Study of Shipbuilding Competitiveness

Benchmarking analysis as a tool to measure shipyards' competitiveness with a focus on Asian yards

Thesis report by

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Preface

The reason why I chose the topic 'competitiveness' for my thesis is because of my sole interest in business and management. Throughout my years in TU Delft, I have taken management courses such as finance, decision making, data analytics and visualization, operations research, etc. My interest in business lives on and evolves into something more concrete. This thesis offers insights about the shipbuilding industry for a business owner (most likely in the maritime field), government or policy-maker, and academia. Here the reader not only will understand the general view of shipbuilding business but also learn a particular method to model the competitive position of a shipyard.

While working on this thesis, I had to go through tough situations. From the long hours collecting and processing data, financial difficulty, learning new programming skills in R and Python and also surviving the COVID-19 pandemic. Therefore I would like to express my biggest gratitude to my supervisor, Jeroen Pruijn, who was being very supportive and patient when guiding me to finish this thesis. I also want to give my biggest thanks to Mrs. Lourdes Gallastegui Pujana, my academic counselor, who helped me through my tough times here in TU Delft. I am sincerely grateful to have met these two people; if not, I may have quit my master program a long time ago, so thank you.

I also would like to express my thankfulness to my biggest supporters, my mom, and dad who believe in me, especially when I didn't believe in myself. I also want to take the time to give thanks to two of my most sincere supporter, who always checks on me and push me to finish my degree, Mas Dito and Amira. Special thanks to Mbak Wuri and Uni Rina, who feed me with proper food when sleeping was the only dinner I had. I also want to give thanks to my friends Rozak, Anchal, Claudia, Karina, Agung, Agis, Widya, Ben, Tingkai, Ivar and mas Pari that help and support me during my master's study. Lastly, I would like to give shout-outs to Korvezeestraat alumni: mas Witjak, mas Dias, Daniel, mas Aldyth, Helmi, mas Oelin, Oecoep, (James) priyadi, Angga, and Kawe, that have been sharing the hard times.

My journey was long and full of obstacles. I feel I have grown so much during my life here in TU Delft. Every failure I had has developed my character to be more resilient and robust. If there is a quote best express the lesson learned, it would be a quote from William of Wykeham;

"Manners maketh man"
- William of Wykeham

I firmly believe that a man's attitude reflects his grit and perseverance in the long run. Throughout my years in TU Delft, I have witnessed breakdowns, burnouts, and people questioning their life choices. I have seen people taking shortcuts, changing study programs, shifting tracks, or even quitting. People perceive failure differently, now that I am getting more comfortable with failures, I start to think that maybe my failures are there to make me stronger. I fail to graduate on time, and also I fail my exams so many times, but my biggest yet auspicious failure is that I fail to quit.

Last words, I hope you, as the reader will find my thesis useful and insightful. This thesis has plenty of room for improvement; hence, I am humbly open to any critics and/or recommendations from anyone who reads my thesis. I hope my long year of hard work can resonate well with the readers. Enjoy!

Muhammad Fareza
Delft, 2020

Abstract

This thesis attempts to study the competitiveness in the shipbuilding industry. The shipbuilding industry is not a standalone industry. It integrates with the shipping market, and therefore one characteristic of the shipbuilding industry is complexity. The shipbuilding industry commonly analyzed by its product type, country/region and its production value. Countries and continents take shifts in dominating the Shipbuilding Industry, starting from Great Britain, Europe, Scandinavian countries, Japan, South Korea, and China. The three Asian countries Japan, South Korea, and China today, dominate the shipbuilding industry by volume CGT. While, European yards still exist in the industry, but play in a more complex and highly-valued ship.

Competitiveness is a multi-dimensional concept that can be measured in numerous ways. There is no exact definition to best represent competitiveness in the shipbuilding industry. From the literature, the author then found that these multi-dimensional concepts can better be translated into three objectives; "the ability to attract new contracts," "the ability to execute shipbuilding contract," and "the ability to stay in business." Three methods are evaluated to find which one is the most appropriate when measuring the shipyard's competitiveness. Some criteria that are taken into account are; flexibility in data availability, ability to handle multiple inputs and outputs, and multi-dimensional inclusiveness. To find which method is the most appropriate, the author conducted the Analytical Hierarchy Process (AHP) and found that benchmarking analysis is the best method.

Data Envelopment Analysis (DEA) is chosen due to its versatility, cautious estimation, and non-parametric characteristics. Data Envelopment Analysis is an operation research method that uses mathematical formulation to find benchmarks among units under study. The Data Envelopment Analysis (DEA) estimate a technology set from observation and create an envelope-form based on the frontiers. The frontiers are then used as benchmarks for other firms (or shipyards in this case) to improve themselves. There are two DEA models presented in this thesis. The DEA models are based on the objectives of shipyards that are found in the literature research. The first model uses deliveries (in CGT) as output, and dock area and number of employees as inputs. The second model uses price/CGT and duration/CGT as inputs, and new contracts (in CGT) as outputs.

To select the shipyard to be evaluated, the author divides the shipyard's type into three size categories; mega-sized, large-sized, and medium-sized. Moreover, shipyards with relatively higher market share are taken into the model. Additionally, to have a country-to-country comparison, the author tries to include shipyard from each country. The models investigated 20 shipyards from Japan, China, South Korea, and additionally Vietnam. The results show that Chinese yards are generally very efficient when it comes to attracting new orders. Chinese yards' prices are attractive and have a quite fast delivery times. However, in terms of allocating its resources, Chinese yards are very inefficient. Japanese yards are very efficient in both models. Most of the Japanese yards are frontiers. Korean yards, on the other hand, are the winner for mega-sized yards, but not in the medium-sized shipyards. From this thesis, it is proven that Chinese yards have a low price/CGT and fast delivery times which in turn favoring Chinese yards to be more attractive.

In conclusion, the appropriate method to study competitiveness in shipyards is benchmarking analysis, which can encapsulate the multi-dimensional nature of the shipbuilding industry. Data Envelopment Analysis (DEA)'s results show the efficiency between the output and input of a system with a quantifiable value and provide a point of improvement by increasing output (for output-oriented) or decreasing input (for input-oriented). The insight can be derived from the results by analyzing the efficiency score and lambda values. **Therefore, the main research question 'How can one measure the competitiveness performance of a shipyard? and what insights can be derived from the measurement model'** is answered.

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Introduction

1.1. Background

The Shipbuilding industry is known as one of the oldest, most open, capital intensive, and volatile industry (Mickeviciene, 2011 [45]). This particular industry is a part of shipping market integration, which has a strong connection with the shipping market. The shipping industry promotes globalization and helping under-develop countries to grow their economy through trade. Without the shipbuilding industry, there will be no supply for the shipping market to promote sea trade and economic prosperity.

Countries and continents take shifts in dominating the Shipbuilding Industry, starting from Great Britain, Europe, Scandinavian countries, Japan, South Korea, and China. By the year 2002, South Korea became the leader of the shipbuilding industry, while Japan and European shipbuilders started to lose its market share to South Korea (as shown in Figure 1.1). At present, the construction of tankers and bulkers is dominated mainly by Japan, South Korea, and China. By having a cost advantage, China's Shipbuilding industry emerged relatively recently but has experienced rapid growth. China has won market share in shipbuilding from its rivals over the past decade (Jiang et al., 2013 [42]).

Figure 1 shows the development of market share by deliveries in-unit CGT.

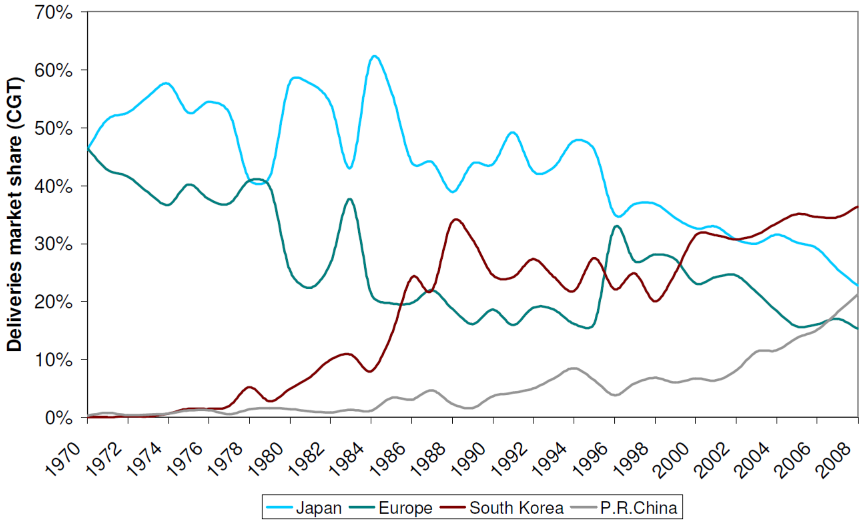

Figure 1.1: Market share based on CGT [56]

Since the 1970s, the shipbuilding industry has grown remarkably (Figure 1.2). In 2010, the deliveries of ships reached its peak value. Although being a volatile industry, the shipbuilding industry is deemed to be a strategic industry for the world economy, especially for trading commodities. For merchant ships, such as bulkers, tankers, and containers, the seaborne trade is one of the primary drivers of the supply and demand of ships (OECD, 2018 [48]).

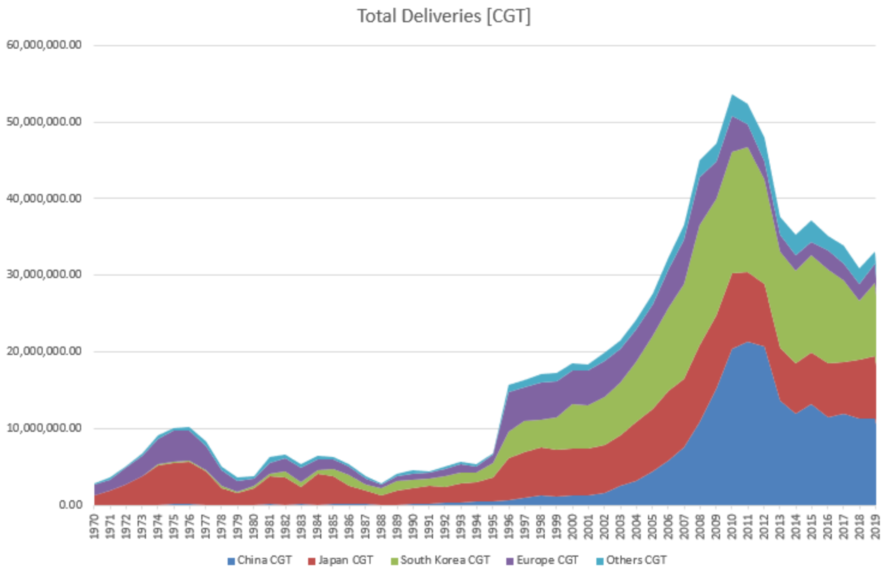

Figure 1.2: Deliveries based on CGT (Author calculation based on data from Clarkson)

1.2. Motivation

It is interesting to see how the shipbuilding industry has shifted geographically. Japan made shipbuilding as a strategic industry, and with its rapid economic growth, Japan was successfully bringing the shipbuilding industry to Asia. Only after Japanese shipbuilders faced difficulties in recruiting new young engineers and suffered from high labor cost, the Japanese yards began to lose their global dominance (Mickeviciene, 2011 [45]). Then because of geographical advantage, South Korea came along and took the Japanese dominant position in the shipbuilding industry, only to challenged by China with their low-cost advantage.

The shipbuilding industry is an essential market for the maritime economy [60]. The demand for ships is driven by the world economy and commodity trades in which further drive a country's economic growth. Japan recognized this and put the shipbuilding industry as a strategic industry. They carefully planned and nurtured the industry to be one of the leading players. South Korea took Japan's footpaths and now has overtaken Japan as the world's leader of shipbuilding in terms of volume. After the successful examples of South Korea and Japan, China, with the help of its rapid economic development, tries to enter the market and aims to be a major player in the industry. However, what kind of strategy can be executed to develop the shipbuilding industry efficiently? What indicators to look at to position oneself in this challenging market? If internal and external factors drive the demand and supply of ship, what can stakeholders do to help the industry develop? Since shipbuilding integrates with the shipping market and the world economy, the stakeholders are the shipyards, shipowners, and government and maybe more. Thus is there any way for these stakeholders to collaborate and find a good strategy to make their shipbuilding industry thrive?

These questions then evolve into more specific issues such as 'Is a low-cost-advantage the indicator for emerging shipbuilding countries/regions?' 'How can European yards survive this challenging environment?' This thesis report attempts to find out what measurement tool is appropriate in giving insights into the yard's status in the shipbuilding market. In this report, the author will discuss what kind of methods exist to quantify the shipyard's position in the market. This report is also seeking out the key points or Key Performance Indicators (KPIs) used by stakeholders in the shipbuilding industry. Furthermore, a mathematical model is expected to be generated in this thesis report.

1.3. Research Focus

To study the competition in the shipbuilding industry, we need to narrow down our focus to obtaining the research objectives. The first step is to see how academia, firms, consultants measure the competitiveness in the shipbuilding industry. A few studies try to analyze the competitiveness in the shipbuilding industry. Commonly, the shipyard's productivity is the primary driver in the shipbuilding industry, responsible for market dominance (Lamb and Knowles, 1999 [38]). Paul Stott suggests that 'Cost' and 'Productivity' are the two parameters that shipyard required to win and execute contracts[62]. However, Bertram argued that cost could be further elaborated into profit and used 'turnover' (profit) as the competitiveness indicator in the shipbuilding[9]. The study from Thomas Lamb attempted to evaluate the performance efficiency of shipyards based on competitiveness indicators of 'cost,' 'time,' and 'quality.' Twelve shipyards from four different regions and countries are evaluated to see which ones are inefficient. By creating frontiers (benchmark) of shipyard performance, Lamb was able to rank shipyards based on their best-practice[39]. A more recent study by Jiang suggests that shipbuilding cost has a direct influence on market share[63]. In his latest research, he shows that the profit rate is the indicator of competitiveness[42]. In this thesis report, these methods will be discussed.

The second step is to choose the appropriate method to measure competitiveness in shipbuilding industry. Shipbuilding industry is very competitive. The information of how yards operate are not publicly disclose. So data availability is a critical factor to consider when choosing a model. However, shipbuilding industry is also very complex. The industry is affected by many internal and external factors. With the variables at hand, what kind of model can be build will be a challenge.

The third step is to choose shipyards to be evaluated. Since competitiveness is a relative concept, the sample shipyards has to be enough to show which shipyard performs better than the others and which are not. Moreover, what insights can be derived from the results will be another challenge. To keep the study in focus, the author formulates a main research question and several sub-research questions. Research questions help to give a framework for the research. The general research question is:

"How can one measure the competitiveness performance of a shipyard? and what insights can be derived from the measurement model"

1.4. Research Questions

This main thesis objective is to study the competitiveness of the shipbuilding industry. To do so, the author has made several sub-research questions as a guideline for this thesis; the research questions are as follows:

1. How did the shipbuilding industry develop throughout history? And what aspects characterize between European and Asian shipyards?
2. How to measure competitiveness in the shipbuilding industry? And what is the appropriate method to measure the competitiveness of a set of shipyards?
3. With the method found, how can the method able to evaluate the competitive performance of shipyards?
4. What variables can be used in the method? And how to choose the shipyards to be evaluated?
5. What are the results of the method, and how less competitive shipyard able to do to be more competitive?

1.5. Document Structure

The structure of this report is as follows: There are seven chapters in this thesis. **Chapter 1** is the introduction, which gives an overview of the overall content of the report. **Chapter 2** discusses the development of the shipbuilding industry. In this chapter, general terms and common knowledge are provided. The purpose of this chapter is for the readers to understand the case at hand better. This chapter answers the first sub-research question. **Chapter 3** is the literature study of shipbuilding competitiveness. As competitiveness is an abstract concept and multidimensional, the author will discuss the existing approach in evaluating competition in shipyards. Based on the literature study, no single definition is best to capture the whole concept of competitiveness. However, one can isolate the competitiveness model by defining the objectives. At the end of chapter 3, the author conducted an Analytical Hierarchy Process (AHP) to find the most appropriate method to measure competitiveness in the shipbuilding industry. Sub-research question two is answered in this chapter.

The conclusion of chapter 3 gives the author's decision to use 'benchmarking' as the appropriate method. **Chapter 4** will discuss the theoretical and mathematical models of benchmarking. This chapter will explain why the author uses benchmarking methods, how to conduct a benchmarking evaluation, what are types of benchmarking, and why a specific method of benchmarking is chosen. Data Envelopment Analysis is believed to be the best method in this study. In this chapter, sub-research question 3 is answered. **Chapter 5** describes the Data Envelopment Analysis (DEA) models. Variables availability and systems of the model will be explained in detail in this chapter. Moreover, sub-research question 4 is answered in this chapter. **Chapter 6** analyzes the results of the DEA models. This chapter answers sub-research question 5. Last but not least, **chapter 7** gives the conclusion of this thesis and recommendation for further study.

2

Development of Shipbuilding Industry

This chapter acts as an introduction to the shipbuilding industry. This chapter also aims to answer the first research question, ”How did the shipbuilding industry develop throughout history? And what aspects characterize between European and Asian shipyards?”. The question is rather broad but will be narrowed down by the sections in this chapter. Section 2.1 gives a brief explanation of the economics of the shipping market. The concept of shipping markets integration, market cycle, and supply and demand will be discussed in this section. The development of the shipyard and shipbuilding industry will be explored in section 2.2. In this section, the history of shipbuilding is discussed. The various perspective in the shipbuilding industry will be elaborated in this section. Finally, section 2.3 will summarize the whole chapter and answer the first research question.

2.1. The Shipping Market

The shipbuilding industry is not a standalone industry. There are internal and external factors of another market affecting the shipbuilding industry. Before we dive into the shipbuilding industry, it would be essential to understand the approach maritime economists have to follow the affiliated markets that play crucial roles in the shipbuilding industry.

Maritime economists differentiate the shipping market into four sub-market: The Freight Market, The Sale & Purchase Market, The Shipbuilding Market, and The Demolition Market (Stopford, 2009[60]). These four markets integrate and can not be separated. The shipping market is also a cyclical industry; it means that this market has its ups and downs. The proceeding subchapter will briefly discuss this issue. The supply and demand in the shipping market will also be addressed.

2.1.1. Shipping Markets Integration

The sea transport services are provided by four closely related markets, each trading in a different commodity (Stopford, 2009[60]). In this section, the author will briefly discuss the four markets that integrate the shipping and shipbuilding market. Without getting too much into detail, the four markets are as follows;

1. **The Freight Market**. The freight market is a market place in which sea transport is bought and sold. The freight market consists of shipowners, charterers, and brokers. There are four types of contractual arrangements: the voyage charter, the contract of affreightment, the time charter, and the bareboat charter.
2. **The Sale and Purchase Market**. The buyers and sellers are shipowners. Ship prices are very volatile, and this makes trading ships a vital source of revenue for shipowners. According to Stopford, the second-hand value of merchant ships depends on the freight rates, age, inflation, and expectations.
3. **The Shipbuilding Market**. This market refers to the newbuilding market. The participants in this market are shipowners and shipbuilders. Because the ship has to be built, the contract

negotiations are more complex than the sale & purchase market, extending beyond price to such factors as specification, delivery date, stage payments, and finance.

4. **The Demolition Market**. Old or obsolete ships are sold for scrap, often with speculators acting as intermediaries between the shipowners and the demolition merchants.

2.1.2. Shipping Market Cycle

Cycles are not unique to shipping; they occur in many industries. Shipping cycles are a crucial part of the market mechanism, and there are five points to remember. First point: shipping cycles have different components - long, short, and seasonal. These three components are nicely illustrated in Figure 2.1. The long-term cycle (showned in the dashed line) is of importance if it is changing, and the big issue here is whether the underlying cycle is moving upwards or moving downwards. The short-term cycle or the 'business cycle' fluctuates up and down, and a complete cycle can last anything from 3 to 12 years from peak to peak. Finally, the seasonal cycles, these are regular fluctutations within the year (Stopford, 2009[60]).

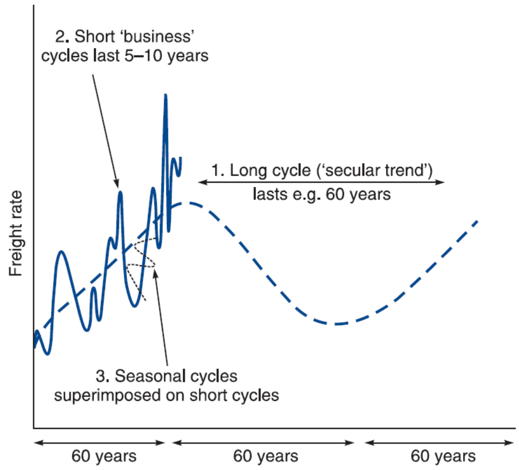

Figure 2.1: Seasonal, short, and long cyclical components [60]

The second point of the shipping cycle market mechanism is the function of the short shipping cycle. The function is to coordinate supply and demand in the shipping market. The third point, a short cycle typically has four stages. A market trough (stage 1) is followed by a recovery (stage 2), leading to a market peak (stage 3), followed by a collapse (stage 4). The fourth point, these stages are 'episodic,' with no firm rules about the timing of each stage. Regularity is not part of the process. The fifth point, there is no simple formula for predicting the 'shape' of the next stage, far less the next cycle (For more details, please refer to "Maritime Economics" by Stopford, 2009 [60]).

2.1.3. Supply and Demand of Ship

The maritime economy is enormously complex, so the first task is to simplify the model by singling out those factors that are most important (Stopford, 2009 [60]). This is not to suggest that detail should be ignored, but rather to accept that too much detail can hinder a precise analysis. Stopford has select ten, from the many influences on the shipping market, as being particularly important. Out of those ten, five are on the demand side, and the other five on the supply side. The demand and supply variables are shown in table 2.1.

The five key demand variables are the world economy, commodity trades, average haul, political events, and transport costs. The demand for ships starts with the world economy. Stopford found that there is a close relationship between industrial production and sea trade, so scrutiny of the latest trends and lead indicators for the world economy provide some warning of changes in the demand for ships. The second important demand variable is the structure of the commodity trades, which can lead to changes in ship demand. Distance (average haul) is the third demand variable, and here again,

Table 2.1: Demand and Supply factor of shipping market [60]

No	Demand	Supply
1	The World Economy	World Fleet
2	Seaborne commodity trades	Fleet productivity
3	Average haul	Shipbuilding production
4	Random shocks	Scrapping and losses
5	Transport costs	Freight revenue

Stopford found that there have been substantial changes in the past. Political events were the fourth variable since wars and disturbances often have repercussions for trade. Finally, transport costs play an essential part in determining long-term demand (Stopford, 2009[60]).

On the supply side, there are also five variables: The world fleet, productivity, shipbuilding production, scrapping, and freight rates. The size of the world fleet is controlled by shipowners who respond to the freight rates by scrapping, newbuilding, and adjusting the performance of the fleet. Because the variables in this part of the model are behavioral, the relationships are not always predictable. Market turning points depend crucially on how owners manage supply. Although the orderbook provides a guide to the size of the world fleet 12-18 months ahead, future ordering and scrapping are influenced by market sentiment and are very unpredictable. Because shipping investors sometimes do things that economists find challenging to understand, relying too much on economic logic can be dangerous (Stopford, 2009[60]).

2.2. The Development of Shipyard and Shipbuilding Industry

The Shipbuilding industry is known as one of the oldest, most open, capital intensive, and volatile industry (Mickevicine, 2011[45]). Ship production increased 8.4 million GT in 1960 to 27.5 million GT in 1977, then halved to 13 million in 1980 then edged to 16 million GT by 1990; after that, it reached 44 million GT in 2005 (Stopford, 2009[60]).

A century ago, the market of shipbuilding was dominated by Europe, having a world market share (in CGT) of some 80% at the beginning of the twentieth century. Initially, Great Britain had a dominant position. Due to various reasons, including the decrease of the European shipping fleet, lack of investment, poor labor relations, and an inability to increase productivity levels, the UK dominance gradually eroded, partially being replaced by continental Europe and Scandinavia (ECORYS, 2009 [56]). For those that are not familiar with the unit CGT (Compensated Gross Tonnage) can refer to Appendix A.

In the 1950s, the position of Europe was being challenged by Japan. Japanese yards have gradually taken over Europe's dominant place in the 70s, mainly due to the rapid growth of the Japanese economy and a coordinated shipping and shipbuilding program. Shipbuilding assumed the position of a strategic industry, and new shipbuilding techniques were introduced that enhanced the Japanese productivity in shipbuilding (ECORYS, 2009[56]). In the early 1970s, Japan and Europe together still dominated the world market with a combined share of some 90% (in CGT deliveries).

In the early 70s, the position of Japan was, in turn, challenged by South Korea as labor costs were rising in Japan. At the same time, South Korea combined low labor costs with a choice to position shipbuilding as a strategic industry for the country. Just as Japan did before, a carefully planned industrial program was initiated, starting with the construction of shipbuilding facilities by Hyundai and Daewoo, later followed by Samsung in the 1990s. In the mid-1990s, the share of South Korea had increased to 25%, and by 2005, it had overtaken the position of Japan measured in CGT deliveries, as shown in Figure 2.2 (ECORYS, 2009[56]).

The latest challenger on the international market is China. China already had an active shipbuilding industry, but major expansion was realized as part of the country's industrial expansion strategy in conjunction with the strong rising demand as a result of China's economic boom. The share of China rose rapidly to over 20% of global ship deliveries in 2008 (in CGT). In terms of orderbook, China surpassed

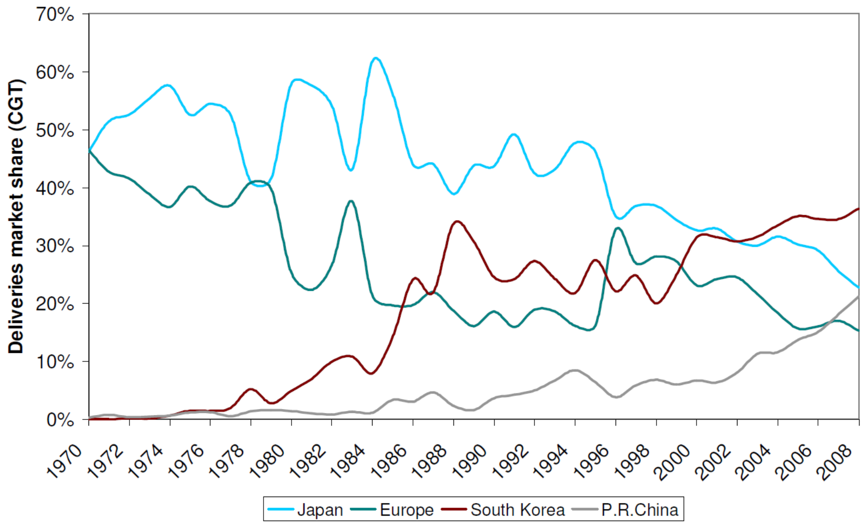

Figure 2.2: Market share based on CGT (ECORYS, 2008) [56]

Japan in 2006 as the second-largest shipbuilding region (ECORYS, 2009[56]).

The current distribution of shipbuilding production thus shows a strong dominance of Asian countries. Figure 2.3 presents the market shares in terms of completions (production), orderbook, and new orders in CGT in 2008. In terms of completions, South Korea, China, and Japan represent almost 80% of world production. In terms of orderbook, especially the increased share of China (62 million CGT) becomes noticeable, while the share of Japan (31 million CGT) diminishes. Also, the percentage of CESA shipyards in terms of orderbook is lower than the percentage in terms of completions, indicating a further erosion of Europe's position in world shipbuilding in CGT volumes. This trend is further confirmed by looking at the new orders, which again show a lower share of CESA countries worldwide.

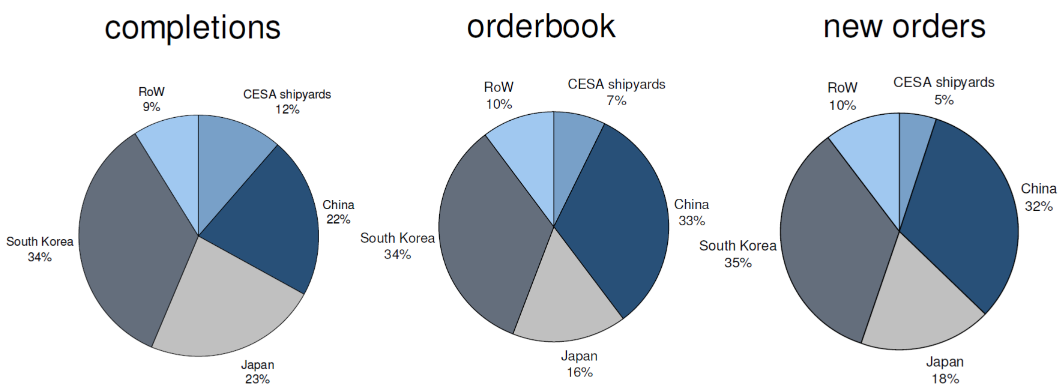

Figure 2.3: Market shares by deliveries, orderbook and by new orders in 2008 in CGT (CESA Shipbuilding Market Monitor,2009[56])

2.2.1. Shipbuilding by Ship Type

Of all demand for newbuilding ships, there exist categories of a vessel by the type of ship's functionality (i.e., goods they carry). Figure 2.4 below shows the distribution of the world market by type of ship (order books) in 2008. Tankers, bulk carriers, and containerships represent the most significant demand (in CGT). They are followed by general cargo ships and gas tankers. Lastly, the passenger ship has the lowest orderbook in terms of CGT, and the rest is slightly higher than the gas tanker ship.

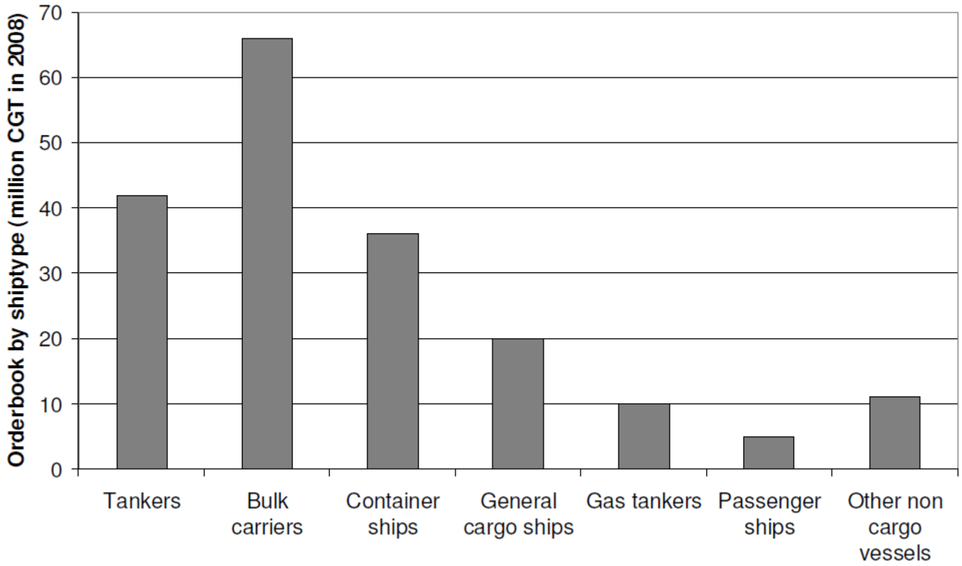

Figure 2.4: Orderbook (million CGT) by ship type in 2008 (ECORYS, 2008) [56]

If we generalize ship type into four and put general cargo ship and gas tanker into bulk carriers and tankers, we see that these four categories dominate more than 50% of ships in orderbook. And in more recent years, the trend still shows the same results, as shown in Figure 2.5.

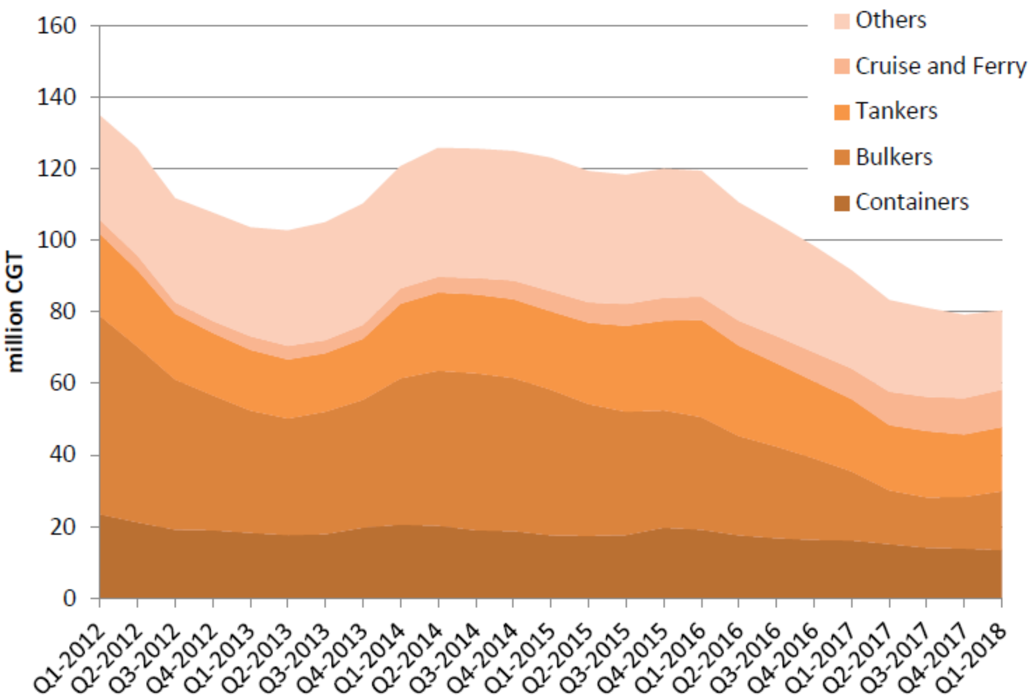

Figure 2.5: Orderbook by Ship Type (OECD, 2018[48])

2.2.2. Shipbuilding by country

Figure 2.6 shows the market shares (in orderbook) by ship type for the main shipbuilding countries/regions in 2008. In the segment of “passenger ships,” CESA countries are dominant. Europe also has a relatively stable position in the sector “other non-cargo vessels.” In the much larger segment of “containerships,” Europe only has a minor share. The newbuilding of tankers, bulk carriers, and gas tankers is nearly absent in Europe. The remarkable share of 44% of RoW (Rest of World) for “other non-cargo vessels” is relatively scattered around the world with markets shares of 7.6% for India, 5.7% for Singapore, 5.5% for Indonesia, 5.3% for the USA, 3.5% for Turkey and 3.1% for Brazil.

