be expanded. If, with the current database, a division per year is made the result would be that for certain ship size categories there are only one or two ships in the database. Thereby, these data points would become very important and their influence on the final result would significantly increase. Due to the limited timeframe of this research, the choice is made not to expand the database and to accept the fact that the results are fluctuating.

Expansion of the database would statistically improve the results in multiple ways, but the exact benefits can't be predicted. The choice is made to work with one reference time line for the entire period, see paragraph 3.3. The consequence, for not compensating for the influences of the economy, is visible in the fluctuating behavior of the time scores in Figure 29. This behavior is the result of the fact that shipyards experience the economic influences at a different speed and in a different year/period. By creating boxplots for each year, the spread in the results becomes even better visible, see Figure 30.

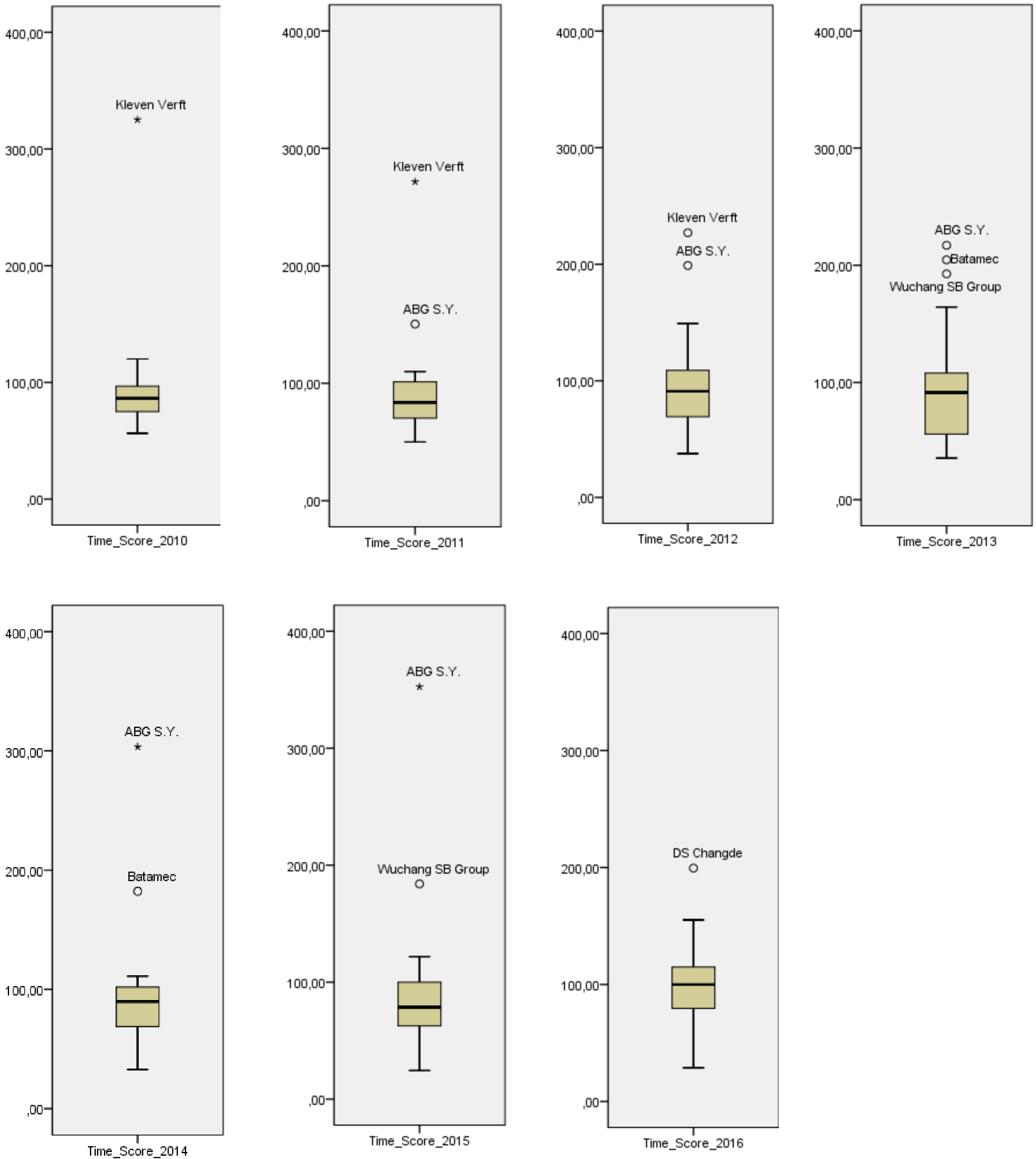


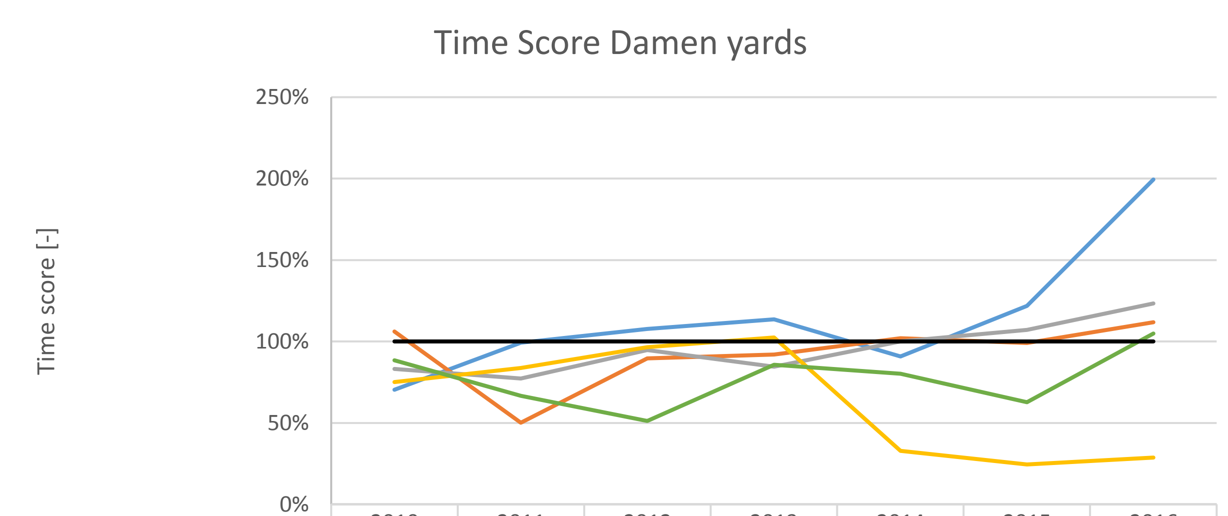
Figure 30: Yearly boxplots with spread of the time scores.

To partly compensate for this fluctuating behavior, it seems logical to compare shipyards based on an average time score, see Table 14. In this way there is partly compensated for the fluctuating response of the shipyards to the economic influences. The average time score is based on the entire assessed period 2010 – 2016.

Table 14: Average time score for the period 2010 - 2016.

Shipyard	Average Time score	Shipyard	Average Time score
Kleven Verft	151%	Cheoy Lee Shipyards	91%
Havyard Leirvik	66%	CSSC Guijiang	82%
Wuchang SB Group	121%	Guangszhou Huangpu	45%
Batamec Shipyard	124%	DMHI	46%
Ulstein Ulsteinvik	67%	FSG	82%
Jiangsu Zhenjiang shipyard	92%	Keppel Singmarine	83%
Muhibbah Marine	47%	Sanmar Ltd	77%
Fujian Southeast	105%	Norht American SB	92%
Nam Cheong Dockyard	76%	Industry Average	100%
A.B.G. S.Y.	192%		

Although the use of an average score will help, expanding the database stays an important recommendation, which will be further treated in the recommendation chapter of this report. The time scores of the Damen yards are depicted in Figure 31.



	2010	2011	2012	2013	2014	2015	2016
DS Changde	70%	99%	108%	114%	91%	122%	199%
DS Galati	106%	50%	90%	92%	102%	99%	112%
DS Song Cam Shipyard	83%	77%	95%	84%	100%	107%	123%
DS Yichang	75%	84%	97%	102%	33%	24%	29%
DS Singapore	88%	67%	51%	86%	80%	63%	105%
Average	100%	100%	100%	100%	100%	100%	100%

Figure 31: Time scores of Damen yards with the average reference time score.

For the Damen yards, it is also possible to calculate an average time score for the entire period 2010 – 2016. These scores can be seen in Table 15.

Table 15: Average time score for the Damen yards in the period 2010 - 2016.

Shipyard	Average time score
Damen Shipyard Changde	115%
Damen Shipyard Galati	93%
Damen Song Cam Shipyard	96%
Damen Yichang Shipyard	63%
Damen Shipyard Singapore	77%
Industry Average	100%

Despite the average score it is also interesting to look at the development of the time performance over the period 2010 – 2016. This shows some interesting trends.

In the period 2010 – 2014 the shipyards of Damen perform very well compared to the industry average. Except for Damen Singapore, all the shipyards are relatively close to the average time score of the industry. The scores are also very constant in this period. This can be interpreted as a good performance, especially if the high waiting times of this period due to the economic boom are taken into account. The fact that Damen was able to keep delivering vessels at a constant rate is most probably the result of the strategic hull stock, which the company uses. This stock enables Damen to flatten out the demand from the market and to quickly respond to changes in this demand. The conclusion is that Damen performed very constant through the tail of the economic boom.

From 2014 onwards all the shipyards tend to increase their production times. In 2014 all the shipyards are approximately on the industry average. The difference keeps increasing in 2015 and 2016. An explanation could be that Damen tried to keep all the shipyards in business, by slowing down the production process. Due to the crises some customers were maybe not that eager to immediately get their ship and the result could be the increase of the production times. Nevertheless, other shipyards were apparently still producing ships at a faster rate, so this trend should be broken to stay competitive.

The only exception on the increase of production time is Damen Yichang Shipyards. However, this shipyard predominantly produces pontoons and barges in 2014 – 2016. The production of a pontoon is in general easier than the production of a ship. Thereby, the production time decreased significantly.

Although the time scores seem acceptable at first sight, there is a point of attention. Damen uses a strategic stock of hulls to enable a fast delivery. The initial reason for this stock is to be able to deliver ships faster than the competition. From the time performance results it seems that, although Damen has this stock, they are not significantly faster in the delivery of their vessels! Especially in the second period 2014 – 2016 the time performance decreases with respect to the competition. It seems that at this moment Damen actually needs the hull stock to keep up with the competition, instead of using it as an competitive advantage to outperform them.

4.2. Cost scores

The results of the cost scores are described in paragraph 4.2.1 and the accompanying productivity scores are described in paragraph 4.2.2. The productivity scores are always calculated against a reference shipyard. Damen Shipyards Galati is selected as reference shipyard and all productivity scores are thereby with respect to DSGa. (Any other shipyard could have been selected as reference).

4.2.1. Cost scores

The cost score is calculated as described in paragraph 3.2. Again, shipyards which don't deliver a vessel in a specific year are excluded from the average calculation in that year. This is done for the same reason as explained in paragraph 4.1.

The results of the competing shipyards can be seen in Figure 32. Again a boxplot is made per year to give more insight in the spread of the results, see Figure 33. An overview of all the cost scores can be found in Appendix M: Performance model: Cost scores. The three excluded shipyards are displayed with a dashed line. The industry average cost price is a straight line through one (black line). This is the result of making the cost scores dimensionless with the industry average value.

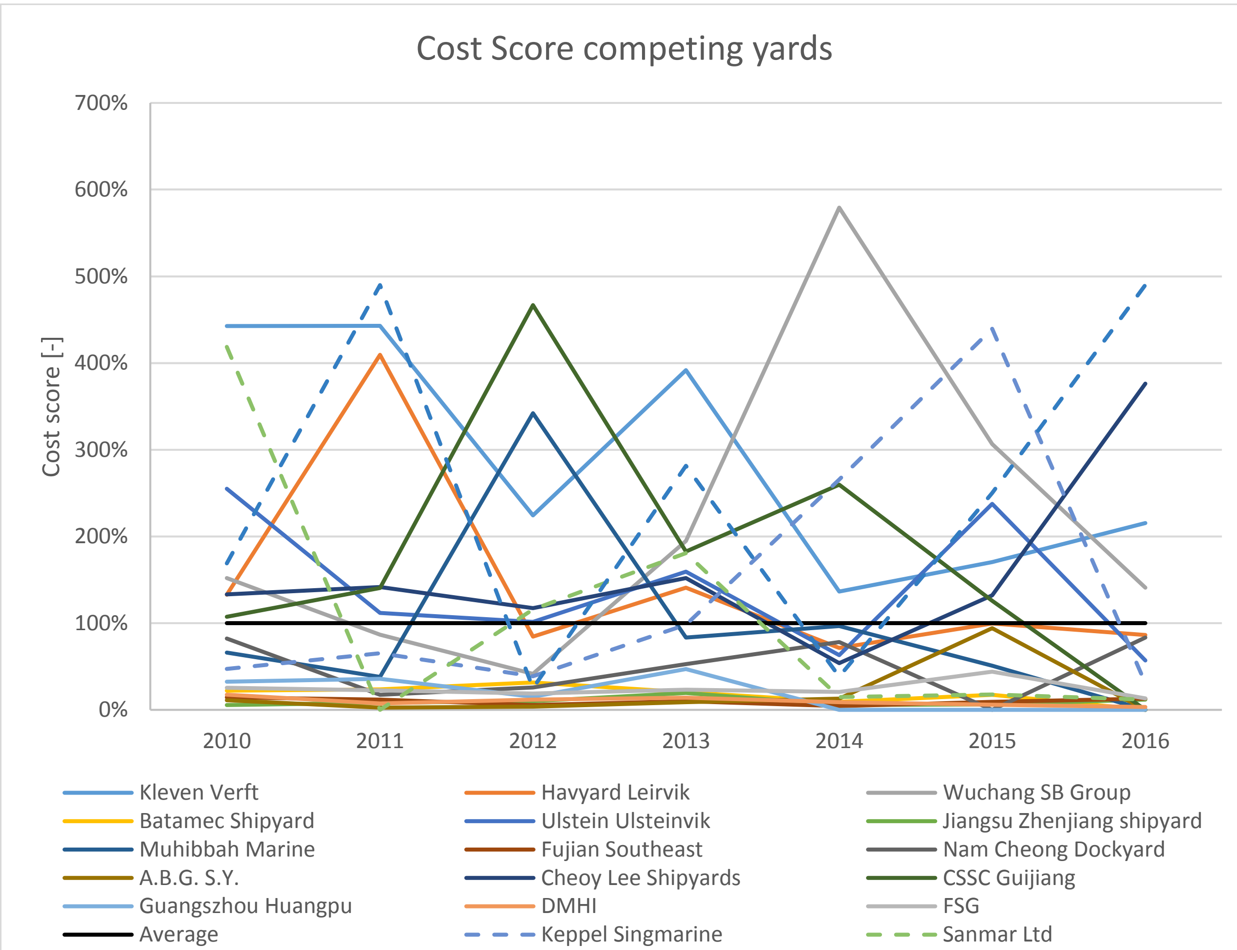


Figure 32: Cost scores of the competing shipyards with respect to the industry average.

