NTNU – Trondheim
Norwegian University of
Science and Technology

Shipbuilding Cost Estimation

Parametric Approach

Haakon Shetelig

Marine Technology
Submission date: June 2013
Supervisor: Arnulf Hagen, IMT

Norwegian University of Science and Technology
Department of Marine Technology

“Suppose one of you wants to build a tower. Won’t you first sit down and estimate the cost to see if you have enough money to complete it?” – Luke 14:28

Preface

This report is the result of the M.Sc. Thesis – Marine Systems Design at The Department of Marine Technology at The Norwegian University of Science and Technology. The goal of this master thesis has been to develop a method to evaluate and investigate the behavior of cost drivers in offshore ship building. Hopefully, the work presented in this thesis will contribute to bring the Norwegian ship building industry a step further in the cost estimation landscape.

The initial scope consisted of gathering cost data from offshore support vessels and to develop a database that were to be used as a basis for the development of a cost estimation framework. Cost data is regarded as confidential information and it is therefore not easy to get access to this data. After working with the subject for a while, it turned out that it was not necessary with a cost database to develop the method presented in this thesis. Luckily, what seemed to be a situation with a lack of cost data prevented this thesis to be just another number crunching exercise.

I would like to give a special thanks to my supervisor Adjunct Professor Arnulf Hagen at the Department of Marine Technology for support, guidance and motivation. Special thanks are also given to Deputy Managing Director in Ulstein International AS Dr. Per Olaf Brett, who showed a great hospitality and openness during my weeklong stay at The Ulstein Group in Ulsteinvik. The visit was an eye opening experience with interesting and valuable discussions with personnel working in companies under The Ulstein Group umbrella.

Last, but not the least, I would like to thank my girlfriend and dentist Hanne, the boys at my office Champagnesvingen and my glamour band Peik Pedros for support and patience throughout my last semester at the University.

Trondheim, 10th June 2013

Haakon Shetelig

Haakon Shetelig

Abstract

A continuously increasing global competition in the ship building industry leads to decreasing margins and an increased cost pressure for Norwegian shipbuilders. The Norwegian ship designers and shipbuilders are known throughout the world for delivering complex vessel with high quality, on time. Shipowners have so far been willing to pay the price for Norwegian offshore support vessels. However, high quality products will at some point be outcompeted by less expensive solutions.

An effective cost estimation framework can contribute to a competitive advantage. This thesis presents a methodology for developing a cost estimation framework to identify, investigate and evaluate the importance and behavior of cost drivers in offshore shipbuilding. The outcome of the method is cost estimating relationships (CER) that express the relative consequences on the total cost due to relative changes of high level performance requirements. These CERs is called relative change-CERs. A relative change-CER could for example express the relative consequence on the total cost due to a 5 % increase of the installed engine power.

The method can be characterized as a parametric top-down cost estimation approach. By using historical cost data and specifications for a population of vessels of a certain ship type, it is possible to find relationships between important performance parameters and costs. With regression techniques, CERs expressing unit costs per cost driving parameter for different technological groups of the vessel can be found. By using these unit cost-CERs on already existing vessels and then theoretically change the ship's performance parameters, one will see the theoretical consequence on the total cost. By changing a chosen cost driving parameter with different intervals for several vessels, the average relative consequences on the total cost is found for that ship type.

The relative change-CERs can be utilized differently by actors in the shipbuilding industry. One area of application is in the negotiation process with a potential customer where features like ship specifications and change orders are discussed. The relative change-CERs contribute to leverage for the yard personnel's arguments, and reduce the response time for rebids and tender requests.

Another area of application for the relative change-CERs is for gaining insight of the behavior of important cost drivers in offshore ship building. With a set of unit cost curves and relative change-CERs, it is possible to identify how the different parts of the ship are affected by a relative change in certain ship parameters. This information can be used to rank the different ship parameters according to their importance and relative influence on the total ship building cost.

Sammendrag

En stadig økende global konkurranse i dagens skipsbyggingsindustri fører til mindre profittmarginer og økt kostnadspress for norske skipsbyggere. Norske skipsdesignere og skipsbyggere er verdenskjente for å levere komplekse fartøyer av høy kvalitet. Skipsredere over hele verden har så langt vært villige til å betale den prisen det koster for å få merkelappen «Made in Norway» på sine offshorefartøy. Det er allikevel et faktum at på et eller annet tidspunkt blir dyre høykvalitetsprodukter utkonkurrert av billigere løsninger.

Et effektivt rammeverk for kostnadsestimering kan bidra til å fortsatt opprettholde et konkurransefortrinn i forhold til resten av verden. Denne masteroppgaven presenterer en metode for å utvikle et rammeverk for å identifisere, undersøke og evaluere hvordan viktige kostnadsdrivere i skipsbygging oppfører seg. Hovedproduktet av metoden beskrevet i denne oppgaven er såkalte «cost estimating relationships» (CER). Dette er matematiske uttrykk hvor de relative endringene av den totale byggekostnaden er avhengige variable. De uavhengige variablene er relative endringer av sentrale ytelsesparametere. En typisk CER kunne for eksempel uttrykt den relative endringen av total byggekostnad på grunn av en 5 % endring av motorytelse.

Metoden kan karakteriseres som en parametrisk ovenfra-og-ned-tilnærming. Ved å benytte kjente kostnadstall og spesifikasjoner for et visst antall skip innenfor en viss skipstype, er det mulig å finne relasjoner mellom viktige ytelsesparametere og kostnader. Ved hjelp av regresjon er det mulig å finne CER'er som uttrykker enhetskostnader per ytelsesparametere for ulike teknologiske av skipet. Ved å bruke disse CER'ene på allerede eksisterende skip og teoretisk endre skipenes parametere, vil man kunne se den teoretiske relative konsekvensen en slik endring har på den totale byggekostnaden. Ved å endre en valgt kostnadsdrivende parameter med ulike intervaller for flere skip er det mulig å finne den gjennomsnittlige teoretiske endringen av totalkostnaden for en skipstype.

Kostnadsrelasjonene og metoden beskrevet i denne masteroppgaven har ulike bruksområder for ulike aktører innenfor skipsbyggerindustrien. Ett av bruksområdene er i forhandlingsprosesser mellom verft og potensiell kunde der et skips spesifikasjoner eller diskuteres. Det nevnte rammeverk kan bidra til både mer tyngde bak verftsrepresentantenes argumenter, men også til å redusere responstiden i anbudssituasjoner.

Et annet bruksområde for relative endrings-CER'er er for å få økt innsikt i virkemåten til viktige kostnadsdrivere i offshore skipsbygging. Ved hjelp av metoden er det mulig å identifisere hvilke kostnadsdrivere som har mest innflytelse og på de ulike delene av skipet og dermed rangere dem etter betydning og viktighet.

Table of Contents

Table of Figures

List of Tables

Nomenclature

AHTS	Anchor handling tug supply
Bmld	Breadth moulded
CAD	Computer aided design
CER	Cost estimating relationship
D	Depth moulded
DNV	Det Norske Veritas
DWT	Metric deadweight tons
EBIT	Earnings before interest and taxes
ESWBS	Expanded Ship Work Breakdown Structure
Fi-Fi	Fire Fighter
HL	Heavy Liquid
ISPA	International Society of Parametric Analysts
kn	Knot
kW	Kilowatt
LOA	Length overall
m	Meter
m^2	Square meter
MS	Microsoft
M/V	Motor vessel
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
OILREC	Oil spill recovery in emergency situations
PSV	Platform supply vessel
R^2	Coefficient of determination
ROV	Remotely operated vehicle
SFI	The Ship Research Institute
t	Metric ton

1 Introduction

A continuously increasing global competition in the ship building industry leads to decreasing margins and a cost pressure in the industry. The Norwegian ship designers and shipbuilders are active players in this globalized game. Traditionally, Norwegian shipyards have been known for delivering high quality products on time. Shipowners all over the world have so far been willing to pay the price for the well reputable Norwegian built offshore support vessels. However, high quality products will at some point be outcompeted by less expensive solutions.

For the Norwegian shipbuilders to keep up and hopefully take a greater market position, it is important to be competitive on cost. Ship building cost estimation as a part of ship building cost management is one of the fields where it is possible to gain a competitive advantage. With robust and reliable frameworks and methods to cope with the increasing complexity and the high demands regarding quick and accurate customer responses, actors in the Norwegian shipbuilding industry will still have a competitive advantage.

Through focusing on relative changes of the total ship building cost instead of the total cost as an absolute number, this thesis will contribute to a broader understanding of the importance of cost drivers for offshore support vessels. A considerable amount of the knowledge and experience in the Norwegian ship building industry is only present the minds of experienced personnel and old timers in the business. A formalizing and systemizing of this type of knowledge will help inexperienced personnel to faster gain the insight required to deal with the daily challenges in shipbuilding costing and pricing.

The work with this thesis did not start out with a specified scientific hypothesis to be tested, but it is possible to express the essence of the work with a working hypothesis[1]:

"Parameter based methods can increase the precision and accuracy in estimates of relative cost effects through the use of historical data, and improve the documentation for the basis of assumptions and rules of thumb for decision makers."

Chapter 2 addresses the general problem and explains more thoroughly why it is beneficial to focus on the relative consequences on the total cost rather than the total building cost as an absolute number.

Chapter 3 is a literature study that takes the reader through different approaches and methods in shipbuilding cost estimation, and leads up to the choice of framework used as a basis for the method developed in this thesis.

Chapter 4 is a detailed description of the developed method which investigates, identifies and evaluates the relative cost effects performance changes have on the total shipbuilding cost. This includes choice of cost driving parameters, subdivision of the vessel, regression analysis using

---

[1] It is a difference between a scientific hypothesis to be tested and a working hypothesis. Working hypothesis: "a hypothesis adopted as a guide to experiment or investigation or as a basis of action" (Merriam Webster 2013)

historical cost data and development of cost estimating relationships expressing the relative consequences for the total cost.

Chapter 5 includes a case study of the PSV M/V Bourbon Monsoon and a demonstration of regression techniques to be used in the method.

Chapter 6 is the discussion chapter where issues regarding the method and case study will be commented on and discussed. The outline of this chapter follows the same pattern as chapter 4 and 5, and addresses topics relevant for discussion in the same order.

Chapter 7 summarizes the discussion in the preceding chapter by drawing some conclusions, recommends further work and gives an indication of what the next step when working with this topic should be.

2 The General Problem

2.1 Relative Change Instead of Absolute Number

Common for all the methods and approaches of shipbuilding cost estimation is that the goal is to estimate the building costs expressed as a currency value. Regarding the actual method and the detail level of input information, there is still incorporated some degree of uncertainty in the final estimate. The requirement for cost estimation accuracy is different for different stages of the design. As the design matures, more cost information becomes available and the uncertainty of the estimate decreases. For the personnel dealing with pricing and bidding it is desirable with accurate cost estimates when they are facing the *Shipbuilder's dilemma* described in chapter 3.1.

Bidding Phase	Requirement for accuracy
Price indication (Brief spec)	10 – 15 %
Budget Price (Outline spec)	5- 10 %
Contract price	0.5 %

Table 1 - Requirement for accuracy of estimates, an example

Table 1 shows an example of the level of accuracy or robustness of the price estimate the sales department personnel need from the cost estimators. The exact numbers of the required robustness may vary from the different project and shipyard depending on the desired risk profile. These numbers represent the robustness of the price offered to a potential customer. As will be explained in chapter 3.1, there is a difference between price and cost. However, these numbers give an indication of the required accuracy for cost estimates used in the bidding processes.

The challenges with shipbuilding cost estimation and cost assessment are well known in the industry and often mentioned in the literature. "In general, the nature of the shipping business leads to situations that place an excessive difficulty on effective cost estimation even for the most experienced ship cost estimator." (Caprace and Rigo 2012) Effective cost estimation can especially be difficult in the early phases of a project where only a small portion of information regarding the construction cost is available. The shipyard has a limited time to come up with a bid to respond to a request for tender. In many cases, newbuilding contracts are signed before the detailed design is completed. A consequence of this can be a cost estimate with a low degree of accuracy.

Estimation of costs can also be a time consuming task seen from a sales department perspective. When a shipbuilder creates a bid, personnel from the yard are in constant dialog with the customer. Specifications and design may vary from the first proposal to what the final product actually becomes. This puts a time pressure on the cost estimators who constantly have to conduct new estimates when the input information changes. "Cost estimators may lack timely technical information and face data inconsistencies. Ship engineers and naval architects commonly lack feed-back on the cost impacts due to their technical decisions. Managers often lack information denoting the level of confidence in cost assessment when they must make business decisions."(Caprace and Rigo 2012)

Instead of having to make new estimates every time the specifications change due to the negotiating dialog between a potential customer and the shipbuilder, it is possible to focus on the consequences of such changes. During these dialogs between customer and shipbuilder, discussions about performance requirements, design and specifications are on a brief specification level. To make the cost estimation process more effective and less time consuming by focusing on the consequences due to changes of high level performance requirements, one can respond quicker to the customer when these issues appear. A framework or method that reduces the response time from the estimators to the sales department would give a competitive advantage for the shipyard. Based on historical cost data of previous built vessels and a top-down estimation approach, it is possible to develop CERs that can express the relative changes of the total shipbuilding cost due to changes of important performance parameters. One of the advantages of CERs expressing a relative change instead of an absolute number, is that cost consequences of a specification change can be compared between different designs with different shipbuilding cost and characteristics.

Another main advantage of focusing on relative changes and not absolute numbers is the expected uncertainty of the estimate. Different cost estimation methods and approaches produce estimates with different degrees of uncertainty. What they all have in common is the intention of predicting the future based on both previous and present information. In this thesis, the future is represented by the total shipbuilding cost. There are many other factors than the ship design that affects the final building costs. Two ships with an identical design built at the exact same time, but at different yards, will not have the same final building cost. There can be many factors that differ one yard from another. This could be anything from labor cost to the overall productivity of the yard’s labor force. Costs are also influenced by external factors outside the yard. Both inflation and deflation can influence the building costs. These factors are not constant and change over time. In a free market, supply and demand also change over time. When the demand is higher than the supply, we generally face inflation and increased costs. The opposite is when supply overtakes demand and prices drop. This is called deflation.

If a cost estimation method predicts the shipbuilding costs based on outdated cost data because of a change in time dependent external market effects, the estimate has little value. The final estimate would then have the original uncertainty plus an error caused by a shift of external factors. If we assume that the external market effects influence the different cost components of a newbuilding project in the same way, then the components’ relative portions of the total cost would still be the same. Different cost drivers of a complex engineering project like an offshore support vessel affect different cost components or portions of the total cost. In this case, with uniform market effects, a change in a cost driving parameter would have the same relative effect on the total cost independent of the external market effects.

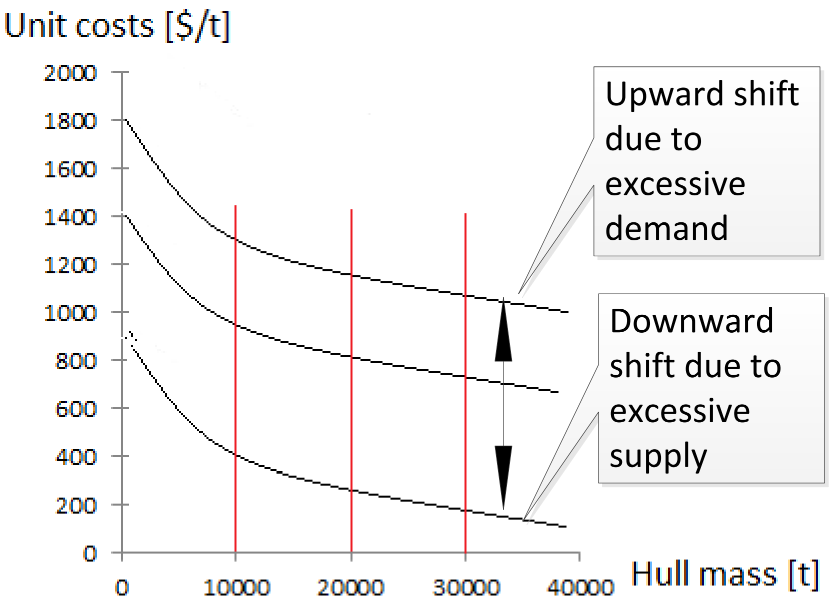


Figure 1 - Hull unit cost example

Figure 1 illustrates that the slope of the hull unit cost remains unchanged for the different hull masses when the steel price varies due to market effects. If we assume that the other cost components are affected by the same market mechanisms, a change of hull mass would have the same relative effect on the total cost. A CER that represent the relative change of the total cost is therefore a robust tool since it may reduce the uncertainty induced by market effects.

2.2 Error Elimination by Focusing on the First Derivative

As mentioned above, a CER that express the relative change of the total cost instead of giving an absolute number is a robust tool because of the error elimination effect. This effect is shown in Figure 1 with a concrete example of hull cost and steel prices. Figure 2 illustrates the principle of error elimination when focusing on the first derivative. The total error of a simple function, F(x), with a constant, c, and a gradient, a, is a result of errors in both a and c. The error ϵ_1 represent an additive error, and the error ϵ_2 represent a multiplicative error. When only focusing on the first derivative or the relative change, one eliminates the additive error component and then reduces the overall uncertainty.