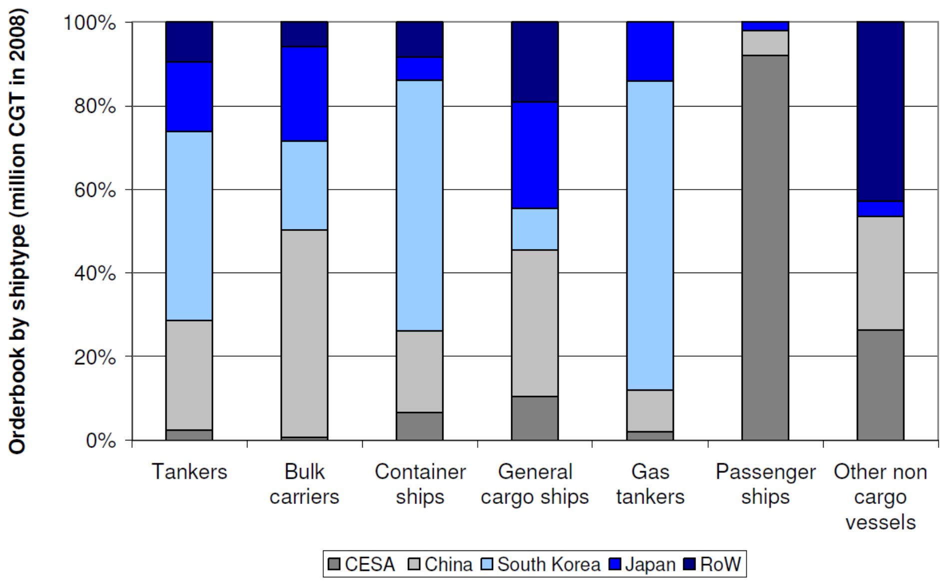

Figure 2.6: Orderbook (CGT) market shares of main shipbuilding regions by ship type in 2008 (ECORYS, 2008) [56]

The graph confirms that Europe has a strong position in the segments of relatively high-value passenger (cruise) and other non-cargo vessels. The position of Europe is relatively strong in specialized complex ships such as cruise vessels and specialized non-cargo ships (including dredgers, off-shore supply vessels). This market is characterized by a limited production (e.g., limited demand in the number of ships, prototypes with few sister ships, tailored and knowledge-based production processes, considerable technical expertise, and a high number of specialized subcontractors) (ECORYS, 2008[56]).

In a more recent year, the trend is similar. Based on the OECD market report, shipbuilding production in terms of CGT is powerfully concentrated in the three East Asian economies, China, Korea, and Japan, which in 2017 represented 86% of all CGT delivered. This high percentage has remained relatively stable over the last years. In 2017, China is the largest shipbuilding economy, followed by South Korea, Japan, and the European Union. Rank five has been taken over by the Phillippines from Indonesia in 2014 (OECD, 2018[48]).

Although all four segments are rather concentrated geographically (bulker, container, and tanker in East Asia and cruise/passenger in Europe), the market seems to be more competitive when regarding the number of players. Shipbuilding is a global industry in which yards/companies are in the international competition for contracts. It is therefore informative to have a closer look at the market share of shipyards for the main ship types to analyze the competitive situation in the different segments.

2.2.3. Shipbuilding market by shipyards

Reports from OECD show the market concentration among shipyards. By calculating the global Herfindahl-Hirschman Index (HHI) for each segment yields a value of 0.073 for bulkers, 0.096 for containers, and 0.093 for tankers. Herfindahl-Hirschman Index (HHI) is calculated by summing the square for each shipyard's market share. The less concentrated the market (high number of shipyards), the lower the HHI Index, and vice versa. Only the cruise ship and passenger's vessel market is slightly more concentrated with 0.142. The reason is that Cruise ship requires different workflows, inputs, and advanced technology (OECD, 2018[48]). An indication for this can be seen in the values, as the price to CGT ratio is about twice as high for cruise and passenger vessels than for the three other investigated ship types bulkers, containers, and tankers (where prices for ships are available). Switching between building containers and tankers might be easier for companies than entering the cruise ship market, which has higher entry barriers (Stopford, 2009[60]). Thus, shipyards' higher flexibility among some ship types might render these segments more competitive (Stott, 2017[61]).

Figure 2.8 shows that in Bulker, the three Asian countries have a relatively competitive market share, being Imabari Shipbuilding from Japan has 15% of the market share, followed by China State Shipbuilding Corporation (CSSC) with 14% and Korea's COSCO Shipping by 7%. Other companies make up by 49% market share, which tells us the competition among shipyards are existing and work quite reasonably. This also applies to Container and Tanker vessels. In the Cruise/Passenger segment, The European shipyards are more concentrated. Two European shipyards take almost half of the market share in terms of delivery. The concentration in market share for Passenger ship is dominated by the Italian shipbuilders, Fincantieri, having a 25% market share, followed by German Meyer Neptune for 24%. Although the accumulated market share of passenger ships, for 'others,' reach 30%, OECD reports state that the market concentration in a particular country is still low, meaning that the competition is healthy. Market concentration is distributed quite fairly in the shipbuilding industry.

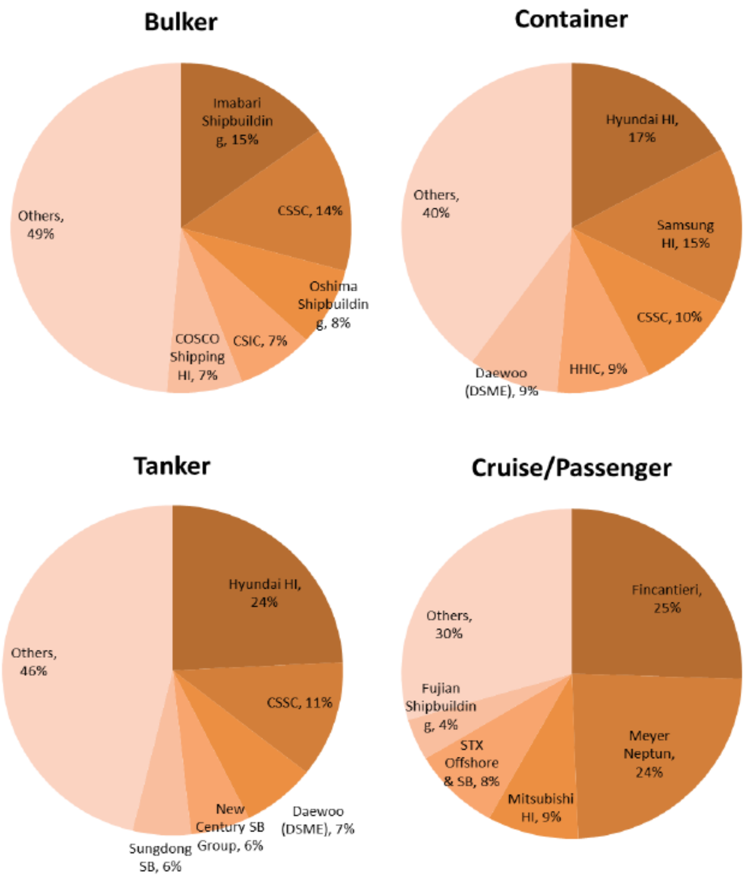

Figure 2.7: Shipyard market shares within segments in 2017 deliveries (OECD, 2018)

2.2.4. Market Share on Production Value

Only looking at volumes being completed by the European shipbuilding industry doesn't sketch the full picture. Although Europe's market share in terms of volumes has declined over the years, Europe has succeeded in retaining a position by building more complex ships with a relatively higher value-added, while the production of more standard mass-production ships moved to other (lower labor cost) countries, especially in Asia (ECORYS, 2008[56]). Whereas in 2007 (Figure 2.9) the market share of production volume completed (in terms of CGT) was 17% for Europe and 82% for Asia in 2007, in terms of its production value (based on actual deliveries) these figures are 22% and 76% respectively. This confirms the statement that Europe builds relatively higher value ships than Asia. In absolute terms, the production-value of Europe (€12.0 bn) was more or less equal to Japan (€12.5 bn), higher than China (€9.0 bn) and lower than South Korea (€17.9 bn).

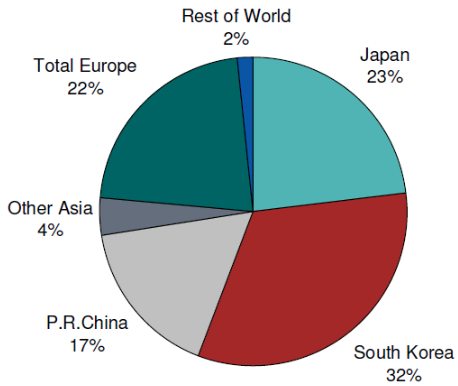

Figure 2.8: World market shares of production-value deliveries by region in 2007 (ECORYS, 2009)

Retake a look at Figure 2.7. While giving useful insights into the development of market shares among countries, the graph conceals absolute production values. Based on the OECD report, in 2017, China holds 35% of all deliveries based on CGT, followed by South Korea with a market share of 31% and Japan with 20%, while European shipyards accounted for 7% of the total ships delivered (Figure 2.7). However, in terms of value, the percentage is somewhat different. According to the OECD report, their share of the total value of ships delivered in that year is rather lower, with 28% in the case of China and 17% for Japan. Korea delivered 31% of all vessels in terms of CGT in 2017, but 35% in terms off value. Finally, European shipyards accounted for 7% of deliveries in CGT but could capture 13% of the value.

A similar number arises when considering new orders in 2017, for which European shipyards dominated the industry with orders totaling approximately USD 22 billion in 2017, driven by the strong cruise ship market, ahead of China (USD 18 billion) and Korea (USD 16 billion). Japan secured orders worth USD 3.8 billion (Clarkson Research, 2018[55]). Of the total 63.8 billion in new contracts in 2017, this translates to shares of 34% for entire Europe, 28%, and 25% for China and Korea and 6% for Japan. This proves that European shipyards have more added value within the ship construction project. However, it is important to remember that value here equal to the revenue of the projects and the value does not considered profit as opposed to cost. It may have a high value, but the cost could also be higher.

These numbers are good representations of the difference of value-added in different types of ships. It is then interesting to see the difference in the number of ships delivered, with the overall revenue of the vessels delivered. Although South Korea, Japan, and China give a high number of ships, the total gain for each Asian country is still less than the European shipyards that operate in the niche market.

2.3. Summary and conclusion of chapter 2

To summarize, the shipping market is integrated with four sub-market, the Freight Market, The Sale & Purchase Market, The Shipbuilding Market, and the Demolition Market. The shipping market is a cyclical industry. Five variables are influencing the demand of ship: The world economy, seaborne commodity trades, average haul, random shocks, and transport costs. Five variables are impacting the supply of ship: world fleet, fleet productivity, shipbuilding production, scrapping and losses, and freight revenue.

The answer to the first research question, How did the shipbuilding industry develop throughout history? is as follows: The domination of the shipbuilding industry started from great Britain, then to European shipyards, then to Japan, South Korea, and lastly, China. The three Asian countries Japan, South Korea, and China today, dominate the shipbuilding industry by volume CGT. While, European yards still exist in the industry, but play in a more complex and highly-valued ship. In terms of CGT, the three Asian countries are still on the lead, but in 2017, based on production value, the European yards have higher production value than Japan, China, and South Korean. However, it is important to remember that the market behaviour on the ship types between the Asian yards and European yards are different. The three merchant ships, bulkers, tankers, and containers are less concentrated than the cruise market. This is proven by using the HHI index conducted by OECD. The concentration of the market shows that the competition in the shipbuilding industry exists and on an international level.

In conclusion, European yards have a characteristic of building more complex ships with a relatively higher value-added such as Cruise ship. In contrast, Asian yards tend to make standardized merchant ships. Although in volume, European yards' productions are very low compared to Asian yards, the production value in terms of USD, the European yards are relatively at the same position as one of the Asian countries. The explanation thus answers the sub-research question, "What aspects characterize between European and Asian shipyards?"

In the management framework by Bertram (2003, [9]) producing merchant ships require more effort in cost and delivery time aspects, while special type ship such as Cruise, requires more on the quality aspect. Quality is hard to measure (more on this in the next chapter), and the cost of getting high-quality work is not publicly accessible, for example, the cost of building a Cruise ship is tough to estimate. Additionally, after the author conducted data collection, the European yards that build merchant ships are nearly absent. Therefore the author leaves out European yards that focus on Cruise market (Fincantieri, Meyer Neptune, etc.)

3

Competitiveness in Shipbuilding Industry

This chapter is the study literature on competitiveness in the shipbuilding industry. Chapter 3 aims to answer the second research question 'How to measure competitiveness in the shipbuilding industry? and what is the appropriate method to measure the competitiveness of a set of shipyards?'.

Measuring competitiveness in the shipbuilding industry is a rather broad question. When we talk about competitiveness, we must first know the preferred definition of competitiveness. Then after the definition is more explicit, we seek to understand how to measure this abstract concept. In other words, what kind of method or model is used based on literature? From the methods found, we need to assess what are the indicators used in the study. The indicators have to be relative to other units under investigation and have value to be compared. After that, we should trace what variables influencing the indicators of competitiveness in a shipyard. In conclusion, three crucial components act as guidelines when studying the competitiveness in the shipbuilding industry, namely:

1. Definition
2. Competitiveness indicator
3. Factors influencing competitiveness

Chapter 3.1 defines competitiveness in general terms and serves as an introductory to competitiveness definition in the shipbuilding industry. Chapter 3.2, 3.3, 3.4, 3.5, and 3.6 discuss the approaches in defining competitiveness in the shipbuilding industry based on the academic paper. Moreover, these chapters highlight the indicators and variables that are influencing the competitiveness of shipyards. Chapter 3.7 will conclude the literature study of this chapter. Lastly, chapter 3.8 will utilize the Analytic hierarchy process (AHP) to find the most appropriate method to measure the shipyard's competitiveness.

3.1. Definition

Competitiveness is an abstract concept. The many theories of competitiveness are neither true nor false. They can, as conceptual tools, only be evaluated with regards to their ability to shed light on the particular issues that they are being proposed to address (Ketels, 2016 [32]). One of the variables defining competitiveness comes from the view of the relation between cost-price and market share. A unit cost level drives companies' ability to compete successfully in the global market. It is inspired by firms' focus on sales and market share.

Another approach defining competitiveness comes from productivity-based perspective. This perspective looks at productivity level, driving the standard quality that the firms can sustain (Ketels, 2016[32]). This definition is motivated by a concern about firms' inherent ability to create value based on the production factors it has at its disposal. It is inspired by the research on cross-country differences in prosperity and long-term growth rates (IADB, 2010[7]; Lewis, 2004[41]).

In a more industrialized definition, the status ”competitive” is given to entities that are able to provide a chance of a successful result in conditions of rivalry. In the context of the marine production industries, Paul Stott defines competitiveness as the ability to gain market share while achieving a level of profitability acceptable to shareholders and staying in business (Stott, 1997[62]).

In this chapter, the definition of competitiveness will be discussed by looking at literature research on scientific papers. The literature study features the approach of a different perspective in defining competitiveness, specifically in the shipbuilding industry. In those various approaches, the factors influencing the defined competitiveness will also be discussed.

3.2. Competitiveness in Marketing Concept

In the context of the international commercial shipbuilding market, the concept of the word ’competitive’ can be explored. Stott and Kattan, in their study of competitiveness, examined the shipbuilding with the marketing concept. Marketing concepts have been used as the medium to investigate the competitiveness of a shipyard.

Marketing is not merely a specific and separate function of an organization that aims to provide a sales team with the opportunity to sell. Marketing offers a framework within which to critically examine a company or organization to ensure that any decisions that are taken are appropriate in the context in which that company works (Stott, 1997[62]).

In summary, based on a study from Stott and Kattan, in order to be competitive a shipyard’s design must meet the requirements and expectations of potential owners, the marketing of the company must be effective, the price offered must be attractive, and the performance (including both productivity and cost) of the company must be adequate to meet the price offered (Stott, 1997[62]).

To make up the concept of competitiveness, four factors have brought up by Stott and Kattan:

- Price, (including subsidy)
- Design,
- Marketing, and
- Performance

3.2.1. Discussion of the factors

Price

In many senses shipbuilders in the international merchant sector are competing against the level of market price, rather than against specific shipyards. Prices rise and fall on a commodity basis, broadly following the laws of supply and demand, but distorted by a number of factors, the two most important being subsidies and price leading by certain nations.

Subsidy

Any discussion of price without mention of subsidies would be incomplete. Subsidies have been an essential feature of the shipbuilding industry for well over a decade, helping shipubilders compete against prevailing low prices, and they are key part of the competitive equations (Stott, 1997[62])

There are large number of means by which shipyards can be subsidized, and these can be grouped broadly into two categories: direct and indirect. Direct subsidies give money directly to the shipyard to cover operating losses generated by the difference between cost and price, and are the most efficient means of providing aid to a shipyard. Indirect subsidies either channel money through a third party (most commonly shipowners), or provide funding for activities aimed at improving performance but not directly linked to contract operating costs.

Design
The ship's design must be targeted at owner's requirements. It is important to understand, for merchant ship, the design is less complex compared to offshore or cruise ship. Merchant shipbuilding design evolves slowly, and most shipowners are conservative with respect to their expectations. Radical solutions may well be met with skepticism, and designers should also be wary of passing fashions.

The owner's primary focus will be on price, delivery, and financing, and to some extents the aspects of the design will provided that the design meets the operational criteria- be secondary to price.

Marketing (Promotion)
The effectiveness of a marketing campaign is a vital element of competitiveness in trying to obtain orders. There is no doubt, however, that the ability of a shipyard to market itself starts with performance. No amount of marketing will sell a poor or inappropriate design, or at a disproportionate price to compensate for high costs (Stott, 1997[62]).

Reputation and track record are the most important elements here in maintaining the perceptation. Having a broker as a middlemen making a company's relationship with its potential customers is one to one. Therefore, finding a reliable ship broker, while maintaining the quality of the ships delivered will thrive in the marketing side.

Performance
As stated in chapter 3.2, Performance in this matter related to both cost and productivity. The three factors of Price (including subsidy), Design, and Marketing promotion, act as the three elements of marketing mix. What is normally meant by the word competitiveness, however, is cost competitiveness.

In other words, we can say, in marketing concept, Price, Design, and Marketing help shipyards to promote their product, while to give chance of successful result in the presence of rivalry, the shipyard competitiveness translates to cost competitiveness.

There are two elements of cost competitiveness, productivity and costs, and both parameters require careful definition to ensure that any analysis is on a common basis (Kattan, 1993[34]) and that comparisons can be made.

Productivity, in general term, is the ratio of output to input, and common parameters are needed as a basis for both of these factors if comparisons are to be made. In shipbuilding, input is normally measured by man-hours or man-years, but even here the situation is not straightforward because of differing classifications of direct and indirect subcontract regimes. To get over these problems, the total labour force (both direct and indirect) should be used as the comparator between shipyards, and an allowance must be included for subcontract effort (Stott, 1997[62]). This has the advantage that it takes into account the level of overhead staff employed in the workforce and the effect they have on efficiency. A shipyard may have a highly productive shop floor workforce, but be disadvantage by heavy overhead staffing.

The unit output used most commonly for comparison between shipyards is the Compensated Gross Tonnage (CGT). CGT is effectivelly a measure of work content (Appendix A). Although it has its weakness, despite this, as competitive benchmarking tool, it is the best available, and it has significant advantages over other measures, in particular gross tons (GT) or Tons of Steel produced, neither of which proves a credible basis for comparison productivity (Stott, 1997[62]). The equation ratio of productivity based on Stott's paper in Shipbuilding Competitiveness is as follows:

$$Productivity = \frac{Man - years}{Unit\ output[CGT]} \tag{3.1}$$

The cost element of competitiveness calculation is fairly straight forward. The basis used is normally $ and all labor and overhead costs associated with the running of the shipyards must be included. The cost element is expressed as:

$$Cost = \frac{Total\ Cost}{Man - years} \tag{3.2}$$

The two cost competitiveness elements thus resulted in:

$$Cost\ competitiveness = Productivity\ x\ Cost \tag{3.3}$$

$$Cost\ competitiveness = \frac{Total\ Cost}{Unit\ output(CGT)} \tag{3.4}$$

3.2.2. Summary of this subchapter

In this research paper, Stott defines competitiveness using the marketing concept. Competitiveness is then the ability for a shipyard to be able to meet the requirements of potential owners, by being competent, having an attractive price, and the performance must be adequate to match the price offered.

The competitiveness of a shipyard in this study refers to the cost of the product. The competitiveness of a shipyard is measured by calculating the ratio between total cost a ship production and the total Compensated Gross Tonnage (CGT) produced, denoted by $\frac{Total\ cost}{Unit\ Output\ (CGT)}$.

This ratio is also known as 'competitiveness index' or 'Key Performance Indicator,' or more simply just the 'productivity' factor that translated from competitiveness. The factors used to determine competitiveness are Price (and subsidy), Design, Marketing, and mostly Performance (cost and productivity).

3.3. Competitiveness in Management Framework

In his study, Bertram evaluated competitiveness in a more general management framework. One useful framework is the three-component analysis, considering 'quality,' 'time,' and 'cost' as the three main components in competing for a customer's decision to buy.

Figure 3.1 shows the three components graphically in the form of quasi-three-dimension. Each component increases in attractiveness in the direction of its axis. If the components are quantified and plotted for each product/competitor completely covers another one, it is superior in all aspects, and will replace the inferior competitor. In addition, minimum requirements of customers can be plotted in the same way.

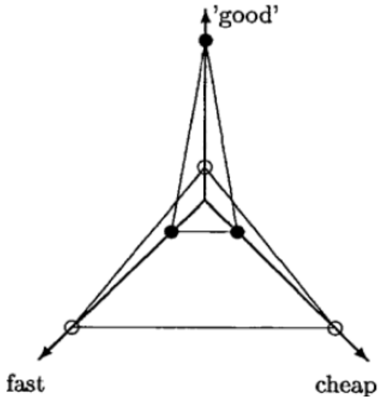

Figure 3.1: 'Cost', 'time' and 'quality' framework defining competitiveness. Navy (black dot) and commercial (white) shipbuilding have different requirements (Bertram, 2003 [9])

It can quickly be seen that naval ships and cargo ships are characterized by very different customer requirements. Naval ships require high quality and have rather generous time and cost allowances. Most cargo ships are subject to strict cost and time budgets, and there is a willingness to accept less quality. (There are some exceptions such as passenger ships that are less sensitive to cost and more sensitive to quality than tankers) (Bertram, 2003[9]).

Unless the customer rewards extra quality by placing more orders and paying higher prices-and this appears to be unlikely-there is no incentive to deliver more quality than required. The quality aspect comes in largely in the quality of the design and much less in the quality of the production process (high-value ships such as navy vessels may be an exception). Nonetheless, quality management is an issue for production, but this is because of cost and time aspects; i.e. the focus in quality management in production is to deliver the minimum required quality within the time and cost budget, preferably constantly improving delivery time and cost. High accuracy construction, laser technology, robot technology and many other recent issues of ship production are primarily motivated by reducing time and labour in fitting on-site components. Therefore time and cost are largely left as the main concerns when thinking about improving competitiveness of shipyards (Bertram, 2003 [9]).

Conclusively, in order to determine the competitiveness, in merchant ship, the 'Time' and 'Cost' components are essential. Ideally, time can be converted into money;i.e. a sales department should quantify how much a customer is willing to pay for each day saved from order to delivery. A lower limit would be the capital cost of the ship. If time is thus expressed in terms of money, focus can be made on the cost side (Bertram, 2003[9]). This leads 'time' -component into cost competitiveness.

3.3.1. Evaluation of Cost Competitiveness

Now we know that 'time' and 'cost' are inseparable. To improve the competitiveness of a shipyard, Bertram, concludes that cost competitiveness as the best approach. However, different than treated discussed from chapter 3.2, Cost competitiveness here is elaborated. To do that, the decisive step is to isolate and examine different factors on their own in order to evaluate and understand the reasons behind changes in competitiveness. At this point the price should be a function of delivery times. Therefore, the time competitive aspects are inherently included in the requirement of 'turnover>cost'. This requirement can be denoted as follows:

$$P\ F\ A\ (1\ +\ S)\ \frac{1}{K}\ X > 1 \tag{3.5}$$

where P is productivity, denoted by $\frac{CGT}{man-year}$. Productivity can be composed further into 'Technical Productivity' denoted by $\frac{CGT}{man-hour}$; and 'Labour Performance' denoted by $\frac{man-hour}{man-year}$. F is 'Production Depth' denoted by $\frac{Personel\ Cost}{total\ cost}$, A is 'attractiveness of the product', denoted in $\frac{market\ price\ in\ \$}{CGT}$. K is 'cost position' denoted by $\frac{Personel\ Cost}{man-year}$. X is 'currency influence' denoted with $\frac{LC}{\$}$ the exchange rate weighted by the share of sourcing in $.

3.3.2. Discussion in factors elaborated in cost competitiveness

The cost competitiveness expansion in Bertram study will be briefly discussed.

Productivity

The ratios $\frac{CGT}{man-year}$ and $\frac{CGT}{man-hour}$, or their reciprocal values, are commonly used for the purpose of evaluating productivity. $\frac{CGT}{man-hour}$ is a measure of the 'technical productivity' of a business. It can be improved through a higher grade of automation, production-friendly design, optimal material flow and other 'engineering solutions'. The 'labour performance' L of $\frac{man-hour}{man-year}$ indicates the actual hours worked by an average employee per year (Bertram, 2003[9]).

$\frac{CGT}{man-year}$, the product of 'technical productivity' and 'labour productivity', is an indicator of a yard productivity talking into consideration the workforce, which as a rule only comprises the permanent workforce. This ratio is relatively easy to obtain for shipyards worldwide, facilitatang external comparisons. Due to long building periods of ships, it is recommended that common practice should be followed and this indicator averaged over three years (Bertram, 2003[9]).

Production depth

Production depth is closely tied to 'productivity'. Production depth is the ratio between personnel cost and total cost. In addition to the salary cost, the total cost include all purchased material and services. Production depth can also be known as added value. Outsourcing, increases the productivity and decreases the production depth. A competitive advantage arises only where the product of both these quantities increases (Bertram, 2003[9]). When a more complex ship design is outsourced, then the production depth gets higher, since the outsourced job probably required more money to spend.

Attractiveness of the product

Shipbuilding is one of the industry with true global competition- at least so far as the building of larger merchant ship is considered (Bertram, 2003[9]). To make a product more competitive, the competitor needs to be able to bid at the lowest price (including subisdies) to have a clear advantage in the market.

The industry cost curve is a useful tool in understanding the market mechanism of markets driven (exclusively or predominantly) by price considerations (Figure 3.2). The industry cost curve arrays the increment of available capacity in a market in order of increasing costs. The increment X-axis shows the capacity of each firm. When the demand is fixed then we can see if the capacity is enough or too much for the demand. In the Y axis, there is cost per unit of each firms represented by the increment. And when the market price is fixed, firms with lowest cost per unit enjoys a higher profit than the firms who have higher cost per unit.

Cost position

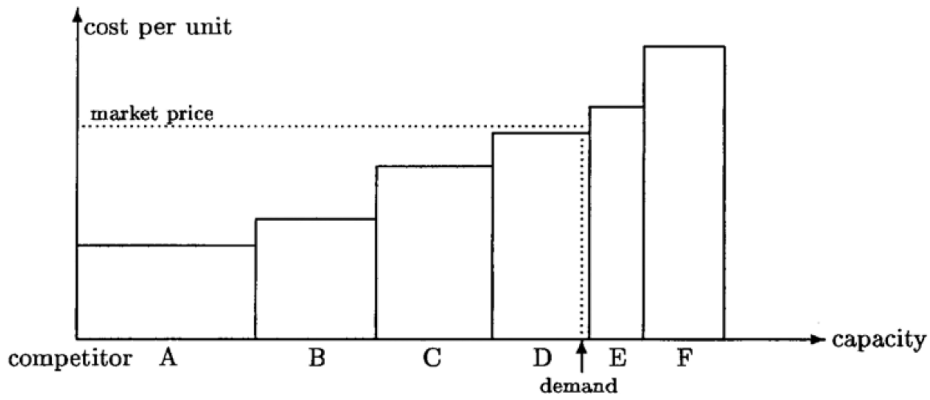

Figure 3.2: Industry cost curve concept (Bertram, 2003)

The 'cost position' covers the combined labour cost including overheads of a shipyard. It shows the ratio of labour cost against the labour work in man-year. This factor is partially open to influence by management with the employees.

Currency influence

Price in ship market usually denoted in $. In domestic market, the price, obviously based on the local currency. In international market, $ is more common.

3.3.3. Summary of this subchapter

In this study, Bertram indicates that competitiveness is composed of three components: 'quality,' 'time,' and 'costs.' A competitive shipyard generally must have a fast delivery time, a low price, and a good quality based on the owner's expectation. However, in real practice, sometimes, one shipyard has either of the competitive edge and not all.

In merchant ship, quality has become functional requirements from the owner and has been standardized. There would be not very much difference in ship design. Nonetheless, the quality of production is vital at the managerial level because it affects delivery time and cost production, hence time and cost are primarily the main concerns when thinking about improving the competitiveness of shipyards.

The indicator of competitiveness in this literature is turnover(profit). The ship's price with the influence of subsidy should be larger than its cost for the shipyard to be able to be cost-competitive. Similar to Stott's study, competitiveness is represented in competitiveness indices. Instead of coming down to one index, Bertram elaborated the competitiveness ratio into seven indices. Thus the method of this study is competitiveness indices.

The factors influencing competitiveness are Productivity (technical Productivity and labor Productivity), Production Depth, The Attractiveness of the Product, Cost Position, and Currency Influence.

3.4. Performance Benchmarking in Shipbuilding

Instead of defining competitiveness, Lamb's paper presents a methodology for shipbuilding performance assessment. However, the method to evaluate the shipyard's performance is based on a competitiveness point of view (Lamb, 2009[39]). The basic criteria for assessing the performance of a shipyard are Production Cost, Building Time, and Quality. This is similar, if not the same approach by Bertram, as discussed in chapter 3.3.

The method takes into account the characteristics of the shipyard, the production pattern, and the industrial environment of the country of origin. A linear programming method by means of Data Envelopment Analysis (DEA) is used as a model to asses shipyard performance. To obtain an indicator of the extent to which the industrial environment of a region is favorable to shipbuilding development, an Analytical Hierarchy Process (AHP) is used. The model compares 12 shipyards in Japan, South Korea, China, and Europe. The data for the model is based on visits to each shipyard and interviews with key technical and managerial personnel (Lamb, 2009[39]).

The Data Envelopment Method identifies efficiency of shipyards and are able to measure inefficiency scores for non-efficient units. This method is based on production frontier theory which study the **efficiency or productivity ratio**. Productivity, in general terms, is the ratio between input and output. The efficiency then can show indices that can translates into competitiveness factors. For example, productivity as discussed in chapter 3.2 and 3.3 where denoted by $\frac{CGT}{man-year}$ can be treated as efficiency. The idea is the same: normally shipyards want to have high CGT produced, and low man-year which can be translated into cost competitive.

This production frontier estimation method (Data Envelopment Analysis) is believed to have **more development and dissemination**, thus it is chosen. Another benefits of this method is DEA is flexible enough to **model production processes or any process in which inputs are resources or influencing factors, and outputs are the expected results.** The production frontier and DEA will be discussed in details in Chapter 4.

In Lamb's study, the influencing factors can be used as indicators that affecting competitiveness. The whole idea of assessing performance is to measure a better performing shipyard hence more competitive. Although the Lamb did not specify the definition of competitiveness literally, his method in assessing performance can not be overlooked. The inputs and outputs of his model are:

1. Capacity
2. Technology
3. Industrial Environment
4. Productivity
5. Building Time, and
6. Quality

Those variables are indeed influencing the performance of a shipyard. A better performing shipyard will have better prospect in competition. Therefore, the inputs and outputs of his model will be discussed.

3.4.1. Shipbuilding performance indicators and influencing factors

Capacity

Shipyard capacity, mainly in terms of total area, erection area and capacity for moving blocks, affects productivity and building times. A greater capacity for moving blocks may imply more productivity and less erection time. Furthermore, there is a margin of substitution between capacity and technological and managerial capability. Without going too much into detail, in Lamb's model, **Erection area** is considered a more robust and representative indicator of shipyard capacity than total area.

Technology
Technological and managerial capabilities are very important in the level of competitiveness of a shipyard (Lamb, 2009[39]). To obtain the technology index, there are methods and systems for benchmarking shipyard technology based on FMI. The technology index is expressed by ITech, which obtained from survey visits to the shipyard.

Industrial Environment
Besides the shipyard's own attributes (like facilities, capacity, and technological level) and production pattern, builder performance depends on the prevalent conditions in the country or region, which define the industrial environment for shipbuilding development (Lamb, 2009[39]). The approach to get this indices is by using Analytic Hierarchy Process (AHP).

Productivity
Same as discussed in 3.2 and 3.3 productivity is denoted as $\frac{CGT}{man-year}$. Productivity explanation is enough represented so there will not be more explanation.

Building Time
Building time is also has been discussed in previous sub-chapters. Building time can be measured by the interval between keel laying and delivery.

Quality
Again, quality is one of the three components of competitiveness in management framework which has been discussed in previous sub-chapter. Quality is hard to measure and in Lamb's DEA model, it is left out.

3.4.2. Summary of this sub-chapter
There is no literal definition treated in this research article. However, the concept of competitiveness refers to the same general framework in chapter 3.3. The shipyard has to compete in the area of 'Production Cost,' 'Building Time,' and 'Quality.' Productivity and Building Time are then the indices of competitiveness. Generally, a better performing shipyard has a low production cost, fast building time, and high-quality product.

To assess the performance, Stott used Data Envelopment Analysis. In DEA, shipyard frontiers are determined and used as benchmarks. In Data Envelopment Analysis, a shipyard acts as a system that has input(s) and output(s). The inputs are resources, or influencing factors and outputs are the expected results. A competitive shipyard has a ratio efficiency (performance) higher than other shipyards.

Lamb predetermines the input and output. The selection comes from literature and 'general' terms of productivity. The output of the DEA model is productivity, expressed in $\frac{CGT}{man-year}$, and building (construction) time. The input of the DEA model is Capacity, Technology indexes (ITech), and Industrial Environment (IndEv).

3.5. Cost Competitiveness and Market Share

Although Cost Competitiveness has been discussed in previous sub-chapters, we have not seen the example usage of cost in case of shipyard competitiveness. Jiang and Strandenes demonstrate how shipbuilding costs and market share are able to evaluate the competitiveness of a country, in this case, China. The competitiveness indicator in this matter is straightforward, which is shipbuilding costs. Jiang and Strandenes believe shipbuilding costs are one of the most critical factors (Jiang, 2012[63]). However, relating shipbuilding costs with market share has not been done, and it is crucial to see the results as validity.