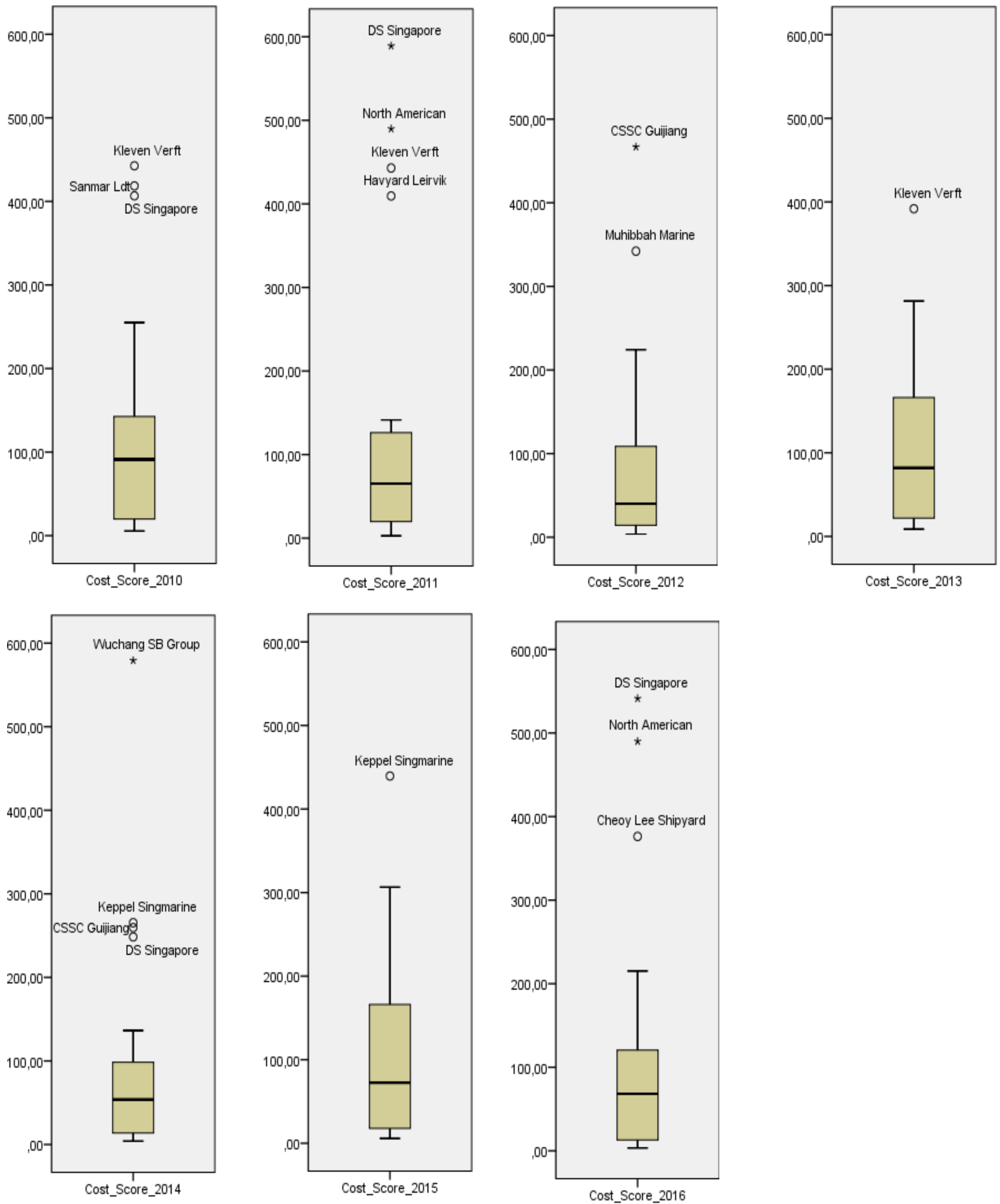


Figure 33: Yearly boxplots with spread in the cost scores.

Although it is hard to see in Figure 32, there are shipyards which perform significantly better than other shipyards. For example DMHI, Jiangsu Zhenjiang Shipyard and Flensburger Shiffbau Gesellschaft (FSG) perform very good. There can be a lot of causes for this high performance, but it is striking that all three build larger size vessels. Especially DMHI, which has a very high cost performance, builds mainly large cargo vessels. These results substantiate the stated concern in paragraph 3.2.3, that lightweight as output parameter doesn't capture the complexity of the ship. This topic is further treated in the recommendations.

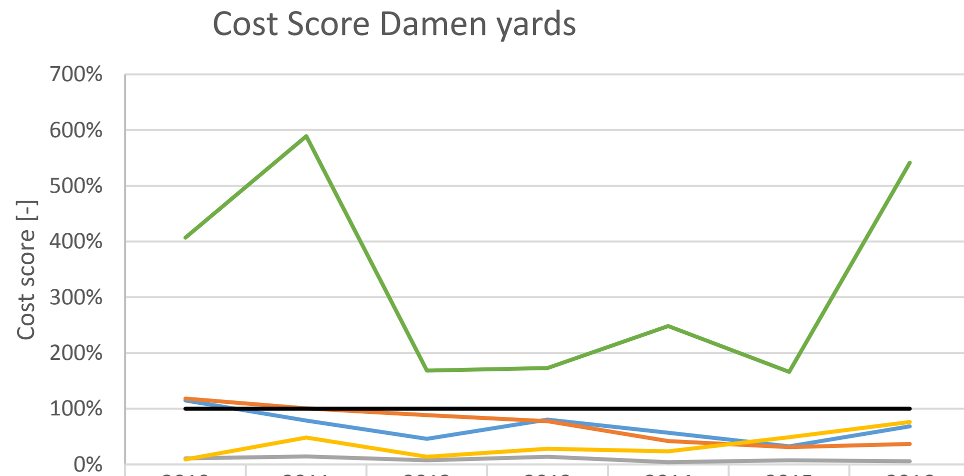
The differences between shipyards in the cost scores are also extreme in some cases. This is the result of the fact that the cost scores only take a part of the total cost into account. Only the labour part is used for the comparison. Thereby, a part of the picture is lost. The found cost score results can only be used for mutually comparison. The excluded 'constant' material cost should be included to oversee the entire picture. This topic is already mentioned in paragraph 3.2.5 and will also be further treated in the recommendations.

In the cost scores the same fluctuating behavior, as for the time scores, is seen. Therefore, just as in paragraph 4.1, an average of the cost scores over the entire period 2010 – 2016 is taken. These averages are depicted in Table 16 for each of the competing shipyards.

Table 16: Average cost score competing shipyards 2010 - 2016.

Shipyard	Average Cost score	Shipyard	Average Cost score
Kleven Verft	289%	Cheoy Lee Shipyards	158%
Havyard Leirvik	146%	CSSC Guijiang	183%
Wuchang SB Group	214%	Guangszhou Huangpu	19%
Batamec Shipyard	18%	DMHI	10%
Ulstein Ulsteinvik	141%	FSG	24%
Jiangsu Zhenjiang shipyard	10%	Keppel Singmarine	141%
Muhibbah Marine	97%	Sanmar Ltd	109%
Fujian Southeast	10%	Norht American SB	249%
Nam Cheong Dockyard	49%	Industry Average	100%
A.B.G. S.Y.	19%		

The cost scores of the Damen yards can be seen in Figure 34. The results are described per shipyard.



	2010	2011	2012	2013	2014	2015	2016
DS Changde	115%	79%	46%	81%	57%	32%	68%
DS Galati	118%	100%	89%	77%	42%	31%	37%
DS Song Cam Shipyard	11%	14%	8%	14%	4%	7%	6%
DS Yichang	9%	48%	14%	28%	23%	49%	76%
DS Singapore	407%	589%	169%	173%	248%	166%	541%
Average	100%	100%	100%	100%	100%	100%	100%

Figure 34: Cost scores of Damen yards with respect to the industry average cost price.

Damen Shipyards Singapore

The first shipyard which stands out is Damen Shipyards Singapore. This shipyard is specialized in smaller fast vessels, which are in general more costly to build. In this perspective, one can expect a higher cost score compared to the other shipyards. In the period 2010 – 2011 the cost score is significantly higher. There is a positive trend, in which the shipyard steadily comes closer to the industry average cost price level, and in 2012 – 2015 the shipyard is much closer to the industry average. In 2016 the cost score drastically increases. An explanation is that in 2016 predominantly small vessels (<100 GT) are constructed. These are not registered in the SIN database. In these results the earlier stated concerns from paragraph 3.6 are seen.

Damen Song Cam Shipyards

Damen Song Cam Shipyard has a very low cost score. This low score can be explained by the fact that the shipyard is focused on outfitting and commissioning of already constructed hulls. Therefore, the output of the shipyard is overestimated in the performance model. The shipyard only uses resources for the outfitting, while it is rewarded credit for the entire ship. The result is a seemingly very good performance with respect to costs. In these results the earlier stated concern about neglecting the cost of outsourcing is found, see paragraph 3.2.

Damen Shipyards Yichang

Damen Shipyards Yichang also has a low cost score. This is partly the result of the relatively simpler product portfolio and partly the result of the low employee costs of the shipyard. This shipyard builds smaller container ships, general cargo vessels and pontoons. Normally, it is easier to create a relatively higher amount of lightweight with these types of vessels compared to more complicated ships like tugs. Nevertheless, due to the decreasing amount of deliveries in 2014 – 2015 the cost score is slightly increasing.

Just as DMHI, DYS shows the same problem with the chosen product output parameter. Simply using the lightweight and neglecting the ship type and complexity of the ship favors certain shipyards. This concerns was already mentioned in paragraph 3.2.3. The results of DYS support the assumption that ship type and ship complexity are important parameters. Extra research into this topic can significantly improve the model. The use of other output parameters is further treated in the recommendation.

Damen Shipyards Galati

Damen Galati can very well be compared to the industry average, because the product portfolio of this shipyard is very similar to that of the competing shipyards in the database. The cost score of Damen Galati is very close to the industry average. Furthermore, the cost score is steadily decreasing. The combination can be seen as a good result

Damen Shipyards Changde

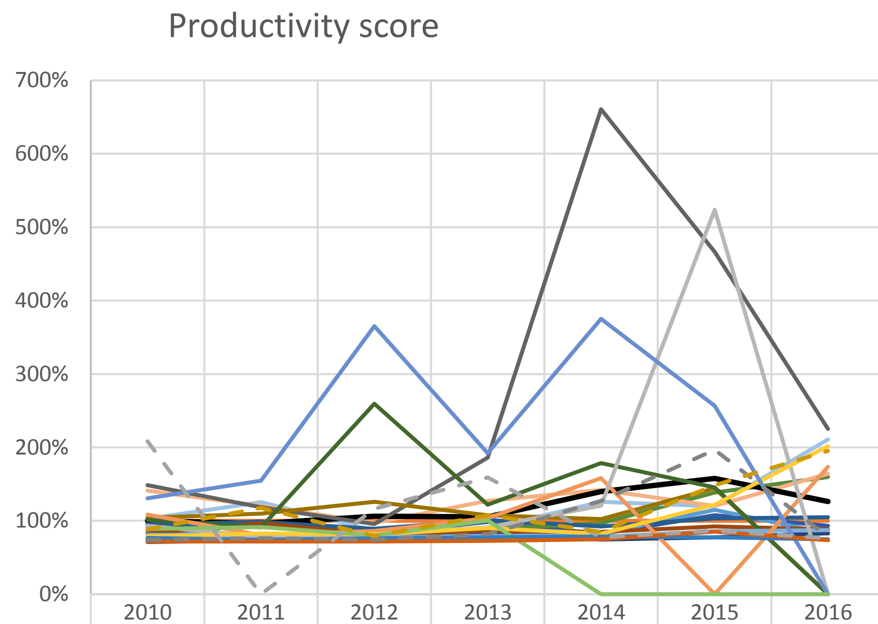
The last shipyard is Damen Changde. This shipyard also has a very similar product portfolio compared to the competing shipyards in the database. In the entire period 2010 – 2016 Damen Changde is below or around the industry average. The trend in the cost score is positive and steady.

4.2.2. Productivity scores

The cost score results can be putted in a different perspective by calculating the accompanying productivity scores, see paragraph 3.2.5. The productivity scores are calculated for the Damen yards. Each time one of the Damen Shipyards Galati is taken as the reference shipyard. There is internal information within Damen about the relative productivity of the included Damen yards. This information can be used for the validation of the productivity scores from the performance model.

Productivity scores (DSGa as reference 100%)

The calculated productivity scores of the all the shipyards in the database with respect to DSGa are depicted in Figure 35.



	2010	2011	2012	2013	2014	2015	2016
Galati	100%	100%	100%	100%	100%	100%	100%
Song Cam Shipyard	92%	99%	82%	98%	82%	108%	93%
Yichang	76%	98%	79%	89%	96%	139%	160%
Ulstein Ulsteinvik	86%	81%	81%	85%	82%	115%	83%
Singapore	103%	126%	87%	89%	126%	120%	211%
Changde	141%	120%	97%	127%	142%	120%	164%
Average	100%	96%	106%	106%	140%	158%	126%
Kleven Verft	95%	99%	89%	101%	92%	103%	105%
Havyard Leirvik	83%	97%	82%	86%	85%	92%	88%
Wuchang SB Group	149%	119%	96%	186%	661%	466%	225%
Batamec Shipyard	104%	110%	126%	107%	102%	144%	0%
Jiangsu Zhenjiang shipyard	71%	73%	74%	81%	75%	77%	83%
Muhibbah Marine	101%	91%	259%	122%	179%	146%	0%
Fujian Southeast	81%	80%	77%	80%	78%	86%	87%
Nam Cheong Dockyard	108%	81%	86%	104%	158%	0%	174%
A.B.G. S.Y.	93%	78%	80%	91%	121%	524%	0%
Cheoy Lee Shipyards	79%	83%	82%	90%	82%	122%	202%
CSSC Guijiang	131%	155%	365%	192%	375%	257%	0%
Guangszhou Huangpu	89%	92%	80%	100%	0%	0%	0%
DMHI	77%	74%	76%	77%	79%	78%	75%
FSG	72%	72%	72%	73%	75%	85%	74%
Keppel Singmarine	74%	76%	74%	82%	127%	197%	78%
Sanmar Ltd	208%	0%	116%	159%	77%	87%	76%
Norht American SB	88%	117%	79%	108%	85%	149%	195%

Figure 35: Productivity scores with respect to DSGa.