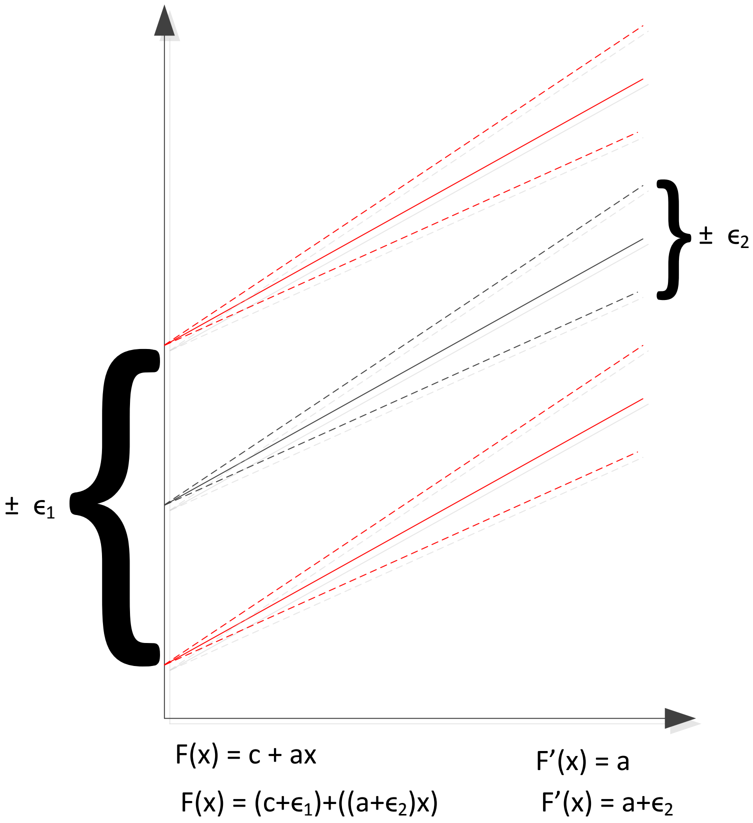


Figure 2 - Error elimination by focusing on relative change

The total error of F(X) is a result of both an additive and a multiplicative error. The error of the first derivative, F'(X), representing the relative change is only a result of a multiplicative error, ϵ_2.

3 Literature Study

3.1 The Shipbuilder's Dilemma – Pricing or Costing?

There is a basic difference between price and cost. Costs are the expenses while price is what generates revenue. The long term goal for a ship constructor is to get a price for a newbuilding project that covers both the expenses and gives a satisfying profit margin. The strategic decisions depend on the market. For short periods, the strategic decisions can be to minimize loss or position in a certain market. In principal there is two ways for a shipbuilder to decide the newbuilding price. One could either approach it from the cost side or from the market side. The fundamental difference is the starting parameter. Bottom-up pricing, or costing, is when the necessary price is found based on the costs. Top-down pricing is when one the allowable production costs are found based on the market price. What this thesis has defined as top-down pricing is also called target costing. (Fischer and Holbach 2011)

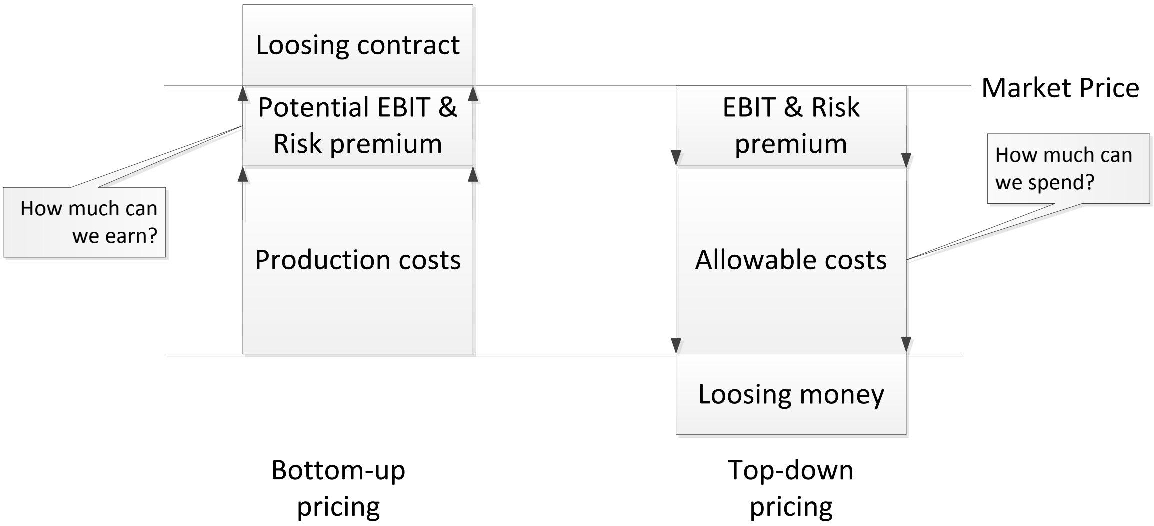


Figure 3 - The Shipbuilder's dilemma - costing or pricing?

The dilemma of the shipbuilder is to decide which starting point to choose to find the newbuilding price; the expected costs of a certain vessel or the expected market price for the same vessel. If a shipbuilder chooses to find the price for a newbuilding with bottom-up pricing, there is a risk for overpricing and then losing a contract. On the other hand, if a shipbuilder use the market price a basis, the main risk is that the price is too low to cover the expenses. In reality, the market price is the dominating starting point, but cost estimation is done to see if one is able to build a ship within the allowable cost range. The going market price of a newbuilding is based on former deals and is communicated to the market through brokers and other actors in the industry with interest in sharing this type of information. From a pure technical point of view, the price for a newbuilding should reflect the actual cost of one specific technical solution. However, when newbuildings are compared in broker reports and maritime press, sometimes only deadweight or similar global parameters are given as references.

Another factor is that suppliers also price their products using a top-down pricing approach. If the current newbuilding prices are relatively high, then the suppliers will increase their prices to maximize profit. The shipbuilders are hence facing market effects from both the cost side and the market side. To succeed in a globalized competitive market, shipbuilders have to use both approaches simultaneously to find the price that secures both winning the contract and a satisfying profit margin.

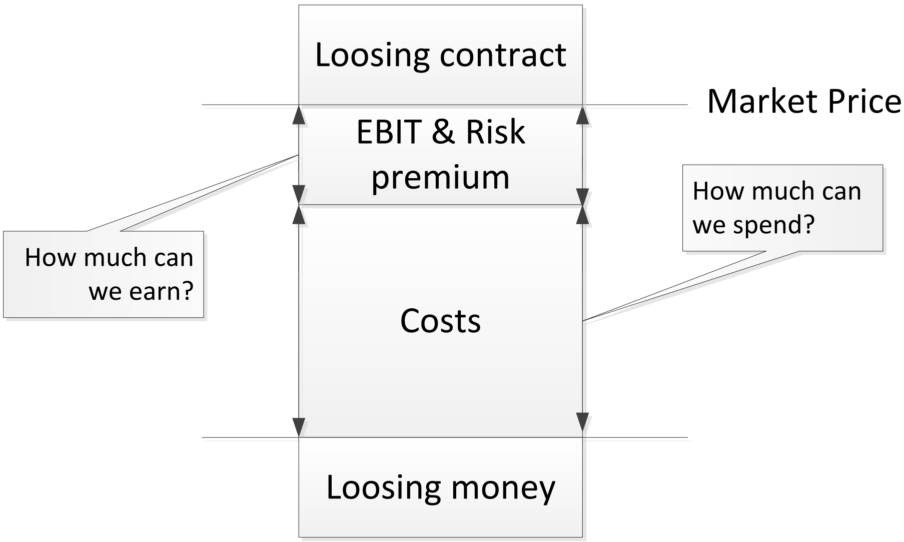


Figure 4 - The Shipbuilder's reality - costing and pricing

Figure 4 illustrates the Shipbuilder's reality. Both approaches are used simultaneously to determine the final price to be offered to a potential customer.

3.2 Shipbuilding Cost Estimation

As mentioned, it is a difference between ship building price and -cost. If this difference is a positive number, the shipbuilder will have a profit. While the shipowner is interested in the price, the shipbuilder's focus is on the difference between cost and price. In an environment of naval architects and engineers with new and innovative solutions, one often tends to view ship design and building from a technical perspective. To succeed as a business venture, one has to look at this from a financial perspective. This is where building cost estimation becomes an important issue as a part of the overall cost management.

There are several reasons for the shipbuilder to conduct a building cost estimate. If a shipbuilder is able to estimate the costs during a tendering phase of a particular order, then it is easy to determine whether a ship design is competitive or not.

If the cost estimate is too high, it is likely that the contract goes to a competitor that can offer a similar product or technical solution to a lower price. On the other hand, if the estimate is too low, the shipyard would face a deficit situation and in the long run face an economical loss, and in worst case, bankruptcy.

Building cost estimation is not only a tool intended for the bidding process and the determination of the price. In design phases, cost estimation of different technical solutions is an important decision making tool for choosing different solutions. To perform a cost benefit analysis of different solutions that are to be developed, the costs of these solutions has to be known.

Ship construction which includes both ship design and ship building is a highly competitive business. When a request for tender is received by the shipyard, they have a limited time to come up with a tender fulfilling the ship owner's requirements. The bidding process begins with a non-binding first offer based on brief specifications and culminates to a binding offer based on more detailed specifications. Whether it is a buyer’s or a seller’s market, the goal is to offer an overall better deal than the competitor and with this win the contract. If we assume the same technological quality from two different shipyards, then the final price will be the decisive factor. In simple terms, this is the case when the Norwegian shipyards with the same experience and cost level are competing against each other over a contract. The other case is when shipyards from high cost countries are competing against shipyards from low cost countries. Then the ship owner has to decide how much he is willing to pay for good quality. In both cases building cost estimation is important; “In this ever-increasing competitive market, cost engineering is becoming a necessity for survival and not a “nice to do”.” (Roy 2003)

3.3 The Importance of Shipbuilding Cost Estimation During Design Phases

Ship design and naval architecture is a set of many very complex tasks. Ship designers face daily problems where they have to prioritize and choose between different technical solutions. The design phases of a ship building project can also be characterized as decision making phases. When a ship design is developed based on a shipowner’s requirements, decisions are made all the way through the process. Seen from a financial point of view, these decisions form the preliminary cost structure. While the design phases not are costly compared to the production and outfitting phases, it is in the design phases most of the costs are being fixed. The numbers in the literature vary, but the conclusion is that it is important to focus on the economic consequences of decisions during the early phases of ship design. “The estimation shows that the design stage, having itself approximately 10 % share in the total building costs, determines 85 % of those costs. Expenses on the design quality - proper choice of the ship main parameters, production technology, structural materials, equipment types etc. – have a significant impact both on the shipyard’s and owner’s economic effects.” (Michalski 2004)

Building stage	Cost of the stage	Impact on total building costs
Preliminary design	3 %	60 %
Other design stages	7 %	25 %
Ship production	90	15 %

Table 2 - Building stage's impact on total cost (Michalski 2004)

The relationship between assigned and accumulated cost throughout the new building project phases are described graphically by (Fischer and Holbach 2011) which claims that 85-90 % of the total costs are fixed before the start of production.

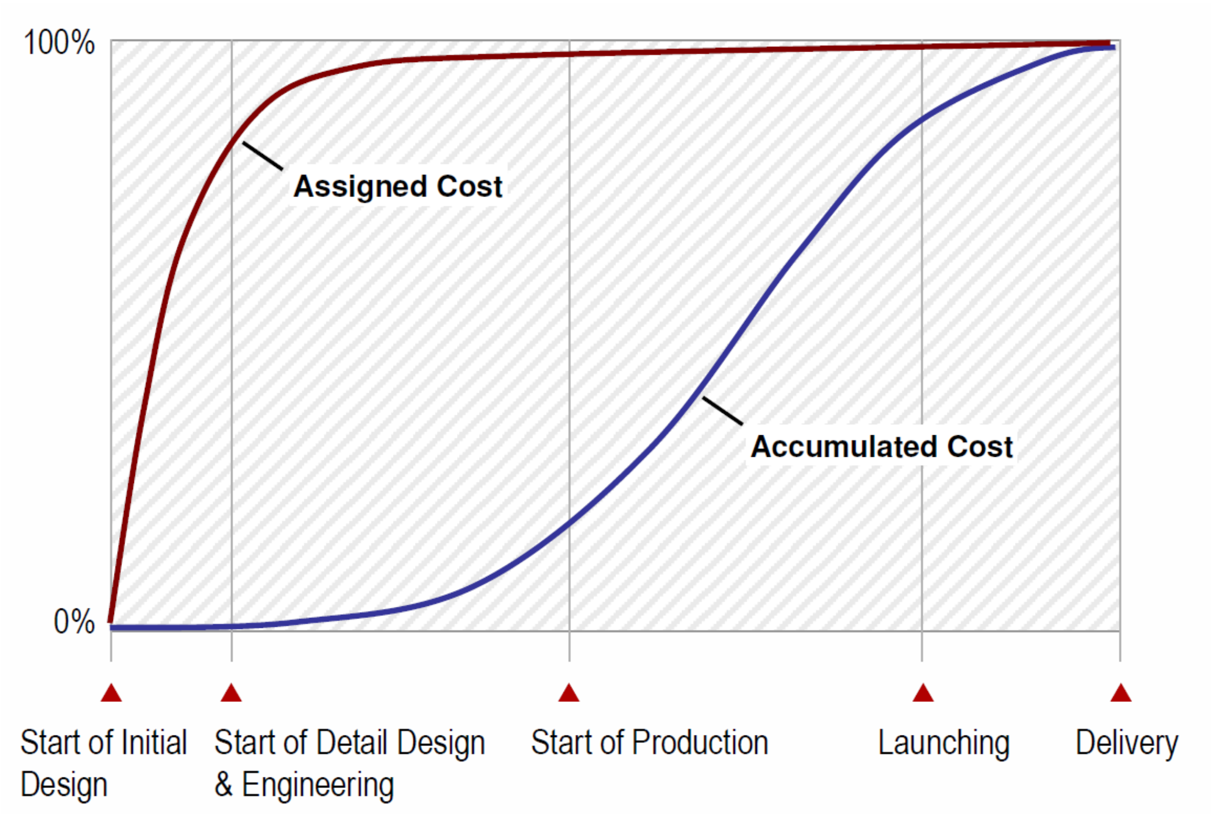


Figure 5 - Cost definition during project process (Fischer and Holbach 2011)

Both of the above numbers come from actors in the European shipbuilding industry (Poland and Germany) which traditionally have built different ship types than the Norwegian shipyards the last years. However, we can assume that this tendency also is present in the offshore support vessel construction industry. For engineering projects in general, (Roy 2003) claims that 70-80 % of a product's cost is committed during the concept phases.

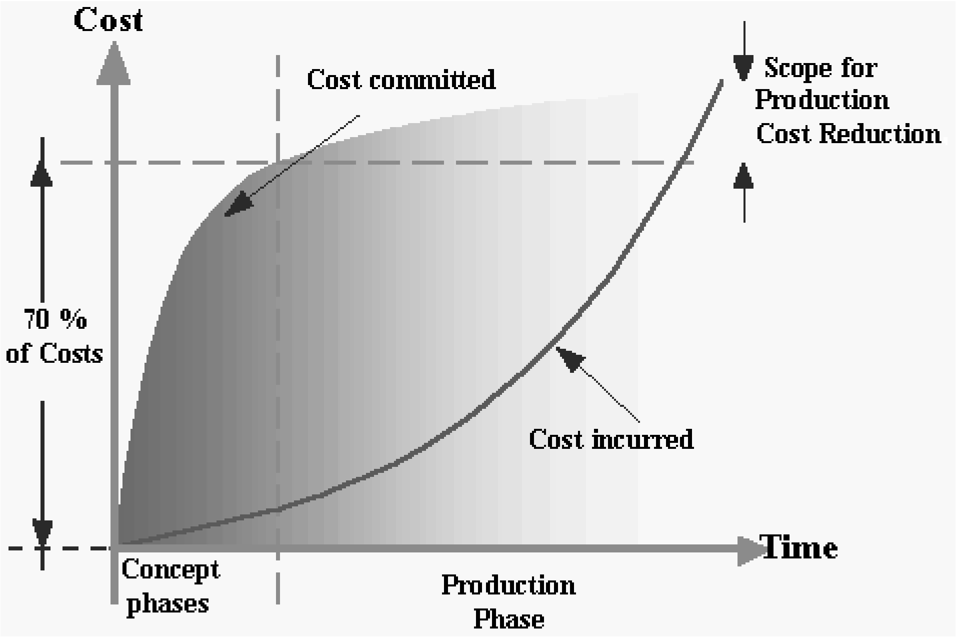


Figure 6 - Cost commitment curve for engineering projects (Roy 2003)

These numbers emphasize the importance of keeping a focus on cost management already from the beginning of an engineering project. The estimation of new building costs in the design phases should therefore be an important element in a newbuilding project. “The information about estimated costs for the ship and its elements, such as components or systems, should be obtained and incorporated into the decision-making process in order to capitalize on its potential.” (Fischer and Holbach 2011)

3.4 Cost Estimation Approaches

Numerous of cost estimation approaches and methods exist today. They vary from the simplest form from an experienced old-timer in a shipyard with lifelong experience of shipbuilding and cost estimation to complex and detailed software counting every little “bits and pieces”. It is possible to group the different approaches and methods in different matters, but the majority within the literature operates with three different cost estimation approaches. The main variations of the three different groups are the amount and detail level of cost information available. How time consuming and complex the methods are, also plays a part in whether they are used or not. Therefore, different methods are used at different stages of the design phases. The names of the three groups vary a bit in the literature, but the essence of these names is the same; top-down approach, bottom-up approach and parametric approach.