In his academic article, Jiang and Strandenes assessed shipbuilding costs and their impacts on the competitiveness of China's shipbuilding industry. In addition to costs development, market share is an important measure of competitive strength. Given a cost advantage, a firm is likely to increase its market share as it may charge a lower price than its competitors (Jiang, 2012[63]). The information about shipbuilding cost development and its market share is used to see 'competitiveness position' of countries under investigation.

Jiang defines competitiveness into four stages: In the emerging state, a shipyard just enter the newbuilding market[63]. In the emerging state, a new entrant has low shipbuilding costs and a relatively small market share. Because of its competitive costs, the shipyard receives an increasing number of newbuilding orders. The yard's market share may increase rapidly, and the yard starts expanding its production capacity.Thereby, the shipyard has moved to the growing competitiveness stage. With the steady entry of new lower-cost competitors, the yard's cost position changes. This change is illustrated in the movement to the right of the horizontal axis in Figure 3.3. This process represents the maturing competitiveness of shipyards, which is coupled with higher costs and stronger market share. The high costs cause a further decline in market share and the yard eventually shifts into declining competitiveness (Jiang, 2012[63]).

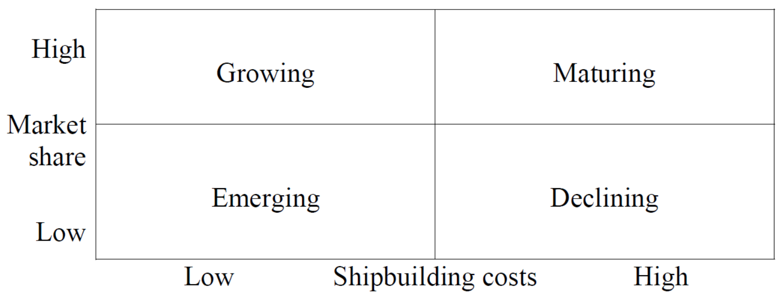

Figure 3.3: The four stages of shipbuilding competitiveness (Jiang, 2012)

3.5.1. Elaboration of Shipbuilding Costs

Shipbuilding costs are composed into three components: labour cost, steel cost, and ship equipment cost. These components account for 90% of all shipbuilding costs and they also represent the largest national cost differences (Wijnolst and Wergeland, 1997[47]). Cost estimation in shipbuilding can be expressed by:

$$C = ULC + S + E \tag{3.6}$$

where C represents shipbuilding costs, ULC represents unit labour costs, S represents cost of steel, E represents costs of ship equipment. Each cost components is expressed in US dollars per Compensated Gross Tonnage (CGT).

It is worth noting that wages alone do not determine labour costs; it is also vital to consider labour productivity. Productivity is denoted by $\frac{CGT}{man-hour}$. As a result the Unit Labour Costs can be defined as follows:

$$ULC = \frac{AIW}{Productivity} \tag{3.7}$$

where AIW is the average industrial wage (US dollar/MH) and Productivity is shipbuilding productivity.

Results in Shipbuilding Costs
The study used dataset of shipbuilding cost in the period of 2000-2009. The cost of labour is taken from many sources (OECD[50]; Lamb, 2002[65]; Chou and Chang, 2004[13]; First Maritime International, 2005[31]; Lamb, 2007[66]; Pires and Lamb, 2008[12]). The cost of steel is estimated by hot rotted plate. Domestic steel prices are converted to US Dollars. The cost of equipment are taken from China Customs, Japanese Ship Machinery Export Association and Korea Marine Equipment Association. The equipment costs are calculated as a 3-year cumulative average.

From the figure 3.4, following points can be made, first China maintained a cost-leading position throughout the period, whereas South Korea surpassed Japan and became the most expensive shipbuilder in 2006. Second, both China and South Korea have experienced cost increases in recent years, whereas Japan has experienced a slow decline in costs. In addition the cost gap between China and Japan has narrowed, whereas the cost gap between China and Korea slightly increased.

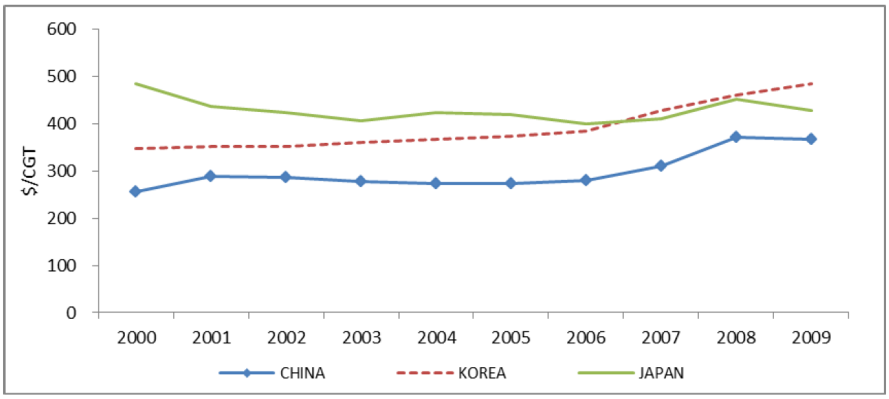

Figure 3.4: Comparison of shipbuilding cost (Jiang, 2012)

Results in Competitiveness Matrix
During the period studied, China's shipbuilding industry increased its share of the market rapidly. It moved from emerging in 2000 to the growing competitiveness in 2009, as shown in Figure 3.5, Figure 3.6, and Figure 3.7. South Korea's shipyards maintained a stable market share of 33% throughout the period while experiencing increased shipbuilding costs. Therefore the trendline of South Korea is flat compared to the rising curve of China. South Korea moved from growing to maturing competitiveness in 2006. Japan has a 'C' shape curve, showing a backward movement from 2000 to 2006. Japan's declining market share was primarily due to competition from China. The decreasing costs, on the other hand, were the result of yen devaluation against the US dollar and reduced ship equipment prices. As the equipment price rebounded in 2006, Japan leveled out at maturity and begun to exhibit declining competitiveness.

3.5.2. Discussion on Competitiveness Matrix

A large body of research has been devoted to understanding shipbuilding competitiveness. Researchers are more inclined to interpret shipbuilding competitiveness based on internal factors, such as cost,

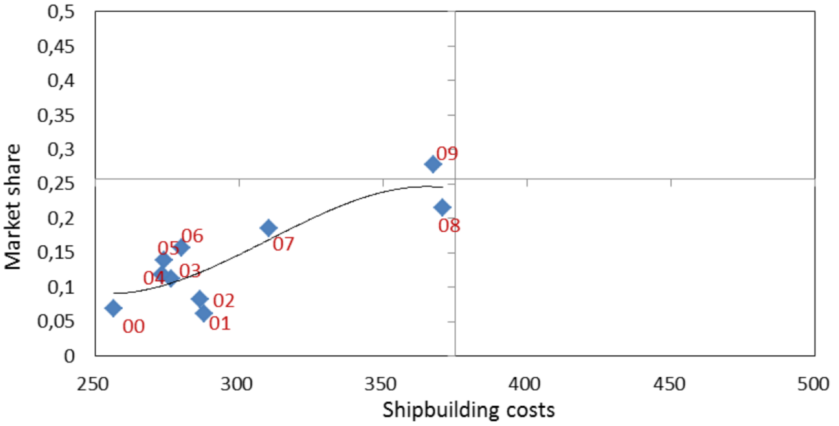

Figure 3.5: China shipbuilding competitiveness (Jiang, 2012) [market in % ; costs in $/CGT]

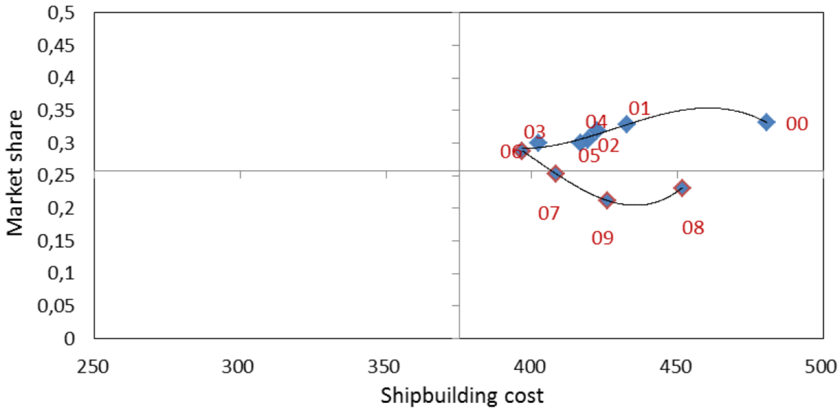

Figure 3.6: Japan shipbuilding competitiveness (Jiang, 2012) [market in % ; costs in $/CGT]

price, ship quality, and delivery time, which, are strictly related with daily productions (Hengst and Koopies[57], 1996; Chou and Chang, 2004[13]; Goldan, 1995[43]; Bertram and Weis, 1997[69]; Cho and Porter[17], 1986; Bertram, 2003[9]; Pires and Lamb, 2008[12]). In particular, shipbuilding costs are considered critical for securing newbuilding orders and determining the yard's competitive position (Bertram, 2003[9]; Wijnolst and Wergeland, 1997[47]).

However, the shipbuilding industry is also highly exposed to the external environment, especially to the strong influence of government policy and market conditions. A notable example is the rapid growth of Japanese and South Korean shipbuilding, which benefited from government-supported shipbuilding programs and favorable credit facilities. While external factors may not directly lead to a shipyard securing a specific newbuilding contract, they will affect the shipyard performance and its competitiveness in the long run.

3.5.3. Summary of this subchapter

In this literature, competitiveness is relative and changes within a period. Shipbuilding costs and market share define the competitiveness of a shipyard. Low shipbuilding costs (cost advantage) are believed to be the driver of the increasing market share of China; thus, china is more competitive in gaining market share due to its cost advantage. However, internal factors are not enough to interpret shipyards' competitiveness in the bigger picture. External factors such as government support policy are also influencing the competitiveness of shipyards.

Using the correlation analysis and times series, Jiang shows how cost advantage responsible for the increasing market share of the china shipbuilding industry. This specific case is only working for merchant ships. The competitive indicator in this research is market share. The factors influencing

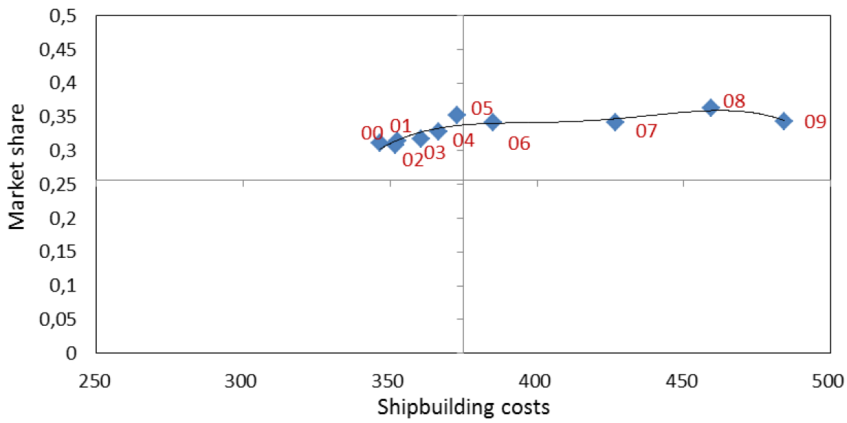

Figure 3.7: South Korea shipbuilding competitiveness (Jiang, 2012) [market in % ; costs in $/CGT]

competitiveness, in this case, are shipbuilding costs, composed of labor costs, ship equipment cost, and steel cost within a country.

3.6. Profit-based Measurement of Shipbuilding Competitiveness

The last research paper from Jiang defines competitiveness in the shipbuilding industry in a very detailed manner. Competitiveness is a multi-dimensional concept that can be measured in numerous ways. 'Competitiveness' specifically applied to the shipbuilding industry has been defined as: 'The ability to win and execute shipbuilding orders in open competition and stay in business' (Peat Marwick, 1992[44]).

This illustration of competitiveness by Marwick is elaborated and given three objectives by Jiang. The objectives of which represent shipbuilding competitiveness. The first objective is the ability to attract shipbuilding orders. The ultimate goal for a shipyard is to get orders and start producing ships. The second factor is the ability to execute shipbuilding orders. This factor shows two things: one is the capacity of the shipyards, two is the ability of a shipyard to build a high number of CGT, regardless of how many resources they have. In this factor, the ability of the management to manage their project, given their capacity, is an important factor. The third factor is the ability to stay in business. The survivability of the volatile shipbuilding demand is a crucial factor a shipyard should have (Jiang, 2013[42]).

Jiang proposed profit rate as a measurement because profitability is a firm's ultimate goal and the primary reason for developing competitiveness strategy. Mathematically, the profit rate of a shipbuilding contract i at time t, $PR_i t$ is defined as:

$$PR_{it} = \frac{P_i}{COST_{it}} \tag{3.8}$$

where P_i is the unit price of newbuilding contract i, and $COST_{it}$ represents the unit shipbuilding costs of contract i at time t. An increase in the profit rate suggests that a company or industry has increasing competitivness and vice versa (Jiang, 2013[42]).

In this study research, Jiang use a regression analysis to examine the effect of profit rate to the competitiveness of China, South Korea and Japan. In this research, the Bulk and Tanker type are used as case study.

The profit rate is dependent variable, while time charter rate, shipbuilding costs, contract price deviation and market condition dummies are independent variables. The regression model is expressed as:

$$PR_{it} = f(TRATE_{it}, COST_{it}, DEV_{it}, DUMMY_{it}, \epsilon_{it}) \tag{3.9}$$

where PR_{it} represents the profit rate, $TRATE_{it}$ represents time charter rate, $COST_{it}$ represents shipbuilding costs, DEV_{it} represents contract price deviation, ϵ_{it} is the error terms, i represent a shipbuilding contract and t represents the month of the shipbuilding contract date.

3.6.1. Data used in Regression Analysis

The data used in this study are as follows:

1. **New building contract prices and new building market prices.** New building contract prices are obtained from actual contracts placed between 2000 and 2009, retrieved from Clarkson Shipping Intelligence Network. Newbuilding market prices on the date of the contract are also retrieved from Clarkson SIN.

2. **Shipbuilding Costs.** The shipbuilding costs used are derived from Jiang and Strandenes (2012[63]). The unit variable costs of shipbuilding is take into account labour costs and material costs (steel and ship equipment).

3. **Shipbuilding market demand.** The demand is derived from the freight market and is positively correlated with the freight rate. Therefore the time charter rate is used as an indicator of newbuilding market demand, which is measured in US dollars per day on the newbuilding contract date. A higher charter rate would lead to a higher profit rate, and vice versa.

4. **Contract price deviation.** The contract price deviation is defined as the difference between the individual contract price and the market price (on the newbuilding contract date). A negative deviation indicates that the contract price is below the market price, thus indicating a lower profit rate than the profit rate obtained based on the market price.Similarly, a positive deviation indicates a higher profit rate.

5. **Profit rate.** The profit rate is the ratio of the unit contract price to unit shipbuilding costs.

3.6.2. Summary of this subchapter

Three objectives make up for the definition of competitiveness in a shipyard. The objectives are:

1. The ability to attract shipbuilding orders
2. The ability to execute shipbuilding orders
3. The ability to stay in business.

The indicator of competitiveness is the profit rate. The method to show the competitive position of profit rate is statistical regression. And the factors that represent the measurement of competitiveness are contract prices (and new building market prices), shipbuilding costs, shipbuilding market demand, and contract price deviation.

3.7. Conclusion and summary of chapter 3

This chapter discusses the approach and method of defining and measuring competitiveness. Five scientific papers are studied to find the definition of competitiveness in the shipbuilding industry, the path to measure competitiveness, the indicator of competitiveness, and the factors that are influencing competition in the shipbuilding industry. The summary is shown in Figure 3.8.

Author	Method	Competitiveness indicator	Factors
(Paul Stott, 1997)	Competitive Indices | Key Performance Indicator (KPI) | Ratio	Cost competitiveness : Total Cost/Unit output (CGT)	Price, subsidy, design, marketing, performance (cost and productivity)
(V. Bertram, 2003)	Competitive Indices | Key Performance Indicator (KPI) | Ratio	Turnover (Ship price > Ship cost)	Productivity (technical productivity and labour productivity), production depth, attractiveness of the product, cost position, and currency influence
(Thomas Lamb, 2009)	Benchmarking; Data Envelopment Analysis	Building Duration and Productivity (sCGT/man-hour)	Capacity, Technology, Industrial Environment, Productivity, Building time, and quality
(Jiang, 2012)	Correlation Analysis; Time Series	Market share (%)	Shipbuilding costs, composed by labour costs, ship equipment cost, and steel cost.
(Jiang & Strandenes, 2013)	Linear Regression	Profit rate (Price/Cost)	Time charter rate, shipbuilding cost, and contract price deviation

Figure 3.8: Summary of literature study

So there are generally four methods with different competitiveness indicators and various factors to measure competitiveness in the shipbuilding industry. This conclusion then answers the second research question. To explain what is the most appropriate method, please proceed to the next sub-section of the discussion.

3.7.1. Discussion on definition

Competitiveness is a multi-dimensional concept that can be measured in numerous ways. Each study defines the competitiveness in their perspective. Although one might overlap the other, the view is complementary. Paul Stott defines competitiveness as the ability for a shipyard to be able to meet requirements of potential owners by being competent, having an attractive price, and the performance must be adequate to match the price offered.

Bertram suggests that a competitive shipyard must have a fast delivery time, a low price, and a good quality based on the owner's expectation. Peat Marwick defines competitiveness in the shipbuilding industry as the ability to win and execute shipbuilding orders in open competition and stay in business (Marwick, 1992 [44]).

There is no exact definition to best represent competitiveness in the shipbuilding industry. It depends on what objectives one wants to achieve. The many approaches to competitiveness then serve as a conceptual tool to shed on the particular issues that they are being proposed to address. Jiang then translates these issues into three objectives. It may not be the approved definition, but it is enough to act as a representation of competitiveness. The objectives are:

1. The ability to attract shipbuilding orders.
2. The ability to execute shipbuilding orders.

3. The ability to stay in business.

In this thesis, the author mainly focuses on the first two objectives: the ability to attract shipbuilding orders, and the ability to execute shipbuilding orders.

3.7.2. Discussion on Methods

Paul Stott and Bertram both use ratios as their method to measure competitiveness[62][9]. In Bertram's study, multiple indices come from the cost variable. The indices introduced by Bertram are also similar to those of KPIs' concept. In the study from Jiang and strandenes, they attempted to encapsulate external factors to their competitiveness measurement. They use correlation analysis, time series, and linear regression. Lamb used a frontier analysis or benchmarking.

The most common method to measure competitiveness is by issuing a 'Key Performance Indicator(s)' or KPIs. KPIs can be a ratio between input and output or just a value of a variable deemed to be important. Some examples of KPIs from literature study are $\frac{Total\ cost}{Unit\ Output\ (CGT)}$ and $\frac{CGT}{man-year}$ or also known as productivity factor. However, KPIs are not enough to represent the whole competitiveness concept of shipbuilding. Most of the indices used in studying shipyard competitiveness are based on internal factors. However external environment variables are also strongly influencing shipyard's competitiveness.

Correlation analysis and Time-series may be able to capture the internal and external factors, as shown by the study from Jiang and Strandenes. However, there is still a limitation in the number of variables. Correlation analysis can also be a ratio analysis as they have the same mechanism. Time series is only limited when one wants to investigate the variable's changes throughout time.

A benchmarking method, i.e., Data Envelopment Analysis (DEA), has also been compared to the use of simple ratio analysis such as KPIs ratio. Halkos and Salamoursi show that compared to simple ratios, the DEA method provides a single objective score, ranking, and the potential targets of improvement. They concluded that ratio analysis and DEA should be used as complementary measures and be used in conjunction with each other. (Halkos and Salamoursi, 2004 [28]).

Linear regression could be a better approach to study the correlation between variables. However, linear regression may not be reliable when more variables are used in a study. Multivariate regression analysis can handle multiple variables, but the procedure of forward-selection or backward elimination depends on the data availability. In other words, regression analysis is one of the best methods when data is abundant and reliable. Also, regression models only provide an estimate of model success while offering no feedback about improvement possibilities compared to the benchmarking method (Donthu, 2005 [20]). A benchmarking approach might be a better solution to this problem. This method can treats any process as a 'black box,' simply considering the resources available to the inputs and measuring the effectiveness of their conversion into desired outputs (Migiro, 2016 [59]).

Chapter 3.8 discuss how the author selects which method is best to answer the two objectives of the competitiveness in the shipbuilding industry.

3.7.3. Selection for methods

So far, the author has discussed four methods: KPIs, benchmarking, correlation analysis (including time-series analysis), and linear regression. In chapter 3.8, only three of the methods will be selected in the selection approach, namely: KPIs, benchmarking, and linear regression. The reason is that KPIs' nature that commonly derived using correlation analysis.

When creating KPIs, firms tend to find a variable that correlates highly with the desired outcome. Badawy et al. (2016 [22]) emphasized that correlation is one of the twelve KPIs' characteristics. KPIs drive desired outcomes (Badawy et al., 2016 [22]). A study from Eckerson shows that when evaluating KPIs, we need to analyze the correlation between one variable and the desired outcomes statistically.

Ideally, when defining KPIs, the team should use statistics to correlate behavior with outcomes (Eckerson, 2009 [21]). Because of this reason, we can assume that correlation analysis and KPIs are interchangeable.

Different than correlation analysis, time-series is explicitly looking at the time dimension of the correlation between variables. Thus, time-series analysis is an excellent candidate to consider. However, time-series analysis, to be used optimally, requires an extended period (to look at the effect of variables understudy in a long period). Due to data availability and the cyclical mechanism of the shipbuilding industry, the author leaves out time-series analysis from the method selection.

3.7.4. Summary of influential factors

Based on the literature research, the indicators of competitiveness are, but not limited to, 1) cost competitiveness, denoted by $\frac{Total\ cost}{Unit\ Output\ (CGT)}$, this indicator is influenced by Price (and subsidy), design, marketing, and performance (cost and productivity), 2) turnover (profit), this indicator is influenced by technical productivity, labor productivity, production depth, the attractiveness of the product, cost position, and currency influence, 3) Building duration and productivity, denoted by 'year' and $\frac{CGT}{man-hour}$ these indicators are influenced by capacity, technology, and industrial environment, 4) market share, influenced by the shipbuilding cost, in such a way by giving cost position advantage, the ship's cost is composed by labor cost, ship equipment cost, and steel cost, 5) profit rate, the profit rate is influenced by time charter rate, shipbuilding cost, and contract price deviation.

3.8. Method Selection Approach

In chapter 3.7.2, we have discussed the methods, now, the author seeks a more formal mathematical approach in making a decision, and AHP is believed to be the solution. The author has selected a few crucial criteria as tools for decision making. Details are in chapter 3.8.1.

The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions based on mathematics and psychology. Thomas L. Saaty developed it in 1970. The primary purpose of AHP is to make a single selection from a group of fixed alternatives in a rather complex decision-making process.

The AHP uses pairwise comparison with either technical data or expert opinion. The reasons are because pairwise is easy for humans to do, and it offers simplicity due to only comparing two times at most at one time. The AHP is also used formal mathematical approach and documented design decision (Kana, 2018 [33]).

There are five steps to perform AHP, namely:

1. Model the problem as a hierarchy containing the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives. The decision, in this case, is to choose the method for competitiveness analysis among a set of options.
2. Establish priorities among the elements of the hierarchy by making a series of judgments based on pairwise comparisons of the features. The pairwise comparison compares two variables at a time with a score individually valuing the level of contrast. Table 3.1 shows the scoring value. The pairwise comparison then forms a comparison matrix that evaluates the alternatives based on each criterion.
3. Synthesize these judgments to yield a set of overall priorities for the hierarchy. Each of the hierarchy will have a set of comparison matrices based on its criteria; hence the number of criteria equals the number of comparison matrices.
4. Check the consistency of the judgments. To check for cardinal consistency, we need to check for the consistency index. For the cardinally-consistent pairwise matrix, there should be only one eigenvalue, and it should equal n, the size of the matrix. The consistency index is defined as follows;

$$Consistency\ Index = \frac{\lambda_1 - n}{n - 1} \tag{3.10}$$

   Finally, we compare the consistency index value to a random index (RI) value generated from random positive reciprocal matrices. For size three matrices, the RI is 0.58 (Kana, 2018).

   Then the consistency ratio is as follows:

$$Consistency\ Ratio = \frac{Consistency\ Index}{Random\ Index} \tag{3.11}$$

   CR <= 0.1 for acceptability.
5. Come to a final decision based on the results of this process.

3.8.1. Criteria for selection process

1. **Flexibility in data availability**
   Flexibility in data availability refers to the ability to give a robust and reliable result in the absence of an abundant amount of data. The shipyard is a highly competitive industry. Most likely, shipyards do not publicly disclose their data. Moreover, having various data sources may give different

standards and, thus, could be misleading. This problem will result in a difficulty to use reliable and consistent data. Therefore flexibility in data availability is an essential point in competitiveness modeling.

2. **Ability to handle multiple inputs and outputs**
As discussed entirely in this chapter. Many variables are affecting the competitiveness in the shipbuilding industry. Shipyard's capacity, commonly represented by the number of orderbook or the number of ships delivered in the CGT Unit. However, in the shipyard's perspective, the number of workers, price & cost, yard area can also be essential factors. Thus the ability to take into consideration many inputs and outputs is vital.

3. **Multi-dimension inclusiveness**
Competitiveness in the shipyard, based on the previous section, is multi-dimensional. Competitiveness can be in the form of productivity, which takes into account workers' output and labor working hours. Productivity highly uses internal factors to model the competitiveness of the shipyards. The ratio of productivity $\frac{CGT}{man-year}$ fails to incorporate the external factors of the shipbuilding industry. The study from Jiang and Stott suggests that the external factors are also indirectly affecting the shipyard's competitiveness. External factors' examples are government subsidy or related industries. These factors are highly influential for the contract price of a ship. Therefore to include many dimensions of competitiveness, it would be a preferable trait when looking for a method to measure shipyard's competitiveness.

Table 3.1: Pairwise comparison score

Description	Score
A and B equally important	1
A is weakly more important than B	3
A is strongly more important than B	5
A is very strongly more important than B	7
A is extremely or absolutely more important than B	9

3.8.2. AHP Result calculation

In this section the author presents the pairwise matrix of each criterion. The vector V indicates the normalized eigenvector of the matrix. The normalized eigenvector associated with the dominant eigenvalue (λ_1) turns out to be the best way of weighting options (Kana, 2018). The lambda is also called the priority vector. The usage of the normalized eigenvector is one of the strengths of AHP, in which we convert pairwise comparisons into weights in a logically consistent way.

The criteria for method selection has been discussed in 3.8.1.

Table 3.2: Criteria table

Criteria-	Description
A	Flexibility in data availability
B	Ability to handle multiple input and output
C	Multi-dimension inclusiveness

$$\begin{array}{c c} & \begin{array}{ccc} A & B & C \end{array} \\ \begin{array}{c} A \\ B \\ C \end{array} & \begin{pmatrix} 1 & 3 & 2 \\ .33 & 1 & .6 \\ .5 & 1.67 & 1 \end{pmatrix} \end{array} \quad \textbf{with} \quad \begin{array}{c} V\_criteria \\ \begin{pmatrix} 0.543 \\ 0.174 \\ 0.281 \end{pmatrix} \end{array}$$

Pairwise Matrix for criterion-1: Flexibility in data availability for each method.

$$\begin{array}{l} \\ KPI \\ Benchmarking \\ Regression \end{array} \begin{array}{c} \begin{array}{ccc} KPI & Benchmarking & Regression \end{array} \\ \begin{pmatrix} 1 & .33 & 3 \\ 3 & 1 & 5 \\ .33 & .2 & 1 \end{pmatrix} \end{array} \quad \textbf{with} = \begin{array}{c} V\_criterion\_1 \\ \begin{pmatrix} 0.258 \\ 0.637 \\ 0.104 \end{pmatrix} \end{array}$$

Pairwise Matrix for criterion-2: Ability to handle multiple inputs and outputs for each method.

$$\begin{array}{l} \\ KPI \\ Benchmarking \\ Regression \end{array} \begin{array}{c} \begin{array}{ccc} KPI & Benchmarking & Regression \end{array} \\ \begin{pmatrix} 1 & .2 & .25 \\ 5 & 1 & 3 \\ 4 & .33 & 1 \end{pmatrix} \end{array} \quad \textbf{with} = \begin{array}{c} V\_criterion\_2 \\ \begin{pmatrix} 0.093 \\ 0.626 \\ 0.279 \end{pmatrix} \end{array}$$

Pairwise Matrix for criterion-3: Multi-dimension inclusiveness for each method.

$$\begin{array}{l} \\ KPI \\ Benchmarking \\ Regression \end{array} \begin{array}{c} \begin{array}{ccc} KPI & Benchmarking & Regression \end{array} \\ \begin{pmatrix} 1 & .33 & 2 \\ 3 & 1 & 5 \\ .5 & .2 & 1 \end{pmatrix} \end{array} \quad \textbf{with} = \begin{array}{c} V\_criterion\_3 \\ \begin{pmatrix} 0.229 \\ 0.648 \\ 0.122 \end{pmatrix} \end{array}$$

3.8.3. Results of AHP

For the pairwise comparison for the criteria matrix, the consistency ratio is 0.00068. Thus this criteria is cardinally consistent.

For criterion 1, the consistency ratio is 0.0327. Criterion 2, the consistency ratio is 0.073. Lastly, the consistency ratio for criterion 3 is 0.0029. Therefore all of the matrices are below 0.1 hence all of them are consistent.

By multiplying the local priorities vector with the criteria weights, the result is as following:

$$\begin{array}{l} KPI \\ Benchmarking \\ Regression \end{array} \begin{pmatrix} 0.2214 \\ 0.6384 \\ 0.1402 \end{pmatrix}$$

Therefore the benchmarking method is 63% favorable compared to the other two methods. KPI is the second-best method for competitiveness analysis. Regression is the least method to analyze shipyard's competitiveness. Nonetheless, input(s) and output(s) can be in the form of KPIs in the benchmarking model, and also, a statistical basis for investigating variables to put into the benchmarking model will need a regression analysis. This conclusion answers the last part of the second research question. Benchmarking is the most appropriate method to measure the competitiveness of a set of shipyards.

The next chapter will discuss more on the foundation knowledge of benchmarking.

4

Benchmarking Method

This chapter aims to answer the third research question, "With the method found, how can the method able to evaluate the competitive performance of shipyards?". From the previous chapter, we found that the most appropriate method is benchmarking analysis. Chapter 4.1 explains the concept of benchmarking. The suitable benchmarking method that is chosen in this study is the Data Envelopment Analysis (DEA). The DEA method is briefly explained in chapter 4.2. In chapter 4.3, an example of DEA modeling to evaluate shipyard performance is discussed in addition to the explanation from chapter 3.4. Lastly, chapter 4.4 gives the summary and conclusion of the whole chapter 4.

4.1. Why benchmarking?

In the previous chapter, the author had concluded that the benchmarking method is more advance than the usage of Key Performance Indicators (KPIs) in handling multiple inputs and outputs. Modern benchmarking methods can handle numerous objectives that are not explicitly aggregated. The ability to manage various objectives hence comes in handy when dealing with the competitiveness concept which are multi-dimensional and has more than one objective. Indeed the ability to handle numerous objectives is one explanation of the popularity and countless applications of modern benchmarking techniques. Thus, benchmarking method thrives in the AHP analysis result from the previous chapter where numerous objectives are in line with competitiveness.

Benchmarking, also known as relative performance evaluation, is the systematic comparison of the performance of one firm against other firms. The idea is that we compare entities that transform the same type of resources to the same kind of products and services. The firm can be any production entities, such as port, shipyards, shipowners, organizations, a holding company, departments, or even individuals. The reason for choosing the benchmark can be understood better by knowing the general objectives of benchmarking, understanding the rational ideal evaluation and the concept of system oriented approach (Bogetoft and Otto, 2011 [10]).

4.1.1. Objectives of Benchmarking

The objectives of bencmarking, according to Bogetoft and Otto are comprised into three [10]. Those are:

1. **Learning**. The stated objective of most benchmarking studies is to learn or get insight. Firms are interested to know how well they are doing compared to others and from which ones they can learn. The nonparametric 'Data Envelopment Analysis' (DEA) method that will later be discussed in detail provide particular strengths in such cases as the peers, or the dominating firms provide valuable and concrete information for performance improvement target.

2. **Coordination**. In some studies, the objectives of the benchmarking explicitly address the allocation of tasks and possibly the restructuring of firms or the industry. Such studies may facilitate coordination, i.e., ensuring that the right firms are producing the right products at the right time

and place. An interesting finding in such studies is that better coordination may be just as valuable as the learning of best practice.

3. **Motivation**. The last objective of benchmarking is to facilitate incentive provision. In the results of the modern benchmarking, the user would be able to point out which input(s) affecting the whole production the most and a quantitative value can be derived. It gives a helpful tools for managers to improve in a targeted objectives.

4.1.2. Ideal Evaluations

When we try to look at a firm or organization, we are often interested to know how well it is doing. To illustrate some of the difficulties and intricacies of benchmarking take a look at figure 4.1.

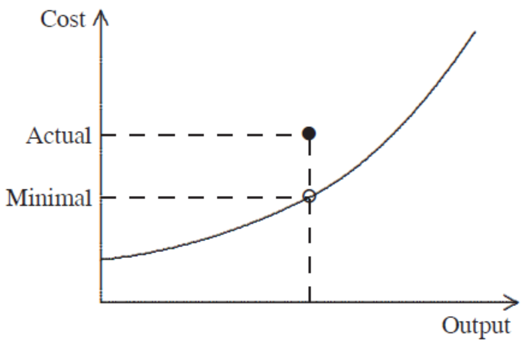

Figure 4.1: An ideal evaluation [10]

Figure 4.1 shows a firm that has produced specific outputs using certain costs, as indicated by the black dot in the output-cost diagram. One might wonder if this is an excellent performance? To evaluate the performance, take a look at the cost function as shown as the curve. The cost function, by definition, is the smallest possible cost of providing different output levels. From the figure, we can say that the firm has been inefficient. It is possible to produce the same outputs with less cost, or more outputs with the same costs, or some combination.

The relative efficiency can be measured by

$$Inefficiency = \frac{Actual\ cost\ -\ Minimal\ cost}{Actual\ cost} \qquad [10] \tag{4.1}$$

The smaller the inefficiency, the better the performance.