Just as for the time and cost scores (paragraph 4.1 and 4.2), the productivity score has a fluctuating behavior. Therefore, the productivity scores will also be compared based on an average score over the period 2010 – 2016. The average productivity scores with respect to DSGa can be found in Table 17.

Table 17: Average productivity scores with respect to DSGa.

Shipyard	Productivity score (DSGa = 100%)	Shipyard	Productivity score (DSGa = 100%)
Damen Shipyard Galati	100%	Nam Cheong Dockyard	118%
Damen Song Cam Shipyard	94%	A.B.G. S.Y.	165%
Damen Yichang Shipyards	105%	Cheoy Lee Shipyards	106%
Damen Shipyards Singapore	123%	CSSC Guijiang	246%
Damen Shipyards Changde	130%	Guangszhou Huangpu	90%
Kleven Verft	98%	DMHI	76%
Havyard Leirvik	87%	FSG	75%
Wuchang SB Group	272%	Keppel Singmarine	101%
Batamec Shipyard	116%	Sanmar Ltd	121%
Ulstein Ulsteinvik	88%	North American SB	117%
Jiangsu Zhenjiang shipyard	76%	Minima	75%
Muhibbah Marine	150%	Maxima	272%
Fujian Southeast	81%	Industry Average	119%

The maxima, minima and average of the industry are also depicted. Especially the minima of the industry is interesting. This value gives a quantification of the possible productivity improvement with respect to the best performing shipyards. To make the differences between the reference shipyard and the other shipyards more visible, it is also possible to only depict the differences in productivity performance. These differences are especially interesting, if direct competitors are included in the comparison. These direct competitors can be selected based on product portfolio, geographical location, etc. This enables a fair selection between the shipyards. This method is used in chapter 5 with the performance results of the Damen yards.

Validation productivity scores

The productivity scores depict the entire picture. Besides the labour costs, also other costs are included, see paragraph 3.2.5. Thereby, the calculated productivity scores from the Damen yards can be validated against internal productivity information from Damen. Such a validation gives some insight in the error marge of the performance model.

For this validation, the productivity scores of the five included Damen yards are compared against internal information. Again the average value over the period 2010 – 2016 is taken, just as in paragraph 4.1 and 4.2. Damen Shipyards Galati (DSGa) is taken as reference shipyard and the productivity scores of the other four shipyards are depicted with respect to DSGa. The results can be found in Table 18.

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Table 18: Comparison productivity numbers Damen Yards.

Productivity numbers Damen yards					
	Damen Shipyards Galati	Damen Song Cam Shipyard	Damen Yichang Shipyards	Damen Shipyards Singapore	Damen Shipyards Changde
2010	100%	89%	91%	99%	133%
2011	100%	96%	98%	120%	114%
2012	100%	81%	92%	84%	94%
2013	100%	95%	95%	87%	121%
2014	100%	81%	98%	121%	134%
2015	100%	103%	112%	115%	114%
2016	100%	90%	119%	199%	154%
Average	**100%**	**91%**	**101%**	**118%**	**124%**
Expected results	**100%**	**120%**	**130%**	**140%**	**160%**

The results are checked with the expectations of (Teuben, 2017) and (Man, 2017). These expected results can be seen in the last row of the table. All the shipyards show the same trend as the expected results. The only shipyard which displays a different performance is Damen Song Cam Shipyard. The initial expected result was that DSGa would have a better productivity performance than DSCS. This isn't the case and therefore an extra comparison is made between these two shipyards.

Comparison of DSGa and DSCS + SK

Due to the unexpected productivity result a comparison is made between DSGa and DSCS + SK to investigate the results in more detail. The comparison is made based on a ASD 2810 tug. This ship is built at both shipyards and there is specific cost information about the construction for both shipyards. A detailed cost comparison for an ASD 2810 can be seen in Table 19. The left side of this table depicts the registered costs for DSGa and the right side of the table displays the costs of DSCS + SK.

Table 19: Detailed cost comparison of an ASD 2810.

ASD 2810					
DSGo				**DSGo**	
General	€ 450.000,00			General	€ 480.000,00
Material	€ 2.300.000,00			Material	€ 2.300.000,00
Total DSGo	€ 2.750.000,00			Total DSGo	€ 2.780.000,00
DSGa				**DSCS + SK**	
Material DSGa	€ 250.000,00			Material DSCS + SK	€ 240.000,00
Total hours DSGa	€ 1.100.000,00			Hours hull	€ 530.000,00
Sub contractors	€ 150.000,00			Hours	€ 250.000,00
				Total hours DSCS + SK	€ 780.000,00
				Sub contractors	€ 150.000,00
Total DSGa	€ 1.500.000,00			Total DSCS + SK	€ 1.170.000,00
Total	€ 4.250.000,00			Total	€ 3.950.000,00

Based on this comparison, it can be stated that the part of Damen Shipyards Gorinchem (DSGo) is similar for both shipyards. Thereby, a difference in cost is predominantly caused by the shipyard itself.

The material costs and outsourcing costs for both shipyards are also similar. The result is that the difference has to be in the only left cost source, which is the labour costs. The difference in cost between DSCS + SK and DSGa is approximately € 320.000,00. If DSGa is taken as a baseline, this is a relative difference of approximately 71% in labour costs.

The difference in hourly rates should be taken into account to say something about the amount of hours which is spent. The hourly rates are (Man, 2017):

- DSGa € 15,00/hr
- DSCS + SK € 11,60/hr (based on $13,00/hr)

If these hourly rates are taken into account, the following division in used hours can be found:

- DSGA 73.333 hours
- DSCS + SK 67.415 hours

DSGa is again taken as reference and now the relative difference between the two shipyards can be calculated. The relative difference between these amounts of hours is 92%. Thereby, it seems that the results from the performance model are in line with the real established results.

4.3. Overall performance scores

The final objective is to combine the three performance aspects to one overall performance score. The effect of the earlier found economic influences is treated in paragraph 4.3.1.

Due to the effect of the economic influences on the results there is a challenge in defining an overall performance score. The defined performance score in paragraph 3.5 is treated in paragraph 4.3.2. This method is based on a weighted average. The use of a weighted average introduced extra subjectivity in the results.

In paragraph 4.3.3 a solution is presented for the problems with the overall performance score. The solution is to make individual rankings per performance aspect for each year.

4.3.1. Economic influences on the overall performance

The economy influence can be seen in the time scores and the cost scores in paragraph 4.1 and 4.2. The result is relatively large fluctuations in the time scores and the cost scores. Due to these fluctuations it becomes difficult to compare the scores of different years with each other. If, for instance due to an economic boom, the production time significantly increases, this would affect the performance of the shipyard in that specific year. If in another year there is a recession, the production time is smaller and the performance seems better. Although, this is merely a result of the economic state in the world. Another important aspect resulting from these economic influences is that shipyards might experience the consequences at a different moment. The combination of these facts make it difficult to combine the found performance scores.

Due to the limited size of the database it is not possible to compensate for the influences of the economy. Ideally there should be an infinitely large database, which makes it possible to define reference lines for the time and cost performance per year. By using this separation of the reference lines, the effect of other influential parameters could be better captured. These reference lines could be used to compensate for these economic influences. Due to the limited timeframe of the research, it is not possible to build such a large database. Therefore another way should be found to come to an overall performance score.

4.3.2. Overall performance score based on weighted average

A solution would be to make a weighted average of the three scores. This could be done with equation (17)

$$Overall\ performance\ score = A * Cost + B * Time + C * Quality \tag{17}$$

The sum of the factors A, B and C should be a 100%. These factors then determine the importance of an aspect with respect to the overall performance score. There is however no literature nor any consensus about the relative weight of the three aspects. The choice in the weight of the three aspects highly influences the overall performance of the shipyard. This would introduce a new form of subjectivity to the model and the initial objective was to make a model based on a quantitative analysis with factual data.

The weight of the factors could be based on the found results, but due to the limited size of the database it is not possible to decide the mutual importance of the three aspects. Therefore, the choice is made to not combine the different performance scores into one number, but to assess a shipyard based on the individual scores.

4.3.3. Individual score rankings

For each year and each aspect, a ranking can be made. In this ranking the performance of a shipyard with respect to the industry is depicted. If there are shipyards which don't deliver any ships, they will get a score of zero. Automatically these shipyards will be put at the bottom of the ranking. The choice is made to keep them in the ranking to maintain a good overview of the database. These kind of rankings can be made for each year and each performance aspect. In this way the best performing shipyard per year and per aspect can be found. The rankings can be found in Appendix N: Ranking of the shipyards. In this appendix the results per year can be found for each shipyard. Furthermore, extraordinary results are investigated and individually described. This yearly comparison is interesting to see what kind of trends shipyards are going through. This says something about general improvement which is achieved.

The actual comparison of the shipyards will be done based on the average performance scores over the period 2010 – 2016. Using the average performance scores will decrease the economic influences on the performance scores. In this way the fact that shipyards might experience economic influences at different moments in time is better captured. Therefore, the Damen yards will be compared with the competing shipyards based on the average performance scores over the period 2010 -2016. This performance is described for each Damen yard and each performance score in chapter 5.

5. Performance results Damen yards

The performance of the Damen yards will be compared with the performance of the competing yards based on the average performance scores over the period 2010 - 2016. The average is used to compensate for the economic influences as described in chapter 4.

For each Damen yard the place in the market will be described based on the average achieved time score (Figure 36) and cost score (Figure 37).

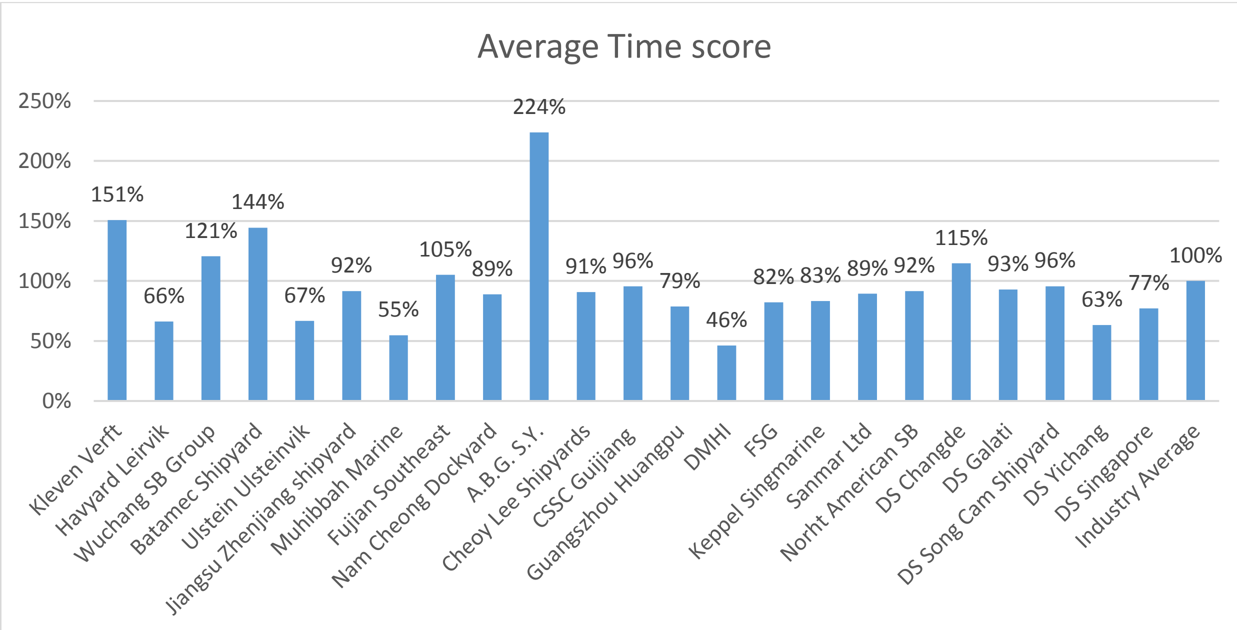

Figure 36: Average time score per shipyard 2010 - 2016.

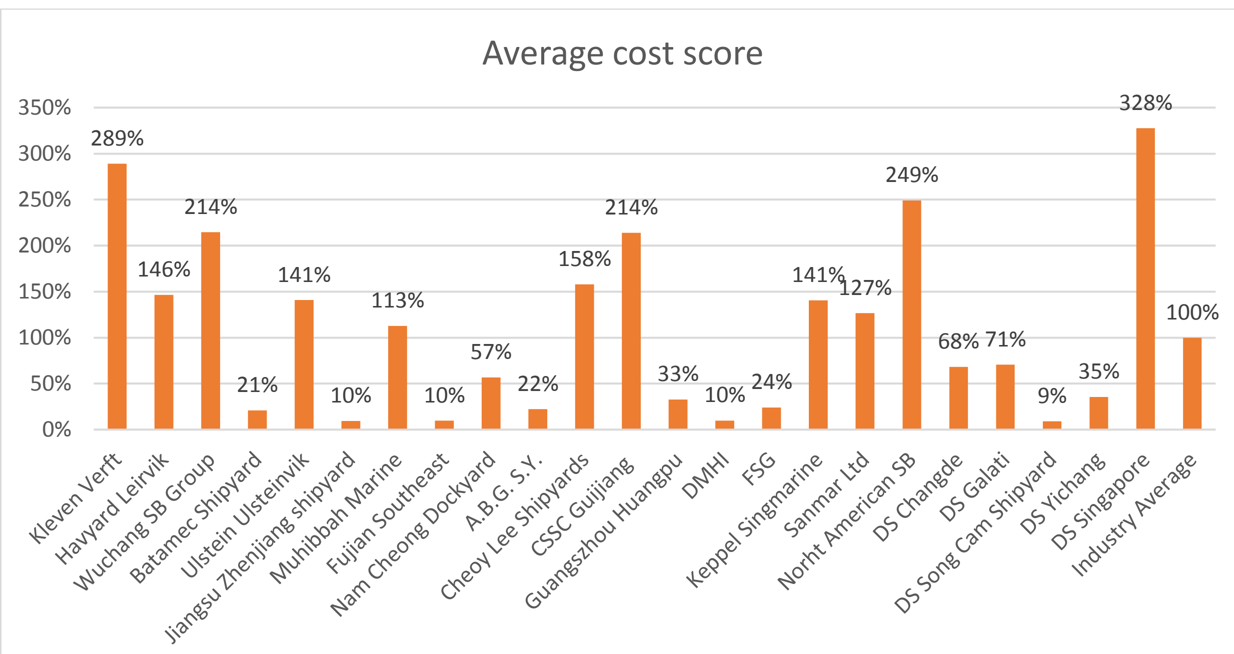

Figure 37: Average cost score per shipyard 2010 - 2016.