Other classification of cost estimation approaches operate with either two or four groups. (Bertram 2005) classify production cost estimation into only top-down and bottom-up approaches where parametric approaches are counted as a part of the top-down group. (Saravi, Newnes et al. 2008) mention a classification of four different methods; intuitive, analogical, parametric and analytical. (Roy 2003) operate also operate with four groups, but have different names on them. As mentioned above, this thesis classifies the cost estimation approaches in three groups.

Shipyards often use a combination of these methods regarding how detailed the information available is. It exist several cost estimation methods within the three groups, and some of them overlap each other.

3.4.1 Bottom-up Cost Estimation

Bottom-up cost estimation methods are the most detailed methods of estimating the ship building costs and are sometimes referred to as grass root or engineering build up estimating. These methods are only valid after the design has reached a level of significant technical maturity. The extreme version of an engineering build up estimation method is close to what would be a deterministic approach and not a subject of estimation. It would have been a subject of accounting where the material cost of every parts and their assembly or labor cost is known and summarized to a total shipbuilding cost by the estimator.

Bottom-up estimations may be based on drawings, bills of materials, historical vendor costs, and existing quotes. (Ross 2004) The growth and development of CAD technology has also played an important role for the use and development for bottom-up models based on data exported from CAD-tools.

3.4.2 Top-down Cost Estimation

Top-down methods are also called analogous methods or extrapolation models. These methods are based on the comparison and extrapolation of known data from objects, in this case ships, with a satisfying technical similarity. These methods are used in the earliest design phases like concept design and preliminary design where there is less detailed information available. Top-down methods are used when the amount of information available are enough to recognize a similarity to previous objects. It is up to the estimator to judge whether a newbuilding project has unique design characteristics or if it is comparable to historical data. Some top-down methods therefore rely on "expert judgments".

Because of the low detail level of information in the earliest design phases, linear extrapolations and cost factors from similar projects are acceptable ways of estimating the costs. Since top-down methods usually are applied in the early processes where there is a lack of detailed information, estimations are often based on global data and parameters. The use and comparison of the overall global data is what distinguish top-down models from parametric and bottom-up models where the total project cost is a sum of portion costs.

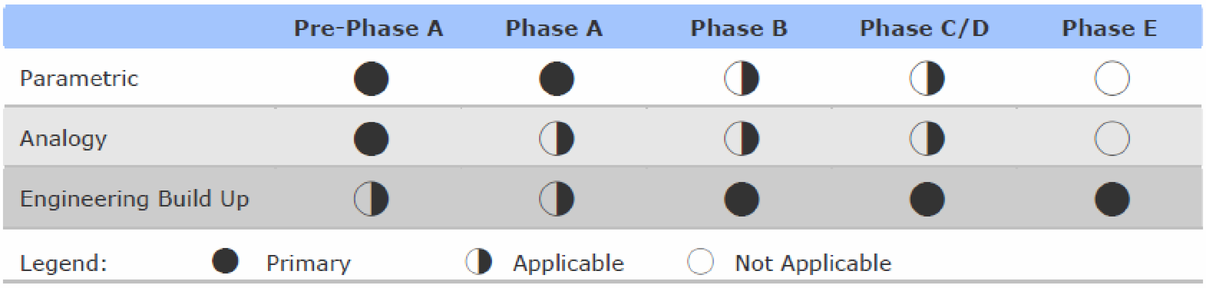
3.4.3 Parametric Cost Estimation

Between the global top-down methods and the accounting bottom-up methods is where we find parametric cost estimation. The basis for parametric cost estimation methods is the use of cost estimating relationships (CER). CERs are mathematical expressions or formulas relating cost as the dependent variable to selected, independent cost-driving variables. These relations between costs and relevant parameters are based on regression of historical data. "The implicit assumption of parametric cost estimating is that the same forces that affected cost in the past will affect cost in the future". (NASA Cost Analysis Division 2008)

Whether a parametric cost estimation method is closest to a top-down or a bottom-up approach is dependent on how the costs are summarized. If the CERs calculate the total cost based on global parameters like length overall (LOA) or deadweight (DWT), some would call this a top-down approach. The opposite would be if costs of every little subsystem were found by CERs and then used an accounting bottom-up approach. In reality, most parametric cost estimation methods are considered closest to top-down methods because of the independent cost drivers chosen and the use of parametric estimation in early phases of design.

3.5 Selection of Relevant Cost Estimation Framework

All of the three cost estimation approaches are appropriate for different stages of the design phases. The amount and detail level of data available determines which approach that is best suited. This thesis investigates the cost effects of main changes in high level performance requirements. The high level performance requirements are discussed already in early phases of a newbuilding project where none or only a small portion of the costs are assigned. For this purpose, a top-down parametric approach would be the best choice to use as a basis according to the description of the approaches above. A bottom-up methodology would not have had the sufficient amount of information available to conduct a cost estimate. "Generally, an estimator selects parametric cost estimating when only a few key pieces of data are known, such as weight and volume" (NASA Cost Analysis Division 2008). Other parameters than weight and volume are also relevant parameters to look at when investigating cost effects of performance requirements. This could for instance be speed, propulsion or cargo capacities which all can easily be expressed by parameters. Other performance requirements are harder to express in numbers. This would be features that the vessel is either equipped with or not, like a certain DP-class, moon pool, helideck etc. In specific cases where these “to be, or not to be” issues emerge, a combination with an analogous approach may be the most suitable alternative. Figure 7 illustrates that the approaches are overlapping.



	Pre-Phase A	Phase A	Phase B	Phase C/D	Phase E
Parametric	●	●	◐	◐	○
Analogy	●	◐	◐	◐	○
Engineering Build Up	◐	◐	●	●	●

Legend: ● Primary ◐ Applicable ○ Not Applicable

Figure 7 - Cost estimating methodology chart (NASA Cost Analysis Division 2008)

The phases are NASAs own definition of project phases. Pre-phase A and phase A are conceptual study and preliminary analysis. The figure above is for illustration and not direct applicable to a ship yard.

3.6 Weight Based Parametric Methods of Cost Prediction

Traditionally, methods based on weight as the independent variable and cost as the dependent variable have dominated the scene of parametric cost estimation in shipbuilding. Both in the literature and in the industry, cost and weight estimation have been closely linked and in several cases been regarded as the same discipline. One example is (Erichsen 1989) stating that: “In general, costs are calculated as a function of *weight.* In a few cases costs are also calculated as functions of *volume or area.* Weight is usually calculated as a function of capacity, i.e., deadweight, volume, area and power. Therefore, it is necessary to determine the *capacity* in some form before estimating the weight or the cost”. With this approach, weight is first the dependent variable, and then used to estimate the cost. It is both pros and cons with using weight as the dominating parameter in cost estimation, but that discussion will not be taken here. As mentioned in chapter 3.4.2, the most general formulas take the ship as a whole and estimate the cost based on global parameters, in this case weight. In more detailed cost estimation approaches, the ship is divided into subgroups and the respective subgroups’ costs are estimated based on their weight. Costs for each subgroup are summarized to get the total estimated ship building cost. There exist a variety of both subdivisions and formulas to estimate weight for different parts or systems of a vessel. According to (Erichsen 1989) the general mathematical structure of the formulas has the form:

$$J = a_0 + a_1 x_1^{b_1} + a_2 x_2^{b_2} + \cdots + a_n x_n^{b_n} \tag{3.1}$$

which is frequently reduced to:

$$J = a_0 + a x^b \tag{3.2}$$

or

$$J = a_0 + a_1 x_1^{b_1} + a_2 x_2^{b_2} \tag{3.3}$$

One of the concrete examples in (Erichsen 1989) for weight estimation of a subgroup is the formula for the weight of the propulsion machinery, W_m.

$$W_m = ax^b \tag{3.4}$$

Where x represent the propulsion power and b is a coefficient which is dependent on the variety of different engine types. In this example, the propulsion power is also estimated by a formula where speed and the wetted surface are the independent variables:

$$x = a_0 x_1^{b_1} * x_2^{b_2} \tag{3.5}$$

Where x_1 is the speed and x_2 is the wetted surface. This example does not give the relationship between the weight and the cost of the propulsion machinery. With a formula describing this relationship, it would have been possible to make a cost estimating relationship expressing the machinery cost as a function of speed and wetted surface.

(Michalski 2004) describe a method for estimating the total shipbuilding cost by using weight based CERs. The ship is divided into three subgroups called technological groups. For each technological group, relationships between unit cost and the subgroups own weight is found. They all have the mathematical structure:

$$q_j = c_{0,j} + c_{1,j} m_j + c_{2,j} m_j^{c_{3,j}} \tag{3.6}$$

Where q_j is the unit cost in dollars per ton [\$/t], j is the technological group, m_j is the technological group's weight and c_{ij} is structural coefficients determined by regression using the method of least squares. When the individual technological group's weights are known, the unit costs are found and multiplied with the weight to find the cost of the technological groups:

$$Q_j(x) = q_j(x) m_j(x) \tag{3.7}$$

$Q_j(x)$ is the individual building cost of the technological groups where x represent an arbitrary set of the ships performance parameter determining the subgroups weight as seen in the example described above. The total cost, $Q_t(x)$ is the sum of the technological groups' individual costs.

$$Q_t(x) = \sum_{j=1}^{5} Q_j(x) \tag{3.8}$$

3.7 Subdivision, Grouping Systems and Work Breakdown Structures

In shipbuilding cost estimation, subdivision and grouping systems are commonly used to address costs to specific parts or systems of the ship. It exist numerous different subdivisions and breakdown structures that are used in shipbuilding and shipbuilding cost estimation. Some subdivisions are based on the different ship systems geographical position, while others are based on the ships different functional systems. Some grouping systems are also based on the different components building life cycle and when their cost is incurred in the building project. The variety of subdivisions is greater when it comes to cost estimation than cost management in shipbuilding. While the different cost estimation approaches can choose to use their own division of the ship based on how much information that is available, the subdivision for cost to a large extent follows standard grouping systems.

As mentioned in chapter 3.6, (Michalski 2004) divides the ship into three different technological groups; hull, equipment and power plant. In (Erichsen 1989) this is called hull engineering: "In a more detailed design, formulas for different parts or systems of the ship are used to derive figures for weights and costs. It is common to split up in weights of *steel*, *machinery*, *outfit* and *equipment* (sometimes referred to as *hull engineering*)."

In general, cost planning in shipyards is based on numeric building group systems based on a ship's component structure. (Fischer and Holbach 2011) These systems vary from one specific shipyard to another, but the basis of the specific work breakdown structures used in Norwegian shipyards follow the SFI group system. Another grouping system is for instance NATO's ESWBS (Expanded Ship Work Breakdown Structure).

The SFI group system was developed at the Norwegian Ship Research Institute, now known as MARINTEK. The SFI group system is an international standard which is used for a functional breakdown of the ships technical and economic information. It structures and systemizes all the ship's different systems and components through a 3-digit coding structure. Through the ships' lifetime, the SFI coding system is used for different purposes. In cost management, this structure works as a cost work breakdown structure. The ship is divided into 10 main groups from 0 to 9, but often only main group 1-8 are used. Main group 0 and 9 are extra posts where the user can address costs related to the ship that does not fit into the other main groups. The main groups are divided into 2-digit groups which are again divided into 3-digit subgroups.

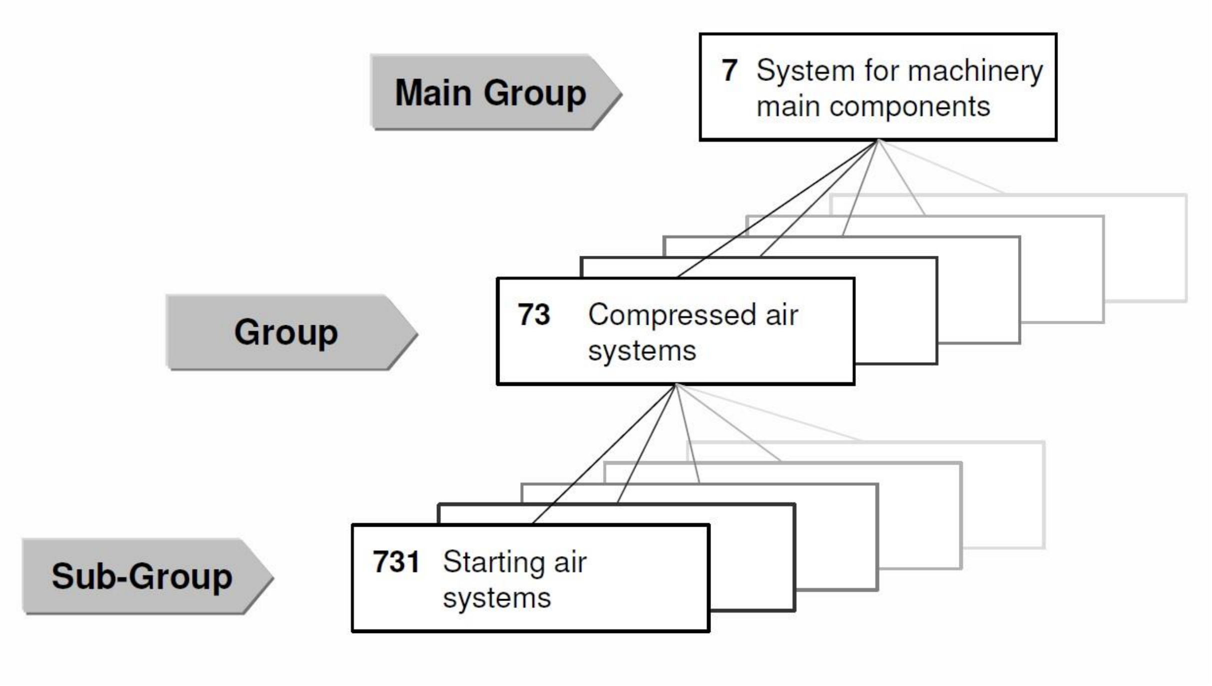


Figure 8 - SFI Group System: Example of subdivision of main group 7 (Fischer and Holbach 2011)

Figure 8 illustrates how the SFI group system is built up with main group, group and sub-group.

4 Method Description

As previously mentioned, this thesis will present a method for developing CERs expressing the relative consequences on the total costs due to changes of cost driving parameters. This method can be characterized as a parametric top-down cost estimation approach. By using known cost data and specifications for several vessels of certain ship type, it is possible to find relationships between important performance parameters and costs. With regression techniques, CERs expressing unit costs per cost driving parameter for different technological groups of the vessel can be found. By using these CERs on already existing vessels and then theoretically change the ship's performance parameters, one will see the theoretical consequence on the total cost. By changing a chosen cost driving parameter with different intervals for several vessels, one can plot the average relative consequence on the total cost. The last step is to perform a regression on these consequence plots to find a CER expressing the relative effect a parameter change will have on the total cost for a certain ship type.

Figure 9 shows the brief algorithm of how to develop these relative change-CERs. As all other methods or approaches that use historical data to say something about possible future outcomes, the quality and format of the input data are important for the final result. The most describing term to describe this issue is the metaphor: "garbage in – garbage out". The point is that is does not matter how good a model is. If the processed data are of poor quality or "garbage", the final product will also be characterized as "garbage".

The objective of this method is to provide decision makers with a framework contributing to increased knowledge of the behavior of cost drivers in the shipbuilding industry.