Likewise, we could measure the relative efficiency directly as the ratio of minimal cost to actual cost:

$$Efficiency = \frac{Minimal\ cost}{Actual\ cost} = 1 - Inefficiency \qquad [10] \tag{4.2}$$

The higher the efficiency, the better the performance.

From Figure 4.1, if we know the actual behavior of the firm (represented by its output and cost numbers) and if we have an appropriate model of the ideal performance (represented by a cost function), we can easily make a performance evaluation. We could call this the ***rational ideal evaluation***. It is rational evaluation in the sense that we specify the preferences (to reduce costs) and possibilities (as given by the cost function), and we seek the best way to pursue the goals. It is an ideal evaluation in the sense that we have all the relevant information (Bogetoft and Otto, 2011 [10]).

In general terms, ***rational ideal evaluations***, from a standard microeconomic perspective, the performance of a firm is reflected in its ability to choose the best means (alternatives) to pursue its aims (preferences). Take a look at Figure 4.2. The alternatives available are given by the technology T, here illustrated by the curved output isoquant. By definition, the output isoquant shows the largest possible outputs for given inputs. The preferences given by a utility function U(•) is represented here by linear indifference curves. The indifference curves show the outputs combinations that are equally good.

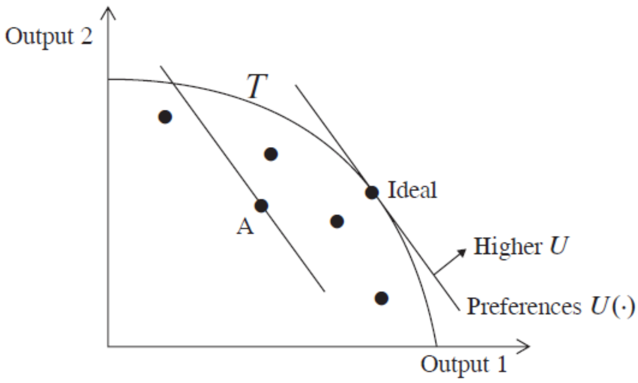

Figure 4.2: Rational Ideal Set-up [10]

The rational ideal performance evaluation would, therefore, compare the attained utility level with the maximally attainable utility level. For firm A this would be to compare U(A) with U(Ideal). This would capture the effectiveness of firm A.

$$Effectiveness = \frac{Actual\ Performance}{Ideal\ Performance} = \frac{U(A)}{max_y \in T\ U(y)} = \frac{U(A)}{U(Ideal)}[10] \tag{4.3}$$

Note the difference between effectiveness and efficiency is that effectiveness has an objective function, and therefore one can seek explicitly about goal attainment. When this is not the case, and one relies on some proxy objective, then instead, it is efficiency.

In real evaluations, it is not entirely easy to apply this microeconomic cookbook recipe. In the typical evaluation, we lack clear priorities U as well as clear information about the production possibilities T. Basically, benchmarking is an attempt to approximate the economic idea of the rational ideal evaluation. A traditional way to overcome some of the difficulties of making rational ideal evaluations is to use what practitioners like to call 'Key Performance Indicators' or KPIs (Bogetoft and Otto, 2011 [10]). These numbers that are supposed to reflect in some essential way the purpose of the firm. Examples of KPIs, in shipbuilding industry, can be found from chapter 3.7, e.g. shipyard productivity (Lamb, 2009 [39]) $\frac{CGT}{man-hour}$, cost competitiveness (Stott, 1997 [62]) $\frac{Total\ cost}{Unit\ Output\ (CGT)}$, attractiveness of product (Bertram, 2003 [9]) $\frac{price\ (\$)}{CGT}$, etc. In section 4.2 subsection, the author will discuss the shortcomings of using KPIs. This is addition to the strengths and drawbacks of KPIs that has already been discussed in chapter 3.7.2.

4.1.3. System Oriented Approach

In the benchmarking literature, the idea of comparing single inputs to single outputs is abandoned. Therefore, we use a more system orientated approach to the firm. A firm is seen as a transformation of resources into products and services. The idea is now to measure the inputs, the outputs, and the non-controllable variables and, as a result of this, to get an idea of the non-measurable managerial characteristics, the skills, and effort. This system-oriented approach is illustrated in figure 4.4. In short, modern benchmarking methods are able to take multiple inputs and outputs.

The systemic view makes comparisons more complicated since we have to handle the multiple dimensions, and firms may be good in some dimensions and bad in others. This is one of the strength

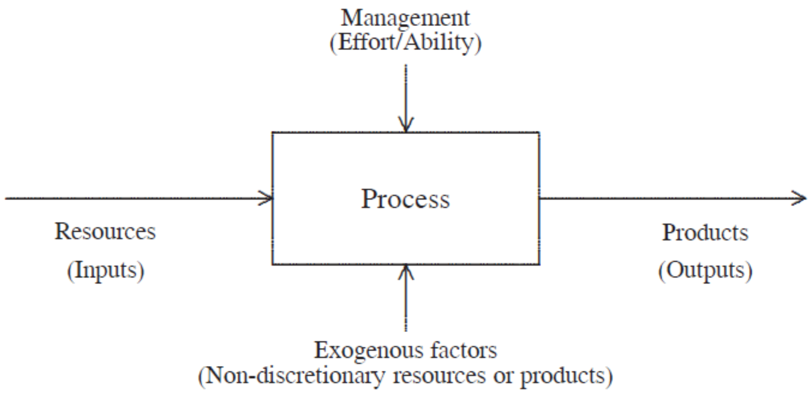

Figure 4.3: Systems View [10]

of systemic oriented as opposed to traditional Key Performance Indicators (KPIs), more of this will be discussed in chapter 4.2.

4.1.4. Frontier Models

Similar with benchmarking, in the traditional statistical literature, it is common to distinguish parametric and nonparametric approaches. Parametric models are characterized by being defined as a priori except for a finite set of unknown parameters that are estimated from data. Nonparametric models are characterized by being much less restricted a priori. Only a broad class of functions, say all increasing convex functions, or even production sets with broadly defined properties, are fixed a priori, and it is used to estimate one of these (Bogetoft and Otto, 2011 [10]).

Another relevant distinction is between deterministic and stochastic models. In stochastic models, one makes a priori allowance for the fact that the individual observations may be somewhat affected by random noise, and tries to identify the underlying mean structure stripped from the impact of the random elements. In deterministic models, the possible noise is suppressed, and any variation in data is considered to contain significant information about the efficiency of the firms and the shape of technology. The taxonomy of methods is illustrated in table 4.1.

Table 4.1: A taxonomy of frontier methods (Bogetoft and Otto, 2011 [10])

	Deterministic	Stochastic
Parametric	Corrected Ordinary Least Squares (COLS); (Lovell, 1993; Greene, 2008) (Aigner and Chu, 1968;)	Stochastic Frontier Analysis (SFA); (Aigner et al, 1997; Coelli et al, 1998a) (Battese and Coelli, 1992)
Nonparametric	Data Envelopment Analysis (DEA); (Charnes et al, 1978) (Deprins et al, 1984)	Stochastic Data Envelopment Analysis; (Land et al, 1993; Fethi et al, 2001); (Olesen and Petersen 1995)

To illustrate the differences, take a look at Figure 4.5. The figure shows a simple cost modeling. In this setting, we seek to model the costs that result when best practice is used to produce one or more outputs. From the figure, the 'Corrected Ordinary Least Squares (COLS)' corresponds to estimating an ordinary regression model and then making a parallel shift to make all firms be above the minimal cost line. SFA, on the other hand, recognizes that some of the variations will be noise and only shift the line -in case of a linear mean structure- part of the way towards the COLS line.

DEA estimates the technology using what is known as the minimal extrapolation principle. It finds the smallest production set (in the illustration the set above the DEA curve) containing data and satisfying a minimum of production economic regularities. Like COLS, the DEA cost function is located below all cost-output points, but the functional form is more flexible, and the model, therefore, adapts closer to the data.

Finally, 'Stochastic Data Envelopment Analysis (SDEA) combines the flexible structure with possibility, that some of the variations in data may be noise, and only requires most of the points to be enveloped. The fifth frontier, term Engineering, the idea is to base the modeling on data from engineers about the best possible performance, perhaps in idealized settings.

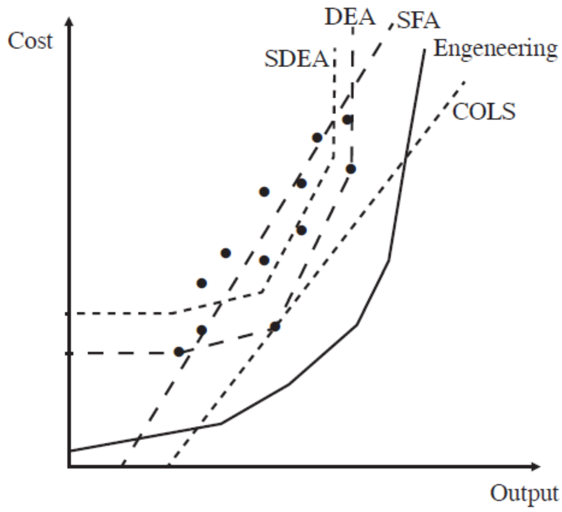

Figure 4.4: Alternative Frontiers [10]

Bogetoft and Otto suggest that the non-parametric models are by nature superior in terms of flexibility (as shown in Figure 4.5). Moreover, the stochastic non-parametric model is the most flexible in terms of the assumptions one can make about data quality. Ideally, then, we would like to use flexible models that are robust to random noise. This would favor SDEA models. However, the problem is the properties come at a cost. The estimation task becomes more prominent, the data need larger, and still, we can not avoid a series of strong assumptions about the distributions of the noise terms. Coping with uncertainty requires us to dispense somewhat with flexibility and vice versa (Bogetoft and Otto, 2011 [10]). Therefore DEA is a useful method when we only have limited data and to avoid noise in the dataset. SFA would give a robust estimation, but SFA requires large sample sizes to obtain better or more degrees of freedom for valid results (Ashraf, 2018 [24]). SDEA is the best method when enough data is available.

In this report, the author chooses DEA as a benchmarking method for the shipbuilding industry due to several reasons. First is the flexibility of the non-parametric method of DEA. Second is in data availability in the shipbuilding industry. The third is the minimal extrapolation principle of DEA gives. DEA takes a cautious approach to the estimation of the technology set (by creating a frontier based on best practice), which in turn leads to a careful (higher) estimate of efficiency (Bogetoft and Otto, 2011 [10]).

4.2. Data Envelopment Analysis

Data Envelopment Analysis or DEA, also called frontier analysis or balanced benchmarking, was first put forward by Charnes, Cooper, and Rhodes in 1978. The Data Envelopment Model by Charnes, Cooper, and Rhodes (DEA-CCR) uses a 'Constant Return to Scale' or CRS assumption. This assumption is the same as the assumption of the traditional use of 'Key Performance Indicators' by Bogetfot and Otto. When we compare a firm with small output to a firm with large output in this manner, we implicitly assume that we can linearly scale input and output, i.e., we assume a constant return to scale.

To understand better how the 'Constant Return to Scale' works, take a look at the table below. Multiple decision-making units (DMUs), stores have data on the number of employees and sales. In this case, the KPIs or 'Productivity' is the ratio between sale and employee. (This example is taken from Cooper et al. book, please refer to the book for a more detailed explanation).

Store	A	B	C	D	E	F	G	H
Employee	2	3	3	4	5	5	6	8
Sale	1	3	2	3	4	2	3	5
Sale/Employee	0.5	1	0.667	0.75	0.8	0.4	0.5	0.625

Table 4.2: Single Input and Single Output Case (Cooper et al., 2007 [72])

In this simple model, the employee is the input, and the sale is the output. Assume that the ratio of output to input as 'Productivity,' then the firm with the highest productivity, is the one with the highest ratio of output per input. In other words, the store with the highest productivity is the store that generates the most top sale with the number of employee as a resource.

From the table, we can see that store B is the most productive store, or in DEA terms, it is called the 'efficient frontier.' Store B has a ratio of 1. Store B, as a frontier, is illustrated in Figure 4.5. From the figure, we can also see the difference between the DEA methodology and the regression line. DEA's method directed to frontiers rather than central tendencies. Compared to regression analysis, DEA focuses on the outliers. Instead of trying to fit a regression plane through the center of the data, one 'floats' a piecewise linear surface to rest on top of the observations.

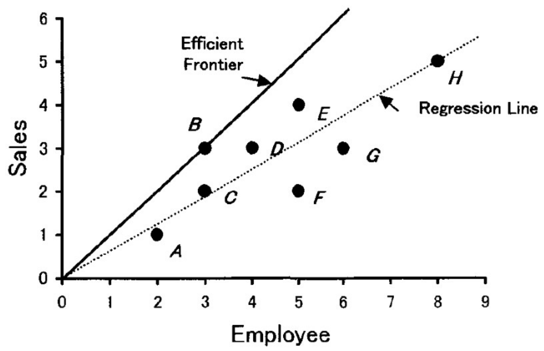

Figure 4.5: Regression line vs frontier line (Cooper et al., 2007)

We can call the productivity for store A compared to store B the efficiency ratio of firm A relative to firm B. Bogetoft and Otto denoted this ratio by E. Let (x^A, y^A) be the input-output combination of store A and (x^B, y^B) be the input-output combination of store B. Then the productivities of the stores are $\frac{y^A}{x^A}$ and $\frac{y^B}{x^B}$, and the efficiency ratio E is:

$$E = \frac{y^A/x^A}{y^B/x^B} = \frac{y^A/y^B}{x^A/x^B} \qquad [10] \tag{4.4}$$

In other words, the relative efficiency measurement of decision-making units (DMUs) is derived by comparing its ratio of efficient DMUs. Since store B is the only efficient DMU, we use this equation:

$$0 \leq \frac{Sales\ per\ employee\ of\ others}{Sales\ per\ employee\ of\ B} \leq 1, \tag{4.5}$$

This relative efficiency is called units invariant. So the DEA model will generate efficient and inefficient units and the value of efficiency or inefficiency.

In the usage of DEA, the inefficient DMUs are expected to have benchmarks (efficient ones) to improve. DEA recognizes two different orientations, the input-oriented and output-oriented. An inefficient DMU can be made more efficient by projection onto the frontier. In an input orientation, one improves efficiency through proportional reduction of inputs, whereas an output orientation requires proportional augmentation of outputs (Cooper, 2007 [72]). The graphic of orientations is shown in Figure 4.6.

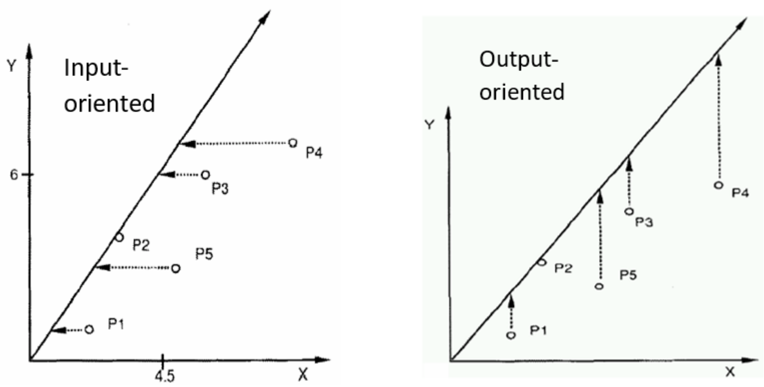

Figure 4.6: Input-oriented vs Output-oriented

4.2.1. Return to Scale Assumption

The example we have discussed so far is the DEA-CCR model. The CCR model uses the Constant Return to Scale (CRS) assumption. However, the DEA model has several assumptions for Return to Scale (RTS) that draw different shapes of an envelope. In the development of Date Envelopment Analysis, the RTS has evolved into various forms based on the scale of operations. A more recent and commonly known RTS is the Variable Return to Scale (RTS) developed by Banker, Charnes, and Cooper in 1984. The model developed by Banker, Charnes, and Cooper that uses Variable Return to Scale is also known as DEA-BCC model.

While the CRS is often a legitimate assumption, in situations where CRS does not prevail, it is vital to compare DMUs based on their scale of operations (Hui, 2013). The type of Return to Scale (RTS) refers to the shape of the DEA best practice frontier. Other kinds of DEA frontiers assumption include variable RTS (VRS), non-increasing return to scale (NIRS), and non-decreasing return to scale (NDRS) (Figure 4.7).

The DEA-CCR model, which uses constant return to scale (CRS), is quite problematic because we assume that we can linearly scale input and output. According to Bogetoft and Otto, the idea of benchmarking is an attempt to approximate the economic notion of the rational ideal evaluation. To do so, we need to collect data to describe actual behavior, we need to estimate an approximation of the ideal relationship between inputs and outputs, and we need to combine the actual performance with the ideal performance to evaluate the efficiency [10].

To understand better how observation of actual behavior creates an envelope-shape, take a look at figure 4.8. Figure 4.8 shows the representation of theoretical frontier compared with the DEA frontier

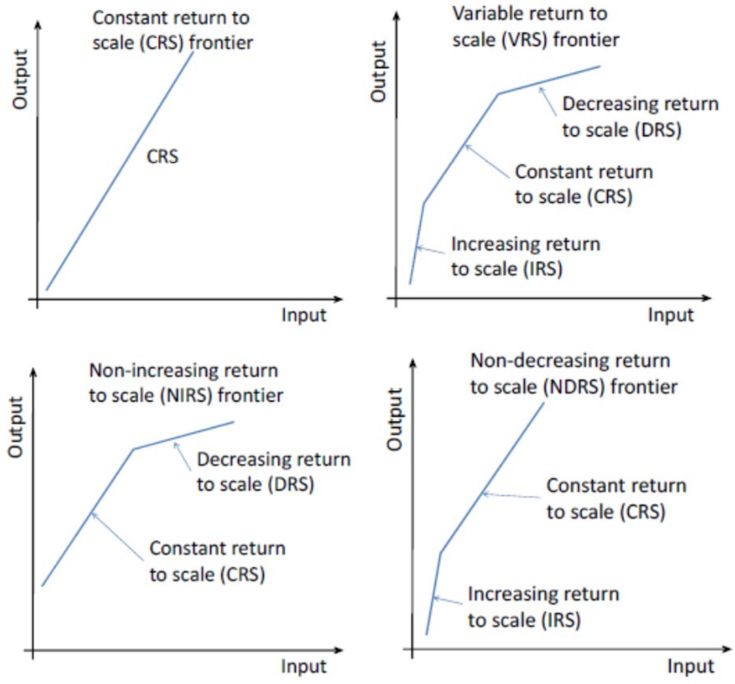

Figure 4.7: Different types of return to scale (RTS) assumptions [30]

in shape more of an envelope.

The frontiers are obtained by applying the DEA approach to the set of points of the DMUs. The DEA model will identify units S1, S2, S3, and S4 as efficient, and they provide an envelope (best practice frontier) round the entire data set; other units are within this envelope and are inefficient. An inefficient DMU can be improved (moved to the efficient frontier) with suggested directions for improvement (to S1, S2, S3, S4, or other points along the boundary). The distance to the efficiency frontier provides a measure for the efficiency or its lack thereof (Hui, 2013 [30]).

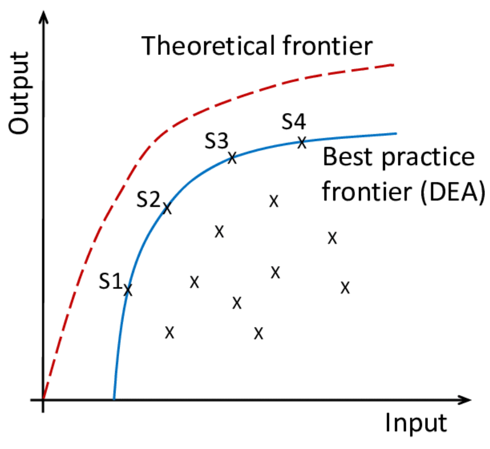

Figure 4.8: Theoretical frontier vs best frontier (Hui, 2013 [30])

4.2.2. Free disposability and convexity

In equation 4.4, we know that E is the efficiency ratio. This ratio defines the efficient and inefficient DMUs. From the example in 4.2, the ratio is based on the CRS assumption. In this section, we will relax this assumption. This approach is based on Bogetoft and Otto. To do that, we need to look for an alternative definition of efficiency E with the same interpretation, but without scaling assumption.

First, we define 'input efficiency' for an input-output combination (x, y) as the smallest factor E by which we can multiply the input x so that Ex can still produce the output y. If we were to use a smaller amount of input than Ex, it would be impossible to produce y. Hence

$$E(x, y) = min\{e|ex\ can\ produce\ y \text{ [10]} \tag{4.6}$$

Another way to look at E is to say that it is possible to save $(1 - E)x$ of the input and still produce the same output y.

To determine whether or not input can produce an output, we need knowledge of the technology. Thus we need to introduce the **technology set**. The technology set T is the set of combinations of input and output such that the input can produce the output.

$$T = \{(x, y)|\ x\ can\ produce\ y\}\text{[10]} \tag{4.7}$$

The main issue in benchmarking is to estimate what the technology set look like starting with some actual input-output observations from several firms. Without going too much into detail, the following assumptions are believed to be needed as the best approach to estimate the technology set. These two assumptions are the foundations of the variable return to scale (VRS) assumption.

The first assumption is that we can dispense with any extra inputs and outputs. If an input-output combination is a feasible production for a firm, then any input-output where the input is larger, and the output smaller is also a viable production, i.e., is also in the technology set. This assumption is called **'free disposability'**. Starting from a set of observations numbered 1 to 6, the resulting free disposability technology set is the dotted area shown in Figure 4.9.

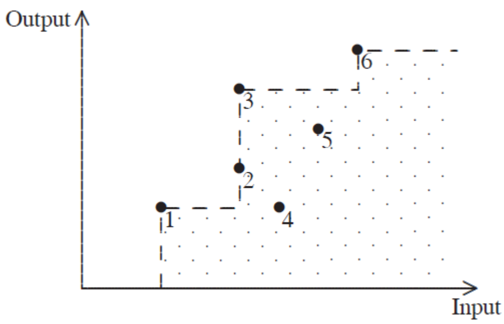

Figure 4.9: Input-output Combinations, and Free Disposability [10]

The second assumption is that if two input-output combinations are feasible productions, then any mixture of the two is also a viable production. A mix of two input-output combinations is called a convex combination, and therefore we can call it **'convexity'** assumption or we can say that the technology set is convex. If we assume both free disposability and convexity and have the six observations from Figure 4.9, the technology set looks like in Figure 4.10.

In DEA, we compare a firm with the best firm. With an estimated technology, we compare a firm with what is feasible given the technology set; in other words, we will compare it to the boundary or frontier of the technology set. Figure 4.10 shows that the frontier of the technology set is determined by the firms 1, 3, and 6, and therefore, we compare any input-output combination in the technology set with a mixture of a convex combination of these firms.

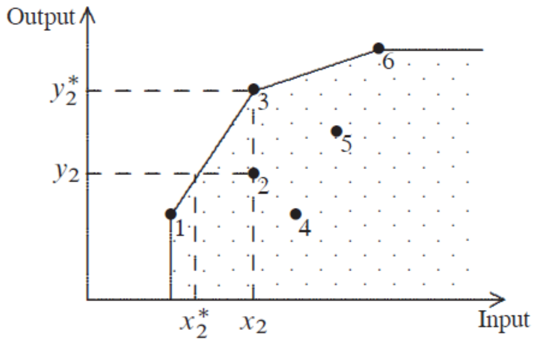

Figure 4.10: Input-output Combinations, Free Disposability and Convex [10]

For example, consider firm 2. We see that its input-output combination is an interior point in the technology set, and it is possible to produce y_2 by just using the input x_2^* instead of the observed input x_2 for unit 2. The input efficiency of firm 2 is therefore

$$E_2 = \frac{x_2^*}{x_2}[10] \tag{4.8}$$

and we have $x_2^* = Ex_2$.

When we compare firm 2 with the boundary, we compare it with a convex combination of firms 1 and 3. If instead, we keep the input for firm two fixed at x_2 then we can calculate the output efficiency by

$$F = \frac{y_2^*}{y_2}[10] \tag{4.9}$$

such that $y_2^* = Fy_2$. For firm 2, using the input x_2 it would be technically possible to produce the output y_2^* and not just the smaller output y_2. The possible increase in output is $(F-1)y_2$.

4.2.3. Multiple Inputs and Outputs

One of the strengths of benchmarking is the ability to handle multiple inputs and outputs.

Let us consider some examples. In the case of two inputs, we can draw the input isoquant for given outputs, and two outputs we can draw the output isoquant or output frontier for given inputs. In the figure, we can also observe the input combination of x and output combination of y for which we can calculate the efficiency.

It is clear in both cases that the firm is inefficient. It is possible to save inputs and still produce the same outputs since there are no points to the south-west of x that are still above the input isoquant. Likewise, it is possible to expand the products and services represented by y since there are points to the north-east of y that are still below the output isoquant (transformation curve). In other words, there are many possibilities to improve, and the question is how to summarize these possibilities.

To measure efficiency in such settings, the modern benchmarking literature has relied in particular on the Farrell (1957) measures. The idea of the Farrell measures is to focus on proportional changes- the same percentage reducing in all inputs or the same percentage increase in all outputs. Such changes correspond to movements along the dashed lines in Figure 4.11.

The Farrel input efficiency measures how much we can proportionally reduce the input and still produce the same output. The input efficiency is therefore calculated as the smallest number E such

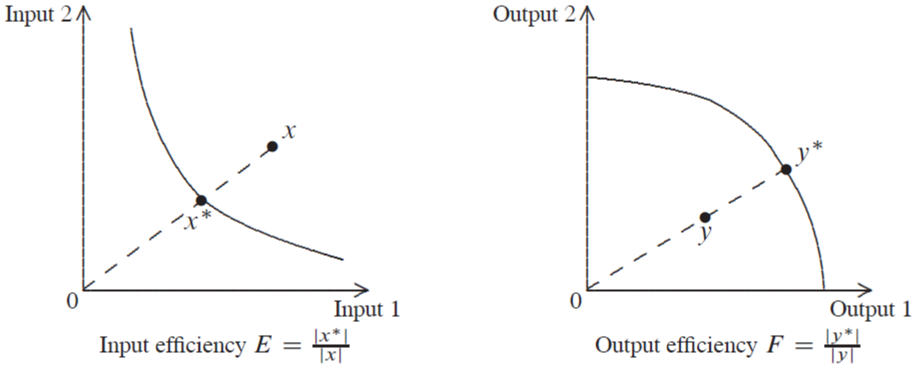

Figure 4.11: Farrell Efficiency [10]

that $x^* = Ex$ where x^* is the point of intersection of the dashed line and the isoquant in the left part of Figure 4.11. In a formal way, we have Farrell input efficiency as:

$$Farrell\ input\ efficiency\ = E = min\{e|ex\ can\ produce\ y\} = \frac{|x^*|}{|x|}[10] \tag{4.10}$$

Where $|x^*|$ is the length of the x^* vector, i.e., of the line between 0 and x^*. In the same way, we can define the output efficiency as the largest factor that we can multiply on the output and still have a possible production for a given input. The output efficiency is therefore calculated as the largest number F such that $y^* = Fy$ where y^* is the point of intersection of the dashed line and the transformation curve in the right part of Figure 4.11. In a formal expression is as follows:

$$Farrell\ output\ efficiency\ = F = max\{f|x\ can\ produce\ fy\} = \frac{|y^*|}{|y|}[10] \tag{4.11}$$

For inputs on or above the isoquant and outputs on or below the output isoquant curve, we have $E \leq 1$ and $F \geq 1$, and the smaller is E, and the larger is F, the more inefficient is the firm.

4.2.4. Mathematical approach for DEA

The previous subchapter discusses the mechanism of Data Envelopment Analysis (DEA) from production theory. With a simplify data, it is easier to understand the concept with graphics. In this subchapter, the author will discuss a rather formal mathematical approach of Data Envelopment Analysis (DEA). DEA is not exclusively a production theory or econometrics area of study. Data Envelopment Analysis is also an operations research method, where the concept of Linear Programming is applied. Before going further, consider this DEA notation:

Entities:

- N DMUs (index i, j)
- K inputs
- M outputs

Parameters:

- x_i = input vector for DMU i Kx1
- y_i = output vector for DMU i Kx1

Variables:

- v = Kx1 input weight vector

- u = Mx1 output weight vector

For each DMU i, we want to obtain a vector **v** of input weights and a vector **u** of output weights, such that the weighed ratio of outputs and inputs is maximized. As shown below:

$$\max \frac{u^T y_i \leftarrow \text{Weighed output}}{v^T x_i \leftarrow \text{Weighed input}}$$

Figure 4.12: Variable weight [72]

Where u, v are variable vectors, and x_i, y_i are respective input and output parameter vectors.

The basic form is given in figure 4.14: (model solved for each DMU j)

$$\begin{aligned} &\max \frac{u^T y_i}{v^T x_i} \\ &\text{s.t.} \quad \frac{u^T y_i}{v^T x_i} \le 1 \ (\forall i) \\ &\qquad u, v \ge 0 \end{aligned}$$

Figure 4.13: Basic (ratio) form of DEA [72]

In other words, we want to find values for the weight vectors u and v, in such a way that the efficiency measure for this DMU j is maximized. This form is also called the ratio form of DEA model.

However, if (u*,v*) is a solution, then $(\alpha.u^*, \alpha.v^*)$ is also a solution. Therefore we might have infinitely many solutions. To restrict the solution, we introduce a constraint $v^T \ x_i \ = 1$ and rewrite the model as shown in Figure 4.14. **v** and **u** are replaced by ν and μ respectively to discern between these two models.

Ratio form of DEA model

$$\begin{aligned} &\max \frac{u^T y_i}{v^T x_i} \\ &\text{s.t.} \quad \frac{u^T y_i}{v^T x_i} \le 1 \ (\forall i) \\ &\qquad u, v \ge 0 \end{aligned} \quad \longrightarrow$$

Multiplier form of DEA model

$$\begin{aligned} &\max \mu^T y_i \\ &\text{s.t.} \\ &\qquad \nu^T x_i = 1 \\ &\qquad \mu^T y_i - \nu^T x_i \le 0 \ (\forall i) \\ &\qquad \mu, \nu \ge 0 \end{aligned}$$

41

Figure 4.14: Ratio form to multiplier form [72]

In the Bogetoft and Otto study, the DEA programs are based from the combination of the idea of minimal extrapolation with Farrell's concept of measuring efficiency as a proportional improvement, and they obtain the mathematical programs that many consider synonym with the DEA approach.

On the input side, we measure the Farrell efficiency of firm o as the input efficiency:

$$E^0 = E((x^0, y^0); T^*) = min(E \in \mathbb{R} | (Ex^0, y^0) \in T^*) \qquad [10] \tag{4.12}$$

And the DEA formulation is:

$$\begin{gathered} \min_{E,\ \lambda^1,\dots\lambda^K} E \\ s.t.\ Ex_i^0 \geq \sum_{k=1}^{K} \lambda^k\, x_i^k, \quad i = 1, \dots, m \qquad [10] \\ y^0 \leq \sum_{k=1}^{K} \lambda^k\, y_j^k, \quad i = 1, \dots, n \end{gathered} \tag{4.13}$$

Hence the DEA approach to efficiency measurement leads to a mathematical optimization problem. This explains why DEA is sometimes referred to as the mathematical programing approach to efficiency analyses (Bogetoft and Otto, 2011 [10]).

On the output side, we similarly measure the efficiency of firm o as the output efficiency using:

$$F^0 = F((x^0, y^0); T^*) = max(F \in \mathbb{R} | (x^0, Fy^0) \in T^*) \qquad [10] \tag{4.14}$$

and the DEA formulation is:

$$\begin{gathered} \max_{F,\ \lambda^1,\dots\lambda^K} F \\ s.t.\ x_i^0 \geq \sum_{k=1}^{K} \lambda^k\, x_i^k, \quad i = 1, \dots, m \qquad [10] \\ Fy^0 \leq \sum_{k=1}^{K} \lambda^k\, y_j^k, \quad i = 1, \dots, n \end{gathered} \tag{4.15}$$

4.2.5. Rules in Choosing Input(s) and Output(s)

Before conducting the DEA model, we need to choose our input(s) and output(s). One of the benefits of the DEA is that the inputs and outputs are predetermined, meaning that it depends on the choice based on the knowledge or study of the user. Although DEA has a strong link to production theory in economics, the tool is also used for benchmarking in operations management, where a set of measures is selected to benchmark the performance of manufacturing and service operations. In the circumstance of benchmarking, the efficient DMUs, as defined by DEA, may not necessarily form a “production frontier” but rather lead to a “best-practice frontier.” (Cook et al., 2013 [70])

As pointed out by Cook, while DEA has a strong link to production efficiency, inputs and outputs do not necessarily have to be in a “production” relations. Under general performance evaluation and benchmarking, inputs are those metrics where a smaller value is preferred, and outputs are those metrics where an immense value is preferred.DEA has been applied to various fields such as banking, healthcare, agriculture, farming, transportation, education, and manufacturing. For more detail on the DEA application, please refer to Liu et al. (2013 [23]).

Is there any rule of thumb in choosing the inputs and outputs? In general, DEA minimizes “inputs” and maximizes “outputs”; in other words, smaller levels of the former and broader levels of the latter represent better performance or efficiency. This can then be a rule for classifying factors under these two headings.

In summary, if the underlying DEA problem represents a form of “production process,” then “inputs” and “outputs” can often be more clearly identified. The resources used or required are usually the inputs, and the outcomes are the outputs. If, however, the DEA problem is a general benchmarking problem, then the inputs are generally the “less-the-better” type of performance measures, and the outputs are usually the “more-the-better” type of performance measures. The latter case is particularly relevant to the situations.

When DEA is employed as an MCDM (multiple criteria decision making) tool, DEA then can be viewed as a multiple-criteria evaluation methodology where DMUs are alternatives, and DEA inputs and outputs are two sets of performance criteria where one set (inputs) is to be minimized. The other (outputs) is to be maximized (Cook et al., 2013 [70]).

4.2.6. Rules of Number of Inputs and Outputs

According to Cook, large numbers of inputs and outputs compared to the number of DMUs may diminish the discriminatory power of DEA. A suggested “rule of thumb” is that the number of DMUs is at least twice the number of inputs and outputs combined. However, such a rule is neither imperative nor does it have a statistical basis. Instead, the rule is often imposed for convenience.

Otherwise, one indeed loses discrimination power. It is not suggested, however, that such a rule is one that must be satisfied. There are situations where a significant number of DMUs are, in fact, efficient. In some cases, the population size is small and does not permit one to add actual DMUs beyond a certain point.