After this placement in the market, the performance scores will be put in perspective by comparing the productivities of the Damen yards and the competing shipyards. This last comparison will also be used to quantify the productivity gap and define the improvement possibilities for the Damen yards. The average productivity scores are calculated using Damen Shipyards Galati (DSGa) as the reference shipyard. The differences between the productivity scores of DSGa and the other shipyards are depicted in Figure 38.

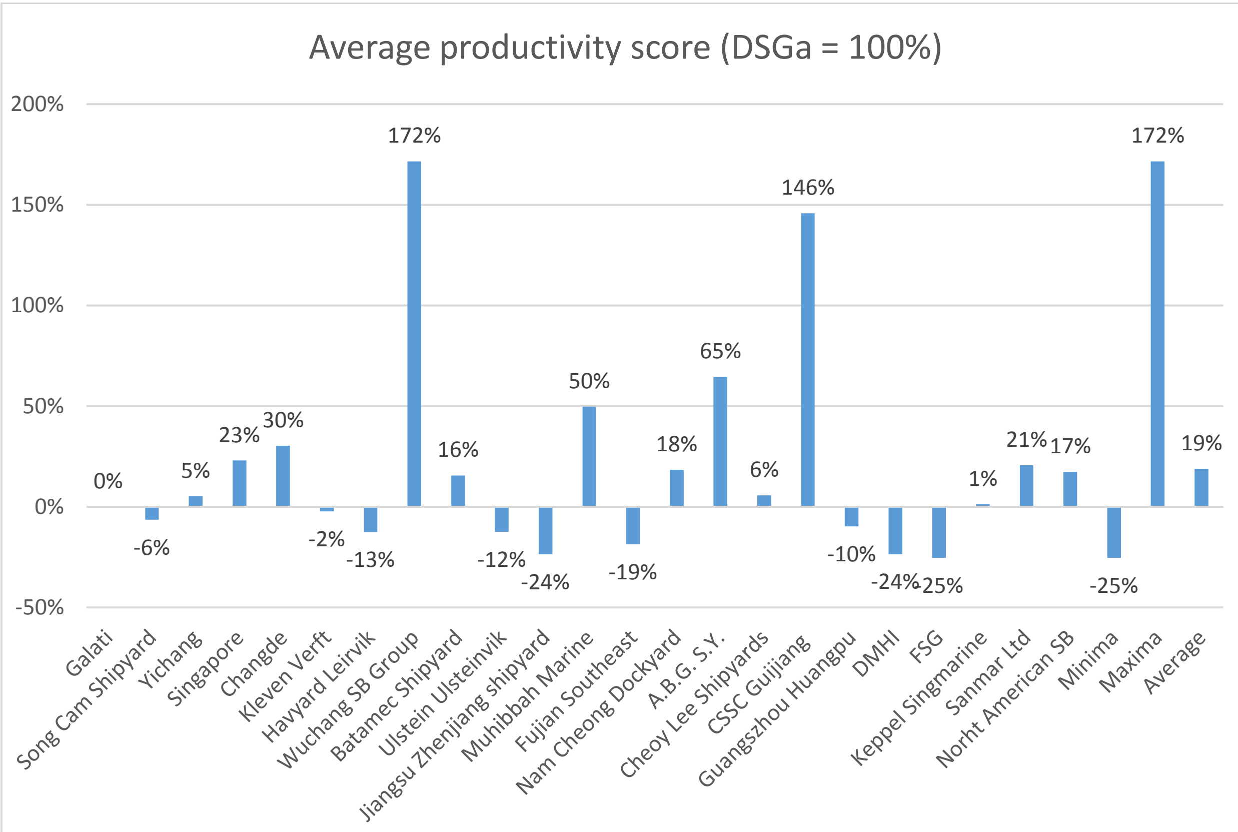

Figure 38: Average productivity scores 2010 - 2016 (DSGa = 0%).

A detailed performance description per Damen yard per year can be found in Appendix O: Damen yards detailed performance scores.

Besides a comparison with the entire industry, the Damen yards will also be compared with direct competing shipyards. These direct competitors are selected based on portfolio and geographical location. These comparisons will enable a better insight in the performance of the Damen yards. Furthermore will the selection of similar shipyards result in a more fair comparison and thereby the results will have more meaning than a simple comparison with the industry average.

5.1. Damen Shipyards Singapore

The first shipyard from Damen which will be treated is Damen shipyards Singapore (DSSi). DSSi is a shipyard which focusses on faster and smaller ship types. The other shipyards in the database are mainly focused on workboats. For this reason there is no specific shipyard in the database with which DSSi can be directly compared. For this reason DSSi is only compared with the industry average. Nevertheless it is interesting to see how the building strategy of this shipyard influences the performance scores compared to the rest of the database.

5.1.1. Time score Damen Shipyards Singapore

DSSi has an average time score of 77% compared to the industry average of 100%, see Figure 36. As previously stated there is no direct competing shipyard with which DSSi can be compared. Nevertheless it is interesting to see that, despite the different product portfolio of DSSi, the shipyard is still able to perform better than the industry average. One has to state that there are a number of outliers in the time performance which increase the industry average, but nevertheless the performance of DSSi seems acceptable.

However, in paragraph 4.1 the usage of a strategic hull stock is already mentioned. This strategic should give Damen an advantage with respect to the competition. Damen should be significantly faster. This advantage is not clearly seen in the time performance results. A worrying conclusion for Damen can be that the stock of hulls is no longer a strategic advantage, but it has become a needed mean to keep up with the competition!

5.1.2. Cost score Damen Shipyards Singapore

DSSi has an average cost score of 328% compared to the industry average of 100%, see Figure 37. This is a bad performance compared to the industry. One should keep in mind that DSSi has a different product portfolio and that it probably takes more resources to build smaller fast vessels than it takes to construct plain steel workboats. Nevertheless the cost score is the highest from all the included shipyards in the performance assessment. Therefore Damen should consider to look at the cost performance of DSSi.

5.1.3. Productivity score Damen Shipyards Singapore

The average productivity differences are depicted in Figure 38. The productivity scores can be seen in Table 20.

Table 20: Average productivity scores 2010 - 2016.

Shipyard	Average Productivity score
Damen Shipyards Singapore	23%
Industry average	19%
Minima	-25%

Although there is no direct competitor, it is interesting how DSSi is performing in the market. It can be seen that the DSSi is performing around the average in the industry. Nevertheless this average is influenced by some extreme outliers. The shipyard is around the middle of the field and this is acceptable if the different product portfolio is taken into account.

The minimum, which indicates the gap with the best performing shipyard in the industry, is approximately 45% lower. This score is achieved by Flensburger Schiffbau Gesellschaft (FSG). This shipyard merely builds fast ferries and more complex vessels. In this perspective they build the same type of ships as DSSI, but the size of the ships produced by FSG is significantly larger. FSG is a highly automated shipyard, which partly explains the higher productivity. Nevertheless they prove that even with a complex product portfolio it is possible to achieve a high productivity. With this in mind the productivity of DSSi should be increasable.

5.1.4. Conclusion performance Damen Shipyards Singapore

The overall conclusion is that, at first sight, DSSi is performing acceptable with respect to the time scores and bad with respect to the cost scores. Nevertheless DSSi is hard to compare with the other shipyards in the database, because of the different product portfolio. The shipyard is specialized in fast crew boats and ferries. The result is that the shipyard has an entirely different building strategy and that it uses different materials which demand more labour and use of other resources. All these differences result in extreme scores.

Nevertheless the productivity scores show that the performance of DSSi is in the middle of the field. A productivity gap of 45% is present with respect to FSG. This gap also strengthens the earlier made concerns with respect to the hull stock. Apparently competing shipyards are able to produce faster or at the same rate as DSSi, without the use of a hull stock. The higher productivity of FSG, which also builds fast aluminum vessels, proves that DSSi has improvement possibilities with respect to the productivity. Such an improvement in productivity helps to increase the cost score performance and thereby would give DSSi a better position in the market.

5.2. Damen Song Cam Shipyard

Damen shipyards Song Cam Shipyard (DSCS) is the outfitting location of Damen in Vietnam. The hulls, which are outfitted at DSCS, are built at another location. This makes it difficult to compare DSCS with other shipyards, while no other shipyard in the database has the same building strategy. Thereby there are no comparable shipyards available in the database with which DSCS can be directly compared. Nevertheless the results give more insight in the usability of the performance model.

5.2.1. Time ranking Damen Song Cam Shipyard

DSCS has a time performance score of 96% compared to the 100% which is the industry average (Figure 36). Thereby the shipyard is very close to the average time score. This score is in the middle of the field and the time performance of DSCS seems acceptable.

Nevertheless DSCS is an outfitting yard. The hulls which are outfitted on the shipyard are constructed at another location. With this knowledge, the time performance of DSCS should be better than the other shipyards in the database, while DSCS has to execute a smaller portion of the work. This isn't the case and this is a point of attention!

5.2.2. Cost ranking Damen Song Cam Shipyard

The average cost score of DSCS is 9% compared to the industry average of 100% (Figure 37). This is exceptionally good! The shipyard is performing at the top of the industry and it seems that they outperform all other competing shipyards.

It has to be mentioned that DSCS is only an outfitting yard. The construction of the hull is performed at another location and thereby outsourced. Nevertheless in the current defined performance model DSCS is assigned credit for the entire ship and the only spent resources on the outfitting. The cost of outsourcing are neglected and this favors the building strategy of DSCS. This explains the exceptionally high cost performance. In these results the concerns of paragraph 3.2 about neglecting the costs of outsourcing comes forward. With the current performance model it is not fair to compare shipyards which have an entirely different building strategy with respect to outsourcing. This will be further treated in the recommendation.

5.2.3. Productivity score Damen Song Cam Shipyard

The average productivity differences are depicted in Figure 38. The results are summarized in Table 21.

Table 21: Average productivity scores 2010 - 2016.

Shipyard	Average Productivity score
Damen Shipyards Song Cam Shipyard	-6%
Industry average	19%
Minima	-25%

It can be seen that only seven shipyards (30%) have a higher productivity than DSCS. This indicates that the productivity performance is very good compared to the rest of the industry. This is in line with the cost performance in paragraph 5.2.2. Again there should be mentioned that DSCS outsources the construction of the hulls and thereby they are given credit for a part of the work which they don't execute.

There is still a productivity gap of 20% with the best performing shipyard in the industry which is again FSG. As mentioned in paragraph 5.1.3 FSG builds complex vessels and is highly automated. This shipyard proves that it is possible to achieve very high productivity and thereby stay competitive, despite the high wages in Germany. The advantage of DSCS is that the wage level in Vietnam is significantly lower. Thereby they have a cost advantage. Nevertheless it is possible to increase the productivity and thereby strengthen their position in the market.

5.2.4. Conclusion performance Damen Song Cam Shipyard

At first sight DSCS is performing acceptable with respect to the time and they are performing excellent with respect to the cost.

A closer examination of the shipyard shows that the scores are less good than they seem. DSCS is only an outfitting yard. Thereby, the hulls are constructed at another location and DSCS is performing a smaller portion of the work than shipyards which do the entire building process themselves.

Based on this fact, the time performance of DSCS should be significantly better! At this moment it is around the industry average and with the knowledge of the building strategy of DSCS this is a bad result.

The good cost performance was already predicted upfront. DSCS has a big advantage, compared to the other shipyards in the database, in the used cost performance model. They only use resources for the outfitting and not for the construction of the hull. This results in lower costs for the shipyard. However, in the performance model, they do receive the credit for the entire ship. The result is a seemingly excellent cost performance.

The same yields for the productivity performance. The productivity seems very good, but there is still improvement possible.

The overall conclusion for the performance model is that it is very hard to compare shipyards from a different type. The different building strategy of DSCS gives the shipyard a big cost advantage compared to the other shipyards in the performance model. This cost advantage is predominantly caused by the fact that outsourcing is not taken into account in this model, see paragraph 3.2. DSCS buys hulls and thereby a large part of the production is outsourced to other parties. These results prove that although it is very hard to incorporate outsourcing, it would significantly improve the applicability of the model. To ensure a fair comparison with the current model, it should only be used to compare shipyards of a similar type.

5.3. Damen Shipyards Galati

Damen Shipyards Galati (DSGa) is located in Romania. Based on the location and the portfolio of DSGa two important competing shipyards are selected from the database:

Sanmar Ltd

The portfolio of Sanmar is very similar to that of DSGa with respect to tugs. Furthermore Sanmar is located in Turkey, which is fairly close to Romania. Therefore Sanmar is seen as an important competitor. Although the personnel information for Sanmar isn't the most certain (see paragraph 3.1) the choice is made to include this shipyard in the comparison.

Ulstein

This shipyard merely delivers platform supply vessels (PSV) in the same size range as DSGa. Ulstein is located in Norway and thereby it is an important competitor.

5.3.1. Time ranking Damen Shipyards Galati

The time performances of the three shipyards can be seen in Table 22. The industry average is set at 100% (Figure 36).

Table 22: Average time scores 2010 - 2016.

Shipyard	Average time score
Damen Shipyards Galati	93%
Sanmar Ltd.	89%
Ulstein	67%

Although the time performance of DSGa is below the average of the industry, Sanmar and Ultstein are performing better. The overall result is that the performance of DSGa is not bad, while the shipyard is performing in the middle of the field. However, the direct competitors are performing significantly better. The result is that an increase in time performance is needed. An increase of approximately 5% - 25% is needed to get in the range of Sanmar and Ulstein.

Thereby, DSGa has the advantage of the strategic hull stock which is used by Damen. Therefore the performance of DSGa should be better compared to the competing shipyards. All together the time performance of DSGa should increase.

5.3.2. Cost ranking Damen Shipyards Galati

The cost performances of the three shipyards can be seen in Table 23. The industry average is set at 100% (Figure 37).

Table 23: Average cost scores 2010 - 2016.