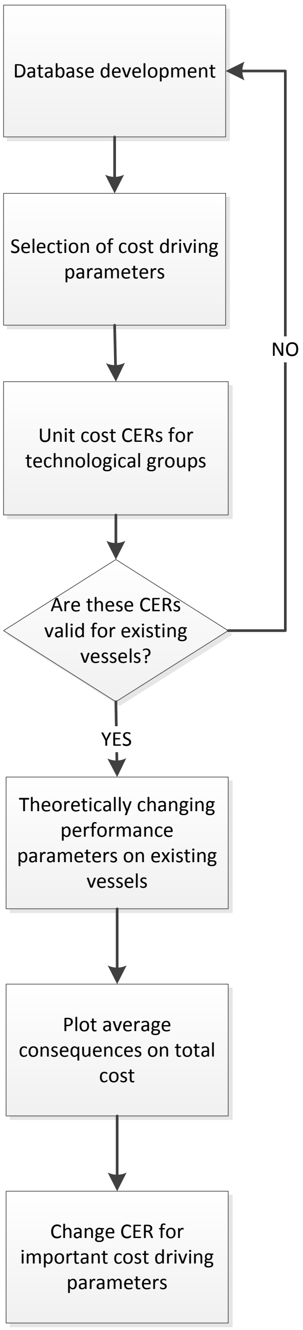


Figure 9 - Flow chart of method

4.1 Selection of Cost Driving Parameters

To find the cost effects of high level performance requirements, the performance requirements have to be defined. Different performance requirements will vary for different ship types. Tankers and other ship types with low complexity are likely to have other cost driving parameters than ship types with a high degree of complexity. Offshore support vessels range from plain cargo carrying PSVs to highly advanced subsea, construction and anchor handling vessels. For the PSVs, important cost drivers could be parameters that have an impact on their cargo carrying capability. The same parameters could also be important for anchor handlers, but for these vessels it is likely that parameters influencing for instance the rig moving capabilities would also have an important role.

This thesis will focus on the PSVs because of the relatively low complexity compared to other offshore support vessel.

To choose which parameters or features to investigate further, it is interesting to look at which main ship parameters that historically have had an impact on the newbuilding price. Having in mind that the market price reflects more than just the building costs, it can still give an indication of where to start. Ulstein has done parametric analysis of different ship types in the offshore support vessel segment. These studies investigated how some main ship parameters where correlated to the newbuilding price. Ulstein did not only investigate the direct correlation between one specific parameter and the newbuilding price, but also tried to identify cost drivers by combining and excluding parameters. The relationship between the different parameters where also investigated. Both based on Ulstein’s plots and to some extent expert judgments from personnel at Ulstein, the following main parameters where chosen to investigate further for PSVs (Ulstein International AS 2011):

1) LOA
2) Bmld
3) D
4) DWT
5) Deck Area
6) Speed
7) Power

4.2 Operationalization and Breakdown Structure

A subdivision of a vessel into functional groups to address costs to different parts of the ship is common in shipbuilding. The SFI group system is the most widely used work breakdown structure on an international basis. (SpecTec 2012) Every cost incurred through the building phase of a vessel is recorded in the cost work breakdown structure. The eight main groups in the SFI group system is a subdivision of a vessel’s different systems that is applicable to most ship types. However, when it comes to investigating cost driving parameters, it is desirable to combine the 2-digit groups and form new technological groups based on the SFI group system. One of the assumptions behind such a decision is that cost driving parameters have different impact on different parts of the ship.

Instead of eight main groups in the SFI system, it is possible to reduce the number to four main technological groups. This is mainly done by combining main groups and groups that is likely to have the same parametric cost drivers. One of the examples is that main groups 6-Machinery Main Components and 7-Systems for Machinery Main Components together with some of the 2-digit groups covering thrusters and propulsion are combined into a technological group called Machinery and Propulsion. The four technological groups derived from the SFI grouping system are:

1) Hull
2) Machinery and Propulsion
3) Cargo containment and handling equipment
4) Common systems and costs

The main philosophy behind this particular subdivision of the ship into four main technological groups is that the ship is viewed from a tool perspective. This task of this tool is to provide offshore installations with cargo and perform other required services like oilrec or acting as a standby vessel. Technological group 1-Hull makes this tool float and that it will be able to operate in the ocean and maritime conditions while technological group 2-Machinery and Propulsion covers the ability to move and maneuver this floating platform for cargo carrying. Technological group 3-Cargo containment and handling equipment covers the functions related to cargo containment and cargo handling and systems that are directly related to the payload. The fourth technological group, Common systems and costs, covers all the other systems that are likely to not differ that much from vessel to vessel. Every sailing ship needs navigation equipment, lifesaving equipment, sanitary systems etc. Some cost drivers may affect more than one of the technological groups, but this thesis assume that the majority of the example parameters mentioned above can be categorized in the same way as the four main groups. It is also possible to add a fifth technological group to cover financial and administrative costs. These are traditionally those covered by SFI main group 1-Ship General and are costs like insurance fees and payments to class societies etc. Without the fifth group, the 1-Ship General costs are accounted for in the fourth technological group, Common systems and costs.

Figure 10 shows the logical structure of the subdivision of the ship and illustrates how some cost drivers may affect the groups and because of this have an impact on the total shipbuilding cost. The complete organizing of the 2-digit groups from the SFI grouping system into four/five technological groups is shown in Appendix A.

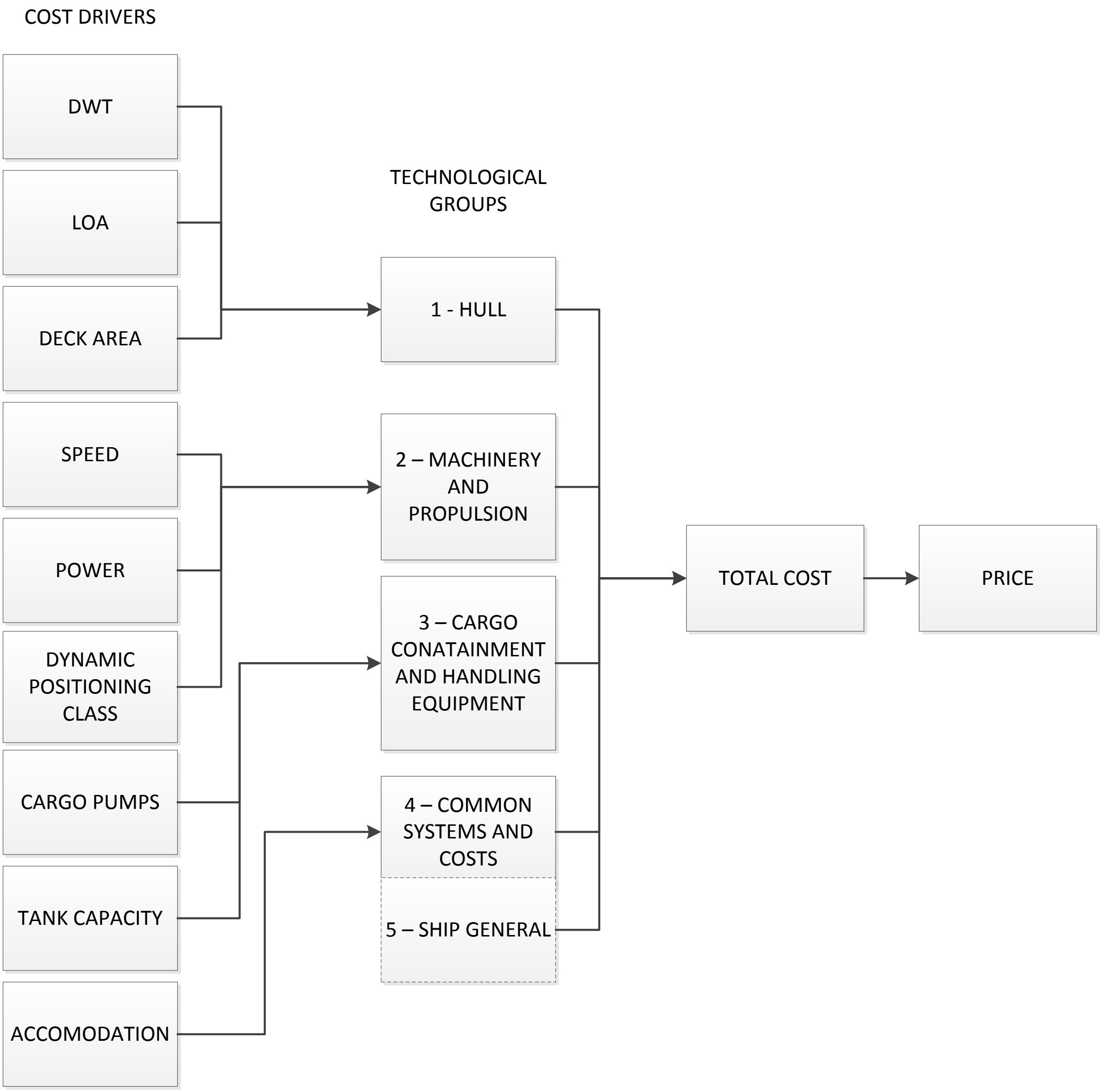


Figure 10 - Subdivision and examples of cost drivers

Another argument for this subdivision is the distribution of the shipbuilding costs. These four or five main groups have approximately the same share of the total cost. According to personnel at Ulstein, a coarse estimate of the cost distribution of a PSV is the following:

Technological group	Portion of total cost
Hull	20 – 30 %
Machinery and Propulsion	25 %
Cargo containment and handling	20 – 25 %
Ship common systems / Ship assembly and systems integration (for outfitting yard)	20 %
Hotel and accommodation	5 %
+ Financial costs	+ Financial costs

Table 3 - Distribution of costs for PSVs

4.3 Unit Costs of Technological Groups

To develop CERs expressing the unit costs of the technological groups per cost driving parameter, a regression analysis has to be performed in order to find possible correlative relationships between costs and parameters. Regression theory and -analysis is a major field of study. This chapter will only describe some of the important aspects and relevant techniques that are to be used in this particular method.

As mentioned in chapter 3.4.3, the implicit assumption of using CERs based on historical data to estimate future costs is that the same forces that affected costs in the past will affect costs in the future. Regression analysis is a statistical procedure to identify and describe the relationship between two or more variables. It differs from correlation analysis, which aims to describe the degree of interdependencies between these variables. Regression analyses in cost estimation are used to find functional relationships between an objects cost as the dependent variable and representative parameters describes the characteristics of the object as independent variables. In this step of the method, the objects are the four or five technological groups of the vessel and the independent variables are the ships performance parameters one want to investigate.

The simplest form of regression analysis to find CERs are those who assume linear relationships and only use one independent variable. The results of such regression analyses is cost indexes and cost factors that assume the same fixed rate between cost and parameter independent of the parameter's absolute value. Linear regression analyses are limited to find fixed rates and are therefore not able to describe non-linarites. Non-linear regression analyses can describe both linear and non-linear relationships and are therefore a more flexible tool when it comes to the development of CERs. A linear approach can lead to a high degree of inaccuracy. "Therefore, non-linear cost functions are preferable in practice." (Fischer and Holbach 2011)

With the assumption that the different cost driving parameters have different effect on the four technological groups, this method is somewhat touching into the multivariate regression domain. Since the cost driving parameters have different impact on the technological group, a relative change in one of the parameters will result in different relative consequences for the four/five groups. By plotting unit costs for each technological group versus a chosen parameter also helps to identify which parameters that actually have a significant effect on the specific technological groups. If none of the chosen parameters correlate with the unit cost, one have to either chose other parameters, other combinations of them or redefine the technological groups.

As Ulstein experienced in their parametric studies, sometimes a combination of the standard ship parameters correlated better than one of them alone. One example is that the combination of speed and deadweight for PSVs with a deadweight above 2000 tons correlate better with the newbuilding price than only the speed.

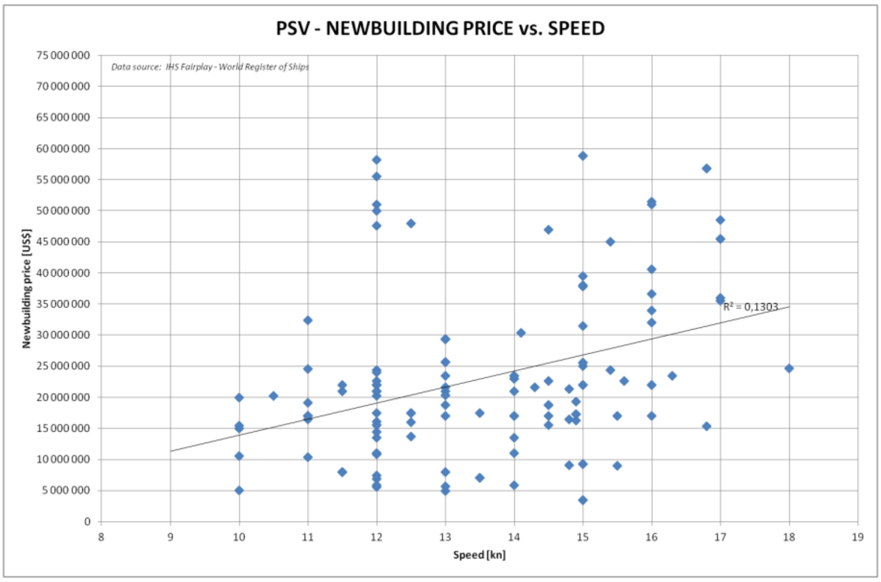


Figure 11 - Newbuilding price versus speed - R^2=0.13 (Ulstein International AS 2011)

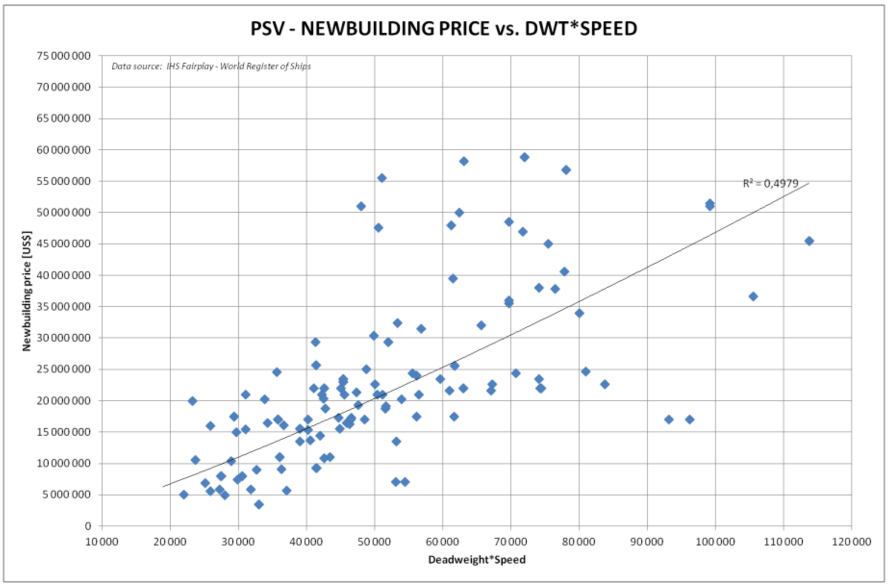


Figure 12 - Newbuilding price versus DWT*speed - R^2=0.50 (Ulstein International AS 2011)

Figure 11 and Figure 12 illustrate that a combination of parameters may correlate better with costs than one single parameter alone. Despite the aforementioned difference between the newbuilding price and cost, these figures still indicate that speed alone is no representative parameter for the total ship building cost in this case.

4.4 Normalization and Regression Analysis

Before performing a regression analysis, it is important to ensure that the input data are of the same format. “Adjustments to the raw data, almost always need to be made to ensure a reasonably consistent, comparable, and useful set of data. Making such adjustment is often referred to as “normalizing” the raw data.” (ISPA 2008) The input data in this case is the recorded costs from previous built projects of ships of the same ship type.

Shipbuilding costs are paid in different currencies. A typical situation for a Norwegian shipyard is salaries paid in NOK, while equipment and materials are paid in EUR and USD. The exchange rate between currencies fluctuates over time, but one could use average exchange rates for a period like a year to normalize the currencies. All recorded costs must be converted to the same currency before comparing them. In addition to the currency conversion, the costs have to be updated according to inflation. A possible solution is to use the average inflation rates and then adjust all costs to one certain year, but have in mind that inflation is not the only market effect that influences the costs' real value over time. One example is the steel price. It is not given that the development of the steel price has followed the same pattern as machinery costs or the consumer price index. In the shipbuilding industry, it is common that some cost components face a higher inflation rate than the ordinary consumer price index. It is also important to define what the accounted costs include. It is a difference whether the accounted building costs include both labor and material costs. This method assumes that both labor and material costs are included in the shipbuilding costs.

When the cost data is normalized and adjusted to the same format, the 2-digit SFI cost components are sorted to fit the grouping system described above and the technological groups' individual costs are found. By taking the ship's performance parameters, the parametrical unit costs are found for each technological group. Before creating scatter plots with unit cost on the y-axis and the respective parameter on the x-axis, one should have a sufficient number of ships to get a representative population to run a regression analysis on. A database of 20 ships should be the minimum amount, but this is dependent on the availability of data.

With a sufficient number of ships, scatter plots of all the parametrical unit costs for the technological groups are made. The scatter plots give a graphical impression of which parameters that correlate with the unit cost for the technological groups. This phase is also useful when the type of regression function is to be chosen in the next step of the regression analysis.