In summary, DEA is not a form of a regression model, but rather it is a frontier-based linear programming-based optimization technique. It is meaningless to apply a sample size requirement to DEA, which should be viewed as a benchmarking tool focusing on individual performance (Cook, 2013 [70]).

4.3. DEA in shipbuilding industry

In the preceding chapter 3.8, Analytical Hierarcy Process (AHP) concludes that benchmarking method is best to measure the competitiveness. In chapter 4.1, the author has discussed the reasoning why a benchmarking method is best to evaluate performance of a firm. The DEA is then chosen due to its flexibility with a limited number of data, and its cautious approach to estimating technology set based on frontier firm (best practice). In chapter 4.2 the concept of Data Envelopment Analysis (DEA) has been explained. In this section, the usage of DEA in the shipbuilding industry will be breifly discussed.

Data Envelopment Analysis (DEA) is actually not a new concept in the shipbuilding industry. The author has studied the literature of using Data Envelopment Analysis (DEA) and its development into the shipbuilding and ship repair industry. For example, to measure the productivity of shipyards, Collin and Pinto (2009 [19]) ranked the performance of the world's major shipyards using DEA. They used dry dock areas, berth length, and total crane load as inputs and deliveries in CGT as outputs.The input and output (I/O) items used in Collin & Pinto provided a fundamental concept for measuring the productivity of shipyards using DEA [19].

Zhangpeng and Flynn (2006 [74]) used the same inputs as Collin & Pinto with addition of worker per CGT (ratios) into the model. Krishnan (2012 [37]) also defined suitable indexes for measuring the efficiency of major shipyards, introducing profit as and additional output. Chudasama (2016 [18]) measure the productivity of 19 major shipyards in India. In addition to assessing the overall productivity of shipyards, Park et al (2014 [51]) investigated the productivity of a shipyard from a micro perspective.

Most of the usage of DEA is linked into the productivity or efficiency of shipyards. These authors predetermined the inputs and outputs based on their specific case. However, the objectives are similar, the objective of their DEA model is to find the most optimum shipyard given the allocation of resources. Without going into detail for each literature, the author provided the summary of literature of Data Envelopment Analysis (DEA) in shipbuilding industry.

No	Author	Year	Description
1	Zhangpeng and Flynn	2006	Analyze productive shipyards
2	Pires and Lamb	2008	Analyze 12 shipyards from Korea, China, Japan and Europe
3	Colin Pinto	2009	Benchmarking shipbuilder's turnover of main assets
4	Seok-ho Park	2010	Analyze efficiency and productivity of 7 korean large shipyards
5	Myung-jae Kim	2010	Analyze efficiency of 50 shipyards
6	Zakaria	2010	Perfromance evaluation of contemporary shipbuilding industries in bangladesh
7	Krishnan	2012	Scientific approach to measure shipbuilding productivity
8	Lee	2013	Analyze efficiency of SMS shipyards
9	Park et al	2014	Investigate productivity in micro perspective
10	Rabar	2015	Setting key performance targets for Croatian shipyards
11	Chudasama	2016	Measure productivity of 19 shipyards in india
12	Yearnmin Kim	2017	Measure the influence of different factors on the measured productivity
13	Guofu	2017	Measurement and evaluation model of shipbuilding production efficiency
14	Morgan	2018	Manpower and efficiency study of Manns harbor shipyard
15	Chao and Yi-Hung	2020	Comparing productivity of major shipyards in China, South Korea, and Japan in metafrontier framework

Figure 4.15: Summary of DEA application in shipbuilding and shipyard industry

The summary is presented in Figure 4.15. The reference for the study paper can be found in here: (Zhangpeng and Flynn, 2006 [74] Pires and Lamb, 2008 [12] Collin and Pinto, 2009 [19] Seok-ho Park, 2010 [52] Kim, 2010 [35] Zakaria, 2010 [73] Krishnan, 2012 [37] Lee, 2013 [64] Park et al., 2014 [51]

Rabar, 2015 [53] Chudasama, 2016 [18] Yearnmin, 2017 [36] Guofu, 2017 [27] Morgan, 2018 [46] Chao and Yi-Hung,2020 [14]).

Most of the literature focuses on the internal part of the shipbuilding process. However, from the previous chapters, we know that the output of DEA model can represent any objectives, and input of the DEA can represent any kinds of resources. In this paper, the author will consider the two objectives that we found in the conclusion of chapter 3.7.1

The author use the DEA model conducted by Pires and Lamb as an example. To refresh the memory, let the author briefly mention the essential points of shipyard performance evaluation by Thomas Lamb. Lamb conducted a performance evaluation to study the competitiveness of 12 shipyards.

The study aimed to identify the critical influencers of shipyard performance in terms of relevant indicators of cost and time competitiveness. The performance evaluation makes use of DEA as a benchmarking method. The DEA model analyzes the efficiency performance of each shipyards. In the model, there are two outputs and three inputs. The outputs are 'building time' and 'productivity.' And the inputs are erection area, technological index (ITech), and non-controlled industrial environment index (IndEnv). The orientation of the DEA model is output-oriented with a constant return to scale assumption (CRS). Figure 4.16 shows the illustration of Lamb's method.

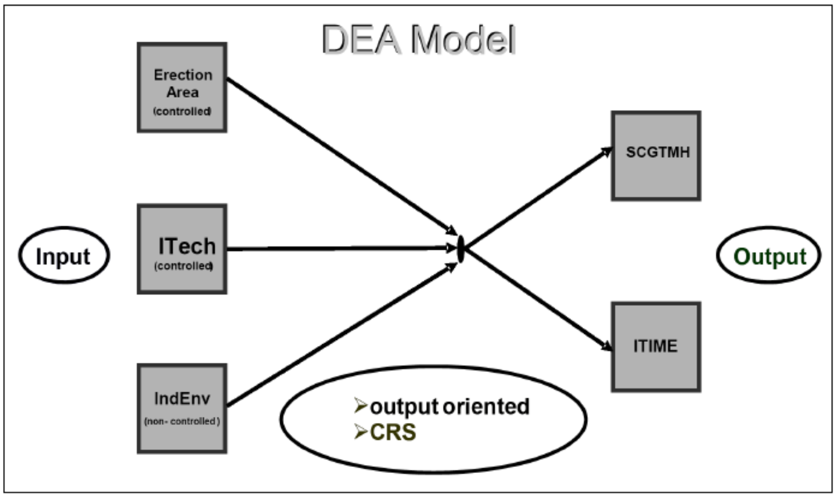

Figure 4.16: DEA Model Structure [12]

The 'objective' of the model is to find which shipyards have the highest 'productivity' with the given inputs (resources). 'Productivity' is predetermined by Pires and Lamb as the ratio of sCGT/man-hour and the variable 'Building Time' (ITIME). The inputs are also chosen from their literature study. The inputs and outputs of DEA model hence depends on the author's choice. As discussed in chapter 4.2, the DEA model will give the efficiency score to all Decision-making Units (DMUs), in this case shipyards. In Pires & Lamb paper, they use notation of 100 instead of 1 as efficiency score.

Figure 4.17 shows the data corresponding to the shipyards in the sample. From the figure we can see the inefficiency scores for the shipyards in the sample (DMU). A score equal to 100 corresponds to an efficient unit.

Now that we understand the strength of the benchmarking method DEA and its proven application in evaluating shipyards performance. We need to build the model in a systemic approach. The model will have:

1. Objectives. The objectives are translated into output.

E1	100
J1	100
E2	100
E3	100
K3	100
J3	96,09
K1	89,15
K2	86,89
J2	86,68
C1	71,84
C2	56,12
C3	44,37

Figure 4.17: Inefficiency Scores [12]

2. Inputs. Influencing factors that affecting the output will be the inputs of the DEA model.
3. Non-discretionary factor. This factor may be found in literature that affecting the output, however, some factors are indirect thus will not be able to be represented as inputs or outputs.
4. Efficiency scores. The scores of each DMUs or shipyards.
5. Peers or Reference point. The inefficient shipyards will have the reference point/s as benchmarks.
6. Orientation. The DEA model recognizes two orientation: input-orientation which focus on reducing the input and output-orientation which foucus on increasing the output.

As an example of systemic approach to build the model, take a look at Figure 4.18. The figure shows how system approach is conducted. The inputs and outputs are taken from chapter 3.7. The indicators of competitiveness for each literature are treated as outputs, and the influencing factors as inputs.

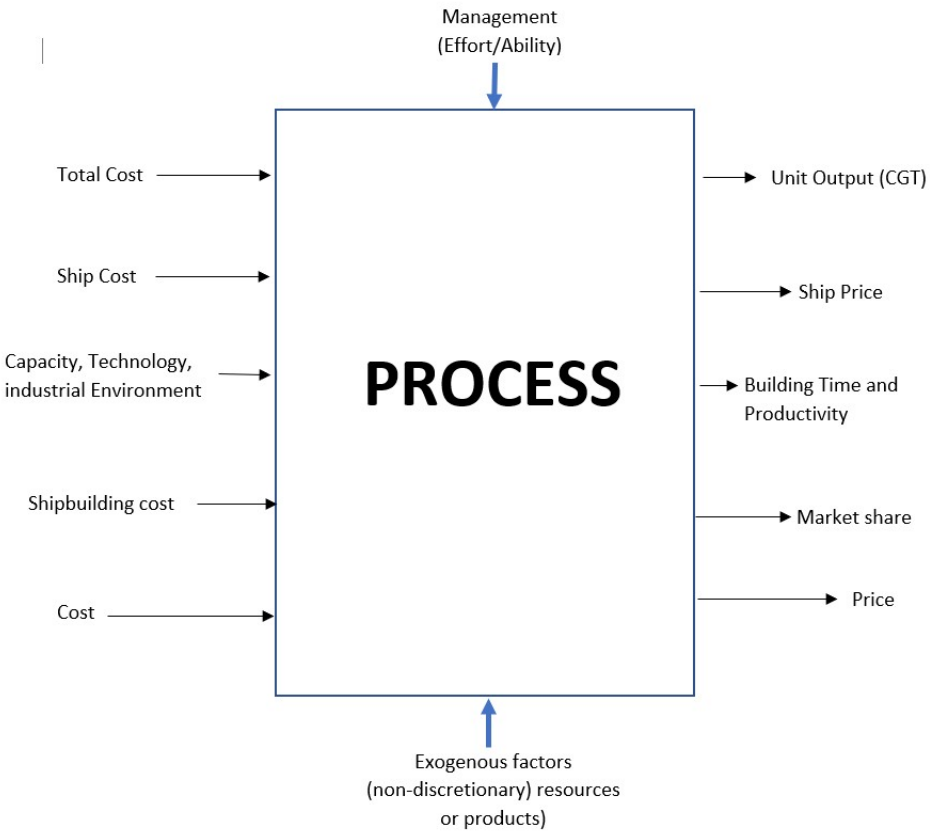

Figure 4.18: Author's Illustration of DEA Structure in shipbuilding case

4.4. Conclusion of this chapter

In summary, this chapter answers research question 4, ”With the method found, how can the method able to evaluate the competitive performance of shipyards?”.

Chapter 4.1 shows the strength of benchmarking. The first strength is its cautious approach to set frontiers based on real observed firms (best practice). The second strength is its ability to handle multiple inputs and outputs, which become more reliable than relying only on Key Performance Indicator ’KPI’. The third is its flexibility for data availability. This conclusion shows why the author uses benchmarking to conduct competitiveness performance analysis.

There are two common benchmarking methods: Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). The Data Envelopment Analysis (DEA) is chosen due to its versatility, cautious estimation, and its non-parametric characteristic. DEA modeling has been proven by Lamb to evaluate shipyards performance.

To answer the question ’How the method (benchmarking) can evaluate the competitive performance of a shipyard,’ we need to see the model in a systemic approach. The systemic approach is one of the characteristics of benchmarking analysis, specifically in Data Envelopment Analysis (DEA). In the systemic approach, the ’objectives’ are translated into outputs or, as referred to in chapter 3.7, the competitiveness indicator. The influencing factors or the factors affecting the output are translated into inputs. Other indirect factors can be treated as non-discretionary resources. In shipbuilding cases, subsidy or government policy is a typical example of non-discretionary resources. Pires and Lamb’s study showed how the DEA model is conducted. Other examples of the usage of DEA are summarized in Figure 4.15. In the next chapter, the model will be explained.

5

Model Description

This chapter will answer the fourth research question, 'What variables can be used in the method? and how to choose the shipyards to be evaluated?'. Rather than calling it the benchmarking method, from now on, we will call it the DEA model. In chapter 3.7, we concluded that competitiveness in the shipbuilding industry could be translated into three objectives. The first objective is the ability to attract shipbuilding orders, the second objective is the ability to execute the shipbuilding orders, and the third objective is the ability to stay in business.

The first objective, the ability to attract new building orders, requires careful study. In the author's knowledge, there has not been any academic paper that considers this objective in the DEA model. The parameter that indicates the ability to attract shipbuilding order, logically, is the new building contracts of shipyards. The influencing factors affecting new building contracts will be discussed in this chapter. The second objective is the ability to execute shipbuilding orders. According to literature research, this ability relates to productivity measures. The third objective, the ability to stay in business, according to Jiang (2013 [42]) is highly affected by the profit rate of a shipyard. Since shipbuilding is a competitive industry, not all information are disclose, especially their profit. Therefore the auhtor leaves out the third objective. Chapter 5.1 elaborates this discussion.

Before we dive into the discussion of factors to put into the model, we need to consider three assumptions of the shipbuilding market. First, as discussed in chapter 2, the shipping market is cyclical. There are times where the demands of new ships are high, and there is a period when it is low. Second, to construct a new merchant ship, it is estimated to finish in 2-3 years period of time, during that time the market may change, thus looking on a span of 3 years is advisable (Bertram, 2003 [9]). Third, we assume that the shipbuilding market works closely to perfect theoretical competition. The theoretical ideal of perfect competition is widely believed to prevail in the shipbuilding industry. There are numerous shipbuilders, each controlling an adequate portion of capacity. At the global level, shipbuilding attempts to fulfill the requirements of an open market, and those yards that fail to produce competitively priced ships will find their customers opting for alternative suppliers (Todd, 1985 [67]; Beenstcok and Vergottis, 1993 [8]).

5.1. Variable Selection

In this section, the author will discuss the inputs and outputs for the DEA model. The first model refers to the second objective, which is the shipyard's ability to execute shipbuilding orders. In most cases, shipyards are only accepting projects that they can execute. Moreover, canceled projects are not publicly disclosed. So we assume that shipyards can execute their orders. This objective is then assumed to be the optimum allocation of resources, in other words, to maximize the given/targeted level of output from a given input (Chudasama, 2016 [18]). In the shipbuilding industry, the ratio between the level of output to the level of input is called 'productivity.' In the older study by Bertram, productivity is commonly denoted in $\frac{CGT}{man-year}$ or $\frac{CGT}{man-hour}$. However, in chapter 3, we have discussed that this single ratio is deemed far from comprehensive in measuring 'productivity.' In chapter 5.1.1 the influencing factors of productivity will be discussed.

The second model refers to the first objective 'the ability to attract shipbuilding orders. Despite their capacity, shipyards are winning and losing new orders. Before receiving contracts, ship owners and shipyards negotiate the price. Chapter 5.1.2 discuss the variables related to this.

5.1.1. DEA Model-1: Shipyard Productivity

Shipyard Capacity and Employees

According to the literature, two variables are commonly selected as input items to measure the shipyard's productivity. The first variable is the shipyard's capacity. Shipyards need to have a high capacity to execute a high volume of shipbuilding orders. Shipyard capacity is mainly represented with dock area, berth length, total area, or erection area (Zhangpeng and Flynn, 2006 [74]; Pires & Lamb, 2009 [12]; Collin & Pinto, 2009 [19]; Krishnan, 2012 [37]; Chudasama, 2016 [18]; Morgan, 2018 [46]; Chao & Yihung, 2020 [14]).

Dock Area

Dock area is the total area of the existing dock within a shipyard. Dock area in this model refers to the place where a ship is built, including the work of hull erection, moving blocks, outfitting until the launching of the ship. The area thus can be a floating, dry dock, slipway dock, etc. For standardized ship such as merchant ship, the docks area are usually as big as the ships built plus the space for workers that work on the ship construction. Therefore the dock area will be the first input of the model. Zhangpeng and Flynn (2006 [74]) suggested that dock area is one of the appropriate input items in shipyard's productivity.

Erection Area

Erection area represents the capacity of a shipyard according to Pires and Lamb (2008 [12]). Pires and Lamb believes that erection area is highly affecting the performance of a shipyard. In their study, erection area and total area are highly correlated. From their shipyards sample, erection area is more robust and representative indicator of shipyard's capacity. However, to measure the erection area, one needs to survey the respecting shipyards, because the data are not readily available.

Crane Total Load

According to Chao & Yihung (2020 [14]) crane total load is one of the appropriate inputs for measuring shipyard's productivity. Collin & Pinto suggests that crane total load's lifting capacity directly correlates with the shipyard's asset which in turn affecting turnover. However, Collin & Pinto did not only use crane total load but also deck area and number of worker in their study of measuring shipyard's productivity [19].

Worker/CGT and **Worker/hour**

Worker/CGT and Worker/hour are common indexes to capture the productivity of employees in a given shipyard. The earliest form may come from Bertram and Stott who used cgt/man-hour to measure shipyard's productivity and additionally man-hour/man-year to compare the difference of working hours between countries or region.

Zhangpeng and Flynn (2006) pointed out that, as the rise of China's shipbuilding industry, all the shipyards in other countries have had to manage the strong pressure to compete. China rose as a major player in shipbuilding due its low cost and abundant workers. However there some study that question the efficiency or experience of Chinese workers. They believe that workers/cgt index is required to give a fair comparison of worker's output [74]. In addition to that Krishnan (2012) also defined suitable indexes for measuring the efficiency of major shipyards, of which workers/hour and workers/CGT requirements were input items in shipyard's productivity [37] [73] [53].

Worker/hour and worker/cgt might be a better indices for measuring workers' productivity. However, to measure worker/hour and worker/cgt, one requires to do an analysis and interview with the worker within a shipyard. For example, Rabar investigated six major croation shipyards. The data was acquired from the Croatian Shipbuilding Corporation – Jadranbrod [53].

Number of worker
The number of workers or employees is the second common variable in the shipyard's productivity. In literature, the number of employees has been utilized frequently as an input to DEA models for similar studies. Chudasama (2010 [18]), Rabar (2015 [53]), and Ok and Feng (2017 [49]) all utilized number of employees as a direct input into DEA. Previous studies, such as that by Seok-ho Park, used the number of labor units as an input variable and completion as an output variable and Myung-Jae Kim selected capital and number of labor units as input variables and turnover and net profit as output variables. In addition to the number of workers, Zhangpeng and Flynn (2006 [74]) used another two ratios related to workers, namely, worker/CGT and worker/hour. However, it is difficult to measure the workload of workers in different shipyards. Therefore, the number of workers will be used as inputs in this model.

ITech
ITech is abbreviation of Industrial Technology. In order to characterize the level of technology employed by the shipyards, Pires & Lamb used a synthetic comparative index. The data was obtained by visiting each shipyards, and the indices were estimated. The technological levels were assessed based on four activities. These activities refer to the evaluation guidebook by COPPE (2007). There is very little detail information about this variable, however the four groups of activities are:

1. Fabrication and assembly
2. Erection and outfitting
3. Product and processing engineering
4. Organisation and management

IndEnv
IndEnv or Industrial Environment refers to the prevalent conditions in the country or region which define the industrial environment for shipbuilding development [12]. In the study from Pires & Lamb the IndEnv index is measured by using Analytical Hierarchy Process (AHP). The criteria to conduct the AHP were based on findings from questionnaires during interviews with engineers and managers of visited shipyards. The criteria were considered relevant for characterising the environments for shipbuilding industry developments. The criteria are:

1. **Production chain organisation.** This criterion considers the size of shipbuilding and the existence of a cluster within a region. This criterion also weigh the availability of suppliers of critical inputs.
2. **Workforce.** The workforce criterion considers shipbuilding workers availability and their qualifications, age and level of commitment to the company.
3. **Shipbuilding policies.** This criterion refers to the direct or indirect subsidies, the strength of government support, and the research and development within the shipyards.

Input and Output Conclusion for Model-1
From the discussion above, the author decided to use **two inputs** for this model. The first input is **'Total Dock Area'**, and the second input is **'Number of workers'**. For the output, **'Deliveries'** of a ship are the most common indicator. The unit for deliveries will be the Compensated Gross Tonnage (CGT). The CGT was suggested as a representative item because it can reflect the complexity of building various types of ships [50]. The summary of inputs and outputs used in the literature study is illustrated in **Figure 5.1 for inputs** and **Figure 5.2 for outputs.**

This discussion concludes the first model. In mathematical form, the model is as follows:

$$x(Dock\ Area,\ No\ Employees) = y(deliveries\ [CGT]) \tag{5.1}$$

Since the DEA model requires the user to choose the orientation of the model, we will need to define if the model will be an input oriented or output oriented. Since we use dock area and employees, a

Study	year	input							
		Dock area	Max DWT delivered	Crane total load	Worker / CGT	Worker / hour	# of worker	erection area	Itech and IndEnv
Zhangpeng and Flynn	2006	●			●		●		
Pires and Lamb	2008							●	●
Colin Pinto	2009	●		●			●		
Seok-ho Park	2010						●		
Myung-jae Kim	2010						●		
Zakaria	2010					●			
Krishnan	2012	●			●	●	●		
Lee	2013						●		
Rabar	2015					●	●		
Chudasama	2016	●	●				●		
Guofu	2017						●		
Morgan	2018	●					●		
Chao and Yi-Hung	2020	●		●			●		

Figure 5.1: Summary of inputs of DEA model from literature study

reduction of the inputs would result, among other things, in layoffs in the shipbuilding industry, which could lead to a decrease in its production volume, and thus indirectly to layoffs in related business areas. A reduction of dock area is also not a practical solution for shipyard's productivity. Consequently, output-orientation is better suited for productivity and performance based DEA model [53]. Therefore the DEA Model-1 will be **output-oriented**.

Study	year	Output					
		CGT (delivery)	Type of Vessel	Building Time	Turnover	Profit	Labour productivity (sCGT/man-hour)
Zhangpeng and Flynn	2006	●					
Pires and Lamb	2008			●			●
Colin Pinto	2009	●	●				
Seok-ho Park	2010	●					
Myung-jae Kim	2010				●	●	
Zakaria	2010	●					
Krishnan	2012	●				●	
Lee	2013				●	●	
Rabar	2015	●			●		
Chudasama	2016					●	
Guofu	2017						●
Morgan	2018						●
Chao and Yi-Hung	2020	●					

Figure 5.2: Summary of outputs of DEA model from literature study

5.1.2. DEA Model-2: Shipyard Ability to Attract New-orders

Price and Building Time

While the global number of shipyards is large, they are highly heterogeneous in terms of dock size, experience, expertise, and the range of designs offered, and this may impact the number and type of orders they attract (Adland et al., 2016 [3]). According to literature research, price is the first determinant for ship owners to decide where they want to build their ships. In ordering standardized ships, the buyer is primarily concerned with the price (Rashwan and Naguib, 2006 [54]; Cho, 1984 [16]).

Other factors may increase the likelihood of placing an order, but if a shipyard's tender price is too high, ships will be built elsewhere (Wergeland, 1999 [71]). Price competitiveness is often evaluated by comparing newbuilding contract prices denoted in a common currency (Landsburg et al., 1988 [40]; Stott and Kattan, 1997 [62]). Since shipbuilding is an international industry, the US dollar is common as the international currency. The usage price is supported by Bertram in one of the variables that influencing the shipyard's turnover in his competitiveness analysis. 'A' or the attractiveness of product denoted by $\frac{market\ price\ in\ \$}{CGT}$ hence can be a relevant unit for price.

The author conducted simple linear regression analysis to find the correlation between $\frac{market\ price\ in\ \$}{CGT}$ and new contract (in CGT). The author uses data of Chinese and Korean mega shipyards. The data is divided into its country and shipyard size to be fair in comparison. The first regression model consists of Shanghai Waigaoqiao, Huangpu Wenchong, and Jiangnan SY Group shipyards. Data from 2009-2018 is used in the model. After eliminating missing data and outliers, the variable new contracts has negative correlation with $\frac{market\ price\ in\ \$}{CGT}$ with R squared 0.31.

The other regression model consists of Korean mega yards, Daewoo, Hyundai Ulsan, and Hyundai Mipo. The data from 2009-2019 is used. After eliminating outliers and missing data, the result shows the same negative correlation with R squared 0.617. In other words, the higher $\frac{market\ price\ in\ \$}{CGT}$, the lower the new building contracts (in CGT).

Sauerhoff (2014 [58]) finds that practical experience affects a shipyard's ability to secure contracts. A vessel with shorter delivery time will have a higher value to the shipowner in present value terms than an equal vessel with longer delivery time (Adland et al., 2006 [4]; Adland and Jia, 2015 [5]). Stott (1995) finds partial empirical evidence for this hypothesis, as shipbuilders with superior delivery times are more likely to attract orders.

In the process building a new ship, there are two time frames. First is the duration between the contract started and the time of delivery. Second is the duration between the key-laying date and the time of delivery. These two have different characteristics. The first time frame, project duration, is influenced by the market conditions [12], thus ship owners would want the delivery to be fast when the market is good, and would less strict on the delivery time when the market is bad. The second time frame, building duration, is the component of time to delivery that depends strictly on performance [12]. In the DEA Model-2, the ability to attract new building time has tendency to be more leaning towards the project duration.

The author conduct regression analyses to find the correlation between new contracts and project time. To give a fair comparison, the project time is divided with the CGT because different type of ships have different working process. The index's unit is then Project duration/CGT. The author finds a very consistent result. By comparing the project duration/cgt and new building contracts of 6 mega shipyards, it is found that project duration/cgt has a negative correlation with new building contracts with R squared of 0.425. Meaning that the longer the project duration is, the lower new building contract is.

Bertram (2003) and Adland et al.(2015 [5]) state that differences in delivery times are likely to be captured in contract prices. Therefore we can say that the two are complement with each other. Ship owners might want to have pay a higher price when they want to have a short delivery time. While to get a lower price, ship owners might sacrifice a delivery duration. Which is consistent with the three-component analysis of management framework used by Bertram (2003 [9]) in chapter 3.3.

Input and output conclusion for model-2

The author thus decided that the first input is related to price. The index from Bertram, Price/CGT is therefore used as the first input. The second input that can complement and substitute price would be delivery times. Delivery times is represented with the duration of the project, calculated by subtracting the delivery date with the contract date. Therefore the DEA model-2 is expressed as follows:

$$x(\frac{market\ price\ (\$)}{CGT}, \frac{project\ duration}{CGT} = y(new\ contracts\ [CGT]) \tag{5.2}$$

The same with the first DEA model. We need to determine the orientation of the model. Since $\frac{market\ price\ in\ \$}{CGT}$ and $\frac{Project-\ duration}{CGT}$ both can be reduced and the smaller the more attractive. Therefore we will use **input-oriented** for the DEA model.

5.1.3. Non-discretionary factors and Environment factors

In chapter 4, we have discussed the system-oriented approach to build the DEA model. The approach introduced resource (inputs), products(outputs), non-measurable managerial characteristics, effort and skills, and the non-controllable variables.

Xue et al. (2020 [25]) indicated that building technique, resource ability, and management level are the three major drivers of the production efficiency of shipbuilding. In their study of Chinese shipyards efficiency, Chao and Yi-hung (2020 [14]) suggest that to improve Chinese shipbuilding efficiency, Chinese shipyards have to improve their management and technique efficiency. Moreover, Guofu et al. (2017 [27]) indicated that facilities and equipment are the factors that affect the performance of shipbuilding entities.

In a study by Hu (2013 [29]), the related industry created a supply chain that supports the shipbuilding industry. Environmental factors and technological and management capability is difficult to capture. Each shipyard has its own unique managerial and technical skills. To measure the effort and ability of each shipyard, we require extensive research and survey to the shipyards itself. Without leaving these factors behind, the author decided to mention it in the system as the non-discretionary factors and environmental factors, as shown in Figure 5.3.

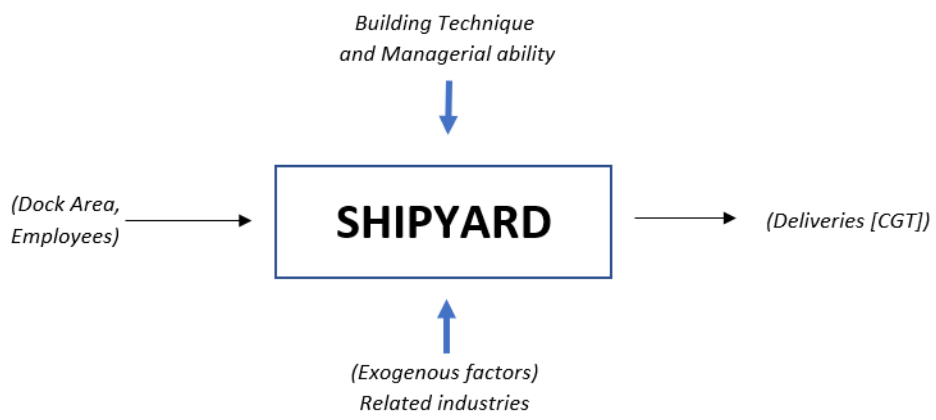

Figure 5.3: DEA Model 1

Shipbuilding is highly exposed to the external environment, especially to the strong influence of government policy and market conditions (Jiang et al., 2013). Government support plays a significant role in creating favorable conditions (Ferraz, 1986 [26]). For example, the massive state support that paved the way for Japanese and Korean shipbuilding has been well examined (Amsden, 1989 [6]; Chida and Davies, 1990 [15]; Todd, 1991 [68]; Bruno and Tenold, 2011 [11]).

The effective development and implementation of industrial policies in shipbuilding also require accurate assessments of shipyard competitiveness. (Jiang et al., 2013 [42]). Direct and indirect subsidies are examples of variables that can create a competitive price for shipyards to offer their ships in the market (Stott, 1997 [62]). Therefore the author chooses the government support (policy and subsidies) and market conditions as non-discretionary factors.

Innovations and managerial capability are crucial to compete with shipyards that highly subsidized. For example, a study from Jiang (2012 [63]) shows that the Japanese shipbuilding workers have been very efficient in producing CGT of work in less time compared to Chinese and Korean shipyard workers. However, this too requires an in-depth study in the $\frac{CGT}{man-hour}$ ratio. Since shipbuilding is a competitive industry, this data is unfortunately not disclosed. In Figure 5.4 we can see the system-oriented approach of the DEA model 2.

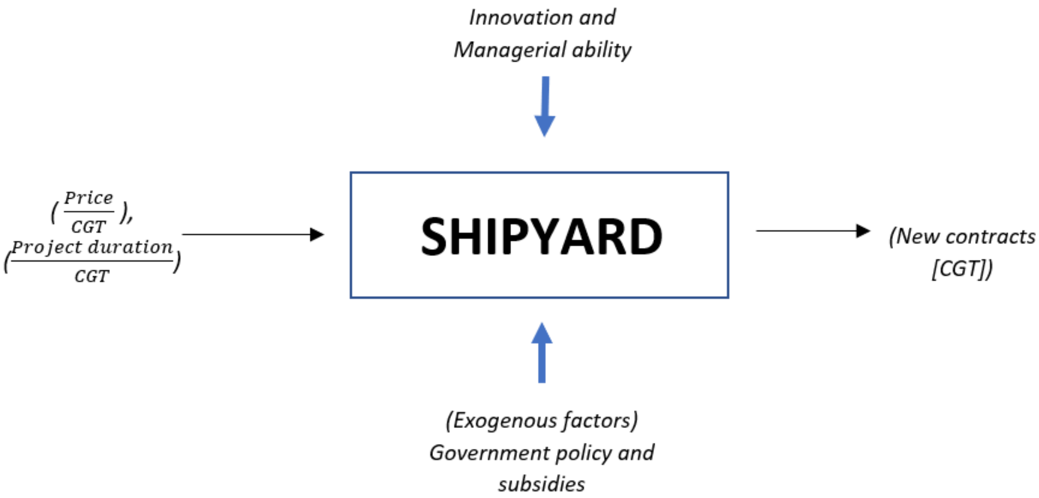

Figure 5.4: DEA Model 2

5.2. Selecting Shipyard as DMUs

5.2.1. Yard-size Model

Now we have two system-oriented DEA models. In Data Envelopment Analysis (DEA), the decision-making units (DMUs) are the firm or organization under study, in this case, shipyards.

Although merchant ships are heterogeneous in terms of design, shipyards are a bit different. Their size generally differentiates shipyards. The capacity of the shipyards, as well as the drydocking capabilities, vary drastically based on the shipyard size classification (Morgan, 2018 [46]). According to Seok-ho Park (2010, [52]), large shipyards are efficient while small to medium-sized (SMS) shipyards are inefficient due to their scale.

To have a fair comparison, the author divides the shipyards based on Clarkson's yard size classifications. Clarksons (2016b) classifies shipyard size based on the size of orderbook in millions of CGT: very small (<0.049), small (0.049<0.01), medium (0.1<0.49), large(0.49<1) and mega (>1). In this study, the author will only consider medium, large, and mega shipyards to put into the DEA model.

Figure 5.5 shows the pie chart of market share (new contract) of mega shipyards in the period of 2013-2015. We can see from the graph that Daewoo (DSME) shipyard has the highest market share of 20%, followed by Hyundai HI Ulsan, Hyundai Samho HI, Samsung HI, and Hyundai Mipo, with market share 16%, 12%, 12% and 11% respectively. The Korean yards take the top 5 position for mega-sized shipyard.

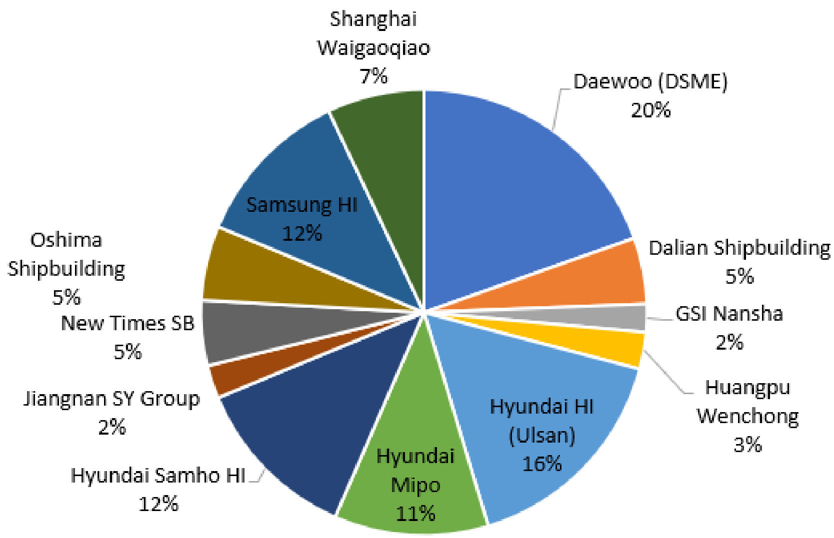

Figure 5.5: Market share (New Contract) of Mega-sized Shipyard 2013-2015

For the DEA model, the author would like to include some of the top 5 yards. South Korean yards, Daewoo DSME, Hyundai HI Ulsan, Samsung HI, and Hyundai Mipo are thus chosen. In order to get a comparison between countries, three Chinese yards are put into the model, namely Dalian SB, Huangpu Wenchong, and Jiangnan SY Group. Due to data availability, only one Japanese yard can be put into the model which is Oshima Shipbuilding. The summary of mega-sized shipyards that are taken into account for the DEA models is shown in Table 5.1.