Shipyard	Average cost score
Damen Shipyards Galati	71%
Sanmar Ltd.	127%
Ulstein	141%

In contrast to the time performance, the cost performance of DSGa is very good over the period 2010 – 2016. DSGa is well below the industry average (+-30%) and the direct competitors are both performing worse than DSGa. The cost score of DSGa is in de middle of the field and thereby acceptable. Other shipyards show that there is still an increase possible, but for now the performance is very acceptable.

In Appendix O: Damen yards detailed performance scores the trend of the cost score over seven years can be seen. The cost performance of DSGa is showing an increasing performance trend, but the same trend is visible for the performance of Sanmar and Ulstein. This indicates that although the cost performance is good at this moment, the competition is increasing and should be watched!

5.3.3. Productivity score Damen Shipyards Galati

The average productivity differences with DSGa as reference shipyard are depicted in Figure 38. A negative difference indicates that the competing shipyard is performing better than DSGa. A positive difference indicates that the competing shipyard is performing worse than DSGa. The productivity scores with respect to DSGa can be seen in Table 24.

Table 24: Average productivity scores 2010 - 2016.

Shipyard	Average Productivity score
Damen Shipyards Galati	0%
Sanmar Ltd.	21%
Ulstein	-12%
Industry average	19%
Minima	-25%

The productivity score of Sanmar is in line with the cost score. On both aspects DSGa is performing better. Nevertheless Ulstein has a better productivity performance than DSGa. Although the cost performance is lower, the productivity performance is better. This means that DSGa has an cost advantage due to the geographical location, but that the actual productivity of DSGa is lower than that of Ulstein. This is in line with the time performance. Apparently Ulstein is capable of delivering ships faster due to the higher productivity. This is an important point for DSGa!

Besides the direct competing shipyards, there is also a gap with the best performing shipyards in the industry of approximately 25%. This means that an increase in productivity is possible and is needed!

5.3.4. Conclusion performance Damen Shipyards Galati

The time performance of DSGa seema acceptable with respect to the industry. However, the direct comparison with Sanmar and Ulstein shows that they are performing better, despite DSGa's advantage of the strategic hull stock,. The conclusion is that an increase in the time performance is needed.

The cost performance of DSGa is good. Although there is an increasing trend in the cost performance of Sanmar and Ulstein. These shipyards should be closely followed. Luckily for DSGa the wages in Romania are relatively low, which provides them with a cost advantage.

The difference in productivity shows that DSGa still can improve up to 25%. This improvement is needed to maintain the cost advantage with respect to the direct competition. An increase in productivity could also increase the time performance. This increase in time performance and productivity performance is needed! Especially to keep up with Ulstein.

5.4. Damen Shipyards Changde

Damen Shipyards Changde (DSCh) is located 1200 kilometers upstream from Shanghai on the Yuan river. Based on the location and the portfolio of DSCh an important competing shipyard is selected from the database.

Jiangsu Zhenjiang shipyard

The portfolio of Jiangsu Zhenjiang shipyard is very similar to that of DSCh. Jiangsu Zhenjiang shipyard is also located in China. The two shipyards are approximately 850 kilometers apart. The biggest difference is the amount of ships, which is delivered by both shipyards. DSCh approximately delivers four to eight ships per year, while Jiangsu Zhenjiang shipyard delivers approximately six to ten ships per year. Nevertheless, Jiangsu Zhenjiang shipyard is seen as an important competitor.

5.4.1. Time ranking Damen Shipyards Changde

The time performance scores of DSCh and Jiangsu Zhenjiang shipyard can be seen in Table 25. The industry average is 100% (Figure 36).

Table 25: Average time scores 2010 - 2016.

Shipyard	Average time score
Damen Shipyards Changde	115%
Jiangsu Zhenjiang Shipyards	92%

The time performance of DSCh is above average. The performance is in the bottom of the field and for this reason an increase in the time performance would improve the competitiveness of DSCh. Jiangsu Zhenjiang is performing below the average of the industry and in the middle of the field. This shipyard shows that there is in increase in time performance possible for DSCh.

Thereby the yearly trends in Appendix O: Damen yards detailed performance scores show a decreasing time performance trend. This trend in combination with the fact that Damen uses a hull stock is a bad sign. The shipyards of Damen should be at the top of the time performance, due to the strategic stock advantage. DSCh is at the bottom and shows a decreasing time performance trend. This combination is very worrying for Damen.

5.4.2. Cost ranking Damen Shipyards Changde

The cost performances of DSCh and Jiangsu Zhenjiang shipyard are displayed in Table 26. The industry average is 100% (Figure 37).

Table 26: Average cost scores 2010 - 2016.

Shipyard	Average cost score
Damen Shipyards Changde	68%
Jiangsu Zhenjiang Shipyards	10%

The cost performance of DSCh is very good compared to the industry average. Its approximately 30% lower. With this performance DSCh is performing in the top of the field, which is very acceptable. \

The cost performance of Jiangsu Zhenjiang Shipyards shows that an increase is possible. It must be noticed that Jiangsu focusses on slightly larger vessels than DSCh. Thereby, the performance of Jiangsu Zhenjiang Shipyard is excellent compared to the other shipyards in the database. Nevertheless, they show that there is a lot of improvement possible.

The yearly trends in Appendix O: Damen yards detailed performance scores show an increase in the cost performance of DSCh. So DSCh already shows by itself that improvement is possible.

5.4.3. Productivity score Damen Shipyards Changde

The average productivity differences are depicted in Figure 38. The productivity scores can be seen in Table 27.

Table 27: Average productivity scores 2010 - 2016.

Shipyard	Average Productivity score
Damen Shipyards Changde	30%
Jiangsu Zhenjiang Shipyards	-24%
Industry average	19%
Minima	-25%

Although the cost performance of DSCh is very good, the productivity performance lacks behind. Almost all shipyards prove to have a better productivity performance. There is a gap with Jiangsu Zhenjiang Shipyards of approximately 55%. DSCh should at least improve the productivity to close the gap with the average of the industry. The productivity scores show that DSCh has a cost advantage, which is based on the low wages in China. To stay competitive the productivity should be largely increased!

5.4.4. Conclusion performance Damen Shipyards Changde

The time performance of DSCh should increase. The trend in is that the time performance is decreasing and this is a point of attention. Compared to Jiangsu Zhenjiang Shipyard the performance is acceptable, but still the negative trend should be stopped. The performance of DSCh is worrying, especially if the use of the hull stock is taken into account.

Based on the cost scores DSCh is performing very acceptable. The yearly trend is moving in the right direction. The shipyard is steadily improving and it stays consequently below the average of the industry.

The comparison with Jiangsu Zhenjiang Shipyard proves that there is still a lot of improvement possible on the area of cost performance and so DSCh should keep improving and try to close the gap.

These improvement possibilities also come forward from the productivity performance. An increase of approximately 55% should be possible, if Jiangsu Zhenjiang is regarded. Based in on this productivity gap it is also evident that the good cost performance is merely based on the advantage of low wages in China. To stay competitive in the future DSCh should improve its productivity. This would strengthen the cost performance and it might also increase the time performance of DSCh.

5.5. Damen Yichang Shipyards

Damen Yichang Shipyards (DYS) is located along the Yangtze river, 1670 kilometers from Shanghai. DYS approximately delivers two to five ships per year. Based on the location and the portfolio of DYS two important competing shipyards are selected from the database. These shipyards are:

Wuchang SB Group

Wuchang SB Group is located approximately 275 kilometers from DYS. The portfolio of this shipyard is very similar to that of DYS. Wuchang SB Group delivers approximately five to ten ships per year

Guangszhou Huangpu

The portfolio of Guangszhou Huangpu is very similar to that of DYS. Guangszhou Huangpu is located approximately 900 kilometers from DYS. The biggest difference is that Guangszhou Huangpu is located closely to the sea, while DYS is located along a river further into the mainland. Guangszhou Huangpu delivers between the fourteen and eighteen ships per year.

5.5.1. Time ranking Damen Yichang Shipyards

The time performance of DYS, Wuchang SB Group and Guangszhou Huangpu can be found in Table 28. The industry average is 100% (Figure 36).

Table 28: Average time scores 2010 - 2016.

Shipyard	Average Time score
Damen Yichang Shipyards	63%
Wuchang SB Group	121%
Guangszhou Huangpu	79%

The time performance of DYS is very good compared to the industry average, but also compared to its direct competitors the performance is very acceptable. This good time performance is partly the result of the fact that DYS only constructed pontoons in the period 2014 – 2016, see Appendix O: Damen yards detailed performance scores. The scores of this period increase the average time performance of DYS in the period 2010 – 2016. The time performance in 2010 – 2013 is less good and in this period DYS constructed ships. Therefore the time performance should be closely monitored. Nevertheless it seems that DYS is the only shipyard of Damen which meets the expected time performance, if the use of the strategic hull stock is taken into account.

5.5.2. Cost ranking Damen Yichang Shipyards

The cost performances of DYS, Wuchang SB Group and Guangszhou Huangpu can be seen in Table 29. The industry average is 100% (Figure 37).

Table 29: Average cost scores 2010 - 2016.

Shipyard	Average Cost score
Damen Yichang Shipyards	35%
Wuchang SB Group	214%
Guangszhou Huangpu	33%

The cost performance of DYS is very good. It is in the top of the field. The cost performance of Guangszhou Huangpu is slightly better, but the results can be regarded as similar. Based on the cost performance DYS is performing very well.

Wuchang is an outlier in the field with respect to the cost performance. Thereby, it seems that they aren't much of a treat to DYS. It should be noticed that DYS is only building pontoons in the period 2014 – 2016. Pontoons are easy to build and thereby this has a positive effect on the performance. Despite this fact, the performance of DYS is still good.

5.5.3. Productivity score Damen Yichang Shipyards

The average productivity differences are depicted in Figure 38.The productivity scores can be seen in Table 30.

Table 30: Average productivity scores 2010 - 2016.

Shipyard	Average Productivity score
Damen Yichang Shipyards	5%
Wuchang SB Group	172%
Guangszhou Huangpu	-10%
Industry average	19%
Minima	-25%

In these productivity differences it can be seen that the actual productivity of DYS is good, but that Guangszhou Huangpu is performing approximately 15% better. The best performing shipyards in the industry are even performing 30% better. This shows that there is still a lot to gain for DYS on the productivity side. An increase in productivity could strengthen the position in the market.

5.5.4. Conclusion performance Damen Yichang Shipyards

Based on the time performance the results seem very good at first sight. There is however a difference in the time performance of DYS in the period in which they constructed ships (2010 – 2013) and the period in which they constructed pontoons (2014 -2016). DYS significantly improves their average time score in the period in which they only build pontoons. The difference in time performance for the construction of ships and pontoons gives rise to extra attention for this topic. If DYS will start producing more ships, Damen should keep a close eye to this time performance.

The cost performance of DYS is very good compared to the industry. Nevertheless the productivity performance shows that there are improvement possibilities. So a part of the good cost performance is based on the wage advantage of being located in China. To maintain a good position the productivity of DYS should be improved. This could result in an even better place in the market.

6. Performance model expansion opportunities

The results with respect to the cost, time, quality and productivity score can be used to investigate if there are differences between shipyards and how to quantify these differences. A following step is to investigate where these differences originate from and if it is possible to improve the performance of a shipyard.

First of all the differences between DSGa and DSCh will be further investigated in paragraph 6.1. There is detailed information within Damen about these shipyards and based on this information a comparison will be made for:

- Shipyard layout
- Areas
- Cranes
- Personnel
- Other influences

The differences between these resources will be coupled to the found scores. The aim of this comparison is to discover relations

Secondly the results of DSGa will be further investigated in paragraph 6.2. A scenario analysis will be done to investigate investment possibilities. Several scenarios will be defined and calculated to see how the performance of the shipyard changes.

6.1. Comparison of Damen Shipyards Galati and Damen Shipyards Changde

Based on the found results in chapter 5 the overview in Table 31 is made. In this table the scores of DSCh are represented with respect to DSGa. So for each year and each score the score of DSGa is taken as the 100% value. A score below 100% means that DSCh outperforms DSGa and a score above zero means that DSGa outperforms DSCh.

Table 31: Comparison DSGa and DSCh with DSGa as reference.

	Cost	Time	Productivity	Cost	Time	Productivity
Year	DS Changde	DS Changde	DS Changde	DS Galati	DS Galati	DS Galati
2010	97%	66%	134%	100%	100%	100%
2011	79%	198%	114%	100%	100%	100%
2012	52%	120%	94%	100%	100%	100%
2013	104%	123%	121%	100%	100%	100%
2014	136%	89%	134%	100%	100%	100%
2015	104%	123%	114%	100%	100%	100%
2016	185%	178%	154%	100%	100%	100%
Average	**108%**	**128%**	**124%**	**100%**	**100%**	**100%**

In general the performance of DSGa is better than the performance of DSCh. The average values over the entire period are all above 100%. Only in for the cost score the performance of DSCh is better in 2010 – 2012. Probably this is the result of the relative low wages for DSCh. Then again this advantage is also there in the latter period and here the cost score of DSCh is worse than the Cost score of DSGa.

The found differences will be coupled to known yard parameters. The aim is to find relationships between them. For this reason three yard aspects are chosen. These yard aspects are chosen based on the available information at Damen.

- Shipyard lay out: paragraph 6.1.1
- Available areas: paragraph 6.1.2
- Available cranes: paragraph 6.1.3
- Available personnel: paragraph 6.1.4
- Other influences: paragraph 6.1.5

Finally a conclusion will be given in paragraph 6.1.6.

6.1.1. Shipyard lay out

It is important to structure the processes in a logical way. This enables a logical and good flow of materials across the shipyard. The chronological structuring of processes helps to improve this flow.

The place of all the processes is identified on the shipyard map for both shipyards. Each process is given a color. The matching color for each process can be seen in Table 32. The idea behind the colors is that a logical structured process will result in a rainbow on the shipyard map. if processes are not logically ordered a more abstract painting will be the result.

Table 32: Color table for the identification of processes in the shipyard layout.

Type of area	Color
Pre-processing fabrication	
Panel assembly (sub-panels)	
Panel assembly (main-panels)	
Section assembly including hot works and pre-outfitting	
Block assembly including hot works, painting and outfitting	
Hull assembly including hot works, painting and outfitting	
Launching	
Outfitting quay - outfit and paint completion, commissioning and delivery	
Warehousing	
Outfit part production workshops	

The shipyard layout for DSGa can be found in Figure 39. The shipyard layout of DSCh is depicted in Figure 40.

Figure 39: Shipyard layout DSGa.

Figure 40: Shipyard layout of DSCh.

DSGa

The process of DSGa depicts two nice material flows. One over the left and one over the right side of the shipyard. in the middle a lot of warehousing can be found. There are some warehousing points inside the pre-fabrication process, but in general all processes are sorted and in logical order.