4.5 Generating the Regression Function

In MS Excel there is two ways of performing a regression analysis. One can either use the already built in function to find trend lines or use the optimization plug-in Solver. Both methods are applicable for the purpose of finding the best relationship between the parameters and the unit costs the technological groups, but Solver is more flexible when it comes to the type and mathematical structure of the regression function. There is only a limited different alternatives of function types in the already built in trend line functions. When using Solver, one can freely define the mathematical structure and type of function. As mentioned above, non-linear cost functions are the preferable before linear functions. "Excel contains the Solver function, which is ideally suited to fitting data with non-linear functions via an iterative algorithm, which minimize the sum of the squared difference between the data points and the function describing the data." (Brown 2001)

The method of least squares is one of the most used methods to develop a best-fit curve in a univariate regression analysis. As for every regression technique, the goal is to find a curve where the difference between a predicted and actual cost is as small as possible. In the method of least squares, the optimal adjustment of the regression function is reached when the sum of the squares of the difference between the actual values and the predicted values is minimized. Solver finds the structural coefficients of the unit cost CERs through an iterative process. To find a unit cost CER with the same mathematical structure as Equation 3.6 mentioned in chapter 3.6, one have to use the

Solver or other similar software tools because of the limitations of the standard built in functions in MS Excel.[2]

4.6 Evaluating the Regression Function

When performing a regression analysis it is important to evaluate the results before using them. It is important to evaluate and get an impression on whether the regression fits the actual data and what degree of accuracy one can expect. The CERs for unit costs are not the final results of the method this thesis describes, but are used in one of the steps for developing the relative change CERs. If the unit cost CERs are of a poor quality, the final result would be the same. It exist different ways to measure the reliability of the regression function and range from graphical comparison of trend lines to values like the coefficient of determination, R^2. R^2 is also called the stability index. The R^2 value is also found by the built in MS Excel functions and it is therefore a good comparison tool when using Solver or other similar software. It is calculated as follows:

$$R^2 = 1 - \frac{SS_{err}}{SS_{tot}} \tag{4.1}$$

Where SS_{err} is the residual sum of squares and SS_{tot} is the total sum of squares:

$$SS_{err} = \sum_{n=1}^{N} (y_i - f_i)^2 \tag{4.2}$$

$$SS_{tot} = \sum_{n=1}^{N} (y_i - \overline{y})^2 \tag{4.3}$$

Where y_i is the observed values, f_i is the predicted values and $\overline{y}$ is the arithmetic mean of the observed values. The R^2-coefficient measures the percentage of variance from the actual costs that than be explained by the regression. An R^2-value of 0.9 indicates that 90 % of the total variance can be attributed to the variables, while the last 10 % is from unidentified influences. The closer the R^2-value is to 1.0, the more reliable the regression function is. (Fischer and Holbach 2011) It is no standard acceptance value of what the R^2-coefficient should be before the regression function is approved or not for further use.[3] However, the R^2-coefficient is useful when comparing different function types. The regression functions giving the highest R^2-coefficient are usually preferred over the ones with lower values. This also helps us choosing between the standard built in MS Excel functions and the “homemade” in Solver.

Although there exist other ways to measure the reliability of the regression function, the easiest and most practical solution is to compare the actual output values to the known values. One could use some of the ships in the original population, but this is not optimal. References vessels with known

---

[2] The actual regression procedure is more thoroughly described in chapter 5.3

[3] Although there is no standard value for the acceptance criteria of the R^2-coefficient, there exist several opinions in the literature and on the internet. “It seems to be a common rule of thumb that $R^2 > 0,7$ shows good relation between data, while $R^2 < 0,7$ is not.” (Bjørhovde and Aasen 2012)

cost data should be used to check the validity of the regression function. The same normalization process has to be done with the reference vessels' cost data. Then the regression function is used to check if the estimated unit costs for the technological groups fit the reference vessels. As for the R2-value, it is no standard measurement of how close or far off original values the predicted values have to be before the regression function is rejected or need to be adjusted.

4.7 Theoretically Changing Performance Parameters to Log Consequences

If we assume that the unit cost CERs are approved and the regression functions are reliable, then the consequence investigation begins. The theoretically maximum number of unit cost CERs is the number of performance parameters we want to investigate times the number of technological groups. However, in practice, it is likely that this number is less since we do not assume that the performance parameters have a significant effect on all the technological groups. The scatterplots of costs and parameters that does not match at all are discarded before this stage in the method.

The performance parameters are individually investigated for already existing vessels. Whether the reliability of the regression function is evaluated based on the external reference vessels or the original population of built vessels, the cost data from the initial vessels have to be tested on the unit cost CERs. In an ideal situation, the unit costs for the technological group that is investigated fit on the predicted trend line and the summarized estimated costs for the technological groups is the same as the actual building costs for all the vessels in the test population.

By theoretically changing the chosen performance parameter of a vessel by a relative interval of for example 5 %, the unit cost for the technological groups may change due to other input values. By multiplying the new theoretical unit cost with the now 1.05 times higher performance variable, the new theoretical cost for the technological group is found. Summarizing all four technological group's cost gives a new total building cost. The difference between the original building cost and the new theoretical building cost is the relative change of the total building cost due to a change in a performance parameter. Figure 13 illustrates how the individual unit cost for a technological group change due to a relative change of an arbitrary performance parameter.

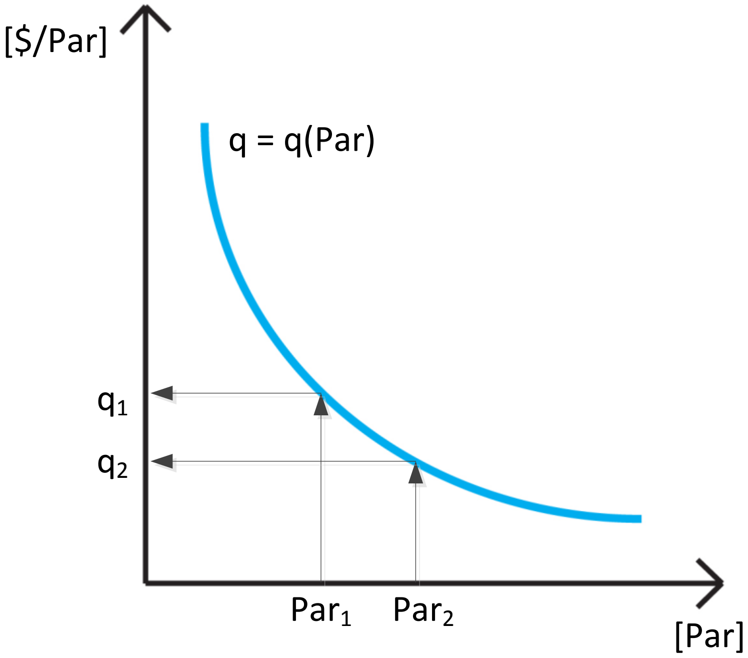


Figure 13 – Theoretical change of unit cost for a technological group

The initial cost before the theoretical change of performance parameter for the technological group in the Figure 13 is the following:

$$C_{TGa1} = q_1 * Par_1 \tag{4.4}$$

Where C_{TG1} is the original cost of the technological group, q_1 is the unit cost and Par_1 is the original value of an arbitrary performance parameter. The total cost of the vessel would be the sum of the four technological groups:

$$TC_1 = C_{TGa1} + C_{TGb} + C_{TGc} + C_{TGd} \tag{4.5}$$

Where TC_1 is the total building cost and C_{TGi} is the costs of the technological groups. A theoretical change in the performance parameter of for example 5 % would change the cost of the technological group.

$$C_{TGa2} = q_2 * Par_2 = q_2 * (1{,}05 * Par_1) \tag{4.6}$$

The new theoretical total building cost would be:

$$TC_2 = C_{TGa2} + C_{TGb} + C_{TGc} + C_{TGd} \tag{4.7}$$

The relative change of the total building cost because of this 5 % increase in the chosen performance parameter would be:

$$Rel_{5\%} = \frac{TC_2 - TC_1}{TC_1} * 100\% = \frac{\Delta TC\ (5\%)}{TC_1} * 100\% \tag{4.8}$$

It is possible that a change in the chosen performance parameter also would have had an impact on one or more of the other technological groups' unit cost. This would also have had a potential effect on the new theoretical building cost.

4.8 Average Relative Total Cost Consequences

The example described above is for one vessel only. By a doing similar theoretical change of the same performance parameter for all the vessels in the test population, one can find the average relative consequences for a particular parameter change. To get enough points to develop a relative change-CER, average building cost consequences of other parameter changes also has to be found and plotted. If we go further with the example above, we can imagine a hypothetical situation to illustrate how to find average relative consequences on the total cost. With a 5 % change of a parameter, the relative consequences are likely to be different for different vessels. By taking the average of the different relative consequences on the total cost, an indication of what the situation looks like for PSVs as a ship type can be found.

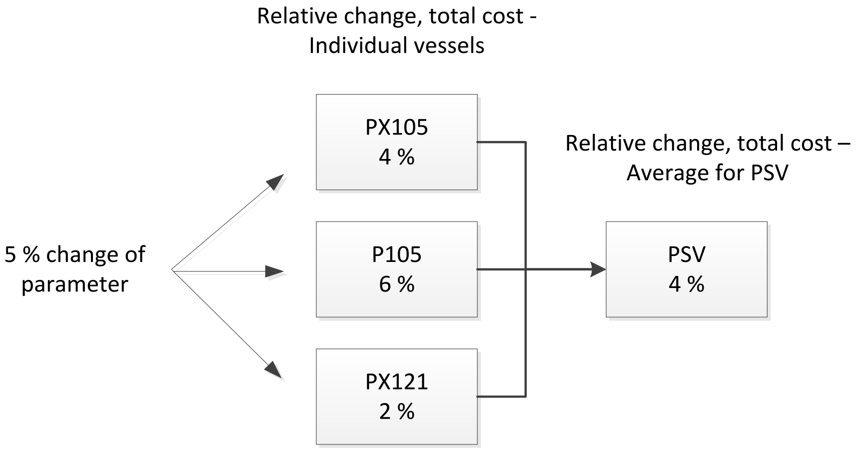


Figure 14 - Average relative change of total cost, hypothetical situation

The same process as illustrated in Figure 14 is done for several different changes of the performance parameter that is investigated. Scatter plots with the relative changes of a performance parameter on the x-axis and relative change of total building cost on the y-axis can then be made. With the same regression techniques as described in chapter 4.5, CERs that express the average relative consequence on total cost when changing a performance parameter can be developed. Figure 15 shows an example of a change CER:

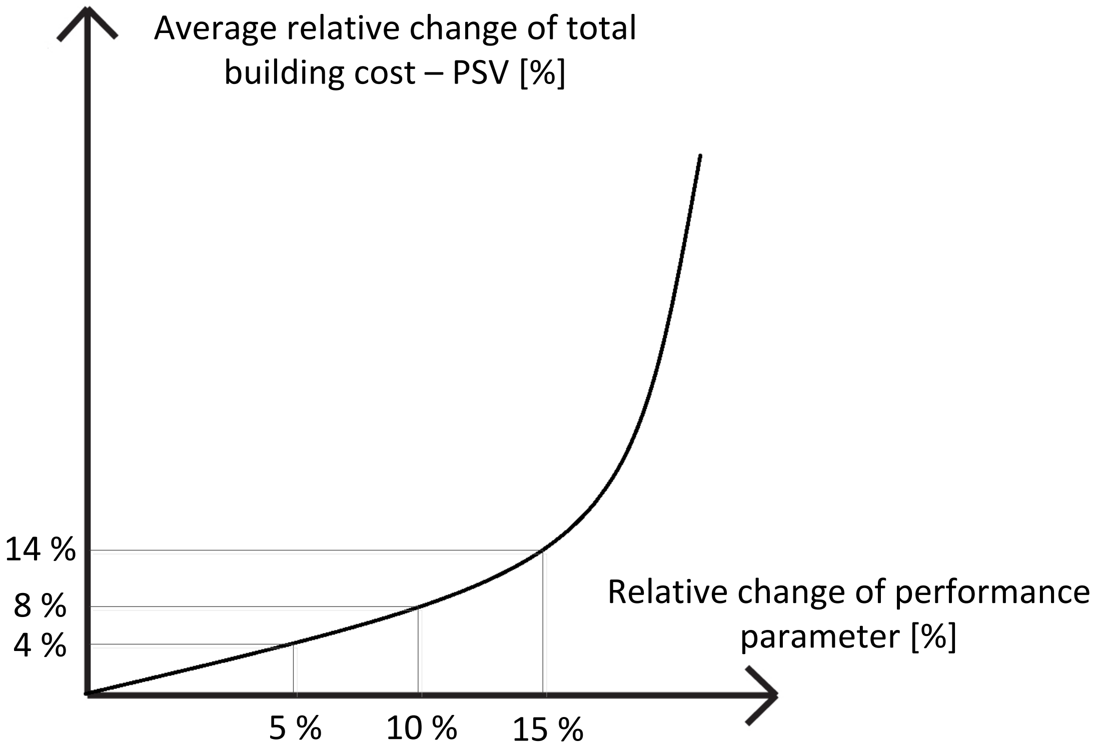


Figure 15 - Average relative change of total cost due to relative change of performance parameter

The final outcome of this method is a CER for each of the parameters selected in the beginning. The CERs express the relative effect of a change in one of these parameters would have on the total ship building cost. As mentioned above, the information that these CERs provide can be utilized differently by a shipbuilder. In negotiation processes with both shipbuilder and a potential customer where the overall performance specifications are discussed, these CERs can help the shipbuilder to respond quicker to a change in customer demands. With change-CERs based on historical data, the shipbuilder will have more leverage behind arguments in a discussion with a customer. The usage of change-CERs in these types of discussions implicit assumes that a change of a baseline or initial design is discussed.

Another area of application for the change-CERs is for gaining insight of the behavior of cost drivers in offshore shipbuilding. By comparing the cost driving effects the different parameters have on the total cost, it is possible to rank the parameters according to how sensitive the total cost is to a relative change. This is valuable knowledge and information for shipbuilders and -designers. Knowing which parameters that have bigger or smaller impact on the total cost can help shipbuilders to prioritize which cost drivers to focus on in a concept design phase.

The unit cost CERs can also be used to rank the importance of the cost driving parameters. As mentioned above, each technological group can hypothetically have one unit cost CER for every cost driving parameter. In reality, it is more likely that the technological groups have up to three relevant unit cost CERs. The comparison of the unit cost CERs for a technological group can help to identify which parts of the ship that are affected of the specific parameters. Or even more important; how they are affected.

"A greater understanding of the factors that drive costs can hopefully lead to a decrease in cost overruns for two reasons: 1. Designers will be in a better position to quickly perform trade off studies and therefore develop a better understanding of how their designs affect costs. 2. With an ability to perform reliable cost assessments at the preliminary level, the shipyards will be able to negotiate more favorable contract terms that could decrease costs." (Caprace and Rigo 2012)

4.9 The Error Compensation Effect

The reason for taking the average relative consequences due to changes in the cost driving parameters is to reduce the overall error. The principle of the error compensation effect is that positive and negative distributions of errors will partially cancel each other out. This is given that the errors are coincidental and that systematic errors do not arise during the calculation of the individual components. "Error cancellation means that if you have methods that are trying to predict the same result, but otherwise unrelated in such way that the error is not correlating to the outcome of the other method, then a cancellation effect will take place when you average the results from all methods." (Bjørhovde and Aasen 2012)

Another error compensation effect occurs because of the subdivision of the ship. "The accuracy of an estimation can be significantly improved when the overall forecasted value is calculated as the sum of its individual parts". (Fischer and Holbach 2011) The relative effects on the total shipbuilding cost are a sum of the effects on the four technological groups of the ship and would therefore benefit from this effect.

(Fischer and Holbach 2011) illustrates how the overall relative error is reduced when increasing the number of single forecast. By assuming a normal Gauss distribution, the relative error of the entire prognosis is:

$$f_{overall} = \sqrt{\frac{\sum_{i=1}^{n}(f_i * y_i)^2}{y_{overall}^2}} \tag{4.9}$$

Where

$f_{overall}$ = relative error of overall forecast value
f_i = relative error of individual forecast value
$y_{overall}$ = overall forecast value (sum of individual forecast values)
y_i = individual forecast value

Figure 16 demonstrates how the relative overall error for a forecast changes due to the number of individual forecasts when each forecast is calculated with an accuracy of ± 50 % and the individual percentages are equal.

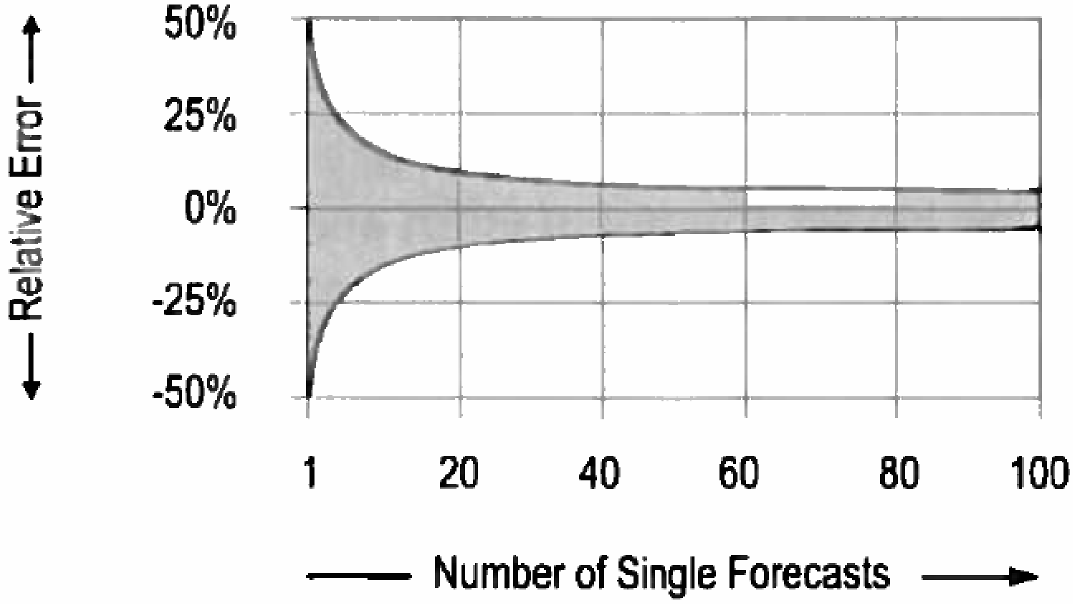


Figure 16 - Dependence of overall error on the number of individual forecasts. (Fischer and Holbach 2011)

The error compensation effect illustrated in Figure 16 is an illustration that shows the advantages of having a significant number of vessels in the database.