Large-sized shipyards are less concentrated than mega-sized shipyards. Jiangsu New YZJ leads the market share for large-sized shipyard with 13%, followed by Imabari SB Hiroshima, Yangzi Xinfu and Imabari Marugame, with 12%, 11% and 10% respectively. The market share for large-sized shipyards are illustrated in Figure 5.6.

After data collecting, seven shipyards from four different countries are chosen. Four Chinese yards that are put into the models are the top two, Jiangsu New YZJ and Yangzi Xinfu SB, and two mediocre

Table 5.1: Mega-sized shipyards summary

Mega-sized Shipyard				
No	Yard	Country	model-1	model-2
1	DSME	Korea	√	√
2	Hyundai HI Ulsan	Korea	√	√
3	Samsung HI	Korea	√	√
4	Hyundai Mipo	Korea	√	√
5	Oshima SB	Japan	√	
6	Dalian SB	China	√	√
7	Huangpu Wenchong	China	√	√
8	Jiangnan SY Group	China	√	√

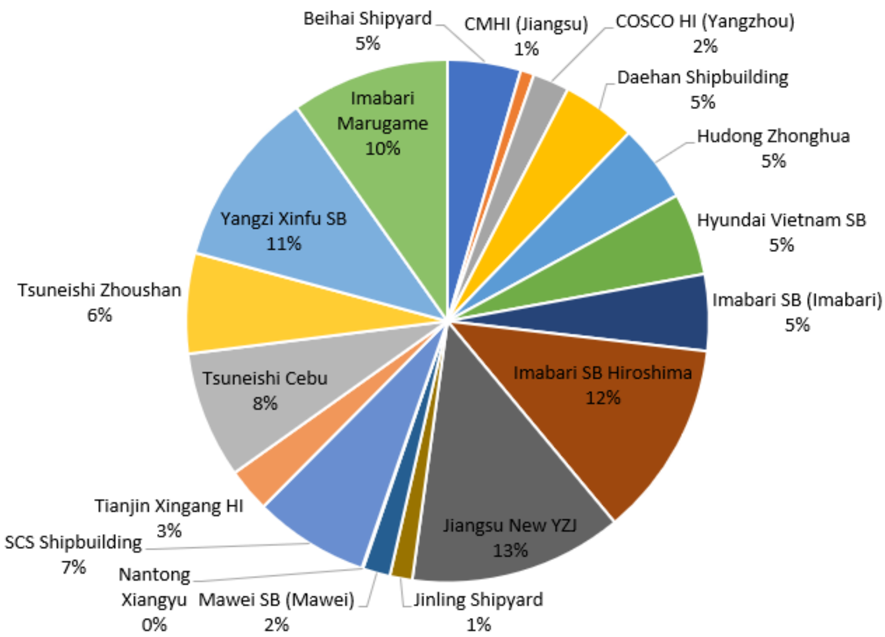

Figure 5.6: Market share (New Contract) of Large-sized Shipyard 2013-2015

yards, Tsuneish Zhoushan and SCS Shipbuilding. One Korean yard and one Japanese yard that are put into the models are Imabari Marugame and Daehan SB. The summary is shown in Table 5.2.

Table 5.2: Large-sized shipyards summary

Large-sized Shipyard				
No	Yard	Country	model-1	model-2
1	Jiangsu New YZJ	China	√	√
2	Hyundai Vietnam SB	Vietnam	√	√
3	Tsuneish Zhoushan	China	√	√
4	Yangzi Xinfu SB	China	√	√
5	SCS Shipbuilding	China	√	√
6	Imabari SB Marugame	Japan	√	√
7	Daehan SB	Korea	√	

For medium-sized shipyards, the market share is very much dispersed. For shipyards with market share less than 2% are collected into 'others' as shown in Figure 5.7. Because of majority of shipyards only have 2-5% market share, the author decided to take a sample of two Chinese yards, two Japanese yards, and two Korean yards.

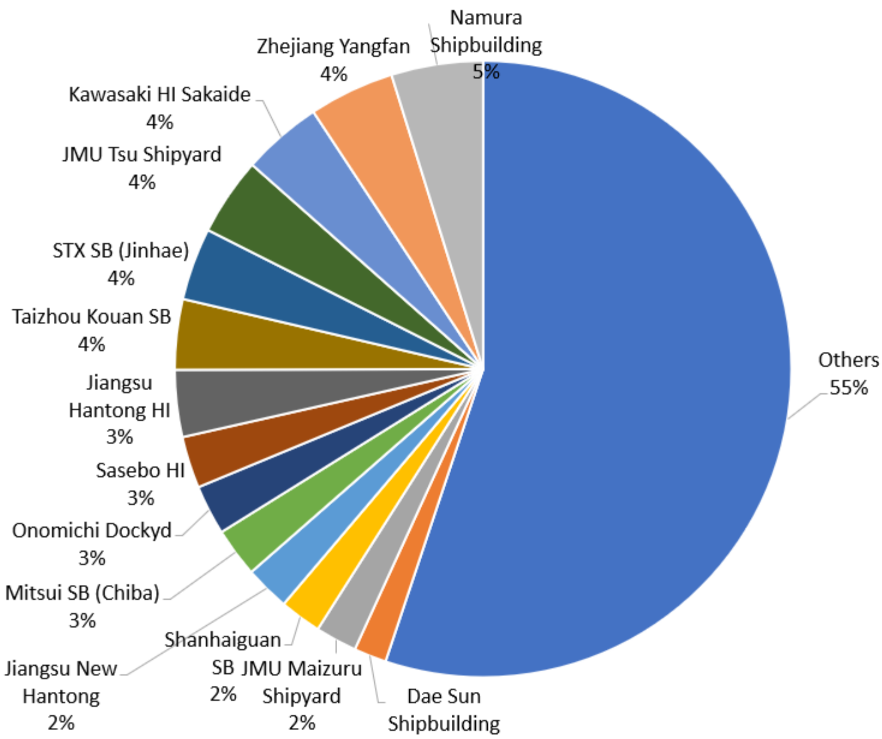

Figure 5.7: Market share (New Contract) of Medium-sized Shipyard 2013-2015

Korean yards, Dae Sun Shipbuilding and STX SB Jinhae have 2% and 4% market share respectively. Two Japanese yards, Sasebo HI and Namura yard both have 3% and 5% market share. Lastly, two Chinese yards, Shanhaiguan SB with 2% and Jiangsu New Hantong with 2% market share.

Table 5.3: Medium-sized shipyards summary

Medium-sized Shipyard				
No	Yard	Country	model-1	model-2
1	Dae Sun	Korea	√	√
2	STX SB Jinhae	Korea	√	√
3	Shanhaiguan SB	China	√	√
4	Sasebo HI	Japan	√	√
5	Jiangsu New Hantong	China	√	√
6	Namura	Japan	√	√

5.2.2. Shipyards Deliveries and New Contracts

At the beginning of this chapter, the author has mentioned that we are going to use Bertram's assumption, which, to analyze shipyard's productivity, a three-year span would be the right approach. Another reason for averaging in three years is to average out the market condition of the shipbuilding industry. As have been discussed in chapter one, shipbuilding is a cyclical industry. Thus market condition is influential in the shipbuilding market.

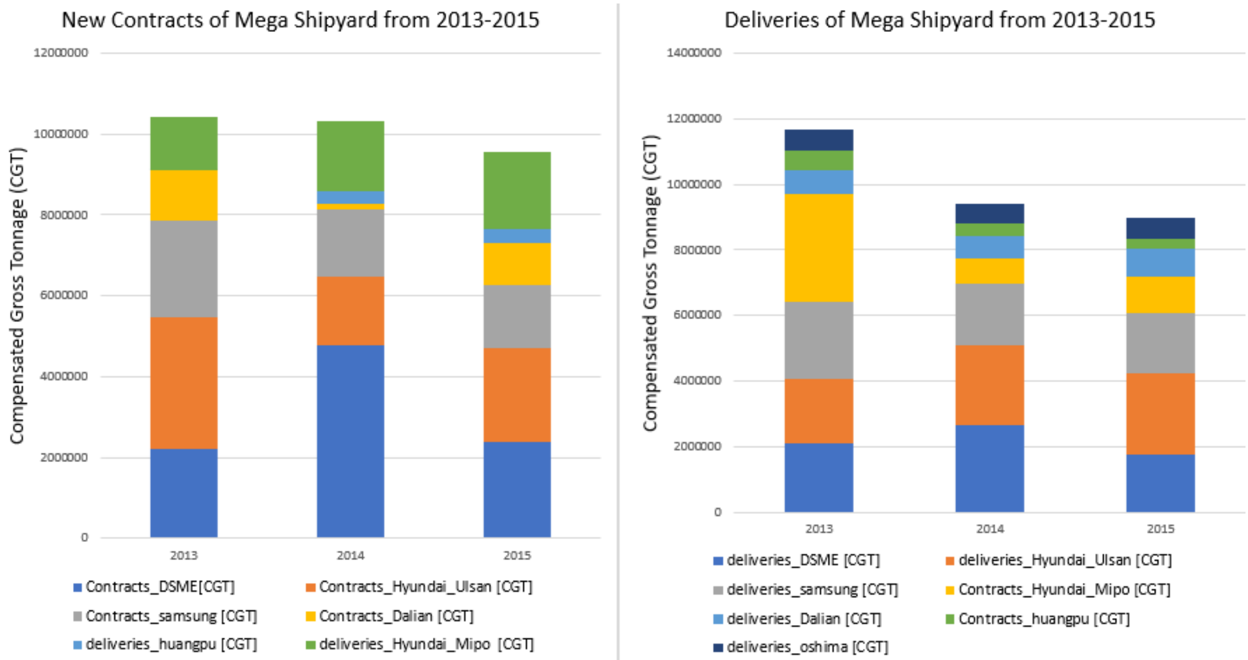

Figure 5.8: Deliveries and new-contracts of mega shipyards

The output for DEA model-1 is the average delivery of each shipyard in CGT. The output for DEA model-2 is the average new contract of each shipyard in CGT. Figure 5.8 shows the new contracts and deliveries for mega shipyards. The left side is the new contracts for mega shipyards, and the right side is the deliveries of mega shipyards in the period of 2013-2015. From the figure, we can see the fluctuation of new contracts and deliveries from all shipyards.

Table 5.4 shows the average number of deliveries of mega-sized shipyards. From the table we can see that Chinese yard, Huangpu Wenchong has the lowest average deliveries between 2013-2015. All of Korean yards are the top four by deliveries for mega-sized shipyards.

Table 5.4: Mega-sized shipyard output deliveries

No	Shipyard	Output - Deliveries [CGT]
1	Daewoo DSME	2,173,942
2	Hyndai HI Ulsan	2,296,155
3	Samsung HI	2,013,358
4	Hyundai Mipo	1,642,523
5	Dalian SB	747,280
6	Huangpu Wenchong	231,265
7	Oshima SB	657,189

Figure 5.9 shows the new contracts of large-sized shipyards (left) and deliveries (right). Similar with the mega-sized shipyards we also see a fluctuation in both new contracts and deliveries. Notice that deliveries of SCS Shipbuilding is actually decreasing while Daehan Shipbuilding is increasing.

Table 5.5 shows the average number of deliveries of large-sized shipyards. The highest deliveries is coming from Chinese yard, Jiangsu New YZJ. The lowest delivery is Korean yard, Daehan SB.

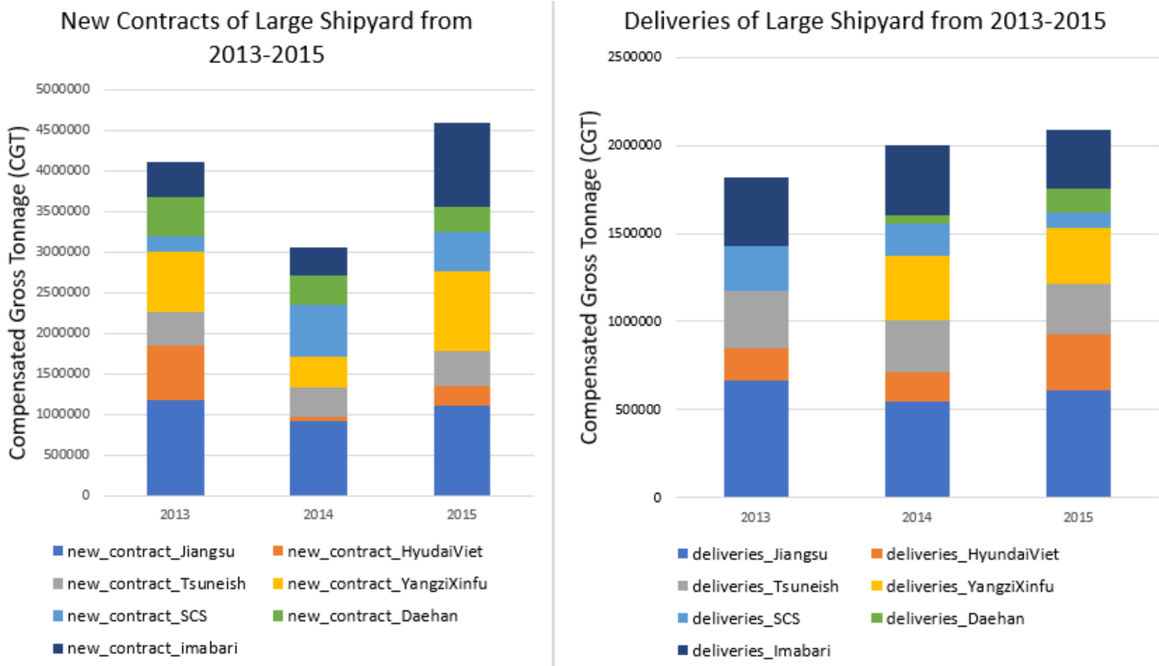

Figure 5.9: Deliveries and new-contracts of large shipyards

Table 5.5: Large-sized shipyard output deliveries

No	Shipyard	Output - Deliveries [CGT]
1	Jiangsu New YZJ	609,801
2	Hyundai Vietnam SB	220,888
3	Tsuneish Zhoushan	303,489
4	Yangzi Xinfu SB	337,187
5	SCS Shipbuilding	176,109
6	Imabari SB Marugame	373,260
7	Daehan SB	94,233

In the figure 5.10 we can see the deliveries (left) and new-contracts (right) of medium-sized shipyards. Notice that Dae Sun Shipyard's new contract is increasing while STX SB Jinhae shipyard's new contract is decreasing. The author suggests that this phenomenon is normal because shipyards are competing for new contracts, and clearly Dae Sun's increase in market share affects other shipyard's market share.

Table 5.7 shows the average number of deliveries of medium-sized shipyards. Korean yard, STX SB Jinhae leads the position by having average delivery of 723.921 while the other shipyards are relatively delivering 100 thousands worth of CGT. A Japanese yard, Namura Shipbuilding has an average delivery of 325.786.

For full data on new contracts and deliveries for all shipyards size, please refer to Appendix D.

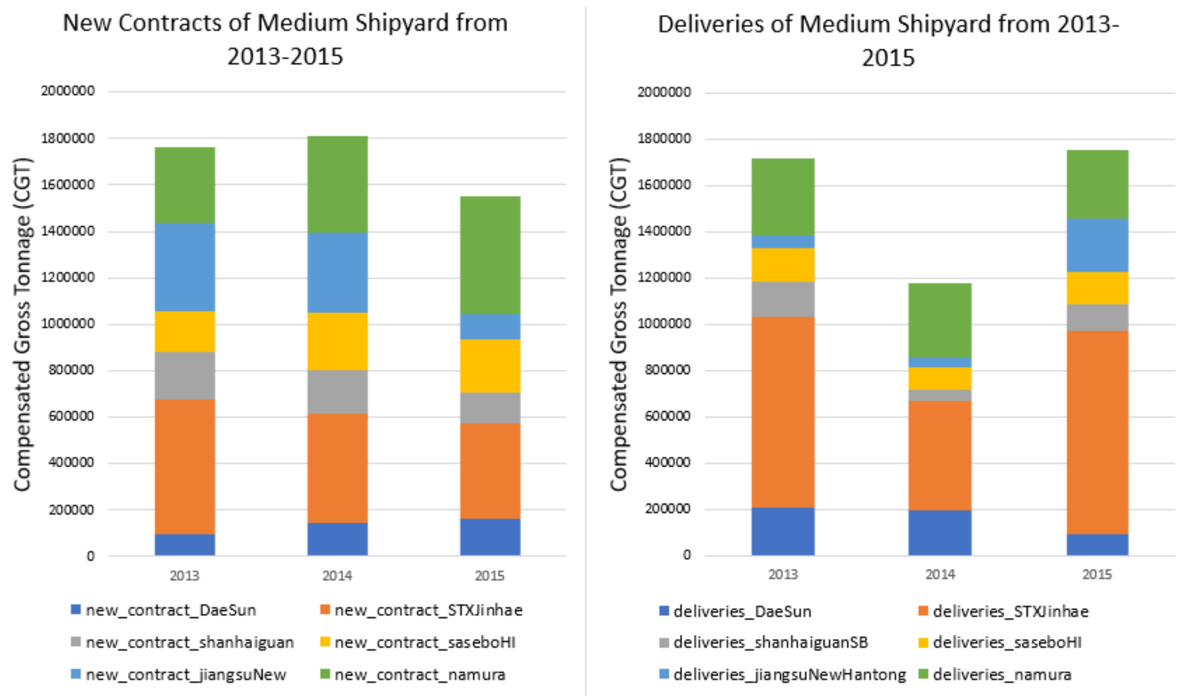

Figure 5.10: Deliveries and new-contracts of Medium shipyards

Table 5.6: Medium-sized shipyard output deliveries

No	Shipyard	Output - Deliveries [CGT]
1	Dae Sun	168,219.00
2	STX SB Jinhae	723,921.00
3	Shanhaiguan SB	107,265.67
4	Sasebo HI	126,236.33
5	Jiangsu New Hantong	108,218.67
6	Namura SB	315,786.33

5.2.3. Shipyards Profile and Input for DEA Model-1

In this section the profiles of shipyards for every size are presented. The data is collected from Clarkson Research Shipping Intelligent Network, Clarkson World Fleet Register, shipyard's website, and other shipyards database.

Mega Shipyard

For mega-sized shipyards, four Korean yards, two Chinese yards, and one Japanese yard are investigated. The profiles of those yards are shown in Table 5.7. The shipyard with the highest number of employees is Chinese yard Dalian Shipbuilding with 15,000, and shipyard with least number of employees is Japanese yard, Oshima Shipbuilding with 1,635. Shipyard with the biggest dock area is Korean yard, Hyundai HI Ulsan with 262,263 squared meters. Lastly, Shipyard with the smallest dock area is Chinese yard, Huangpu Wenchong with 15,402 squared meters. Huangpu Wenchong is also the youngest shipyard in this set. The oldest yard in this set is Hyundai HI Ulsan with 28 years old. Followed by two other yards, Hyundai Mipo and Oshima Shipbuilding. In this set the two youngest yard are Chinese yards.

Table 5.7: Mega shipyard profile

No	Yard	Country	No. Employees	No of Dock	Total Dock area	Founded	Age
			#	#	m^2		year
1	Daewoo DSME	Korea	10,792	6	144,602	1981	39
2	Hyundai HI Ulsan	Korea	10,310	9	262,263	1972	48
3	Samsung HI	Korea	11,073	8	146,121	1983	37
4	Hyundai Mipo	Korea	13,509	4	17,942	1975	45
5	Dalian SB	China	15,000	5	126,937	2005	15
6	Huangpu Wenchong	China	6,000	5	15,402	2013	7
7	Oshima SB	Japan	1,635	1	42,800	1975	45

The descriptive statistics for mega shipyards is shown in table 5.8.

Table 5.8: Descriptive Statistics of Mega Shipyard Profile

	No. Employees	Total Dock area
Mean	9759.85714285714	108009.578571429
Std Error	1723.48842576372	33765.4724566909
Median	10792	126937
Std Deviation	4559.921762069	89335.0430210054
Range	13365	246860.6
Minimum	1635	15402.4
Maximum	15000	262263

Large Shipyard

As for large shipyards, seven shipyards are investigated. Table 5.9 shows the summary of the medium-sized shipyards under investigation. Shipyard with the highest number of employees is Chinese yard Yangzi Xinfu Shipbuilding with 8000 employees, and the least is also Chinese yard, SCS Shipbuilding with 600 employees. On the other hand, SCS Shipbuilding has the biggest dock area of 93,580 meters squared. Shipyard with the smallest dock area is Chinese yard, Tsuneish Zhoushan.

The oldest yard in the large-sized set is the Japanese yard, Imabari Shipbuilding Marugame. This Japanese yard was founded in 1971. The other yards are relatively young, with less than 20 years old. The only exception is the Hyundai Vietnam Shipbuilding, which is a joint venture between the Hyundai Group and Vietnam Shipbuilding Group with the age of 24 years old.

The descriptive statistics for large shipyards is given in table 5.10.

Table 5.9: Large Shipyard Profile

No	Yard	Country	No. Employees	No of Dock	Total Dock area	Founded	Age
			#	#	m^2		year
1	Jiangsu New YZJ	China	4,000	2	64,080	2008	12
2	Hyundai Vietnam SB	Vietnam	3,500	2	36,400	1996	24
3	Tsuneish Zhoushan	China	1,000	1	5,535	2003	17
4	Yangzi Xinfu SB	China	8,000	1	79,821	2012	8
5	SCS Shipbuilding	China	600	2	93,580	2008	12
6	Imabari SB Marugame	Japan	1,720	3	81,240	1971	49
7	Daehan SB	Korea	3,000	2	57,408	2008	12

Table 5.10: Descriptive Statistics for Large Shipyards

	No. Employees	Total Dock area
Mean	3117.142857	59723.42857
Std Error	945.5704106	11461.999
Median	3000	64080
Std Deviation	2501.744153	30325.59889
Range	7400	88045
Minimum	600	5535
Maximum	8000	93580

Medium Shipyard

In medium shipyards, each country of Japan, South Korea, and China has two representative yards. The medium shipyards profile is given in table 5.11. The shipyard with highest number of employees is Chinese yard, Jiangsu New Hantong, with 3000 employees. The shipyard with the least number of worker is Japanese yard, Sasebo HI. The shipyard with the biggest dock area is Chinese yard Shanhaiguan SB and the least is Japanese yard Namura Shipbuilding.

Chinese yards are relatively younger than Korean and Japanese yards, with age of less than 20 years. Korean yards, Dae Sun is 49 years old, while STX SB Jinhae was originally founded in 1967 but has been changed ownership and went under re-branding into STX Offshore and Shipbuilding in 2002. All of the Japanese yards are 45 years and older.

Table 5.11: Medium shipyard profile

No	Yard	Country	No. Employees	No of Dock	Total Dock area	Founded	Age
			#	#	m^2		year
1	Dae Sun	Korea	2,131	2	8,638.0	1971	49
2	STX SB Jinhae	Korea	2,819	2	53,702.0	2002	18
3	Shanhaiguan SB	China	2,735	6	112,760.0	2003	17
4	Sasebo HI	Japan	732	2	8,654.9	1968	52
5	Jiangsu New Hantong	China	3,000	1	46,080.0	2008	12
6	Namura SB	Japan	861	1	5,175.0	1975	45

The descriptive statistics of medium shipyards can be seen in table 5.12.

Table 5.12: Descriptive Statistics for Medium Shipyards

	No. Employees	Total Dock area
Mean	2046.333333	39168.31
Std Error	413.1348179	17022.97666
Median	2433	27367.45
Std Deviation	1011.969499	41697.60671
Range	2268	107585
Minimum	732	5175
Maximum	3000	112760

5.2.4. Shipyards Profile, Input and Output for DEA Model-2

In this section the data for inputs and output for model-2 is given. The first input, 'average price/CGT' is caluclated by averaging the aggregate value of price/CGT index by the period of 2013-2015. The second input is calculated by aggregating the difference between delivery date and contract date of a ship divided by its CGT for every shipyard. The equation for the two inputs are given in equation 5.3 and 5.4. Lastly, the output for the model is the average deliveries between the period of 2013-2015.

$$\overline{input-1} = \sum_{i=1}^{N} \frac{ship's\ price\ (in\ \$)(i)}{CGT(i)}\ (shipyard, year) \tag{5.3}$$

$$\overline{input-2} = \sum_{i=1}^{N} \frac{Delivery\ date\ -contract\ date(i)}{CGT(i)}\ (shipyard, year) \tag{5.4}$$

Where i is a ship in the set of ships N. The equation is a function of shipyard and year. The summary of inputs and outputs for mega, large, and medium shipyard is given in Table 5.13, 5.14, and 5.15 respectively.

In table 5.13 we can see that Samsung HI has the highest level of price/CGT and Huangpu Wenchong has the lowest level of price/CGT. However, Huangpu Wenchong's project-duration/CGT is the higest among other shipyards. This means that low price level of Huangpu Wenchong is compensated with its long delivery times. Daewoo DSME is the shipyard with the fastest delivery time for mega-sized shipyards with a close second of Hyundai HI Ulsan.

Table 5.13: Input and output of DEA model-2 for mega shipyards

No	Shipyard	Input-1 avg price/cgt	Input-2 project_duration/cgt	Output - New contracts
		(x1000$/CGT)	(day/CGT)	(CGT)
1	Daewoo DSME	3.465213	0.018050153	3,130,115
2	Dalian SB	1.955741	0.025442023	805,668
3	Huangpu Wenchong	1.619509667	0.072035857	435,564
4	Hyundai HI Ulsan	2.588455667	0.019721783	2,426,252
5	Hyundai Mipo	2.199527667	0.039065263	1,731,681
6	Samsung HI	5.004418667	0.023729113	1,864,224

A similar case also can be found in large-sized shipyard. SCS Shipbuilding has the highest price/CGT level but the fastest delivery time. Again, shipyard with lowest price/CGT level is Tsuneish Zhoushan, but also has the second longest delivery time. It means that price/CGT and project-duration/CGT are complementary. Lastly, the shipyard with the longest delivery time/CGT is Imabari SB Marugame. (Table 5.14)

Table 5.14: Input and output of DEA model-2 for large shipyards

No	Shipyard	Input-1 avg price/cgt	Input-2 project_duration/cgt	Output - New contracts
		(x1000$/CGT)	(day/CGT)	(CGT)
1	Jiangsu New YZJ	1.557377567	0.046670453	1,066,317
2	Hyundai Vietnam SB	1.658971967	0.04225242	326,118
3	Tsuneish Zhoushan	1.0559484	0.056708303	407,241
4	Yangzi Xinfu SB	1.686087333	0.02079787	698,251
5	SCS Shipbuilding	1.8744189	0.02050655	437,464
6	Imabari SB Marugame	1.8257474	0.05725994	601,168

Table 5.15 shows the inputs and output DEA model-2 for medium-sized shipyards. The same case is also applied for medium-sized shipyards. The shipyard with higest price/CGT level is SCS Shipbuilding

and also has the fastest delivery time. Tsuneish Zhousan has the most attractive price level but is the shipyard with the second longest delivery times. Only second to Imabari SB Marugame for the longest delivery time.

Table 5.15: Input and output of DEA model-2 for medium shipyards

No	Shipyard	Input-1 avg price/cgt (x1000$/CGT)	Input-2 project_duration/cgt (day/CGT)	Output - New contracts (CGT)
1	Dae Sun	1.808790222	0.055820613	136,959
2	STX SB Jinhae	2.336014889	0.039478407	483,562
3	Shanhaiguan SB	1.851041333	0.064445997	175,582
4	Sasebo HI	1.768090667	0.043205057	217,800
5	Jiangsu New Hantong	1.492683	0.043223363	275,766
6	Namura SB	2.017695	0.051704613	417,773

5.3. Conclusion chapter 5

In this chapter, the benchmarking method is called the DEA model. The DEA model follows the system-oriented approach that gives inputs, outputs, environmental factors, non-discretionary factors, orientation and decision-making units (DMUs). Shipyards are the DMUs in this case. Based on the objectives derived from competitiveness in chapter 3, the DEA model is divided into two. The first model refers to the second objective 'The ability to execute shipbuilding orders.' The second model refers to the first objective 'The ability to attract shipbuilding orders'.

The summary of DEA Model-1 is as follows:

1. Objective: The ability to execute shipbuilding orders
2. Inputs: Dock Area and Number of Employees
3. Output: Deliveries (CGT)
4. Environmental factors: Building Technique and Managerial ability
5. Non-discretionary factors: related industries
6. Orientation: output-oriented

The summary of DEA Model-2 is as follows:

1. Objective: The ability to attract newbuilding orders
2. Inputs: $\frac{market\ price\ (\$)}{CGT}$ and $\frac{Project-\ duration}{CGT}$
3. Output: New contracts (CGT)
4. Environmental factors: Innovation and Managerial ability
5. Non-discretionary factors: Government policy and subsidies
6. Orientation: input-oriented

The summaries of DEA Model-1 and DEA Model-2 hence answer the fourth research questions 'What variables can be used in the method? '.

The decision-making units (DMUs) in the DEA model are shipyards. The author classifies shipyards based on Clarkson yard size classification. In this thesis, only Medium, Large and Mega shipyards are considered. Medium-sized, Large-sized, and Mega-sized shipyards have an orderbook size of (0.1<0.49), (0.49<1), and (>1) in millions of CGT respectively. Then top shipyards based on market share are selected. Moreover the author attempts to include at least one shipyard for every top country in terms of market share. This selection approach then answer the remaining fourth research question 'how to choose the shipyards to be evaluated?'.

5.3.1. Innovation and contribution to academia

This thesis report is expected to have a contribution or innovation to academia. It is essential to understand that creating innovation is not an easy task. The approach to propose an alternative or adding more variables to an existing method must be treated carefully.

In this section, the author wants to summarize the crucial remarks for innovation that are presented in this chapter. The first one is the DEA models. The DEA model-1 uses common and general variables that have been widely used by many researchers. However, the DEA model-2 is derived from literature research based on the shipyard's competitiveness objectives. The ratio price/CGT was introduced by Bertram (2003, [9]) but, in the author's knowledge, this variable has not been used as inputs in benchmarking analysis. The other variable, project-duration/CGT, is based on literature research and also have not been used in benchmarking analysis, but its influence is supported by statistical regression (chapter 5.1.2).

The second innovation is the two illustrations of a system-oriented approach for each objective (Figure 5.3 and Figure 5.4). The pictures attempt to capture all the relevant factors of the shipyard's competitiveness based on the shipyard's objectives. The general system-oriented approach is introduced by Bogetoft and Otto (2011 [10]). The factors (inputs, outputs, non-discretionary, and environment) in this thesis are based on literature research. The third innovation (or contribution) is the long list of shipyards under study. 20 yards are investigated, taking into account the three Asian giants, Japan, South Korea, and China, plus a Vietnamese shipyard.

6
Data Envelopment Analysis (DEA) Model Results

This chapter will answer the last research question, 'What are the results of the method, and how less competitive shipyard able to do to be more competitive?'. To summarize this thesis so far, the second chapter of this thesis explains the characteristics of the shipbuilding industry. The third chapter of this thesis discusses methods to measures shipbuilding competitiveness. The author conducted literature research to find competitiveness indicators and influencing factors. The result of the Analytical Hierarchy Process shows that the benchmarking method is the appropriate method to measure competitiveness. In chapter 4, the author goes through the theoretical and mathematical concepts of benchmarking. The Data Envelopment Analysis (DEA) is thus chosen as the frontier analysis. The procedure and application of DEA in the shipbuilding industry are also provided. Chapter 5 discusses the common inputs and outputs variable for Data Envelopment Analysis in shipbuilding.

For those not familiar with the application of DEA, Appendix E gives an illustration of the DEA in a simple case and how to interpret the results. Chapter 6.1 shows the first analysis, 'Efficiency Score,' one of the traits of Data Envelopment Analysis. In section 6.2, the improvement of how inefficient shipyards can improve themselves are discussed. The analyses of the results are elaborated in chapter 6.3. Lastly, chapter 6.4 concludes the whole chapter 6.

6.1. Result and Analysis: Efficiency Score

This section depicts the efficiency score for the two DEA models. Each model divides the shipyards into three categories based on their size; mega-sized, large-sized, and medium-sized. The efficiency score ranges from 0 to 1 ($0 \leq E \leq 1$). One being the efficient ones or also known as the frontier.

6.1.1. DEA Model-1

In the first DEA Model, we measure the efficiency of shipyards in terms of 'productivity.' The input for this model is the dock area and the number of employees, and the output for this model is deliveries (in CGT).

Mega shipyards

For mega-sized yards, three Korean yards, Daewoo DSME, Hyundai Heavy Industry Ulsan, and Hyundai Mipo are all efficient. One Chinese yard, Huangpu Wenchong, and one Japanese yard, Oshima SB are also frontiers. One Korean yard, Samsung Heavy Industry comes close to become a frontier, with efficiency score of 0.925. The least efficient shipyard is Chinese yard, Dalian Shipbuilding with a low efficiency score of 0.355. (Table 6.1)

Large shipyards

Chinese yards dominate in this study set with three of them as frontiers for large-size shipyards. Chinese yard, Jiangsu New YZJ, Tsuneish Zhoushan, and SCS Shipbuilding are all frontiers with an efficiency score of 1. Japanese yard, Imabari SB Marugame comes very close with an efficiency score of

Table 6.1: Mega Shipyards and Efficiency Values for Model-1

Model-1	
Shipyard	Efficiency (theta)
Daewoo DSME	1
Hyndai HI Ulsan	1
Samsung HI	0.925
Hyundai Mipo	1
Dalian SB	0.355
Huangpu Wenchong	1
Oshima SB	1

0.99. Another Chinese yard, Yangzi Xinfu Shipbuilding, has an efficiency score of 0.5529. Vietnam-based Korean shipyard, Hyundai Vietnam Shipbuilding, has an efficiency score of 0.4751. Lastly, the least efficient shipyard under this category is the Korean yard, Daehan Shipbuilding, with an efficiency score of 0.1856. The summary can be seen in Table 6.2.