DSCh

The yard map of DSCh shows a generally good material flow over the left side of the shipyard. on the right side the process is less structured. Furthermore there are everywhere small colored dots. This means that processes aren't perfectly separated. Thereby it seems that there is still some improvement possible in the structuring of the processes on the DSCh yard.

6.1.2. Available areas

Each shipyard has a certain amount of area available for the production processes. This area is defined as the net area. The available gross area, net area and the ratio between them can be seen in Table 33.

Table 33: Available area per shipyard.

Shipyard	Gross area [m²]	Net area [m²]	Used percentage [-]
DSGa	172996,5	164938,6	95%
DSCh	48680,0	45766,3	94%

From this comparison it becomes clear that DSGa is a lot larger than DSCh, but it seems that both yards use the same relative amount of the available area. The net area can divided according to the way in which it is used. Is it an open area (outside), are there offices or is there a facility (hall). This division can be seen for both shipyards in Figure 41.

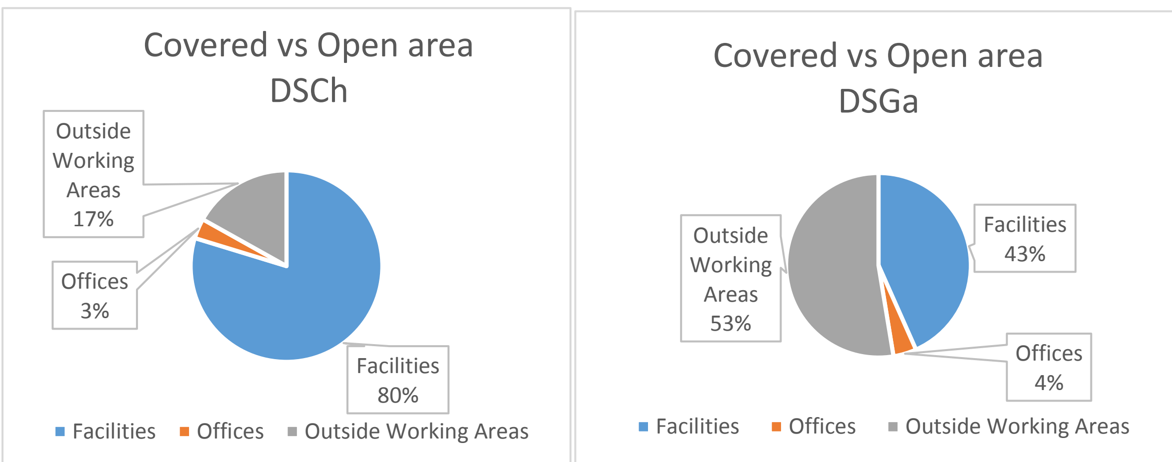

Figure 41: Area usage for DSGa and DSCh.

From this comparison it can be seen that DSCh has relatively more covered building area. This is an advantage with respect to the building strategy. Covered working areas are not influenced by the weather. Thereby the conditions are constant and this results in a constant building strategy and quality of the work. Working outside comes with much more unpredictable circumstances. This influences the building strategy and makes it more difficult to attain a constant quality. The amount of offices is the same for both shipyards.

It is also possible to look at the division of the net area per process step. This division is displayed in Figure 42.

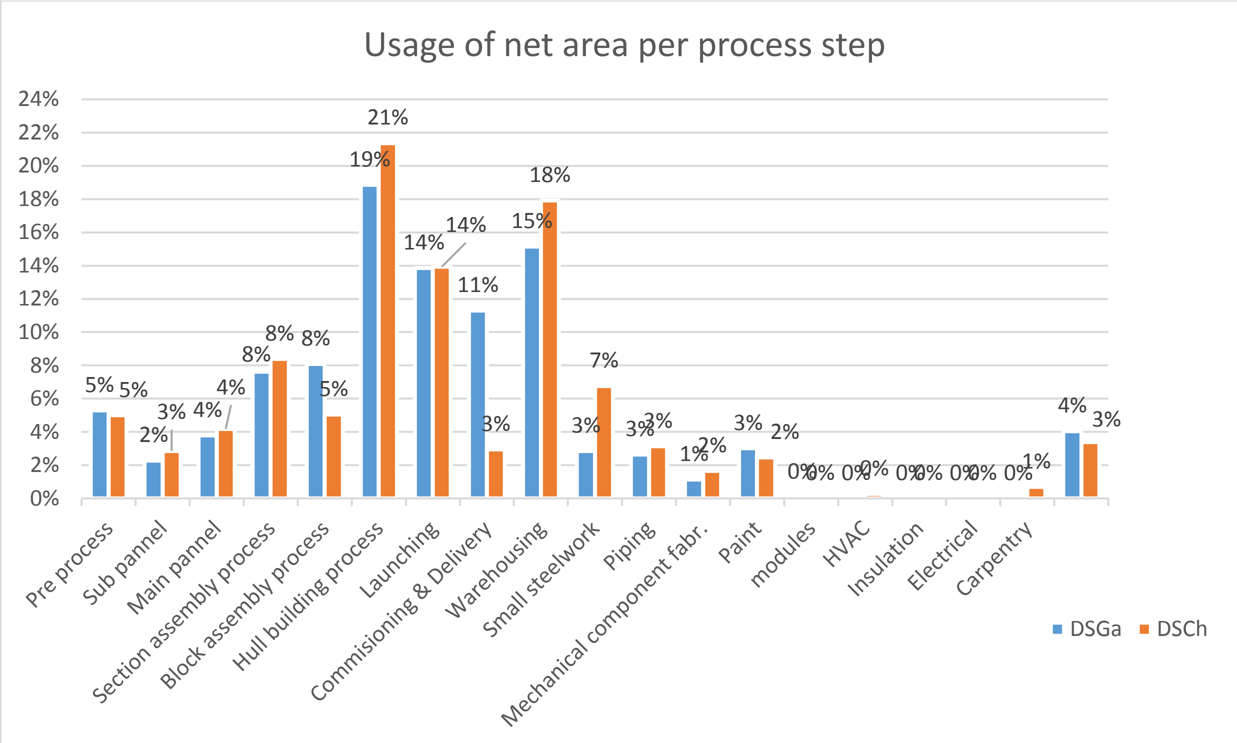

Figure 42: Usage of net area per process step.

The relative use of the net areas is similar for both shipyards. There are however some differences:

- <u>Block assembly process:</u>
  DSGa has almost twice as much space available for block building. Thereby DSGa has more capabilities for pre-outfitting which should result in a higher productivity. This higher productivity is also achieved in the performance model.
- <u>Hull building process:</u>
  DSCh uses relative 3% more space for the hull building process. This can be a result of the smaller pre-outfitting possibilities. Probably DSCh has to do more outfitting and construction work at the dock/slipway. This decreases the productivity and increases cost and delivery time.
- <u>Commisioning & Delivery</u>
  In contrast with the previous two points, DSGa uses a lot more space for the commissioning and delivery of the ships. Probably DSGa chooses to intensify the production speed in the dock/slipway, because this is a bottleneck. The result is that more work has to be done after the launching of the vessel. This feels somewhat contradictonary to the found performance results.
- <u>Warehousing:</u>
  DSCh uses relative 3% more space for warehousing. This could be an indication of buffers. Buffers could be an indication of bottlenecks in the process. bottlenecks in the process result in a lower productivity and longer delivery times, which is in line with the found performance results.
- <u>Small steel work:</u>
  DSCh uses relative 4% more space for small steelwork. This is twice as much space as DSGa. This can be a result of the product portfolio. Probably the ships of DSCh have more small parts, or the process is less efficiently organized than for DSGa, which is in line with the found performance.

The net available area per process step can be divided among five production aspects.

1. Machine area
2. Work area
3. Buffer area
4. Transport area
5. Rest area

This division is depicted for both shipyards:

- DSGa: Figure 43
- DSCh Figure 44

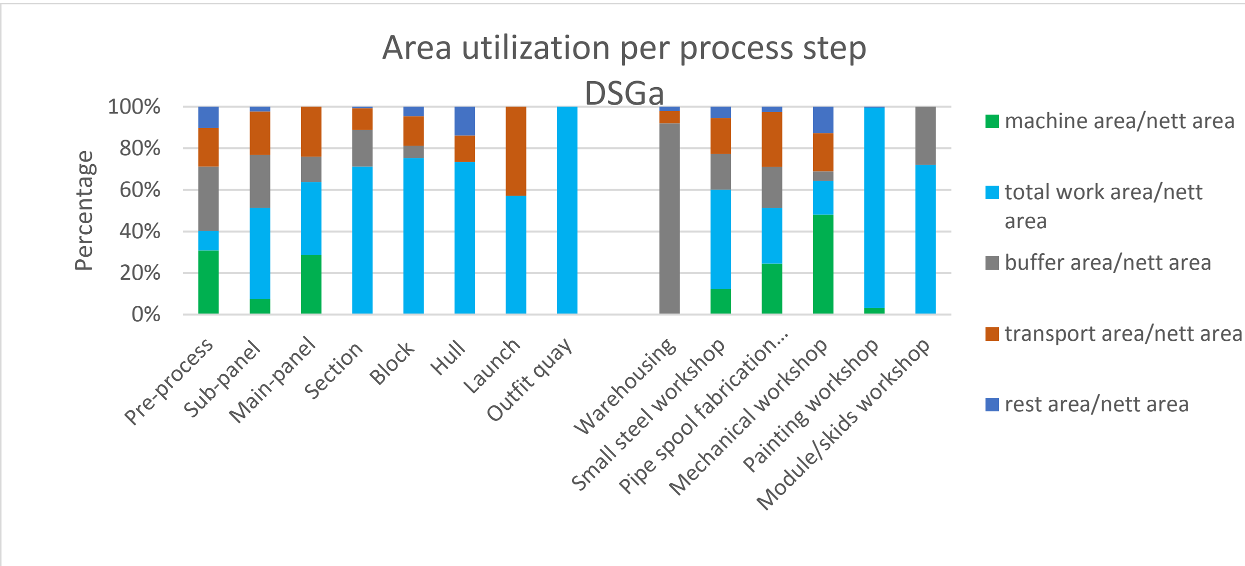

Figure 43: Area utilization of DSGa.

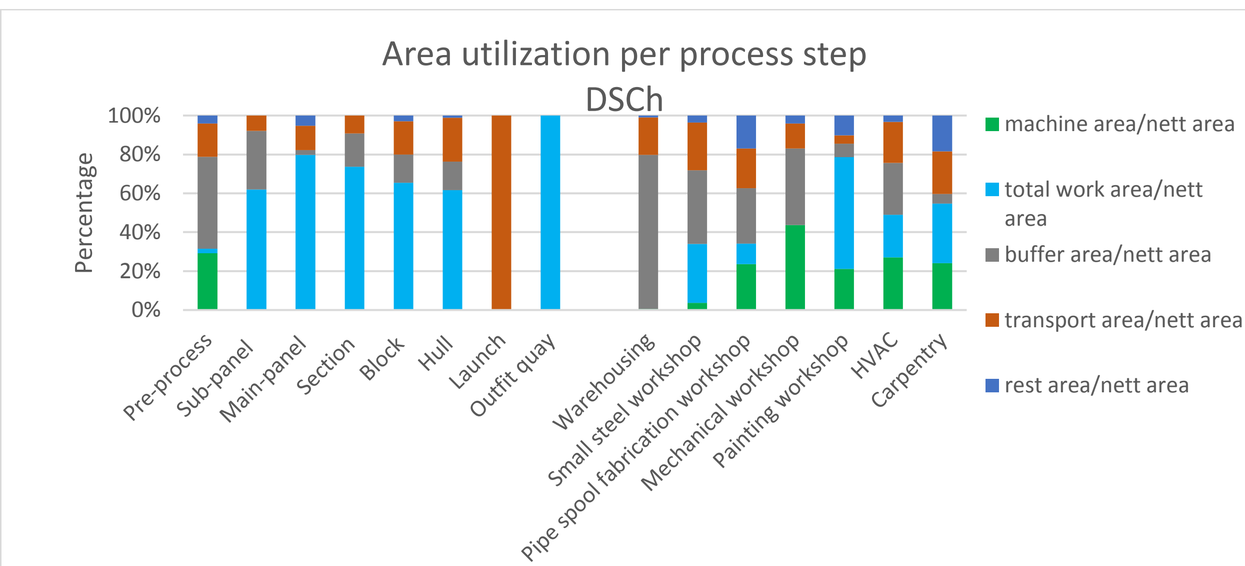

Figure 44: Area utilization of DSCh.

Machine area

DSCh has relatively less machine area in the sub-panel and main-panel process. This is the result of the fact that DSCh is less automated than DSGa. Which is in line with the lower productivity

Work area

Due to the smaller amount of automation in the sub-panel and main-panel process there is more workspace area in these process steps. Furthermore there is no workspace area at the launching area at DSCh. This is a big difference with DSGa, while here workspace area is available for this process step

Buffer area

In all process steps DSCh has relatively more buffer area than DSGa. This space is 'wasted' on materials which are just waiting. Therefore is an indication of a worse material flow on the shipyard or worse performing processes which demand safety buffers. This is in line with the found lower productivity of DSCh.

Transport area

The relative transport areas are approximately the same on both shipyards. The only exception is the launching process. DSCh uses all the space in the launching process for transport, while DSGa also has workspace available at the launching process.

Rest area

The relative amount of rest area is the same for both shipyards.

Conclusion

The overall conclusion is that there are no spectacular differences in the use of areas between the two shipyards. Nevertheless, in each of the addressed areas the process of DSGa is somewhat better organized than the process of DSCh. The result of all these advantages adds up to the fact that DSGa is performing significantly better than DSCh. Thereby this investigation proves that it is very important to keep track of the usage of the available areas on a shipyard, because this seems to have a strong relation with the performance of the shipyard.

For the Damen yards the information about these areas is internally available. For competing shipyards it could prove to be more difficult to find this kind of information. An important source could be the use of satellite images. Internet sources like google maps (Google, 2017) and company websites could be used to retrieve this information. An example of the use of google maps is given in Appendix P: Calculation of areas from satellite images.

6.1.3. Available cranes

There are certain perspectives which can be used if the crane capacity of shipyards is compared. An important aspect is the maximum hoist capacity and then especially the maximum hoist capacity which is available for the hull assembly. This capacity determines the size of the sections which can be pre-fabricated. Thereby it determines a great part of the building strategy of a shipyard. In general a shipyard would like to pre-outfit as much as possible in large sections. Thereby a ship can be assembled very fast and the dock/slipway is intensively utilized (high number of ships per dock/slipway). For most shipyards the amount of dock/slipway is the limiting factor (bottleneck). Thereby a high utilization of this production asset is favorable for a shipyard. The maximum hoisting capacities for both shipyards can be found in Table 34.