5 Case study – Testing Aspects of the Method

The initial intention of this chapter was to gather enough detailed cost data of modern built Norwegian PSVs to develop a database to perform a complete case study. With a database of normalized building cost data for several vessels, it would have been possible to test the method described above. It is a well-known fact within the shipbuilding cost estimation literature that gathering building cost data is a difficult task. Shipbuilding cost data is treated as confidential business information by shipyards and shipowners. The author got one set of complete cost data for the PSV M/V Bourbon Monsoon from Ulstein. With the cost data for M/V Bourbon Monsoon it is possible to group the 2-digit SFI groups according to the new subdivision into four or five technological groups and compare their portion of the total cost. However, it is not possible to perform regression analyses and find unit cost CERs with one set of cost data. One can only find the individual unit costs per parameter for the technological groups of Bourbon Monsoon alone. Despite the lack of a PSV cost database, it is still possible to demonstrate other aspects of the method. By using weight based cost CERs found in the literature one can show the regression technique in Solver and compare it to some of the built in functions in MS Excel.

5.1 M/V Bourbon Monsoon

Bourbon Monsoon was designed by Ulstein Design & Solutions AS and delivered by Ulstein Verft AS in 2007. The characteristics and specifications of the Bourbon Monsoon is representative for today's Norwegian PSVs fleet. She is also representative for the global PSV fleet. The main performance parameters are the following:

M/V Bourbon Monsoon		
Length over all	88,8	m
Breadth moulded	19	m
Draught max	6,6	m
Deadweight	4.779	t
Deck area	985	m^2
Speed	15,5	kn
Power	6.660	kW

Table 4 - Main dimensions M/V Bourbon Monsoon

The deadweight, deck area and LOA distributions for Norwegian PSVs delivered after year 2000 show that the majority of the vessels are in the same range as Bourbon Monsoon. (Shetelig 2012) These distributions are based on statistics on Norwegian offshore support vessels from the internet database www.ship-info.com (Shipping-Pubilcations 2012). The distributions are shown in Appendix B. 58 % of the global PSV fleet above 3.000 DWT per 1st January 2012 were classed by DNV. The M/V Bourbon Monsoon's DNV class notations are also representative for the PSVs classed by DNV. 72 % of the DNV classed PSVs from 2005-2011 had the same DYNPOS class, AUTR (DP2), as Bourbon Monsoon. The majority of the DNV classed PSVs also had the same heavy liquid class, HL (2.8), and environmental class, CLEAN DESIGN. (DNV; Eknes 2012)

5.2 Cost Distribution and Subdivision of M/V Bourbon Monsoon

The subdivision and regrouping of the SFI-groups of Bourbon Monsoon show that the cost components distribution follows the expected pattern as described in Table 3 in chapter 4.2. The hull and therefore most of the steel production was made in Poland and then towed to Ulstein Verft AS in

Ulsteinvik for outfitting and commissioning. This building strategy, with external steel production in low cost countries, is typical for both Ulstein Verft AS and several other Norwegian shipyards. There are some exceptions, like the neighboring yard Kleven Maritime AS which build their own hulls, but the cost components are most likely addressed at the same posts in the grouping system as well.

As described in chapter 4.2 it is possible to either include the SFI main group 1-Ship General in the new technological group 4-Common systems or keep it as an own technological group. In this case, the building costs are divided into a subdivision of five technological groups with Ship General as an individual group. The technological groups' relative portions of the total building cost are shown in the Table 5:

Technological group	Portion of total cost
1 - HULL	27 %
2 - MACHNIERY AND PROPULSION	31 %
3 - CARGO CONTAINMENT AND HANDLING EQUIPMENT	8 %
4 - COMMON SYSTEMS AND COSTS	25 %
5 - SHIP GENERAL	9 %

Table 5 - Cost distribution M/V Bourbon Monsoon

By comparing these values with the expected cost distribution in chapter 4.2, we see that the technological groups 1, 2 and 4 are in the same magnitude as expected. Main group 3-Cargo containment and cargo handling equipment have only a portion of 8 % which is less than the expected values. The reason may be that cargo tanks and the steelwork associated with them are accounted for in technological group 1-Hull. If this is the case, a theoretical increase of the required tank capacity as a performance parameter would have had larger impact on a unit cost curve for hull than for cargo equipment. Despite the differences in expected and the actual cost distribution in this particular case, it looks like the chosen subdivision and definition of technological groups is a good starting point for developing unit cost curves. Technological group 3-Cargo containment and handling equipment should be better defined and probably include some of the 2-digit groups from the SFI-system and not only the original groups from the SFI-group 3-Equipment for cargo. This group is mainly hatches, pumps and cranes, but do not include the tanks themselves. Tanks for both liquid and bulk cargo are important parts of a PSV, therefore one should be conscious of how the costs associated with them are addressed in a subdivision of the vessel.

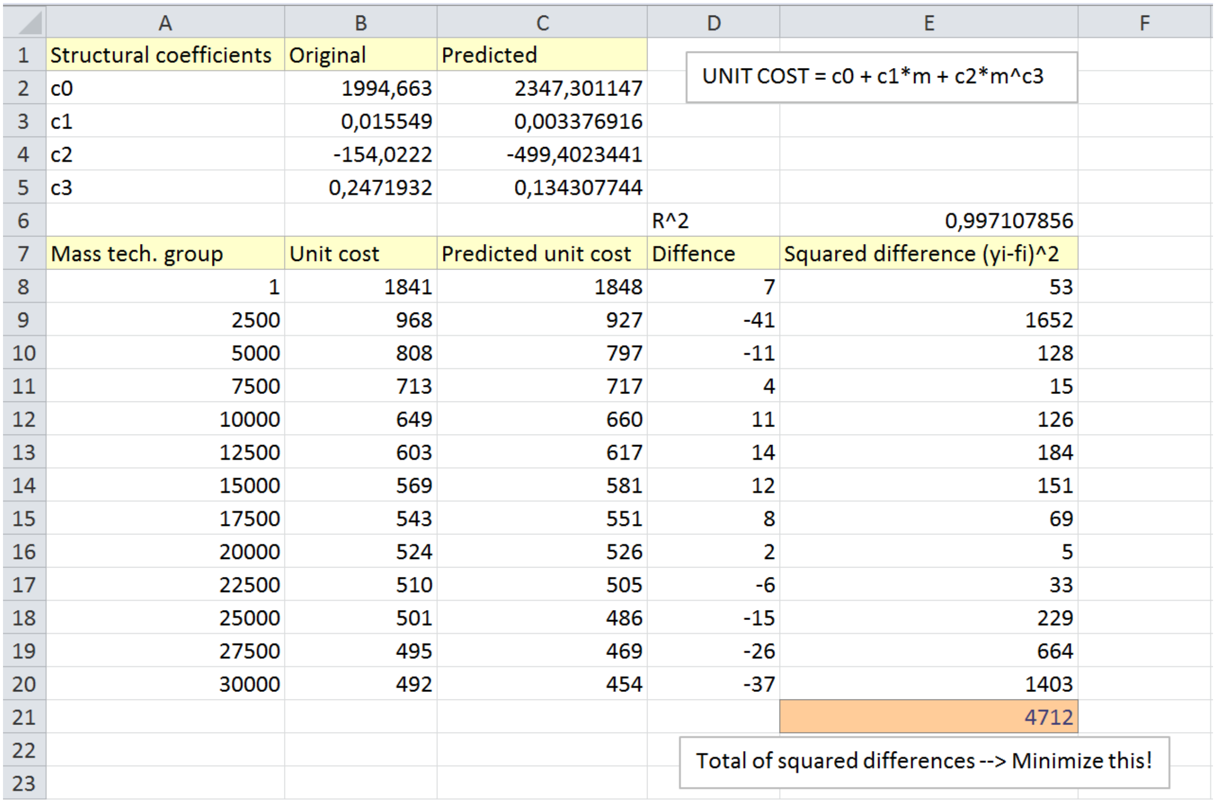
5.3 Regression with Solver in MS Excel

In some cases it is desirable to use regression functions with a different mathematical structure than the built in functions in MS Excel. In fact, one can only assume which function type that would describe a scatter plot best. By testing the different function types against each other, one can find the one with for example highest R^2-value and use that one. To show the process of finding a unit cost CER with Solver in MS Excel, weight based CERs found in the literature are used as a basis.

The original cost CERs were taken from (Michalski 2004) and express the relationship between a unit cost of a ships technological group and its weight. These were used to create scatter plots to test the Solver-regression and work as a control sample. The mathematical structure of the original unit cost CERs were the same as mentioned in chapter 3.6. To create the plots, the following function was used:

$$q_H = 1994{,}663 + 0{,}015549 * m_H + (-154{,}0222) * m_H^{0{,}2471932} \tag{5.1}$$

Where q_h is the unit cost for the technological group "Single deck hull" and m_h is the weight of the hull. First, unit costs for 0 to 30.000 tons with a step of 2.500 tons were found to generate a known scatter plot to use later for the Solver. Then a column with predicted unit costs for the same individual hull masses was set up. Since we know the mathematical structure of the original CER, we assume the same structure to be used for the regression function. The two next columns in the spreadsheet is the difference between the original values and the square of these differences. With reference to the method of least squares, we can use the Solver to minimize the total sum of the squared differences.



	A	B	C	D	E	F
1	Structural coefficients	Original	Predicted			
2	c0	1994,663	2347,301147			
3	c1	0,015549	0,003376916			
4	c2	-154,0222	-499,4023441			
5	c3	0,2471932	0,134307744			
6				R^2	0,997107856	
7	Mass tech. group	Unit cost	Predicted unit cost	Diffence	Squared difference (yi-fi)^2	
8	1	1841	1848	7	53	
9	2500	968	927	-41	1652	
10	5000	808	797	-11	128	
11	7500	713	717	4	15	
12	10000	649	660	11	126	
13	12500	603	617	14	184	
14	15000	569	581	12	151	
15	17500	543	551	8	69	
16	20000	524	526	2	5	
17	22500	510	505	-6	33	
18	25000	501	486	-15	229	
19	27500	495	469	-26	664	
20	30000	492	454	-37	1403	
21					4712	
22						
23						

UNIT COST = c0 + c1*m + c2*m^c3

Total of squared differences --> Minimize this!

Figure 17 - Screenshot of arrangement to be used in Solver

The total of squared differences is set as the objective cell, while the predicted structural coefficients are set as the variable cells. There is no need for constraints and the coefficients can be both positive and negative. In Solver, it is possible to choose different solving methods. When the equation producing the objective is not linear but continuous, the GRG Nonlinear method is chosen. With these settings, Solver returned predicted structural coefficients that gave a close to perfect regression result. The R^2-value of 0.99 also confirms this.

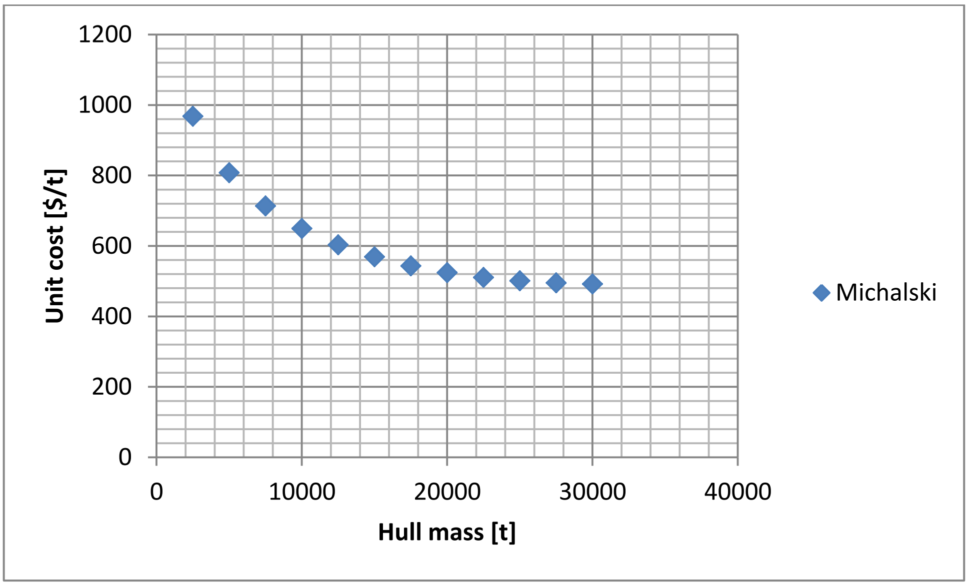


Figure 18 - Original unit cost curve from (Michalski 2004)

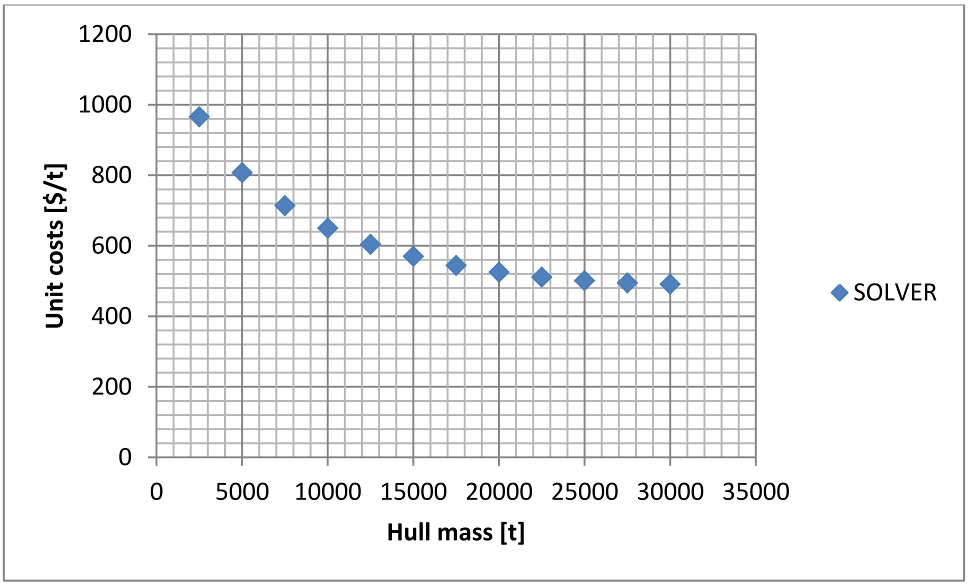


Figure 19 - Predicted unit cost curve with Solver – R^2=0.9971

Figure 18 and Figure 19 show both the original unit cost curve from (Michalski 2004) and the unit cost curve predicted by Solver. As we see from the plots, the unit cost curve from Solver is almost identical with the original one. It is not a surprise that a regression of a function returns the same function. The point is to show that it is possible to use Solver as a regression tool.

When comparing the regression in Solver with the built in function in MS Excel, the difference is insignificant. The built in power function in MS Excel returned a trend line with R^2-value of 0.99. This is shown in Figure 20.

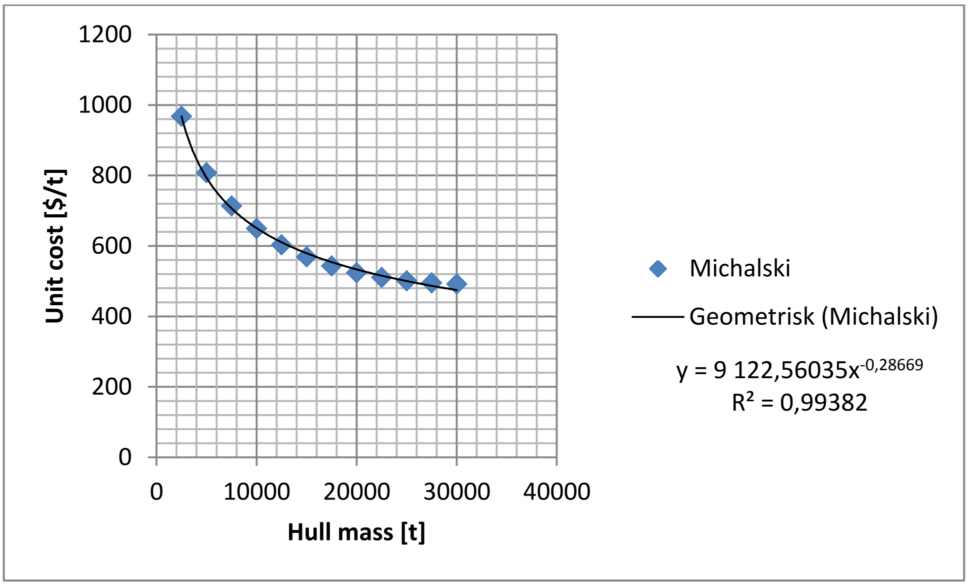


Figure 20 - Power function in MS Excel - R^2=0.99382

6 Discussion

This chapter will discuss specific choices and assumptions that are made in this thesis, but will also comment on some general challenges when dealing with shipbuilding cost estimation. Experiences made when working with the case study will also be discussed. The discussion regarding the method and the case will follow the same outline as chapter 4-Method description and 5-Case study and discuss relevant issues in the same order as they are addressed in the earlier chapters.