Table 6.2: Large Shipyards and Efficiency Values for Model-1

Model-1	
Shipyard	Efficiency (theta)
Jiangsu New YZJ	1
Hyundai Vietnam SB	0.4751
Tsuneish Zhoushan	1
Yangzi Xinfu SB	0.5529
SCS Shipbuilding	1
Imabari SB Marugame	0.9901
Daehan SB	0.1856

Medium shipyards
For medium-sized shipyards, two Japanese yards are efficient, Sasebo Heavy Industry and Namura Shipbuilding. One Korean yard, STX SB Jinhae is also a frontier. Korean yard, Dae Sun, Chinese yards, Jiangsu New Hantong, and Shanhaiguan SB are all inefficient shipyards with an efficiency score of 0.4877, 0.164, and 0.1518, respectively. The summary can be seen in Table 6.3.

Table 6.3: Medium Shipyards and Efficiency Values for Model-1

Model-1	
Shipyard	Efficiency (theta)
Dae Sun	0.4877
STX SB Jinhae	1
Shanhaiguan SB	0.1518
Sasebo HI	1
Jiangsu New Hantong	0.164
Namura SB	1

Conclusion for Model-1
From the results we can conclude that Japanese yard, having only small portion representing each yard size, are the most efficient. In mega-sized yard, Japanese yard, Oshima SB is a frontier. In large-sized yard, Imabari SB Marugame, has a high efficiency score of 0.99. Namura Shipbuilding and Sasebo Shipbuilding are both frontiers in medium-sized shipyards.

Korean shipyards dominate in mega-sized shipyard. Three out of four frontiers are Korean yards, with the inefficient one, Samsung Heavy Industry, having a close score of 0.925. According to study from Park (2010 [52]) small to medium sized (SMS) shipyard are operating inefficiently, which is further validated by this report. In large-sized yard, Korean yard, Daehan SB has a low efficiency score of 0.1856. For medium-sized shipyard, Korean yard, Dae Sun has a low efficiency score of 0.4877. However, STX SB Jinhae is a frontier in medium-sized shipyard. This is because in October 2013, STX Offshore Shipbuilding was restructured into more selective and focused business divisions such as mid-sized merchant vessels and gas carriers. STX offshore shipbuilding is a leader in the market in building value-added ships [2]. Therefore their resources (capacity and workforce) might be adjusted to their needs for their operation in targeted market.

Chinese yards have a good position in large-sized shipyard having three out of four yards to be frontiers. In mega-sized shipyard, only one Chinese yard is a frontier, Huangpu Wenchong. The other Chinese yard in mega-sized shipyard is Dalian, with a low efficiency of 0.355. The reason of this low score might be the resiliency of market leader from South Korea yards. Huangpu Wenchong is a merger of two shipyards, Huangpu SB Ltd and Wenchong SB Ltd, which effectively merged in 2013. This shipyard is the main shipbuilding base in southern China for the construction of military vessels, specialized vessels, and offshore units, although its main products are barges and feeder container ships [1]. One might suggests, since this yard produces military vessels, government intervention by means of subsidy or protectionism policy might be the reason why this shipyard is very efficient. In medium-sized shipyard, Chinese yards are very far from being efficient, in fact their efficiency score is very low.

6.1.2. DEA Model-2

In the DEA model-2, we focus on the ability of the shipyard to attract new building orders. Price and project duration are the inputs for this model, and new contracts (in CGT) is the output of this model.

Mega shipyards

In mega-sized shipyards, almost all shipyards are frontiers. Leaving only Samsung Heavy Industry as the inefficient one with efficiency score of 0.7607. The result indicates that in terms of the ability to attract new building orders, Daewoo DSME, Dalian SB, Huangpu Wenchong, Hyundai Heavy Industry Ulsan, Hyundai Mipo are very efficient in offering their price and delivery duration. The result can be seen in table 6.4.

Table 6.4: Mega Shipyards and Efficiency Values for Model-2

Model-2	
Shipyard	Efficiency (theta)
Daewoo DSME	1
Dalian SB	1
Huangpu Wenchong	1
Hyundai HI Ulsan	1
Hyundai Mipo	1
Samsung HI	0.7607

Large shipyards

Four Chinese yards are the frontier in their ability to receive new contracts in large-sized shipyards. Jiangsu New YZJ, Tsuneish Zhoushan, Yangzi Xinfu Shipbuilding, and SCS Shipbuilding are the efficient frontiers in this case. Following the frontiers, Vietnam-based Korean yard, Hyundai Vietnam Shipbuilding with an efficiency score of 0.8545, and China yard, COSCO Heavy Industry Yangzhou with an efficiency score of 0.7401. Table 6.5 summarizes the results.

Medium shipyards

In medium-sized shipyards, each country has their own representative of frontiers; Korean yard, STX SB Jinhae, Chinese yard, Jiangsu New Hantong, and Japanese yard Namura SB. The other inefficient yards are not var from the frontiers, at the second position, Japanese yard, Sasebo Heavy Industry with efficiency score of 0.9764, followed by Korean yard, 0.8252, and lastly Chinese yard with 0.8064.

Table 6.5: Large Shipyards and Efficiency Values for Model-2

Model-2	
Shipyard	Efficiency (theta)
Jiangsu New YZJ	1
Hyundai Vietnam SB	0.8545
Tsuneish Zhoushan	1
Yangzi Xinfu SB	1
SCS Shipbuilding	1
Imabari SB Marugame	0.7401

Table 6.6: Medium Shipyards and Efficiency Values for Model-2

Model-2	
Shipyard	Efficiency (theta)
Dae Sun SB	0.8252
STX SB Jinhae	1
Shanhaiguan SB	0.8064
Sasebo HI	0.9764
Jiangsu New Hantong	1
Namura SB	1

6.2. Result and Analysis: Peers and Variable Weight

6.2.1. DEA Model-1

Mega shipyards

Figure 6.1 depicts a 7x7 matrix that shows the peer and variable weight (λ) of the shipyards. The diagonal part of the matrix (highlighted yellow) shows when a shipyard is peered by itself. For example, a frontier, Daewoo DSME, when it peers to itself, it will have a (λ) value of one. Samsung HI, an inefficient shipyard, is peered to two shipyards; one is Daewoo DSME with a lambda value of 0.9871 and Hyundai HI Ulsan, with a lambda value of 0.129. The lambda value is consistently sum up into one (as explained in Appendix E). From the matrix we can derive who is the peers for every shipyard and what are the corresponding λ values.

	Daewoo DSME	Hyndai HI Ulsan	Samsung HI	Hyundai Mipo	Dalian SB	Huangpu Wenchong	Oshima SB
Daewoo DSME	1	0	0	0	0	0	0
Hyndai HI Ulsan	0	1	0	0	0	0	0
Samsung HI	0.9871	0.129	0	0	0	0	0
Hyundai Mipo	0	0	0	1	0	0	0
Dalian SB	0.8605	0	0	0.1395	0	0	0
Huangpu Wenchong	0	0	0	0	0	1	0
Oshima SB	0	0	0	0	0	0	1

Figure 6.1: Peers and Lambda Matrix for Mega Shipyards Model-1

Table 6.7 shows the λ value of each shipyard to its respecting peers. The first column shows the inefficient shipyards. The second, third, and fourth columns are the respecting peers. Output columns depict the value of output (delivery in CGT) of each peer. Lambda value columns represent the lambda value for its inefficient respecting unit (each row).

Table 6.7: Inefficient mega shipyards with its peers and its peers' value

Model-1	peer-1: Daewoo		peer-2: Hyundai Ulsan		peer-3: Hyundai Mipo	
Shipyard	output	lambda	output	lambda	output	lambda
Samsung HI	2,173,942	0.9871	2,296,155	0.129	1,642,523	0
Dalian SB	2,173,942	0.8605	2,296,155	0	1,642,523	0.1395

Table 6.8 highlights the improvement needed for each inefficient shipyards to become efficient. In the first column, Output-deliveries depicts the output value (deliveries in CGT) for each inefficient

shipyards. The 'Improvement Target' column is the sum of multiplication between output and lambda of each peer (data from the previous table 6.7). The 'improvement' column is the difference between the inefficient shipyard's output with the total lambda. For example, In the improvement column, Samsung HI requires to increase its output by 428,744.52 ton (CGT) to be efficient.

Table 6.8: Improvement value for inefficient mega shipyards output

Model-1		Improvement Target	Improvement
Shipyard	Output - Deliveries		
Samsung HI	2,013,358	2,442,102.52	428,744.52
Dalian SB	747,280	2,099,809.29	1,352,529.29

Large shipyards
We then use the same approach as mega shipyards to find the improvement for inefficient shipyards. For simplicity the peers matrix and lambda values-peers table will not be shown.

Table 6.9 shows the four inefficient shipyards, Hyundai Vietnam Shipbuilding, Yangzi Xinfu Shipbuilding, Imabari Shipbuilding Marugame, and Daehan Shipbuilding and their improvement target.

Table 6.9: Improvement value for inefficient large shipyards output

Model-1		Improvement Target	Improvement
Shipyard	Output - Deliveries		
Hyundai Vietnam SB	220,888	464,976.70	244,089.04
Yangzi Xinfu SB	337,187	609,801.33	272,614.83
Imabari SB Marugame	373,260	377,003.71	3,743.37
Daehan SB	94,233	507,799.22	413,566.22

Medium shipyards
Table 6.10 shows the three inefficient shipyards, Korean yard, Dae Sun, and two Chinese yards Shanhaiguan SB and Jiangsu New Hantong. Again, the improvement target is shown in the table.

Table 6.10: Improvement value for inefficient medium shipyards output

Model-1		Improvement Target	Improvement
Shipyard	Output - Deliveries		
Dae Sun	168,219	344,927.15	176,708.15
Shanhaiguan SB	107,266	706,412.02	599,146.36
Jiangsu New Hantong	108,219	659,803.04	551,584.38

6.2.2. DEA Model-2

Mega shipyards
Since model-2 is input-oriented, the improvement is a reduction of input. There are two inputs hence the reduction is applied to both inputs.

For mega-sized shipyards model-2, only Korean yard, Samsung Heavy Industry is inefficient. Samsung HI yard has to reduce its price/CGT level by 1.537 (x1000$) for every ton CGT of ships built (Table 6.11). subsequently Samsung HI requires to reduce its delivery time by 0.005679 day/CGT for every CGT built (Table 6.12).

Large shipyards
Table 6.13 shows the improvement targets and reduction value for medium-sized shipyards. As we can see, two inefficient shipyards are Hyundai Vietnam SB and Imabari SB Marugame. From the table, Hyundai Vietnam SB must reduce its price/CGT level by 0.2414498 (x1000$) for every ton CGT

Table 6.11: Reduction value for inefficient mega shipyards input-1

Model-2		Improvement	Reduction
Shipyard	Input-1 avg price/cgt		
Samsung HI	5.002593	3.465213	1.53738

Table 6.12: Reduction value for inefficient mega shipyards input-2

Model-2		Improvement Target	Reduction
Shipyard	Input-2 project_duration/cgt		
Samsung HI	0.023729113	0.0180502	0.005679

in order to become efficient. Imabari SB Marugame needs to reduce its price/CGT level by 0.4745243 (x1000$) for every ton CGT in order to become a frontier.

Table 6.13: Reduction value for inefficient large shipyards input-1

Model-2		Improvement	Reduction
Shipyard	Input-1 avg price/cgt		
Hyundai Vietnam SB	1.658971967	1.4175221	0.2414498
Imabari SB Marugame	1.8257474	1.3512231	0.4745243

In table 6.14 Hyundai Vietnam needs to reduce its duration/CGT by 0.0061495 while Imabari SB Marugame 0.0148818.

Table 6.14: Reduction value for inefficient large shipyards input-2

Model-2		Improvement	Reduction
Shipyard	Input-2 project_duration/cgt		
Hyundai Vietnam SB	0.04225242	0.0361029	0.0061495
Imabari SB Marugame	0.05725994	0.0423782	0.0148818

Medium shipyards

In medium-sized shipyards, each country has their inefficient shipyard. A korean yard, Dae Sun will need to reduce its price/CGT level by 0.3161072 price/CGT. Chinese yard, Shanhaiguan SB will need to reduce its price/CGT level by 0.3583583 price/CGT, and Japanese yard, Sasebo HI requires to reduce its price/CGT level by 0.417204 price/CGT. The data can be seen in table 6.15.

Table 6.15: Reduction value for inefficient medium shipyards input-1

Model-2		Improvement	Reduction
Shipyard	Input-1 avg price/cgt		
Dae Sun SB	1.808790222	1.492683	0.3161072
Shanhaiguan SB	1.851041333	1.492683	0.3583583
Sasebo HI	1.768090667	1.7263703	0.0417204

From table 6.16 we can see the reduction requirement for delivery times of inefficient shipyards. Dae Sun Shipbuilding must reduce its delivery times by 0.0125972. Shanhaiguan SB needs to reduce by 0.0212226. Lastly, Sasebo HI by 0.0010194.

Table 6.16: Reduction value for inefficient medium shipyards input-1

Model-2		Improvement	Reduction
Shipyard	Input-2 project_duration/cgt		
Dae Sun SB	0.055820613	0.0432234	0.0125973
Shanhaiguan SB	0.064445997	0.0432234	0.0212226
Sasebo HI	0.043205057	0.0421856	0.0010194

6.3. Results Analysis

Table 6.17, 6.18, and 6.19 summarize the result of DEA model-1 and model-2 side by side. In chapter 3 we discussed that competitiveness can be translated into two objectives. According to literature research, the ability to execute shipbuilding orders and the ability to attract new orders are what make shipyards competitive.

In chapter 4, the author conducted a literature study of Data Envelopment Analysis (DEA) in the shipbuilding industry. The author concluded that the ability to execute shipbuilding orders refers to the so-called 'productivity' of shipyards and build the DEA model-1. The inputs for DEA model-1 are dock area and number of employees with output-orientation. Output orientation means that the improvement should focus on increasing the output of the model, in this case, deliveries (CGT). Output orientation also indicates that there is a potential for shipyard to improve their output. The reason of choosing output-oriented is discussed in chapter 5. In short, input orientation is not preferable because it means a reduction in number of employees (worker layoffs) and selling assets (which means shipyard is downsizing).

The other objective, the ability to attract new building orders, is converted into DEA model-2. The DEA model's inputs are price/CGT and project-duration/CGT with input orientation. Input orientation means that the improvement should focus on the reduction of inputs. The reduction of price can be by means of government subsidy or policy. Thus the DEA model-2 acts as a consideration for policy makers, shipowners, and shipbuilders to analyze the competitiveness of shipyards in respecting country/region. Technology and R&D are also important aspects to reduce the inputs.

Now, take a look at Table 6.17. Samsung Heavy Industry's efficiency is close with the frontiers with 0.925 and 0.7607 for model-1 and model-2 respectively which means there is a room for improvement for Samsung HI. A surprising result is for Dalian SB. For productivity, Dalian SB is very inefficient, with a score of 0.355. However for the ability to attract new orders, Dalian is a frontier. The reason why Dalian is good at model-2 is because Dalian is very attractive in attracting new orders. Dalian has low price/cgt and duration/cgt with proportional new contracts. However, in capacity term, Dalian is very inefficient. It is because Dalian has the most workers of 15,000 people and fourth biggest dock area of 126,937 meter squared. Therefore Dalian SB is a very capital intensive shipyard. The next question would be if the employee and overhead cost of Dalian compared to other shipyards are in equal standing. One might suggest that Dalian yard operating cost should be low enough to stay in business. One guess would be that their business is supported by the government.

Table 6.17: Result analysis Mega Shipyards

Mega shipyard			
Model-1		Model-2	
Shipyard	Efficiency (theta)	Shipyard	Efficiency (theta)
Daewoo DSME	1	Daewoo DSME	1
Hyndai HI Ulsan	1	Hyundai HI Ulsan	1
Samsung HI	0.925	Samsung HI	0.7607
Hyundai Mipo	1	Hyundai Mipo	1
Dalian SB	0.355	Dalian SB	1
Huangpu Wenchong	1	Huangpu Wenchong	1
Oshima SB	1	-	-

For large-sized shipyard, we can see the result from table 6.18. Hyundai Vietnam productivity's efficiency is quite low with 0.4751 but Hyundai Vietnam ability to attract new contracts is quite close to the frontier with 0.8545. A Chinese yard, Yangzi Xinfu has an efficiency of model-1 of 0.5529 and a frontier in model-2. For productivity results, Hyundai Vietnam and Yangzi Xinfu have a low ratio between capacity and output. The two results show that both yards have attractiveness to attract new contracts, although Hyundai Vietnam is not a frontier, but has a quite high score. Their low price/CGT could be a result of low building costs and fast delivery times. A low building cost could be traced to the subsidy from the Chinese government and a low duration could be the advantage of high employee. Yangzi Xinfu has the highest employee of 8,000 workers and the third biggest dock area of 79,821 squared meters. While Hyundai Vietnam has the third highest number of employee with 3,500 but a second low dock area. Hyundai Vietnam SB is a joint venture company between Hyundai Group (Korea) AND Vietnam Shipbuilding Industry Group. It was established on September 30th, 1996. It specializes in building bulk carrier, ship-repair, conversion and offshore fields since then. Their inefficiency might be stemmed from the previous Vietnam SB Industry group where they have a large area and high number of employee but focused more on ship repair and conversion.

Table 6.18: Result analysis Large Shipyards

Large shipyards			
Model-1		Model-2	
Shipyard	Efficiency (theta)	Shipyard	Efficiency (theta)
Jiangsu New YZJ	1	Jiangsu New YZJ	1
Hyundai Vietnam SB	0.4751	Hyundai Vietnam SB	0.8545
Tsuneish Zhoushan	1	Tsuneish Zhoushan	1
Yangzi Xinfu SB	0.5529	Yangzi Xinfu SB	1
SCS Shipbuilding	1	SCS Shipbuilding	1
Imabari SB Marugame	0.9901	Imabari SB Marugame	0.7401
Daehan SB	0.1856	-	-

The last efficiency analysis is for medium-sized shipyard. The result is shown in table 6.19. A Korean yard, Dae Sun has a mediocre efficiency for productivity and a close-to-frontier efficiency for new contract attractiveness. Chinese yards, Shanhaiguan has a high efficiency for attractiveness and Jiangsu New Hantong is a frontier. However, both are very low at productivity efficiency. The reason for this is because Shanhaiguan SB has the highest dock area of 112,760 squared meter and the third highest worker of 2,735 workers. Jiangsu New Hantong has the highest number of employee of 3,000 and third biggest dock area of 46,080 squared meters. A suggestion may arise that although Chinese yards have a low price and fast delivery times, they quality are still questionable, and ship owners do not build their ships in Chinese yards.

Table 6.19: Result analysis Medium Shipyards

Medium shipyards			
Model-1		Model-2	
Shipyard	Efficiency (theta)	Shipyard	Efficiency (theta)
Dae Sun	0.4877	Dae Sun SB	0.8252
STX SB Jinhae	1	STX SB Jinhae	1
Shanhaiguan SB	0.1518	Shanhaiguan SB	0.8064
Sasebo HI	1	Sasebo HI	0.9764
Jiangsu New Hantong	0.164	Jiangsu New Hantong	1
Namura SB	1	Namura SB	1
Daehan SB	0.1856	-	-

A summary of output improvement and input reduction of mega-sized yards is given in Table 6.20. For mega-sized shipyards, Samsung HI has a potential to be an efficient frontier if it improves its deliveries by 21%. Dalian SB on the other hand, needs to increase its output for 181%. For example the delivery of Samsung HI is 2,013,358 CGT. The target output for Samsung in order to become efficient is 2,442,102 CGT. Therefore Samsung, with its given resources (inputs) should be able to increase its output by 428,744 CGT.

For the ability to attract new orders, only Samsung HI requires to decrease its inputs. Samsung HI has to decrase its price/CGT by 31% and its duration/CGT by 24% for it to be a frontier.

Table 6.20: Summary of output improvement and input reduction for mega shipyards

Mega shipyard		
Shipyard	Improvement Deliveries (percentage)	
Samsung HI	21%	
Dalian SB	181%	
Shipyard	Reduction (percentage)	
	Input-1 avg price/cgt	Input-2 project_duration/cgt
Samsung HI	31%	24%

Table 6.21 shows the summary of input reduction and output improvement for large-sized shipyards. A Japanese yard, Imabari SB Marugame, only needs to increase its output by 1% in order to become a frontier. This is a good indication that the Japanese yard is very close of being efficient. Chinese yards, Yangzi Xinfu SB requires to increase its output by 81% to become efficient frontier. Korean based yards, Hyundai Vietnam and Daehan SB are very inefficient. They both requires to increase their outputs by 111% and a staggering number of 439% each for Hyundai Vietnam SB and Daehan SB respectively. The numbers explain that both Korean yards have a big room for improvement. Especially, Daehan SB, this yard does not use their resources effectively.

In terms of input reduction, Hyundai Vietnam SB and Imabari SB Marugame need to reduce their inputs. To increase the attractiveness of their shipyards, Hyundai Vietnam requires to decrease its price/CGT nad duration/CGT by 15%. Imabari SB Marugame needs to decrease its in inputs price/CGT and duration/CGT by 26%.

Table 6.21: Summary of output improvement and input reduction for large shipyards

Large shipyard		
Shipyard	Improvement Deliveries (percentage)	
Hyundai Vietnam SB	111%	
Yangzi Xinfu SB	81%	
Imabari SB Marugame	1%	
Daehan SB	439%	
Shipyard	Reduction (percentage)	
	Input-1 avg price/cgt	Input-2 project_duration/cgt
Hyundai Vietnam SB	15%	15%
Imabari SB Marugame	26%	26%

For medium-sized shipyards, the result can be seen in table 6.22. A Korean yard, Dae Sun needs to increase its output by 105% to be an efficient frontier. The number of Dae Sun's potential improvement is dwarfed by two Chinese yards, Shanhaiguan SB and Jiangsu New Hantong due to its significantly higher number of required improvement. Shanhaiguan SB and Jiangsu New Hantong need to increase its outputs by 559% and 510%. The number means that both Chinese yards are very far from being productive as opposed to its neighbor counterparts.

For inputs reduction, a Korean yard Dae Sun needs to decrease it price/CGT level by 17% and its duration/CGT level by 23%. A Chinese yard Shanhaiguan SB requires to decrease its price/CGT level by 19% and its duration/CGT level by 33%. Lastly, a Japanese yard only requires to decrease its price/CGT level its duration/CGT level by 2%.

Clearly in the medium-sized shipyards, Chinese yard, Shanhaiguan SB is at the bottom in competitiveness. Their productivity is very far from efficient and their price/CGT and duration/CGT level is not attractive enough compared to the frontier. This problem may arise from the trust of shipowners with Chinese yards.

Table 6.22: Summary of output improvement and input reduction for medium shipyards

Shipyard	Improvement Deliveries (percentage)	
Dae Sun	105%	
Shanhaiguan SB	559%	
Jiangsu New Hantong	510%	
Shipyard	Reduction (percentage)	
	Input-1 avg price/cgt	Input-2 project_duration/cgt
Dae Sun SB	17%	23%
Shanhaiguan SB	19%	33%
Sasebo HI	2%	2%

6.4. Conclusion and discussion of chapter 6

This chapter concludes the whole chapter 6. Research question 5 is hence answered 'what are the results of the (benchmarking) method (DEA model)'. The results of the DEA model are already presented in chapter 6.1-6.3. The DEA model provides the frontier by means of efficiency score and the values for improvement. The less competitive shipyards (inefficient shipyards) can reduce their inputs and/or increase their outputs to be more competitive.

The DEA model-1 focuses on increasing the delivery. In other words, improving the output for the inefficient shipyards. The target improvement shows a competitive potential of a shipyard in general, and shows a lack of efficiency in particular. DEA model-2 focuses on reducing the inputs of price/CGT level and delivery times. The improvement target shows the appropriate price/CGT level and delivery times in terms of product attractiveness.

7 Conclusion and Recommendation

7.1. Conclusion

This chapter marks the conclusion of this project. In this thesis report, the author studies the competitiveness in the shipbuilding industry. The first approach to study competitiveness is to understand the characteristics of the shipbuilding industry. In the second chapter, the author discusses the shipbuilding markets and the development of shipbuilding. Commonly shipbuilding is analyzed by its type, yard country, and production value. The top three countries in the shipbuilding industry are South Korea, Japan, and China. The three Asian countries dominate merchant type ships. European yards, on the other hand, focuses more on the niche market such as Cruise ship, passengers ship, and particular type ship such as naval ships and offshore ship. Although in volume, European yards' productions are very low compared to Asian yards, the production value in terms of USD, the European yards are relatively at the same position as one of the Asian countries. **Therefore, in this chapter the sub-research question one is answered 'How did the shipbuilding industry develop throughout history? And what aspects characterize between European and Asian yards'**

In chapter 3, the author presents a literature study about competitiveness in the shipbuilding industry. Three important points to seek when studying competitiveness are: 'Definition,' 'Indicator,' and Influencing 'factors.' The literature shows that competitiveness is a multi-dimensional concept that has several and overlapping definitions. One way to capture the whole idea of competitiveness is by formulating objectives. From literature, there are three objectives for shipyards to be competitive. The first one is 'the ability to attract new orders.' The second objective is 'the ability to execute shipbuilding orders,' which is related to 'productivity.' And the third one is 'the ability to stay in business.' The third objective requires information about the financial strength of shipyard and a broad time thus is neglected in this study.

Methods of measuring shipyard competitiveness are by using ratios (Key Performance Indicators), Benchmarking Analysis, Correlation Analysis, Time Series, and Regression Analysis. By using the Analytical Hierarchy Process, the author finds that benchmarking thrives for competitiveness characteristics that require 'Flexibility in data availability,' 'Ability to handle multiple inputs and outputs,' and 'Multi-dimension inclusiveness. **Therefore the second sub-research question 'How to measure competitiveness in shipbuilding industry? And what is the appropriate method to measure competitiveness of a set of shipyards?' is answered.**

The third sub-research question 'With the method found, how can the method able to evaluate the competitive performance of shipyards?' is answered in chapter four. Chapter four explains the basic concept of benchmarking and its well-known type (Data Envelopment Analysis and Stochastic Frontier Analysis). The author chose Data Envelopment Analysis as the most appropriate method for this study. This chapter discusses the usage of Data Envelopment Analysis to measure the 'performance' and 'productivity' as sub-parts of competitiveness. The step-by-step procedure of Data Envelopment Analysis (DEA) is discussed in this chapter. By using the systemic approach we are then able to evaluate the competitive performance of shipyards.

Chapter 5, the Data Envelopment Analysis model, is elaborated. The model is divided into two, based on the objectives found in chapter 3. The competitiveness indicators and influencing factors are discussed in this chapter. Another literature study was conducted to find the appropriate input and output for the Data Envelopment Analysis (DEA) model. This chapter discusses the variables for the model and the selection of shipyards to put into the model. Shipyard's capacity in the form of the dock area and number employees are the standard variables to measure shipyard's productivity. Shipyard's productivity focuses on the output or deliveries of shipyards. However, from chapter 3, we also have another objective "the ability to attract shipbuilding orders." Two variables are proposed, namely, price/CGT and duration/CGT. To choose the shipyard to be evaluated, the author divides the shipyard's type into three: mega-sized, large-sized, and medium-sized. After that, shipyards with relatively higher market share are taken into the model. To make a country to country comparison, the author tries to include shipyard for each country. **Therefore, this chapter 5 answers the fourth sub-research question 'What variables can be used in the method? and how to choose the shipyards to be evaluated?'.**

Chapter 6, the results of the Data Envelopment Analysis models, are presented. **In this chapter, the last sub-research question 'What are the results of the method, and how less competitive shipyard able to do to be more competitive?' is answered.** The results show that Chinese yards are generally very efficient when it comes to attracting new orders. Chinese yards have price attractiveness and quite fast delivery times. However, in terms of allocating its resources, Chinese yards are very inefficient. Japanese yards are very efficient in both models. Most of the Japanese yards are shipyards frontiers or quite close to the frontiers. Korean yards, on the other hand, are the winner for mega-sized yards, but not in the medium-sized shipyards. This result is in line with the analysis by Seok-ho Park about the efficiency of small to medium (SMS) Korean shipyards [52]. The results also validate the study from Jiang and Strandenes (2012, 2013 [63] [42]) on how Chinese yards are able to increase their market share. In their study, they estimate the shipbuilding cost and suggests that the cost is the sole factor to the increase of Chinese yards. From this thesis, it is proofed that Chinese yards have a low price/CGT and fast delivery times which in turn favoring Chinese yards to be more attractive.

This chapter then finishes the study of competitiveness in the shipbuilding industry. All five research questions have been answered accordingly. The appropriate method to study competitiveness in shipyards is benchmarking analysis which can encapsulates the multi-dimensional nature of shipbuilding industry. Data Envelopment Analysis (DEA)'s results show the efficiency between the output and input of a system with a quantifiable value and provide point of improvement by increasing output (for output-oriented) or decreasing input (for input-oriented). The insight that can be derived from the results can be found on the discussion of the two models in chapter 6. **Therefore the main research question 'How can one measure the competitiveness performance of a shipyard? and what insights can be derived from the measurement model' is answered.**

As the thesis progress, the author found more ideas to improve the study in shipbuilding competitiveness.

7.2. Improvement recommendation

The author believes that from this thesis, more research can be done to improve further or validate the results. The author divide the points of improvement into two categories, one is improvement from technical standpoint, some of the ideas that can be used for further research are:

- Quantifying non-discretionary variables such as government policy, subsidy, technological capabilities and research and development for the model
- Increase the Decision-Making Units
- Incorporate profit and turnover values into the DEA model

The second cateogry is improvement from academic standpoint, some of the ideas that can be used for further research in academia are:

- The study of competitiveness for non-merchant producing shipyards
- Considering greenfield shipyards competitiveness
- The usage of Stochastic Frontier Analysis and compare it with the Data Envelopment Analysis

A

Appendix Chapter 2

A.1. Review in CGT

Compensated Gross Tonnage

One ship is different than another. As we know now that shipbuilding industry is divided into many sectors in which one ship could have higher added value than the other. So how do we measure ships equally? Container ship is usually measured in TEUs, Bulk carrier is measured by Deadweight Tonnage (DWT), but what about other ship? Is the dimension of the ships can representing the value of the ship?

In the shipbuilding industry we know a common unit called the Compensated Gross Tonnage (CGT). This unit is a measurement of dimension with adjustment with the ship's type. CGT is taking into account the differences in vessel type and work effort [56] A more complex ship is awarded with higher CGT to include the complexity and man hours needed for a unit of volume relative to the other ship type which has less complex and man hours needed. The CGT concept was first coined by shipbuilder associations and later adopted by OECD Council Working Party on Shipbuilding. The initial concept was based on DWT and use coefficient as a basis. After 2007, the Community of European Shipyards Associations (CESA) and Korean Shipbuilders Association (KSA) who representing around 75% of world shipbuilding output, created a new system of CGT and made it a formula-based system.

The new CGT system defines CGT as a unit of measurement intended to provide a common yardstick to reflect the relative output of merchant shipbuilding activity in large aggregates such as ”World”, ”Region”, and ”Groups of many shipyards” [50]. The formula and table of different ship is better explain the system. The value of A and B is available in Figure A.1.

The formula of CGT is:

$$CGT = A * GT^{B} \tag{A.1}$$

Series Effect

CGT was based on the yard data collected from various shipyard. Because of this, the learning curve or series effect has to be taken into account by evaluating on man-hours used for specific designs built in series. In the definition of the CGT factor it has been assumed that the factor reflects the workload for the first ship in a series, without any adjustment for subsequent increases in efficiency as workers become more familiar with their tasks.[50] The series effect is better represented on the figure A.2.

Ship type	A	B
Oil tankers (double hull)	48	0.57
Chemical tankers	84	0.55
Bulk carriers	29	0.61
Combined carriers	33	0.62
General cargo ships	27	0.64
Reefers	27	0.68
Full container	19	0.68
Ro ro vessels	32	0.63
Car carriers	15	0.70
LPG carriers	62	0.57
LNG carriers	32	0.68
Ferries	20	0.71
Passenger ships	49	0.67
Fishing vessels	24	0.71
NCCV	46	0.62

Figure A.1: CGT Factor

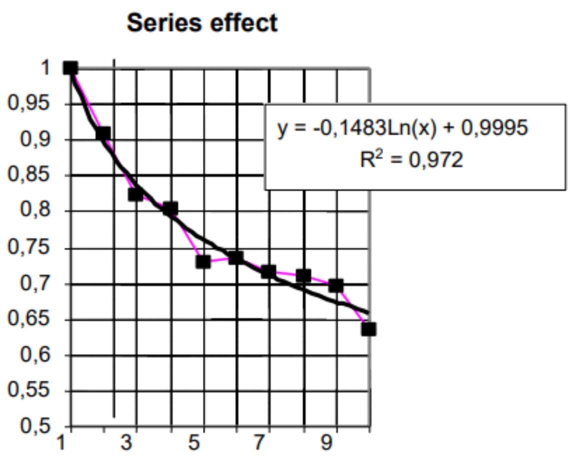

Figure A.2: Reduction of workload (series effect) from the first to the 10th ship

B

Appendix Chapter 3

In this Appendix the pairwise comparison of selection criteria is given. To simplify, each criterion is assigned to code- A, B, and C. Table B.1 shows the criterion and its code.

Table B.1: Criteria Code

Code	Criteria
A	Flexibility in data availability
B	Ability to handle multiple input and output
C	Multidimension inclusivness

In chapter 3 the author has discussed three selection criteria for measuring competitiveness. From table B.2 we can see that the first criterion ”flexibility in data availability” is weakly more important than criterion ”ability to handle multiple input and output” and criterion ”multi-dimension inclusiveness”. This is because data is the most crucial aspect when conducting a numerical model. In table B.2, the matrix is reciprocal, meaning that if A is 3x of B then B is 1/3 of A.

Table B.2: Comparison matrix of selection criteria

	A	B	C
A	1	3	2
B	0.333333	1	0.6
C	0.5	1.666667	1

Table B.3 shows the eigenvalues, eigenvector, consistency index, and consistency ratio of the matrix in table B.2. Matlab is used to find the eigenvalues and eigenvector. The ’normalized’ column show the normalized value of the eigenvector. Consistency index and consistency ratio are both calculated as have explained in chapter 3.8.

For the first criteria ’flexibility in data availability’, the methods under study is again analyzed. KPI is weakly less preferable than linear regression. Benchmarking is weakly more important than KPI and strongly more preferable than linear regression. Therefore we can see the comparison matrix in table B.4.