Table 34: Maximum available hoisting capacity per shipyard.

Shipyard	Max hoist cap. [ton]
DSGa	320
DSCh	120

This comparison is favorable for DSGa. Based on the maximum hoisting capacity DSGa is capable of building section which are almost three times heavier than the sections which can be built by DSCh. Thereby DSGa can built sections which are larger and further equipped. This should speed up the hull construction process.

6.1.4. Available personnel

The available amount of personnel is also an important resource for a shipyard. Therefore the performance model is primarily based on this information. The relative amount of available personnel is depicted in Figure 45.

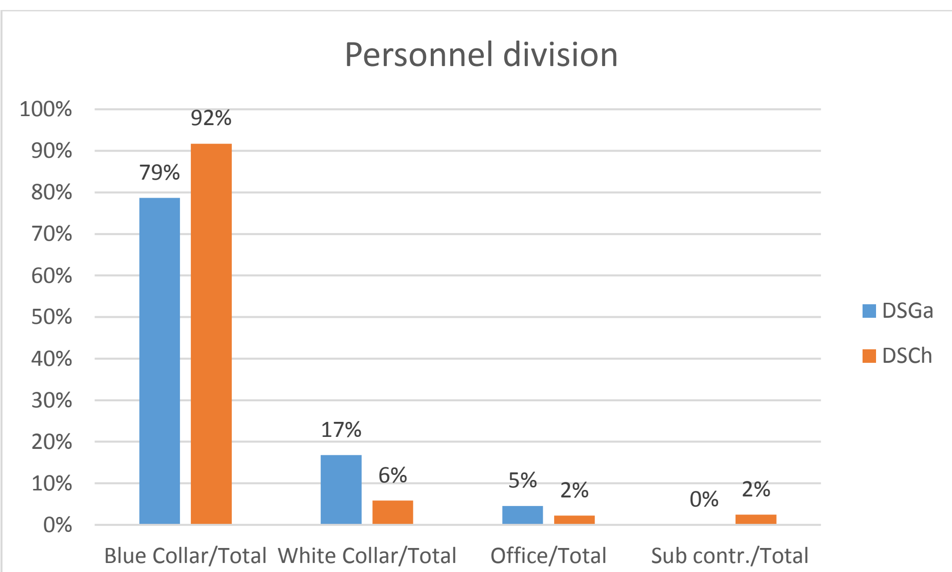

Figure 45: Personnel division per shipyard.

The differences in office personnel and sub contracted personnel are relatively small. There is however a difference between the amount of blue collar and white collar workers. It seems that DSGa has relatively more white collar and less blue collar employees than DSCh. This could be an indication that more emphasis is putted on work preparation, engineering and automation. Thereby one could expect that the processes of DSGa are better engineered and that this will give an advantage to the shipyard. This should result in a higher productivity and this is in line with the found performance results. However, white collar employees are also more expensive. This can also partly be seen in the achieved cost performance. The differences in cost performance are smaller than the differences in the productivity performance. Of course there are also other influences, like the geographical location, but it is striking that the performance results are in line with the differences in personnel.

It could also be interesting to look at the division of the personnel across the process steps. Unfortunately this information is not available and thereby it is not included in this comparison.

6.1.5. Other influences

Besides the resources which are treated in the previous paragraphs there are also a lot of other elements which influence the production performance of a shipyard. Some of them can be given a quantitative number others are more soft elements. Examples are:

1. Management structure
2. Country culture
3. Building strategy
4. Ship type

These influences can all be related to the performance of a shipyard. especially the building strategy of a shipyard is influencing the performance. This is highly related to the previous described resources. Thereby research into the relation between the building strategy of a shipyard and the performance of a shipyard seems promising.

6.1.6. Conclusion

Based on these comparisons between the two shipyards the following conclusions can be drawn.

Shipyard lay out

Based on the structuring of the processes on the shipyard, the process of DSGa seems better organized than the process of DSCh. The logical structure of the DSGa yard should provide a better and faster material flow than on the DSCh yard. Thereby DSGa should perform better than DSCh and this relation is also seen in the performance results. It is not yet possible to quantify this relationship, while this is only investigated for two shipyards.

Available area

Based on the made comparison, it seemed that the found differences in performance scores can't directly be explained by one factor of the available areas. Although the combination of advantages seem to result in a significant performance differences between DSGa and DSCh. This shows that it is an advantage to investigate the use of areas on a shipyard.

Available cranes

There is a relation between the maximum hoisting capacity of a shipyard and the performance. There is expected that a larger maximum hoisting capacity is associated with more building strategy possibilities.

Thereby a larger hoisting capacity should be favorable for the performance of a shipyard. this expectation is in line with the found results. It is not yet possible to quantify this relationship, while this is only investigated for two shipyards.

Available personnel

If the assumption is made that a larger part of white collar workers is the result of more emphasis on work preparation and engineering, than should a shipyard with relatively more white collar employees have a higher productivity. This assumption is in line with the found productivity differences between DSGa and DSCh. On the other hand are white collar employees more expensive. This result is also partly visible, while the difference in cost performance between DSGa and DSCh are smaller than the differences in productivity performance. Thereby a relation between the division in blue collar vs white collar employees and the performance can be assumed. It is not yet possible to quantify this relationship, while this is only investigated for two shipyards.

Other influences

As said there are much more influences which have an effect on the performance of a shipyard. Most of the mentioned influences are not inserted in the model, because they are very hard to capture. Some of them could be coupled to the described yard parameters. For example the available building facilities and maximum crane capacity are closely related to the building strategy of as shipyard. In the same way will the building strategy influence the amount and type of employees which are needed. The amount and type of employees will have a relation with the used management structure.

Almost all the mentioned resources and influences are related. This gives rise to a need for extra research into these relationships. Besides the relationships between these resources and influences, the relationship with respect to the performance scores is also important. A more detailed research is needed to find and quantify these relationships. A good starting point for deeper analysis are:

- Shipyard lay out
- Available areas
- Available cranes
- Available personnel
- Building strategy

These influences seem related to the performance scores and thereby to the performance of a shipyard.

6.2. Improving possibilities for Damen Galati

The found differences in performance scores between Damen Galati and the rest of the industry give rise to the question how the shipyard can improve itself. It is outside the scope of this research to define an exact investment plan with investment possibilities. Nevertheless it is interesting to do a scenario analysis in which different cost and productivity changes are assumed. Thereby it is possible to get more feeling for the magnitude of the involved numbers.

The assumption is made that the performance of Damen Galati can be increased based on the found performance scores. To increase the performance an investment is needed. The result of this investment will be an increase of the productivity, but also an increase of the depreciation costs. Based on the integral costing principle, this increase of the depreciation will result in an increase of the labour costs. For now the assumption is made that the entire investment has to be earned back by the blue collar employees. Thereby and investment will increase the productivity, decrease the amount of blue collar employees, but also increase the wage of the remaining blue collar employees.

The calculation of the investment sum will be clarified in paragraph 6.2.1. After that the used scenarios will be defined in paragraph 6.2.2. Finally the results for each scenario and a conclusion will be given in paragraph 6.2.3.

6.2.1. Investment sum

The chosen depreciation period for the fictional investment is 10 years. The hourly rate at Damen Galati for blue collar personnel is €15,00/hr. A normal workweek at Damen Galati is 40 hours and on average an employee will work 45 weeks per year. Together with the assumption that the wage increase is totally caused by the investment, it is possible to calculate an investment. This investment is thereby dependent on the assumed wage increase and can be calculated with equation (18).

$$Investement\ [€] = (40 * 45)\left[\frac{hr}{yr}\right] * 10\ [yr] * (rate * increase)\left[\frac{€}{\mathrm{hr}}\right] * \text{ employees } [-] \qquad (18)$$

In this equation is the first part the amount of working hours per year. This will be the corrected amount of workers. In other words if the productivity in a scenario is increased with 10%, the amount of employees will decrease with 10%. With this new amount of employees the investment sum is calculated. This amount of employees is multiplied with the assumed depreciation period of ten years. Then the increase of the employee rate is calculated and multiplied with the amount of workhours per year and the amount of employees. The result is an fictional investment.

6.2.2. Scenarios

Three series of scenarios are defined. Each series consist of five scenarios. In each scenario a fictive increase in the productivity is assumed. The result of this fictive increase in productivity is a decrease of the amount of blue collar personnel. At the same time an increase of the wage is assumed. This wage increase is needed to compensate for an investment sum which can be used to establish the increase in productivity. The calculation of this investment sum is defined in paragraph 6.2.1.

The three series of scenarios each have a different ratio between the productivity increase and wage increase. Each series consists of five scenarios. The in total fifteen scenarios are depicted in Table 35.

Table 35: Performance scenarios.

Scenarios					
	Wage increase	Productivity increase		Wage increase	Productivity increase
basis	0,0%	0,0%	**8**	7,5%	30,0%
1	5,0%	10,0%	**9**	10,0%	40,0%
2	10,0%	20,0%	**10**	12,5%	50,0%
3	15,0%	30,0%	**11**	7,5%	10,0%
4	20,0%	40,0%	**12**	15,0%	20,0%
5	25,0%	50,0%	**13**	22,5%	30,0%
6	2,5%	10,0%	**14**	30,0%	40,0%
7	5,0%	20,0%	**15**	37,5%	50,0%

For each of the scenarios the cost scores are calculated using the method described in paragraph 3.1. These cost scores are compared to the baseline. The baseline is the initial cost performance score of DSGa without an investment. Against this baseline an increase or decrease in performance can be calculated. The difference in cost scores only depict the differences in labour costs. Therefore these differences are again scaled, just as the productivity number, to depict the entire picture (see paragraph 3.2.5).

6.2.3. Results

The results for the three series of scenarios are depicted in:

- Scenarios 1-5: Figure 46: Investment scenarios 1 to 5 for DSGa.
- Scenarios 6-10: Figure 47: Investment scenarios 6 to10 for DSGa.
- Scenarios 11-15: Figure 48: Investment scenarios 11 to 15 for DSGa.

The yellow column depicts the investment sum which is available based on the new amount of employees and the increase of the wage (see paragraph 6.2.1). The blue line depicts the difference between the new cost score and the cost score in the basis scenario. This is the cost score which only takes the labour part of the performance into account! (see paragraph 4.2). The orange line depicts the difference between the new cost score and the cost score in the basis scenario, including the entire picture. In these scores there is compensated for the constant costs which initially are not taken into account in the performance model.

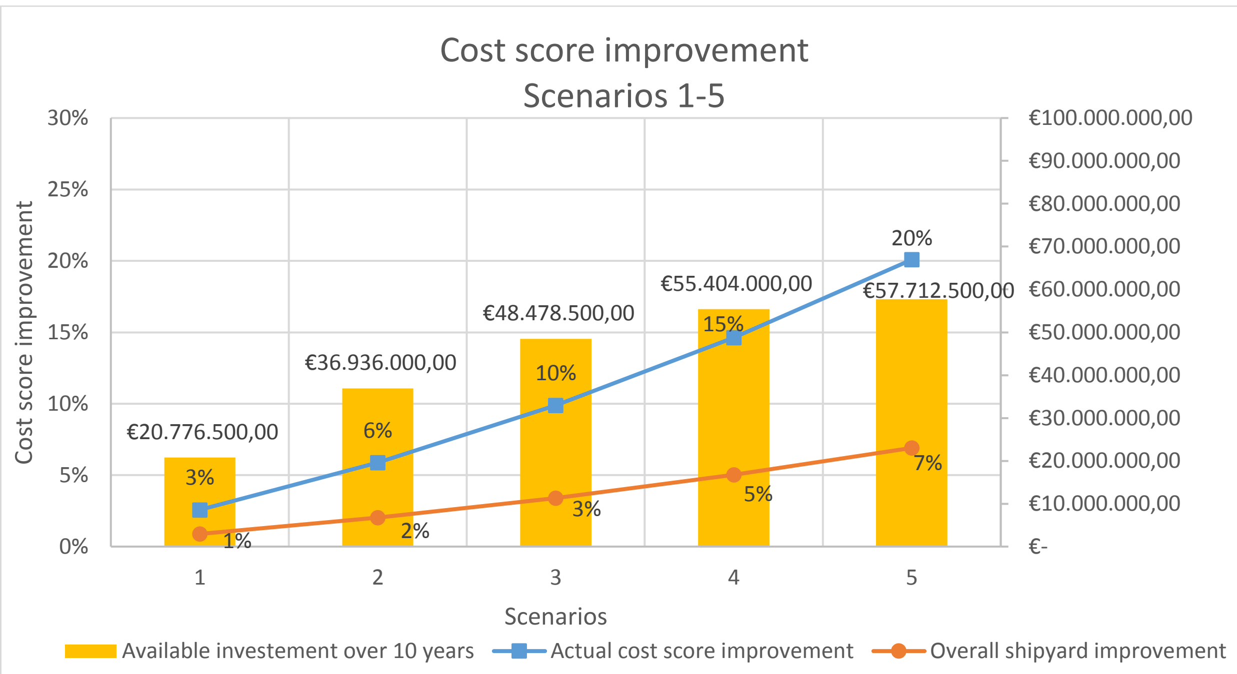

Figure 46: Investment scenarios 1 to 5 for DSGa.