6.1 Discussion of the Method

The method in this thesis shows how to develop cost estimation relationships that express the relative change of the total ship building cost due to a relative change in a main ship parameter.

6.1.1 Selection of Cost Driving Parameters

The term parameter itself is a subject for discussion. By only focusing on parametric performance characteristics, it is difficult to trace and investigate the effects design choices with a more binary character have on the building cost. This would be features or characteristics the ship either have or do not have. Design choices of binary character are more typical for offshore support vessels than for conventional vessels because of the offshore vessels' relative high density of equipment and their complexity. Examples of these design features could either be specific equipment or equipment packages like an ROV-hangar, helideck etc. It could also be of more complex character which could be reflected in a class notation. For offshore support vessels, the actual DP-class is an important design feature that obviously would have had a huge impact on costs related to both machinery and propulsion.

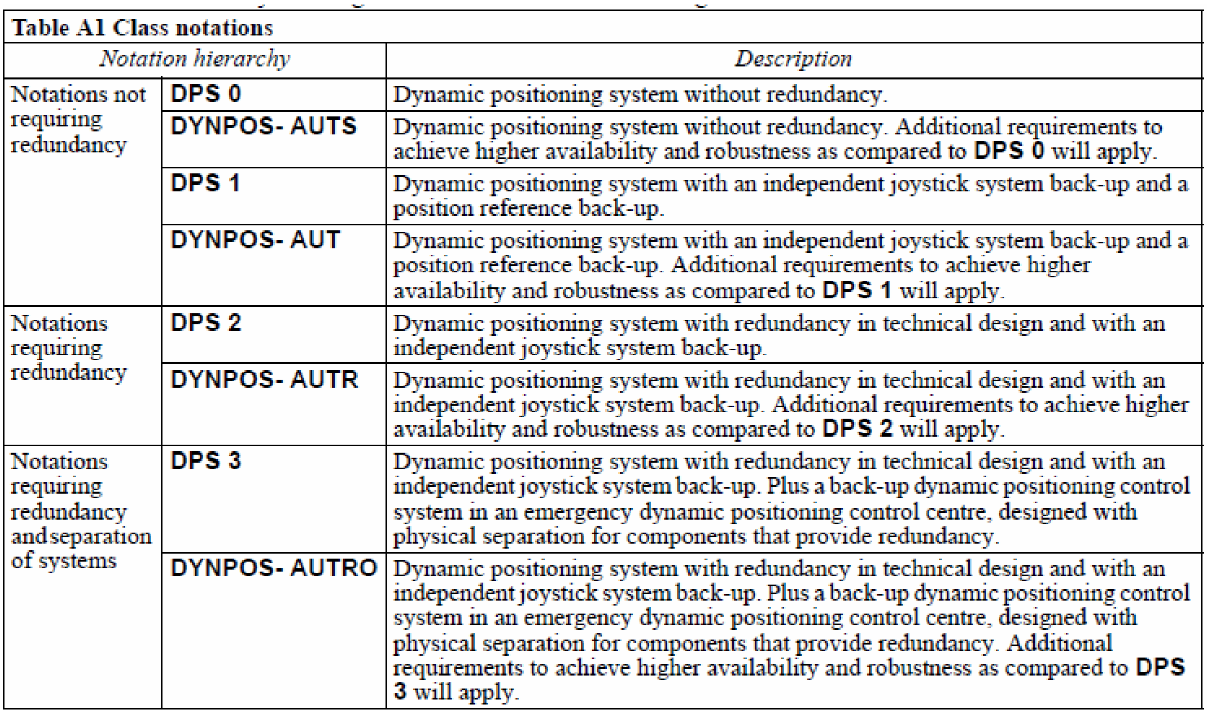


Table A1 Class notations

Notation hierarchy		*Description*
Notations not requiring redundancy	**DPS 0**	Dynamic positioning system without redundancy.
	DYNPOS- AUTS	Dynamic positioning system without redundancy. Additional requirements to achieve higher availability and robustness as compared to **DPS 0** will apply.
	DPS 1	Dynamic positioning system with an independent joystick system back-up and a position reference back-up.
	DYNPOS- AUT	Dynamic positioning system with an independent joystick system back-up and a position reference back-up. Additional requirements to achieve higher availability and robustness as compared to **DPS 1** will apply.
Notations requiring redundancy	**DPS 2**	Dynamic positioning system with redundancy in technical design and with an independent joystick system back-up.
	DYNPOS- AUTR	Dynamic positioning system with redundancy in technical design and with an independent joystick system back-up. Additional requirements to achieve higher availability and robustness as compared to **DPS 2** will apply.
Notations requiring redundancy and separation of systems	**DPS 3**	Dynamic positioning system with redundancy in technical design and with an independent joystick system back-up. Plus a back-up dynamic positioning control system in an emergency dynamic positioning control centre, designed with physical separation for components that provide redundancy.
	DYNPOS- AUTRO	Dynamic positioning system with redundancy in technical design and with an independent joystick system back-up. Plus a back-up dynamic positioning control system in an emergency dynamic positioning control centre, designed with physical separation for components that provide redundancy. Additional requirements to achieve higher availability and robustness as compared to **DPS 3** will apply.

Figure 21 - Dynamic positioning class notations (DNV 2011)

For DNV-classed offshore support vessels, it is typical to talk about dynamic positioning classes as; AUT (DP1), AUTR (DP2) and DP3 (AUTRO). The different requirements to redundancy for the different classes are significant as shown in Figure 21. This opens for a broad variety of different engine and machinery configurations. With only parametric performance parameters like speed or power related to machinery and propulsion, the effects the different machinery configurations have on the building costs are difficult to investigate. One idea could be to divide ship types like PSVs and AHTSs into subgroups according to for example their dynamic positioning class and then investigate the effect changes of parametric performance requirements would have on these subgroups. However, by doing this, it opens up for an unlimited forest of subgroups within the ship types. One would meet the same kind of problems with other class notations and binary design decisions. There would be one class of PSVs with helideck and one class for those without. The worst consequences of being too detailed when defining ship types would be a situation where every offshore support vessel represented their own specific ship type to investigate.

Other class notations and binary design decisions are not that important to focus on. With a majority of the newbuildings being delivered with for example FI-FI or OILREC class, it is not interesting to look at vessels without these characteristics. It is not interesting to investigate the consequences of removing these class notations either, since “all” the vessels have them.

In chapter 4.1 seven different parametric cost drivers are chosen to be investigated further for PSVs based on which parameters Ulstein looked at when doing studies regarding the relationship between different ship parameters and contract prices. Without the sufficient amount of cost data to perform own parametric studies and then get own experience, it is difficult to recommend specific parameters others should investigate further. The point is that Ulstein is a well reputable actor in the shipbuilding industry and that these seven parameters can be a reasonable starting point for further studies. Having in mind that there is a close relationship between shipbuilding cost and shipbuilding price, parameters that have had an effect on price are likely to have an effect on the costs as well. With that said, there is no guarantee that the effects changes in these parameters have on the total cost are easy to identify and describe with univariate scatter plots. As mentioned in chapter 4.3, Ulstein experienced in several cases that combinations of performance parameters correlated better with newbuilding price than individual parameters.

6.1.2 Operationalization and Breakdown Structure

There is no doubt that different cost driving parameters and design choices affect different parts of the vessel. An increase in bollard pull capacity will for example have large effect on cost components related to machinery and propulsion arrangement. Another example is length. There is no doubt that there is a need for more steel to increase a parameter that directly affects the hull. The question is whether the particular subdivision done in chapter 4.2 is the most suitable one for the development of unit cost CERs. Besides the main philosophy of looking at the ship as a tool with different tasks as referred to in chapter 4.2, and therefore divide it into four/five technological groups, it is advantageous to reduce the number of the original SFI main groups because of simplicity.

The advantages of using a standard work breakdown structure like the SFI-system as a basis is bigger than the flexibility of creating a new breakdown structure. It is more important to discuss the actual sorting of the 2-digit SFI-groups than the exact number of technological groups. The organizing shown in Appendix A is based on the author’s assumptions of costs components that are related. A more experienced ship constructor would maybe have combined the 2-digit SFI-groups differently. The relative small portion of the total costs technological group 3-Cargo containment and handling equipment had when sorting the building costs of M/V Bourbon Monsoon indicates that the current organizing of 2-digit groups should be revaluated.

Another issue to look at when organizing the 2-digit SFI-groups is the relative portion the cost components have within the technological groups. The author assumes that within each technological group, it is possible to identify a small quantity of components that make up a high percentage of the costs. These cost components sort of represent their technological group. With an organizing of the cost components from the SFI-system in such a way, it is easy to identify which components that actually are the physical cost drivers when a technological group is found to represent changes by a certain performance parameter. This contributes to a situation where decision makers hopefully can focus on the important components and identify them easily. "In order to maximize the efficiency of cost management measures, it is advisable to identify the main cost sources and to concentrate on these when searching for optimization potential. A ship consists of:

- A few components that make up a large percentage of the costs.
- A medium amount of components that make up a medium percentage of the costs.
- A large percentage of components that make up only a low percentage of costs." (Fischer and Holbach 2011)

This type of distribution occurs naturally in several different systems and with different types of parameters and is called the Pareto principle. It is also called the 80-20 rule which says that for many events; roughly 80 % of the effects come from 20 % of the causes. The actual expression 80-20 is more a rule of thumb than exact science and is therefore called a principle and not a rule or law. Figure 22 shows how the principal cost distribution described above.

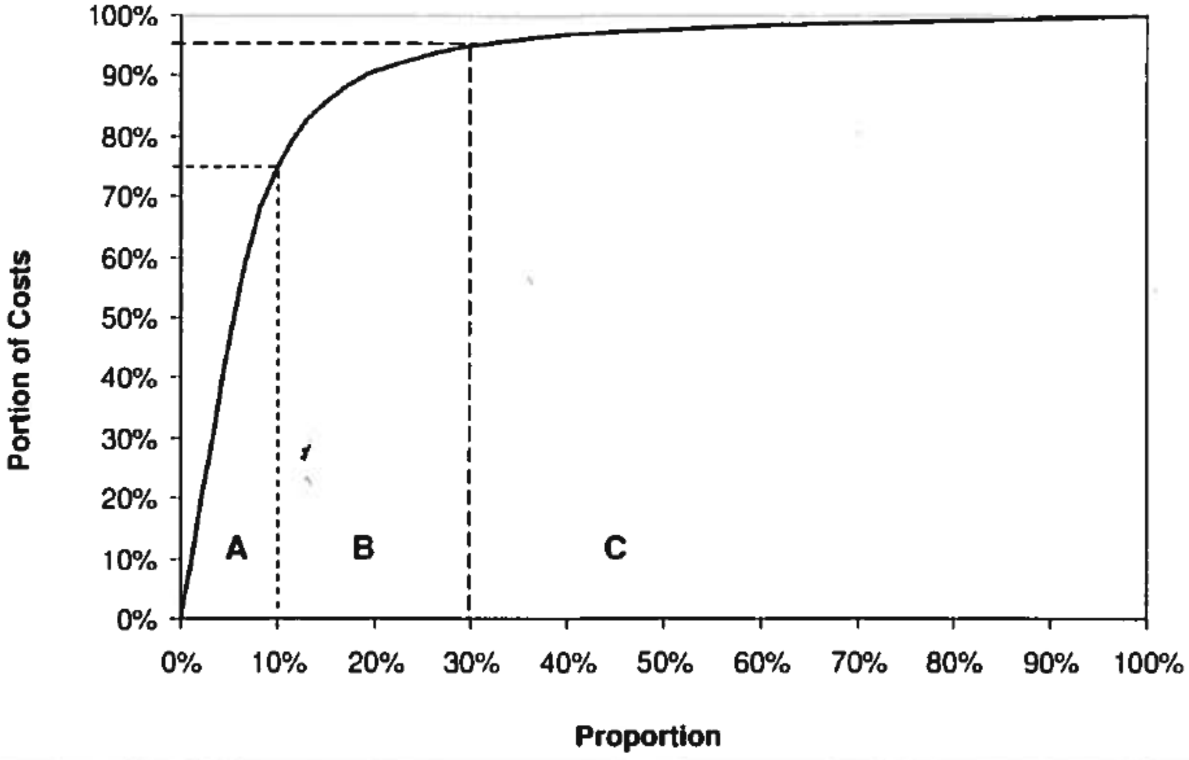


Figure 22 - A few components make up a large percentage of the costs (Fischer and Holbach 2011)

6.1.3 Unit Costs of Technological Groups

The reason to find unit cost per parameter for the technological groups is that it opens up for the opportunity to theoretically change the performance parameters and then trace the direct cost effects of the technological groups. Linear CERs and fixed cost rates are useful when actors in the industry are talking costing and pricing in lunch discussions. Without depreciating the value of a good lunch discussion and its potential commercial outcome, literature show that non-linear cost functions are preferred. Although non-linear cost functions are preferred before linear ones, it can still be difficult to find reasonable unit cost CERs. One of the big drawbacks so far with the method presented is that the unit cost CERs are so called univariate. The unit costs CERs have only one independent variable, the respective parameter. This is a natural consequence because the initial intention was to investigate the cost effects due a change in only one parameter at the time. The fact is that many of the ship's parameters are either loosely or closely tied together. It is difficult to show these relations formally even if experienced personnel tell which parameters that are corresponding.

We use the hull cost as an example. It is a well-known fact in the industry that hull costs are not only dependent on the actual amount of steel used or the steel weight. The curvature or shape defines how advanced the actual steel work is and a hull that requires a lot of steel work becomes more expensive because of the labor costs. According to personnel at Ulstein, the length parameter is known for being a relative expensive cost driving parameter compared to other main dimensions when it comes to hull cost. When a hull is lengthened, the midship bending moment increases and thicker steel plates are required in the decks at the middle. Despite that Ulstein is aware of this fact, it has been difficult to prove a significant relationship between newbuilding price and length.

Another issue to considerate when talking about unit costs is that the most expensive models of a product type tends to have a significant higher unit cost than the cheaper models of the same product type. There are several reasons for this effect. One reason is that suppliers allow themselves to charge higher relative prices for their top models or most expensive products. Another reason is that the biggest components may require extraordinary production resources at the suppliers' facilities and then rapidly increase the relative production costs. The effect is expected to show up as a hockey stick-shaped unit cost curve for the products where it is present. Figure 23 illustrates the hockey stick effect for a unit cost curve.

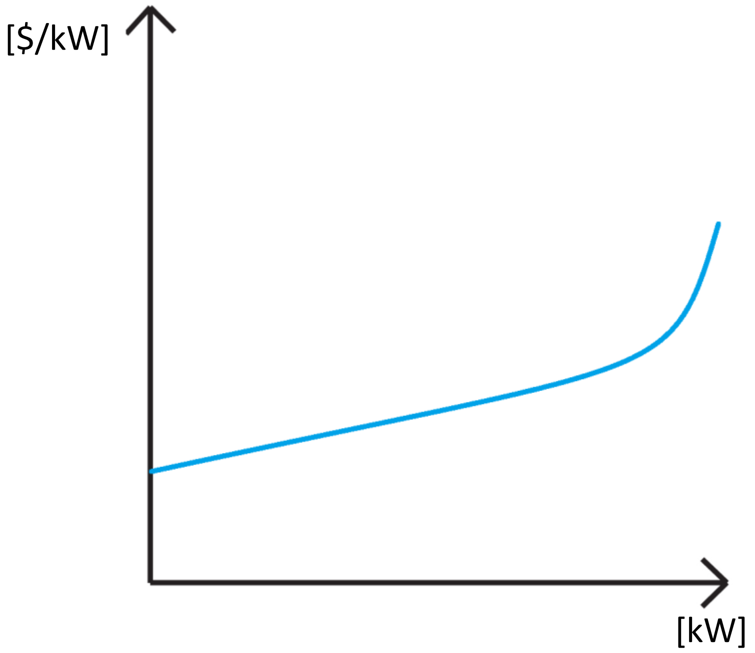


Figure 23 - Hockey stick-shaped graph for unit cost of ship main machinery

At first glance, there should be no problem to deal with the hockey stick effect. The only consequence would be a characteristic shape on the unit cost curve. However, despite the fact that the most expensive components dominate their technological group because of the Pareto principle, this effect can make some difficulties combined with another market effect. Namely that for example engines for the main machinery come in series with different sizes. This can result in discontinuous cost curves for the main machinery. The hockey stick-effect could therefore be present several places because every size series has its own hockey-stick.