In terms of second criterion ’the ability to handle multiple input and output’, bencmarking is strongly better than KPI and weakly better than linear regression. Linear regression is weakly better than KPI in this matter. We can see the full matrix in table B.5.

In terms of ’multidimension inclusiveness’ or criterion 3. KPI is slightly better than linear regression. Benchmarking is weakly better than KPI and strongly better than linear regression (table B.6).

Table B.3: Table of calculating eigenvalues, eigenvector, consistency index and consistency ratio

eigenvalues	eigenvector	normalized	consistency index	consistency ratio
3.0008	0.8539	0.543642962	0.0004	0.000689655
	0.2747	0.174890176		
	0.4421	0.281466862		

Table B.4: Criterion-1 Method Selection

Flexibility in data availabilty			
	KPI	Benchmarking	Linear regression
KPI	1.00	0.33	3.00
Benchmarking	3.00	1.00	5.00
Linear regression	0.33	0.20	1.00

Table B.5: Criterion-2 Method Selection

Ability to handle multiple input and output			
	KPI	Benchmarking	Linear regression
KPI	1.00	0.20	0.25
Benchmarking	5.00	1.00	3.00
Linear regression	4.00	0.33	1.00

Table B.6: Criterion-3 Method Selection

Multidimension inclusivness			
	KPI	Benchmarking	Linear regression
KPI	1.00	0.33	2.00
Benchmarking	3.00	1.00	5.00
Linear regression	0.50	0.20	1.00

C

Appendix Chapter 4

C.1. Graphical illustration of multiple inputs and outputs for Data Envelopment Analysis (DEA)

The illustration above takes into account two inputs and two outputs separately. In the DEA model, there may be multiple inputs and outputs. In the case of dozens of inputs and outputs, it will be hard to visualize. However, for two inputs - one output, or one input - two outputs, it is still possible to understand using graphs. Now let's consider two inputs and one output model. The example is taken from Charnes et al. (2007). Take a look at table C.1.

The example shows the sale, employee, and floor area of stores. Here, the stores are the DMUs. The employee and floor area are inputs, and the sale is output. For simplicity, let's consider a unit invariant of output as 1.

Store		A	B	C	D	E	F	G	H	I
Employee	x1	4	7	8	4	2	5	6	5.5	6
Floor Area	x2	3	3	1	2	4	2	4	2.5	2.5
Sale	y	1	1	1	1	1	1	1	1	1

Table C.1: Two Inputs and One Output Case (Cooper, 2007)

Figure C.1 plots the two inputs and one output model. The x-axis shows the x1/y, and the y-axis shows the x2/y. The shaded area is called the **'Production Possibility Set'**. We can see that store C is the best concerning floor area. Store C has a floor area of 1. Store E is the best concerning employee with a value of 2. Lastly, store D has the best combination.

Now, let's consider store A. Store A is inefficient, and its efficiency is only 85.71%. To find the efficiency of store A, we divide the distance of origin to point P by the distance of origin to store A, which results in 0.8571. This measurement is the same as the Farrel efficiency measurement. However, in this example, the ratio between the first and second inputs and the output are represented into the x- and y- axes.

To become efficient, A must multiply both inputs by 85.71% (input orientation). D and E are the peers/reference set of A. In other words, A must consider D and E as examples to become technically efficient. C and D are the peers/reference set of F. Therefore, the DEA model not only shows the efficiency scores but also gives the peer/reference unit in which the inefficient units benchmark to.

Now consider another example from table C.2. There are two inputs and two outputs. When the inputs and outputs increase, the complexity is also growing. To solve this complexity, we need to assign weights to inputs and outputs, i.e., weight for doctors: weight for nurse = 5:1 or weight for outpatient:

Figure C.1: Two inputs one output model (Hui, 2013)

weight for inpatient = 1:3. The problem is these fixed weights are arbitrary.

Hospital	A	B	C	D	E
Doctors	20	19	25	27	22
Nurses	151	131	160	168	158
Outpatients	100	150	160	180	94
Inpatients	90	50	55	72	66

Table C.2: Hospital case

DEA, by contrast, uses variable weights. In particular, the weights are derived directly from the data with the result that the numerous a priori assumptions and computations involved in fixed weight choices are avoided (Charnes et al., 2007). In the DEA model, each hospital chooses weights individually such that their productivity is maximized, and between 0 and 1, and all other DMU productivities are also between 0 and 1. In the next subchapter, the variable weights will be discussed in a more formal mathematical approach.

C.2. Mathematical Approach for DEA

Now take a look at Table C.3. We will use the multiplier form to conduct the DEA model. Figure C.3 shows the graphical representation of the table C.3. The example given will be for DMU B. We want to maximize the $\mu^T\ y_i\ \rightarrow Max\ \mu.1$ and the constraints is given in Figure C.2.

	DMU	A	B	C	D	E	F
Input	x1	4	7	8	4	2	10
	x2	3	3	1	2	4	1
Output	y	1	1	1	1		1

Table C.3: Example Two Inputs and One Output

$$
\begin{array}{ll}
7v_1 + 3v_2 = 1 & \mu \le 4v_1 + 2v_2\ (D) \\
\mu \le 4v_1 + 3v_2\ (A) & \mu \le 2v_1 + 4v_2\ (E) \\
\mu \le 7v_1 + 3v_2\ (B) & \mu \le 10v_1 + v_2\ (F) \\
\mu \le 8v_1 + v_2\ (C) & \mu, v \ge 0
\end{array}
$$

Figure C.2: Constraints example

The model is conducted for all DMUs. The optimal solution for B: is $v_1 = 0.0526, v_2 = 0.2105; \mu =$

$0.6316 = \theta^* = efficiency$. The reference set of B is C and D (as shown in Figure C.3). Note that v2/v1 = 4 so input 2 is four times as important to B as input 1. Another example if we consider DMU F. The optimal solution for F is $v_1 = 0, v_2 = 1; \mu = 1 = \theta^* = efficiency$. DMU F is a frontier.

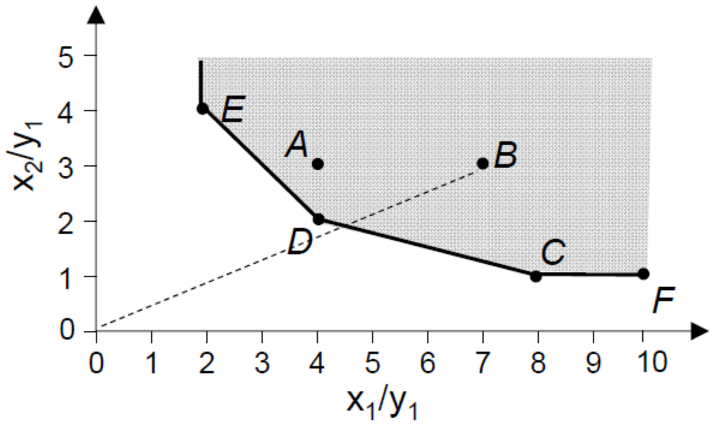

Figure C.3: Production Possibility Set (Hui, 2013)

In linear programming, we know the concept of duality. The dual of given linear programming (LP) is another LP that is derived from the original (the primal) LP. In dual form, each variable in the primal LP becomes a constraint in the dual LP. Each constraint in the primal LP becomes a variable in the dual LP. The objective direction is inversed - maximum in the primal becomes minimum in the dual and vice-versa.

In the Data Envelopment Analysis (DEA) model, there is two orientation which is the input-orientation and output-orientation. As discussed in chapter 4.2, the difference between the two is if one wants to minimize the resource (input) or to maximize the product (output). In the mathematical expression, we need to change the form from maximization to minimization. In Data Envelopment Analysis (DEA) this dual form is also called the envelopment form.

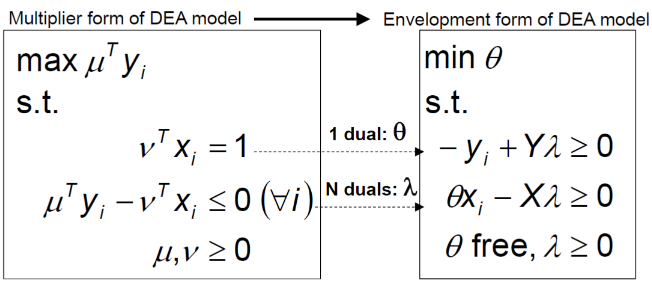

Figure C.4: Multiplier form of DEA to Envelopment form of DEA

To interpret the dual form of the DEA model, take a look at Figure C.5. θ = efficiency score for DMU j $(\theta \leq 0)$. The model radially contracts input vector x_i while remaining in the feasible input area. The radial contraction of input vector x_i produces a projected point $(X\lambda, Y\lambda)$ on the efficient frontier.

C.3. Convexity

In benchmarking, convexity serves the role of enlarging the technology, especially when there are only a few observations available. In turn, convexity also creates technologies that are better able to distinguish between average performance and best practices. In this subsection, the weight λ is important, as it will be the 'virtual weight' that the firms can refer to. This weight can determine the scale of improvement for non-frontier firms to its frontier peers.

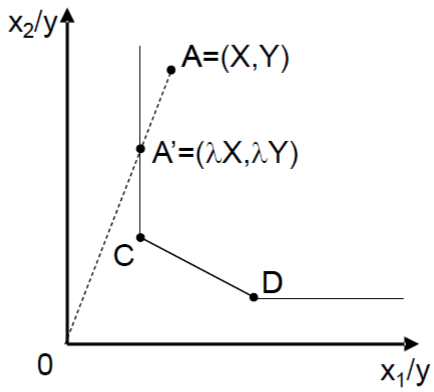

Figure C.5: Radial Distance and λ illustration (Cooper, 2007 [72])

For example, if we have two feasible production plans, it is often assumed that all weighted averages of the two are also feasible. In geometric terms, this would mean that for any two points in the technology set T, the plans on the line between them are also in T. In mathematics, a set T with this property is referred to as convex. A common assumption in benchmarking is can therefore be summarized as.

T is convex.

Formally, the set T is convex if for any two points $(x^0, y^0) \in T, (x^1, y^1) \in T$, and any weight $0 \leq \lambda \leq 1$, the weighted sum $(1-\lambda)(x^0, y^0) + \lambda(x^1, y^1)$ is also in T; i.e:

$$(x^0, y^0) \in T, (x^1, y^1) \in T, 0 \leq \lambda \leq 1 \Rightarrow (1-\lambda)(x^0, y^0) + \lambda(x^1, y^1) \in T$$

The weighted sum of the two plans

$$(x^\lambda, y^\lambda) = (1-\lambda)(x^0, y^0) + \lambda(x^1, y^1) \; for \; (0 \leq \lambda \leq 1)$$

is called a convex combination of (x^0, y^0) and (x^1, y^1) with weight λ for $\lambda = \frac{1}{2}$ we get $(x^{\frac{1}{2}}, y^{\frac{1}{2}} = (1-\frac{1}{2})(x^0, y^0) + \frac{1}{2}(x^1, y^1) = \frac{1}{2}(x^0 + x^1 + y^1)$. In Figure C.6, the illustration position of $x^{\frac{1}{4}}, y^{\frac{1}{4}}$ and $x^{\frac{1}{2}}, y^{\frac{1}{2}}$ are shown.

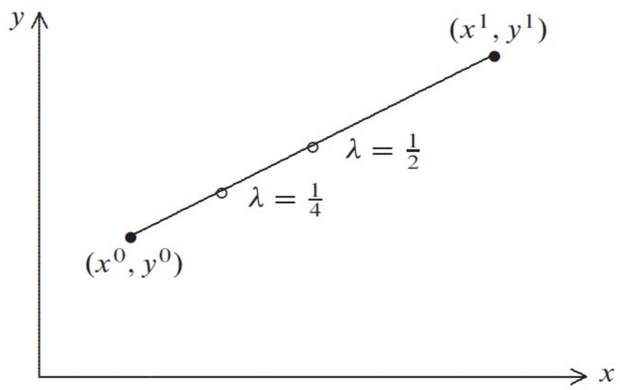

Figure C.6: Convex Combination [11]

C.4. Peer units

The right hand sides in the DEA program defines the 'reference unit'

$$(\sum_{k=1}^{K} \lambda^k \, x_i^k, \; \sum_{k=1}^{K} \lambda^k \, x_i^y) \tag{C.1}$$

against which we compare firm o. We see that the DEA program identifies a specific reference unit, most often a weighted average of the existing units and that the reference unit may vary with the evaluated unit. The units with positive weights are typically called 'peer units',

Peer Units = $(k \in (1, \ldots, K) \mid \lambda^k > 0)$

and we can therefore say that DEA identifies explicit real peer-units for every evaluated unit.

Graphically, the reference unit is the unit on the technological frontier that firm o is projected onto, and the peer units are the actual frontier units that span the part of the frontier where the reference unit is located. The reference unit and the associated peer units are usually interpreted as the ones how firm o can improve (Bogetoft and Otto, 2011). In the modeling using Rstudio (which will be explained in a later chapter), the library 'benchmarking' gives the peer reference for inefficient firms and provide the quantity of improvement.

D

Appendix Chapter 5

In this appendix the full new-contracts and deliveries of all DMUs (shipyard) is given. Figure D.1-D.6 shows all the data collectd by the author from Clarkons World's Fleet Register (WFR).

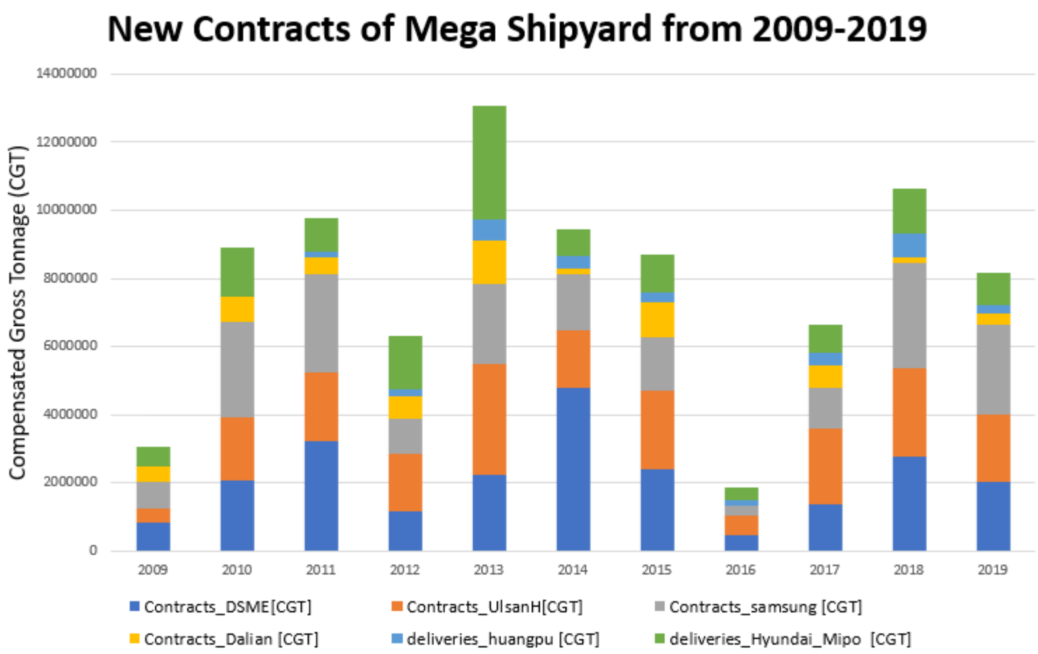

Figure D.1: New contracts of mega-sized shipyards

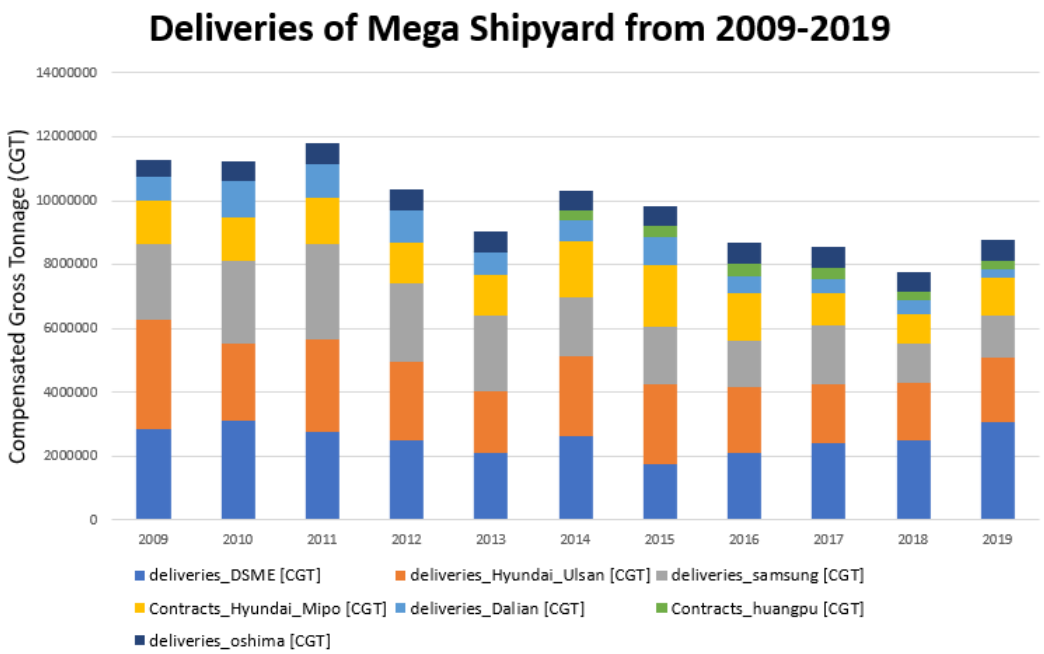

Figure D.2: Deliveries of mega-sized shipyards

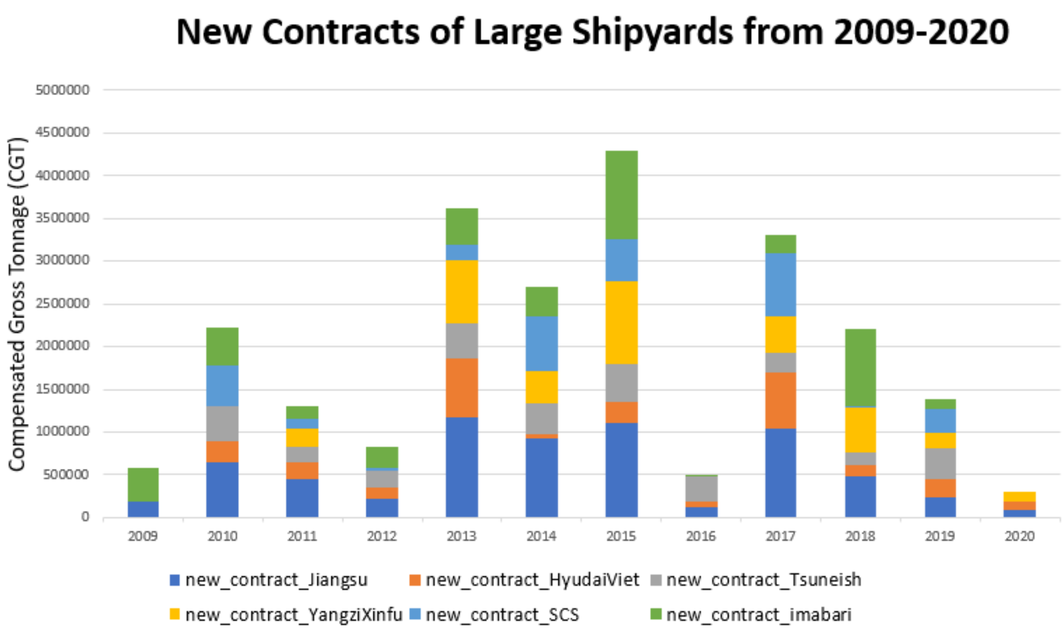

Figure D.3: New contracts of large-sized shipyards

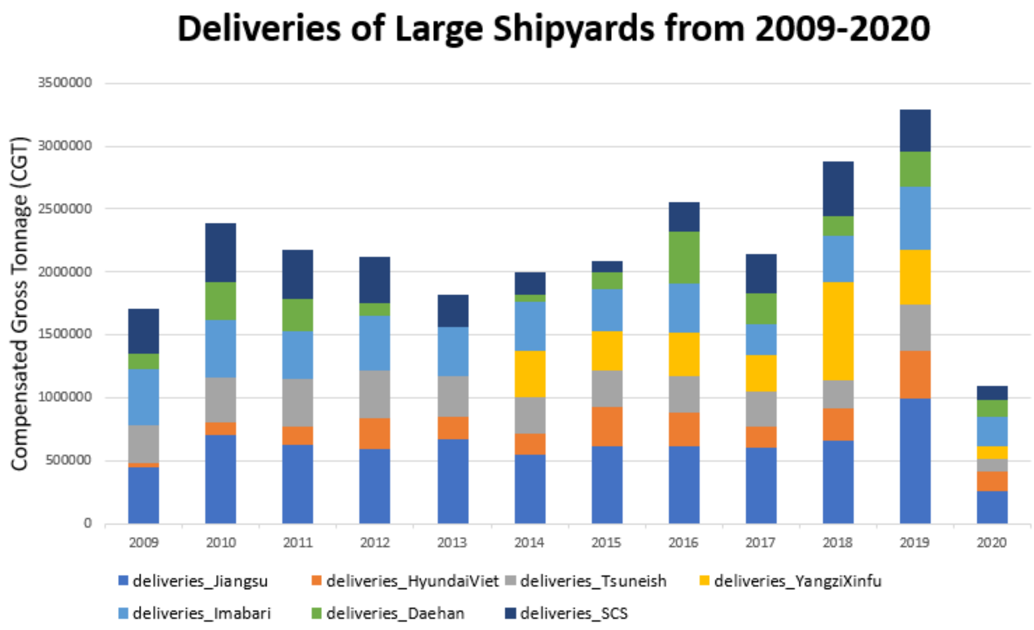

Figure D.4: Deliveries of large-sized shipyards

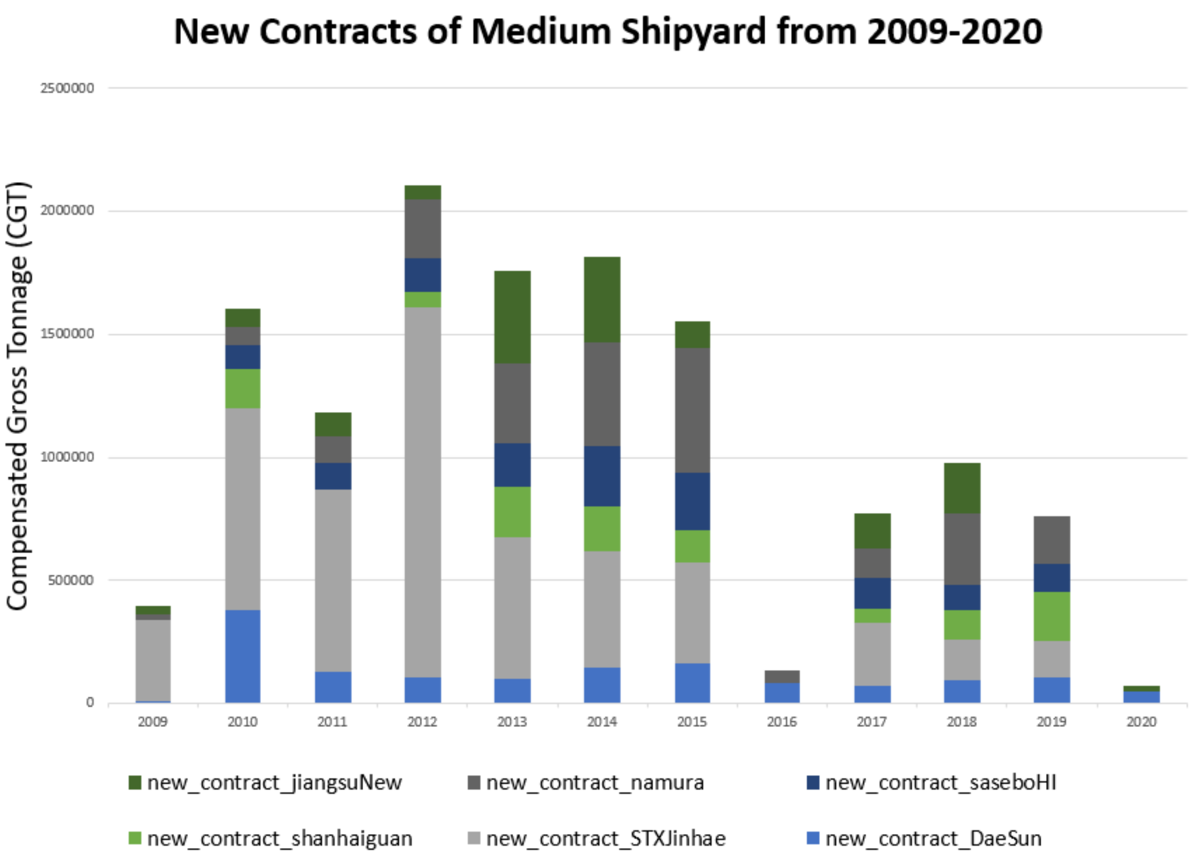

Figure D.5: New contracts of medium-sized shipyards

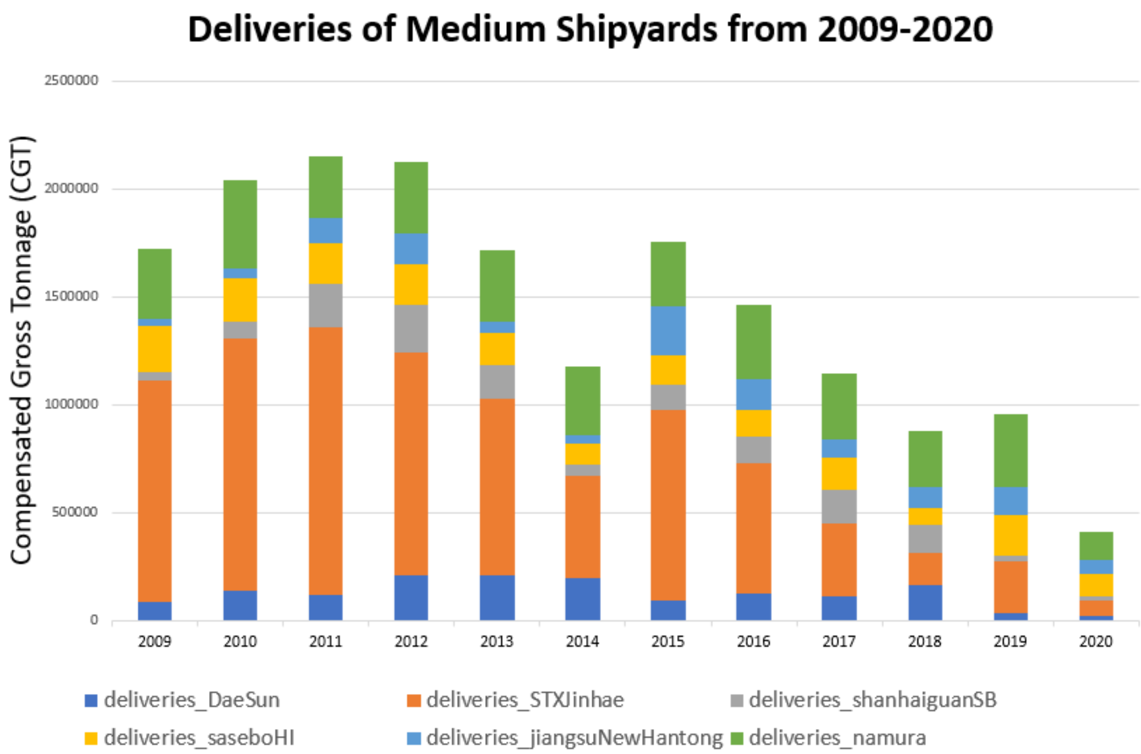

Figure D.6: Deliveries of medium-sized shipyards

E

Appendix Chapter 6

The example is based on Bogetoft and Otto's case and modified by the author.

In this section the author wants to illustrate the application of Data Envelopment Analysis in a simplified dataset. Although this concept has been discussed thoroughly in chapter 4, the author believes that an example will help the reader to understand better.

Now let us consider five shipyards. Shipyards A, B, C, D, and E, each has one input and one output. We want to conduct a DEA model with Variable Return to Scale (VRS) hence DEA-BCC. The orientation is input-oriented. The data is given in Table E.1.

Table E.1: Shipyard DEA Example

shipyard	input-x	output-y
A	20	20
B	40	30
C	40	50
D	60	40
E	70	60
Point P	25.4	28.4

We will then use equation 4.13 because the DEA is input-oriented. We want to minimize E. As discussed in chapter 4, Bogetoft and Otto use notation E instead of θ because they used Farrell Efficiency. Nonetheless, the envelopment form of DEA with θ is the same as equation 4.13. Using the data from the table, we can plot the graph between input and output as shown in Figure E.1.

Generally, we must formulate the mathematical program and then find a solver actually to do the calculations. As an example, the author tries to find the input efficiency of shipyard B using the VRS technology. Thus we need to solve the following program:

$$\begin{gathered} \min_{E,\ \lambda^1, \dots \lambda^K} E \\ s.t.\ E x_1^B \geq \lambda^A x_1^A + \lambda^B x_1^B + \lambda^C x_1^C + \lambda^D x_1^D + \lambda^E x_1^E \\ y_1^B \leq \lambda^A y_1^A + \lambda^B y_1^B + \lambda^C y_1^C + \lambda^D y_1^D + \lambda^E y_1^E \\ \sum_{k=1}^{K} \lambda^k = 1 \end{gathered} \tag{E.1}$$

We then plug in the input $(x1)$ and output $(y1)$ for every shipyards. Thus we will have:

$$s.t.\ E\ 40 \geq \lambda^A\ 20\ +\ \lambda^B\ 40\ +\lambda^C\ 40\ +\lambda^D\ 60\ +\lambda^E\ 70$$
$$30 \leq \lambda^A 20 + \lambda^B 30 + \lambda^C 50 + \lambda^D 40 + \lambda^E 60 \tag{E.2}$$
$$\lambda^A\ +\ \lambda^B\ +\ \lambda^C\ +\ \lambda^D\ +\ \lambda^E\ =\ 1$$

Regularly to find the efficiency of all shipyards, we need to conduct equations 6.1 and 6.2 for all shipyards ($E\ \forall\ K$). However, such an approach would, of course, become tedious if not impossible when one had to solve several large problems. With just a few more observations and more inputs and outputs, calculations by hand become overwhelming; thus, we must rely on computers. It is, therefore, more convenient to use a particular type of software that can handle the Data Envelopment Analysis or Linear Programming problem. Microsoft Excel solver, Python, and R are all able to conduct this type of analysis. Using RStudio and 'benchmarking library' then the author conducted the DEA. The results are shown in Table E.2.

Table E.2: Efficiency result

Shipyard	Efficiency (theta)
A	1
B	0.667
C	1
D	0.556
E	1
Point P	(1)

As we can see, the shipyard with efficiency one is shipyard A, C, and E. Therefore, they are the 'frontier' in this example. It is also shown in Figure E.1 that shipyard A, C, and E, create a frontier envelope with the Variable Return to Scale (VRS). Shipyard B has an efficiency of 0.667, and shipyard D has an efficiency of 0.556. Both shipyard B and D are within the 'production possibility set'.

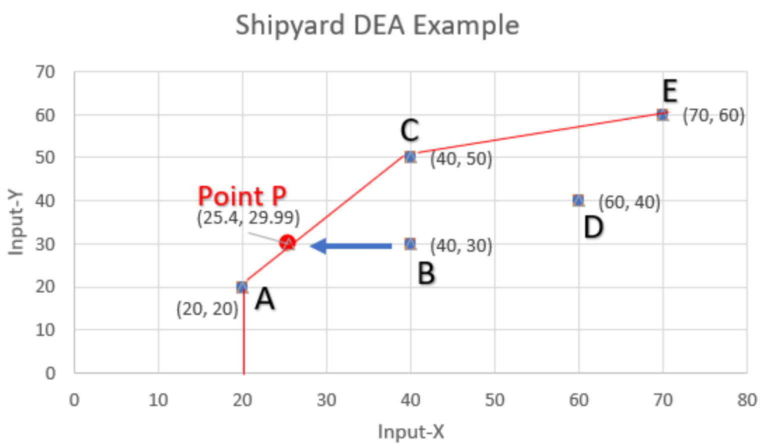

Figure E.1: Shipyard DEA Example (Author own calculation)

E.1. The use of Variable Weight (Lambda)

Variable weight or lambda (λ) value is one of the strength of benchmarking. The explanation of lambda has been discussed in chapter 4. Now the author will an illustration to use the lambda. For example we want to know how shipyard B can improve itself. In other words, we want to know how much the reduction of input can shipyard B conduct. A reduction of input, in the graphical term, means that point B has to shift towards the envelope. RStudio gives the peers and variable weight λ of each DMUs (shipyards) in a matrix (table E.3).

Table E.3 is a 6x6 matrix. Each shipyard is paired with the other shipyards. The values in the matrix are λ values. For example, lambda value for shipyard A is one because shipyard A is a frontier. The same can be applied with shipyard C, and E. The λ of B is 0.667 of A and 0.333 of C. Mathematically, we need to multiply 0.667 with the input of A and multiply 0.333 with the input of C and sum it to get shipyard B to the frontier.

Let us walk through the equation. We now consider shipyard B which has $\lambda^A = 0.667$, and $\lambda^C = 0.333$, and $\lambda^B = \lambda^D = \lambda^E = 0$. Using equation 6.2 we get:

$$\begin{gathered} 40 \geq 0.667 * 20 + 0 + 0.333 * 40 + 0 + 0 = 25.4 \qquad (x) \\ 30 \leq 0.667 * 20 + 0 + 0.333 * 50 + 0 + 0 = 29.99 \approx 30 \ (y) \\ \lambda^A + \lambda^C = 0.667 + 0.333 = 1 \end{gathered} \tag{E.3}$$

The (in)equalities are fulfilled and we get value of $(x, y) = (25.4, 30)$. The red dot in Figure E.1 indicates these coordinates. It is, therefore, if we decrease the input of shipyard B from 40 to 25.4 and keep the output as 30, we then shift the shipyard B to the envelope (indicated by the blue arrow). Therefore shipyard B is improved and become efficient.

For shipyard D, we can make the same approach as shipyard B. The result of the DEA model in RStudio gives the matrix of all λ.

Table E.3: Peers and λ values matrix

	A	B	C	D	E
A	1	0	0	0	0
B	0.667	0	0.333	0	0
C	0	0	1	0	0
D	0.333	0	0.667	0	0
E	0	0	0	0	1

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