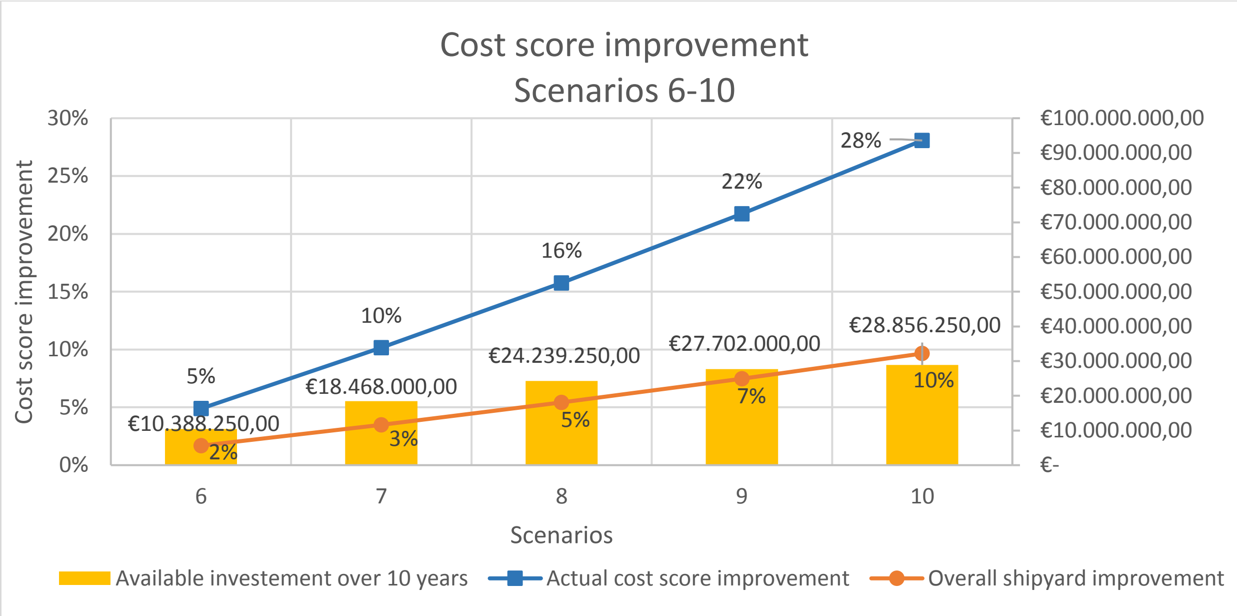

Figure 47: Investment scenarios 6 to10 for DSGa.

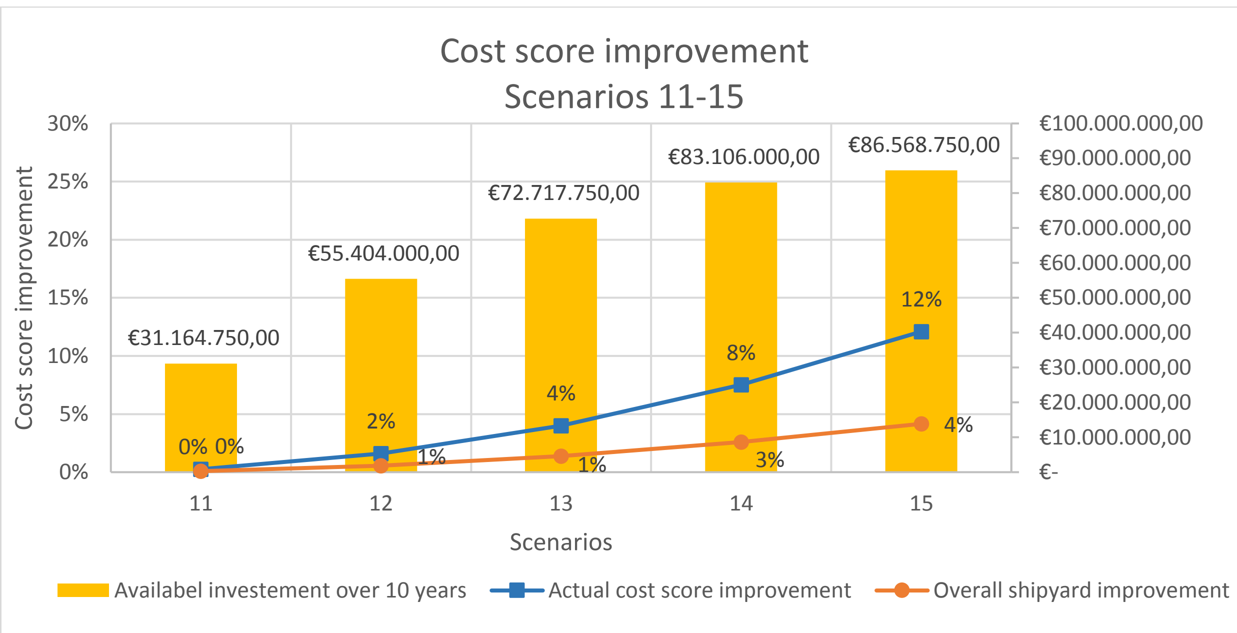

Figure 48: Investment scenarios 11 to 15 for DSGa.

The most conservative scenarios are the scenarios 11 to 15. In these scenarios the wage increase is in each scenario relative the highest. Thereby it gives a lot of investment space to achieve an relatively low performance increase. The result is that these scenarios are not very attractive.

The scenarios 6 to 10 are the most positive scenarios. The increase of the productivity is relatively high compared to the increase of the wage level. Thereby the performance level increases significantly, but the accompanying investment sum is also a lot smaller. It is approximately three times smaller compared to the scenarios 11 to 15. This results in scenarios which are most probably very optimistic.

The scenarios 1 to 5 are in the middle of the other two groups. Of the three series these scenarios seem the most reasonable. Accordingly to these scenarios it should be possible to attain an increase of the cost score performance of 1% to 7%. For this increase an investment sum of approximately 21 to 57 million euros is available, if the wages are increased with the proposed percentages. With these amounts of money it seems possible to make changes to a shipyard and to rearrange and improve processes. Furthermore the increase in cost score performance would bring DSGa much closer to the top of the industry.

Although the results are linear and very straight forward, they give an indication about the investment sum which is needed to close the cost score performance gap with the competition. To make a good investment plan, much more research is needed. Nevertheless these results give a first indication in the magnitude of the numbers.

7. Conclusion

Concluding from this research, the answer to the main question is two sided. The phrased main question in paragraph 1.3 is:

''Can the performance level of Damen yards be quantitatively compared to competing yards under the constraint of limited data availability?''

Yes, because based on the defined cost, time and productivity performance score it is possible to define the differences between Damen yards and competing shipyards in a quantitative way. Furthermore it is possible to quantify a productivity difference between shipyards and thereby it is possible to place shipyards in the market and define the playing field.

No, Because it was not yet possible to define an overall performance score. Furthermore it seemed that it is difficult to compare shipyards only based on numbers. There are differences between shipyards which are very hard to capture in one number.

At the basis of the answer to the main question lies the answers of the sub questions.

1. Which parameters are important if the performance of a shipyard has to be assessed?

The important parameters for the performance model are captured in four areas of interest. These areas of interest are the input for the performance model:

1. Product output
2. Economy & Market
3. Process & Facilities
4. Personnel & Organization

2. Which required parameters can be obtained and what is their quality?

Data is gathered from shipyards that have a similar shipyard profile as:

- Damen Shipyards Galati
- Damen Shipyards Changde
- Damen Yichang Shipyards

There are eighteen shipyards selected. It turned out that the following data could be retrieved, see Table 36. The quality of the found data is ranked (0 = bad to 5 = excellent).

Table 36: Four areas of interest with available data.

Areas of interest	Available data	Quality [0-5]
Product output	Lightweight	3
Economy & Market	Exchange rates, global wage levels	5
Process & Facilities	Production times	3
Personnel & Organization	Number of employees	3

3. ***How can these parameters be structured in a performance model which captures the relationships and the importance of the parameters?***

The final model structure is based on three structuring methods:

1. *Iron triangle (Time, Cost, Quality)*
2. *Production performance*
3. *Cost price of a ship*

Eventually the performance of a shipyard is based on three scores which provide an overall performance:

1. *Quality*
   The quality performance is defined as effectiveness. The effectiveness is assumed to be one, because a shipyard is expected to deliver a ship and the final product of a shipyard is a ship.
2. *Time*
   The time performance of a shipyard is based on the duration of the projects. The duration is benchmarked against the industry to define the time performance.
3. *Cost*
   Only the fluctuating part of the cost is included, because the aim of the performance model is to compare shipyards. Thereby the cost price is based on the use of direct and indirect labour..

The aim was to combine these three scores to an overall performance score, due to limitations in the model and data this wasn't possible. Therefore shipyards are ranked on each score individually to define their place in the market.

To provide more insight in the found differences, a productivity performance is introduced. This performance is used to quantify the productivity gap between shipyards. The result is that a shipyard can be ranked based on quality, time and cost and that the improvement possibilities are quantified with a productivity number.

4. ***What is the performance of Damen yards compared to other shipyards?***

The performance of the Damen yards is established based on the average performance scores over the period 2010 – 2016. The performances, compared with the other shipyards in the database, proved in general to be acceptable. The shipyards of Damen perform around the average of the industry. Nevertheless this doesn't mean that there is no improvement possible. None of the shipyards is performing at the top of the industry regarding time, cost and productivity performance.

Especially a better performance was assumed on the time performance. Damen uses a strategic hull stock. This should enable Damen to deliver ships faster than their competitors. However, it turned out that the time performance of the Damen yards is comparable to that of its competitors. Apparently the hull stock isn't a strategic advantage anymore, but it has become a needed mean to keep up with the competition. This fact is supported by the found productivity performances, which show that Damen is lacking behind the competition.

Based on the found results, each of the Damen yards should be able to increase their productivity.

- Damen Shipyards Singapore — Increase: 45%
- Damen Shipyards Song Cam Shipyard — Increase: 20%
- Damen Shipyards Galati — Increase: 25%
- Damen Shipyards Changde — Increase: 55%
- Damen Yichang Shipyards — Increase: 30%

The increase in productivity should help to improve the time performance and strengthen the position of Damen in the market. Extra research is needed to define the exact causes of these performance differences.

For Damen Shipyards Galati and Damen Shipyards Changde a comparison of the available yard resources is made. Based on this comparison it seems that there is a relation between:

- Shipyard lay out
- Available areas
- Available cranes
- Available personnel
- Building strategy

Although there seems to be a relation between these five aspects and the performance, it was not possible to define the exact relationship. Extra research into these aspects is needed to quantify these relations.

Recommendations

During the research several limitations are found in the defined performance model. The limitations give rise to extra investigation. Due to the limited time frame of this research, it was not possible to go into further detail. Therefore the found limitations, with possible solutions, will briefly be described in the following chapter. The resulting recommendations are captured in three topics:

- Performance model limitations
- Data limitations
- Performance model expansion

Performance model limitations

During the use of the defined performance model there are some limitations discovered. The most important limitations are discussed in the following five paragraphs.

Production output

First of all the definition of the production output. For the current performance model the choice is made to use lightweight as the production output parameter. Although this gives a good indication about the amount of steel which comes out of a shipyard, it doesn't give any information about the complexity of the output. Thereby this parameter will favor shipyards which build bigger and simpler vessels compared to shipyards which build smaller more complex vessels. This can also be seen in the results in chapter 4.

To overcome this issue, the parameter for the production output should reflect both the amount and the complexity of the output. An solution could be found in the compensated gross tonnage. At the moment the division in ship categories of the CGT system is not specific enough. The addition of extra categories to the CGT system could make it more useful.

Variable personnel numbers

Secondly the amount of personnel is in the current model based on the personnel numbers of 2016. These numbers are kept constant for the entire period of 2010 -2016, because it proved very hard to retrieve detailed personnel information. Thereby the personnel numbers aren't exact for every year. Especially economic influences, as seen in chapter 4, will cause a shipyard to make changes in the amount of personnel. These changes aren't captured in this performance model. A better definition of the use of personnel will therefore significantly improve the model.

Outsourcing

Thirdly the amount of outsourcing is neglected. This will favor shipyards which use outsourcing, compared to shipyards which do the entire building process themselves. In the current model such a shipyard that uses outsourcing is assigned credit for the entire ship, while it only builds a part of it. This point really came forward in the results of DSCS, see paragraph 5.2.

Including the cost of outsourcing in some way will make it possible to compare shipyards with different building strategies. In the current model it is only possible to compare shipyards with a similar profile. This is an major limitation while lots of shipyards have different building strategies.

Constant costs

The fourth limitation of the defined model is that the constant costs are neglected. The choice is made to only include the costs which significantly differ for each shipyard. Thereby a part of the picture is lost. The found differences can only be used for relative comparison of shipyards. They don't depict real numbers. Thereby the found cost performance differences are out of proportion, see chapter 4. Including the constant part of the cost would result in scores which better depict the reality.

Production time

With the current definition of the production time (delivery date – contract date), see paragraph 3.3. it is possible that this production time is therefore overestimated, while the contract date and actual start of production date can differ. This can partly explain the fluctuating behavior in the time performance in chapter 4. Getting data about the real start of production date would significantly improve the quality of the time performance.

Data limitations

Besides limitations in the defined model, there proved also to be limitations in the used data. Especially the quality and the size of the database proved to be important. There are two important limitations in the currently used database.

Database size

First of all the size of the database. In the current model the information of five Damen Yards and eighteen competing shipyards is included for 2010 – 2016. Due to the limited time frame it was not possible to expand the database any further. The focus on similar shipyards, compared to the Damen yards, resulted in clustered data, see paragraph 3.3. To make the model more widely applicable, the information of more shipyards, ship types and ship sizes should be included.

The expansion of the database will increase the quality of the statistical results. Furthermore it will become possible to filter out more external influences if the size of the database increases. This will make it possible to assess the influence of the economy. These influences can then be corrected and results of different economic periods can be compared. In the current model this is not possible.

Database variation

The current database is only based on one source, the SIN database from Clarksons. Although the quality of this database is acceptable, it can be significantly improved, see paragraph 3.6. A more complete database could be created by combining the information from the SIN database with other databases like:

- IHS Fairlplay database
- World Fleet Register

A small peek into the IHS Fairplay database already proved that this database would be an excellent complement to the SIN database. A cross check of the information would improve the completeness and the quality of the current database and thereby increase the quality of the results in the performance model.

Performance model expansion

The currently defined model is suited to define differences between shipyards. It is even possible to quantify productivity differences between shipyards to some extent, but it is not possible to define the root cause of these performance differences. To enable a full improvement cycle, a deeper analysis into the causes and an accompanying improvement plan is needed.

Relations between yard resources and performance

In chapter 6 a first step is taken to make a deeper analysis about the involved yard resources. It seemed that there is a relation between the performance and the available resources on a shipyard. This small research showed that it might be interesting to look at the relation between the performance and the following aspects:

- Shipyard lay out
- Available areas
- Available cranes
- Available personnel
- Building strategy

There is reason to believe that there are relations between these five aspects and the performance. Further investigation into these aspects is needed quantify the exact relations.

Improvement and investment possibilities.

A last step would be to look at investment possibilities. A small sensitivity analysis is conducted in chapter 6. If the root causes for the performance differences are found and the relations between them are established, it becomes possible to improve these causes. For this a detailed investment plan is needed. Based on the performance gap and the identified causes, a plan of improvement can be made. The effect of these investments on the performance can be calculated and thereby the circle is complete. The next step would be to start all over again with a calculation of the new performance after the made improvements. In this way an improvement cycle or plan, do, check, act cycle is started.

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Appendix

The appendices can be found in a separate report. The included chapters of this report are mentioned below.