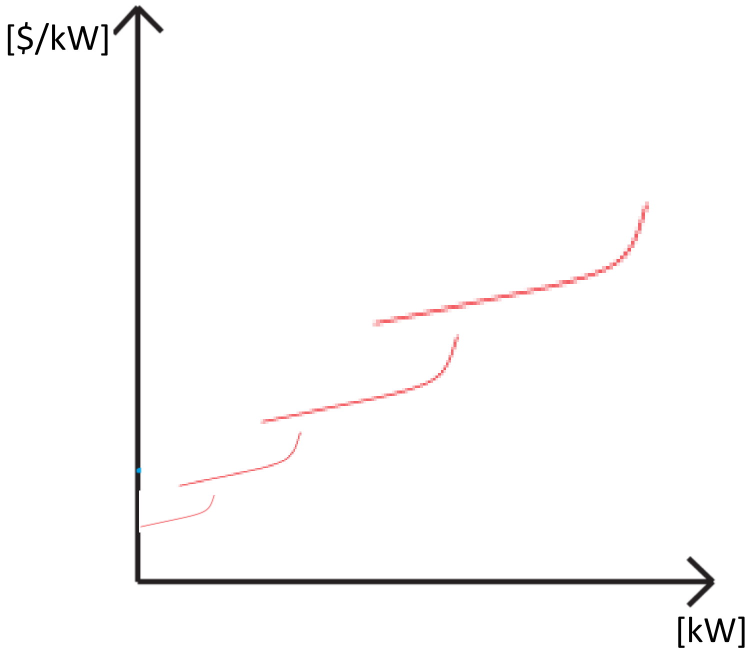


Figure 24 - Several hockey sticks because of engine series

In the example above, engine power is used to illustrate the hockey stick effect for ship engines. With many different engine configuration alternatives due to for example different redundancy requirements, it may be hard to develop a CER for machinery and propulsion that only has power as the independent parameter.

6.1.4 Normalization and Regression Analysis

Normalization and preparation of input data is maybe the most important step to prevent the "garbage in – garbage out" effect. As mentioned in chapter 4, a good model is not worth anything with poor quality of the input data. Nevertheless is it a fact that the world has never been perfect, nor has the input data been. One can do endless tweaking and adjusting of the historical data before feeding them to model. Still, the most important thing is to know what the original data represented in the first place. Worse than presenting results based on garbage data, is to present results based on garbage data without being aware of it. Before starting the normalization process at all, one has to keep track of which expenses that are included in the recorded cost data. There are for example different types of labor costs. In periods with high activity, external personnel are hired to help the yard cope with peaks in production. Another relevant issue is how hull costs are recorded when a yard buys the hull from an external yard like many Norwegian offshore ship yards do.

The point is that if the information obtained by using this method is used to support arguments in either an internal or external negotiation process, the user has to know what that information is based on. This contributes to both increased integrity and trustworthiness for the negotiator and works as an insurance against counter-arguments from the other part.

According the recommended amount of at least 20 ships in the database, as mentioned, this is dependent on the availability of data. The number 20 is meant as a guiding number. As for the quality and format of data, the most important issue is that the user of the final outcome knows what the results are based on also in terms of how many ships that are in the database. Because of the fact that the method described in this thesis is based on historical data and its nature demands a database, it may be hard for green field yards, start-up companies or other actors without own building record to utilize this method’s potential.

6.1.5 Generating the Regression Function

The two different regression alternatives presented in the thesis are both based on MS Excel. It exist other computer software for regression analyses on the market. Some programs are even tailor made for the purpose of statistical- regression analysis. The advantage of using MS Excel is its already huge market share and that many people are already familiar with this software. One potential problem when using the built in trend line functions in MS Excel is the number of digits the regression function returns. When checking the box that displays the function, the predefined settings in MS Excel return the regression function with only a few digits. If not aware of this fact, the later use of the regression functions may result in an unnecessary inaccuracy. On the other hand, the built in trend lines in MS Excel are very easy to use even for the most inexperienced personnel. The Solver is also easy to use, but it requires that the user put a bit more effort in understanding the procedure.

6.1.6 Evaluating the Regression Function

As mentioned in chapter 4.6, the R^2-value is a good measurement index to evaluate the regression function because it is easy to compare the built in functions and the Solver-function. There are some issues to be aware of when using the R^2-value as an indicator to ascertain whether the regression function fulfills the minimum requirements of prognosis quality. Besides the actual degree of correlation, the size of the control sample also has an influence on the R^2-value. Smaller populations tend to lead to an increase in the stability index. Because of this, there is no reason to get over enthusiastic when obtaining a R^2-value close to 1.0 if the population is small. (Fischer and Holbach 2011) There is no strict definition of how small a “small” population is. Therefore it is advantageous to test the regression function with objects that are not present in the control sample.

6.1.7 Theoretically Changing Performance Parameters to Log Consequences

Chapter 4.7 shows an example of how a 5 % relative change of an arbitrary performance parameter affects the total building cost through first changing the affected technological group’s individual cost. In the example, only one technological group’s cost is affected because of the change in the parameter. If the technological group’s relative cost is known, one could directly calculate the relative change of the total building cost instead of summarize the costs for all the technological groups. However, in cases where more than one technological group is affected, the method described in chapter 4.7 is the preferred one.

6.1.8 Average Relative Total Cost Consequences

Chapter 4.8 describes how the final CERs are developed by plotting the average relative consequences on the total cost versus the relative change of the performance parameters. What this thesis does not define, is which intervals of relative parameter changes that is reasonable to investigate. It is hard to say whether for example 20 % or 50 % relative increase (or decrease) of propulsion power is the reasonable upper limit for investigating the total cost consequences before getting clearly unrealistic results at a certain point. In reality, this should not be a problem because the upper limit of how big relative changes that are possible to investigate are limited by the individual unit cost curves for the technological groups.

In contrast to the unit cost curves for the technological groups, it is difficult to test the actual reliability of the average relative change-CERs with real cases. Because there most likely is no existing formal framework to check validity of the change CERs, one has to trust the R^2-values and that quality of the input data are satisfactory. Another way of testing the validity of the final change CERs is to discuss the results with experienced personnel at the shipyard. They often have a set of rules of thumb that can give an indication of whether one is on the right track or not. As mentioned in chapter 4.8, an incentive for developing and using a method like the one described in this thesis is to get more formal backing behind arguments that traditionally have been based on exactly rules of thumb.

6.1.9 The Error Compensation Effect

The error compensation effects described in chapter 4.9 is based on situations where different independent methods are trying to predict the same result. With a certain number of methods, the theory is that their individual errors will cancel each other out. There is no guarantee that we will face a normal Gauss distribution like in the illustrative example taken from (Fischer and Holbach 2011) in practice. However, the example gives an extra motivation for both gathering sufficient amounts of cost data and keeping a focus on a sane subdivision of the vessels' cost components.

6.2 Discussion of the Case

As mentioned in chapter 5, the initial intention of that chapter was to test the method in practice with a real database of normalized cost data for PSVs and get relative change-CERs to discuss. In fact, the original idea was that the final outcome to be presented from this thesis was supposed to be a set of relative change-CERs for offshore support vessels. When working with the subject, the author realized that final product instead would be the actual development of the method itself.

The obvious advantages of testing the method with actual cost data would be the ability to check and verify the validity of the method. Especially the issue with the degree of uncertainty is very difficult to evaluate and discuss without having results to compare with original data. With an impression of which accuracy domain both the returned unit cost curves for the technological groups and the relative change-CERs operated in, it is easier to define and recommend areas of application for the method.

6.2.1 Cost Distribution and Subdivision of M/V Bourbon Monsoon

With the cost data for the M/V Bourbon Monsoon it was possible to sort the 2-digit SFI-groups into the same technological groups as presented in chapter 4.2. The comparison of the expected cost distribution and the actual cost distribution for M/V Bourbon Monsoon showed that it could be an idea to evaluate the particular subdivision used in this method. However, only one set of cost data is not enough to draw strict conclusions.

6.2.2 Regression with Solver in MS Excel

Chapter 5.3 shows an alternative way of generating a regression function in MS Excel than the standard built in functions. There is no doubt that the built in functions in MS Excel can produce regression functions with satisfying results. From the regression performed in the case study, the two methods were equally accurate in terms of the R^2-cofficient. The extraordinary high R^2-values obtained by both methods are not representative for what one could expect in a real regression analysis. In lack of other cost data, the weight based unit cost CERs worked as a scatter plot. Since the coordinates was not scattered at all, but all were lying on the same function line, it is no surprise that it was easy for regression software to generate accurate functions.

What this thesis has not described or discussed is the use of other regression tools than those available in MS Excel. This is because the author has little experience in the use of commercial statistical software. There is no strict requirement to use MS Excel to generate the different cost curves and regression functions. If other software can provide either better user interface, results or both, it is obvious that the best product should be used. Such decisions are up to a potential user of this method to make.

7 Conclusion and Further Work

Offshore support vessels are known for their complex nature, a high density of expensive equipment and varieties in equipment configurations. This makes cost estimation of these ship types more difficult and comprehensive than for other low complexity ship types. Besides factors specially related to offshore support vessels, ship building cost estimation is still a difficult task for shipyard personnel. In a globalized industry, external market effects play a significant role in both costing and pricing of every cost component in a newbuilding project. This would be labor, material and financial costs.

The main conclusion of this thesis is that it is possible to develop and use cost estimating relationships to evaluate and express the relative consequences changes of high level performance requirements have on the total ship building cost. The relative change-CERs can be utilized differently by actors in the shipbuilding industry. In negotiation processes, change CERs based on historical cost data can provide a better foundation and documentation for arguments in discussions with potential customers. With change CERs based on historical data, the shipbuilder will have more leverage behind his or hers sales arguments.

In situations where changes of important performance parameters are discussed between yard and customer, the use of change CERs can contribute to reduced response time for the yard to come up with a new ship building cost estimate.

Another area of application for relative change CERs is for gaining insight of the behavior of important cost drivers in offshore ship building. With a set of unit cost curves and change CERs, it is possible to identify how the different parts of the ship are affected by a change in certain ship parameters. That information can be used to rank the different ship parameters according to their importance and relative influence on the total ship building cost.

Without a sufficient amount of available building cost data for offshore support vessels, it is difficult to investigate and draw conclusions of what the level of accuracy would be for the relative change-CERs. The next phase of working with this subject would be to develop a database with cost data for offshore support vessels and test the validity and level of accuracy for the method described in this thesis. It is important to know in which domain of uncertainty one operates when dealing with estimates and forecasts.

Further work would also include developing the method to cope with not only parametrical performance requirements, but also binary design features. This is especially important when dealing with offshore support vessels where these issues are most relevant.

8 References

Bertram, V. M., Jean-Jacques ; Caprace, Jean-David; Rigo, Philippe (2005). "Cost Assessment in Ship Production." RINA.

Bjørhovde, S. and R. Aasen (2012). 3562. Parametric Estimation Of Anchor Handling / Towing Winches. 71st Annual Conference, Bad Gögging, Germany. Bad Gögging, Germany, Society of Allied Weight Engineers, Inc.**:** 13.

Brown, A. M. (2001). "A step-by-step guide to non-linear regression analysis of experimental data using a Microsoft Excel spreadsheet." Computer Methods and Programs in Biomedicine **65**(3): 191-200.

Caprace, J. D. and P. Rigo (2012). "Towards a short time “feature-based costing” for ship design." Journal of Marine Science and Technology **17**(2): 216-230.

DNV (2011). Rules for classifications of Ships, Part 6 Chapter 7. Dynamic Positioning systems.

DNV; Eknes, A. (2012). Platform supply vessels in DNV class - Internal Presentation.

Erichsen, S. (1989). Management of marine design. London, Butterworths.

Fischer, J. O. and G. Holbach (2011). Cost management in shipbuilding : planning, analysing and controlling product cost in the maritime industry. Koeln, GKP Publishing.

ISPA (2008). Parametric estimating handbook, 4th edition.

Merriam-Webster (2013). "Working hypothesis." Retrieved 05.06.2013, from http://www.merriam-webster.com/dictionary/working%20hypothesis.

Michalski, J. P. (2004). "Parametric method of preliminary prediction of the ship building costs." Polish Maritime Research.

NASA Cost Analysis Division (2008). 2008 Cost Estimating Handbook.

Ross, J. M. (2004). A practical approach for ship construction cost estimating. COMPIT.

Roy, R. (2003). Cost Engineering: Why, What and How? Decision Engineering Report Series, Cranfield University.

Saravi, M., et al. (2008). Estimating cost at the conceptual design stage to optimize design in terms of performance and cost, Belfast.

Shetelig, H. (2012). Design parameters and system choices as cost drivers. NTNU. Trondheim.

Shipping-Pubilcations (2012). "Ship-Info." Retrieved 22.10.2012, from http://ship-info.com/prog/search2.asp.

SpecTec (2012) AMOS SFI Group System.

Ulstein International AS (2011). Parametric Analysis - AHTS 10.000+ BHP, PSV 2000+ DWT - Internal Presentation.

9 Appendices

Appendix A – Subdivision Based on SFI Group System

MAIN GROUP	GROUP
0 - SHIP GENERAL	10 - Specification, estimating, drawing, instruction, courses
	11 - Insurance, fees, certificates, representation
	12 - Quality assurance, general work, models
	13 - Provisional rigging
	14 - Work on ways, launching, docking
	15 - Quality control, measurements, tests, trials
	16 - Guarantee/mending work
	17 - Ship repair, special services
	19 - Consumption articles
	SUM SHIP GENERAL
1 - HULL	20 - Hull materials, general hull work
	21 - Afterbody
	22 - Engine area
	23 - Cargo area - hull small vessels
	24 - Forebody
	25 - Deck houses and superstructures
	26 - Hull outfitting
	27 - Material protection, external
	28 - Material protection, internal
	29 - Miscellaneous hull work (not standard
	SUM HULL
2 - MACHINERY AND PROPULSION	40 - Manoeuvring machinery, equipment
	45 - Lifting, transport equipment for machinery components
	60 - Diesel engines for propulsion
	61 - Steam machinery for propulsion
	62 - Other types of propulsion machinery
	63 - Propellers, transmissions, foils
	64 - Boilers, steam, gas generators
	65 - Motor aggregates for main electric power production
	66 - Other aggr., gen. for main, emergency el. power production
	67 - Nuclear reactor plants
	70 - Fuel systems
	71 - Lube oil systems
	72 - Cooling systems
	73 - Compressed air systems
	74 - Exhaust systems, air intakes
	75 - Steam, condensate, feed water systems
	76 - Distilled, make-up water systems
	79 - Automation systems for machinery
	84 - Central heat transfer systems w/chemical fluids/oil
	SUM MACHINERY AND PROPULSION

3- PAYLOAD EQUIPMENT	30 - Hatches, ports
	31 - Equipment for cargo in holds/on deck
	32 - Special cargo handling equipment
	33 - Deck cranes for cargo
	34 - Masts, derrick posts, rigging, winches for cargo
	35 - Loading/discharging systems for liquid cargo
	36 - Freezing, refrigerating, heating systems for cargo
	37 - Gas/ventilation systems for cargo holds/tanks
	38 - Auxiliary systems, equipment for cargo
	82 - Air, sounding systems from tanks to deck
	46 - Hunting, fishing equipment
	47 - Armament, weapon, weapon countermeasures
	48 - Special equipment
	49 - Fish processing equipment
	83 - Special common hydraulic oil systems
	SUM PAYLOAD EQUIPMENT
4- COMMON SYSTEMS	41 - Navigation, searching equipment
	42 - Communication equipment
	43 - Anchoring, mooring, towing equipment
	44 - Rep./maint./clean. equip. workshop/store outfit, name plates
	50 - Lifesaving, protection, medical equipment
	51 - Insulation, panels, bulkheads, doors, sidescuttles,skylights
	52 - Internal deck covering, ladders, steps, railing
	53 - Ext. deck covering, ladders, steps, fore, aft gangway
	54 - Furniture, inventory, entertainment equipment
	55 - Galley/pantry equip., provision plants, laundry/ironing equ.
	56 - Transport equipment for crew, passengers, provisions
	57 - Ventilation, air-conditioning, heating systems
	58 - Sanitary syst. w/discharges, accommodation drain systems
	59 - Passenger vessel cabins, public rooms
	80 - Ballast, bilge systems, gutter pipes outside accommod.
	81 - Fire, lifeboat alarm, fire fighting and wash down systems
	85 - Common electric, electronic systems
	86 - Electric power supply
	87 - Common electric distribution systems
	88 - Electric cable installation
	89 - Electric consumer systems
	SUM COMMON SYSTEMS
	SUM

Appendix B – PSV Distributions 2000-2012 Taken From (Shetelig 2012)