NTNU
Norwegian University of
Science and Technology

# Configuration Based Design, Standardization and Modularization in Offshore Vessel Design

**Marcus Langseth Nickelsen**

Marine Technology
Submission date: June 2017
Supervisor: Stein Ove Erikstad, IMT

Norwegian University of Science and Technology
Department of Marine Technology

# PREFACE

This document constitutes the Master's thesis, which is the final part of the Master of Science degree, conducted at the Department of Marine Technology at The Norwegian University of Science and Technology (NTNU). The workload corresponds to 30 ECTS, and was in this case conducted during the spring semester of 2017.

I want to acknowledge my supervisor, Professor Stein Ove Erikstad, for constructive feedback, inspiring discussions and helpful comments during this thesis.

Further, gratitude is extended to Ulstein Group ASA for providing the offshore vessel database and to NTNU Aalesund for providing the licence for Siemens NX.

The problem description is attached in Appendix A. There are some deviations between this description and the thesis. Firstly, the overall aim and focus has been re-written as "The Goal of the Thesis" (see page 6), but still captures the same overall aims. Further, point 3e, 5bc and 6 in the problem description are not included in the thesis, due to insufficient time and resources, and unforeseen challenges with the application mentioned in point 5. For the latter, it became apparent that developing an application would consume too much time.

Trondheim, 11.06.2017.

Marcus L. Nickelsen

Marcus L. Nickelsen

# SUMMARY


Recent low oil prices have caused a downturn of activities in several maritime industries, resulting in increased competition and pushing companies to simultaneously increase their position in the market and reduce cost levels to gain a competitive edge. For many companies, it is problematic to maintain a sufficient level of profit, even avoiding bankruptcy, during a downturn of such magnitude as the oil price drop in 2014. Short-term solution includes laying off employees who are deemed excessive. However, this is presumably not a sustainable solution for companies with long term goals. In a tough and competitive market, other solutions are required. The *solution space* is represented by the solutions which in return increases value robustness, that is, the ability of a system to continue to deliver stakeholder value in the face of changing contexts and needs (Ross and Rhodes, 2008).

Utilizing proven concepts and solutions from other industries towards ships and maritime systems can prove to be efficient, and is the solution chosen for further research. The overall goal of this thesis is to investigate the potential benefits, drawbacks and challenges with a configuration based design (CBD) strategy, including standardization and modularization. In addition, the following questions are to be answered: (1) What are the key challenges to why CBD is not a standard in ship design, as it is in industries such as the automotive and computer industry? (2) Why should the ship customer be allowed heavy influence the design and engineering decisions? (3) In the context of the topics covered in this thesis, what is expected from the future of ship design?

A case study is constructed as a tool to help achieve the goal of the thesis. It combines the three distinct areas of research in a single, practical case. The case will use a platform supply vessel (PSV) as the study object. The result of the case is a ship configurator, that is, an intuitive interface, through which a designer can configure a ship, based on a set of given customer requirements. Simultaneously, a 3D-model is developed, and is after configuration, exported to AutoCAD for development of a general arrangement.

The main findings show that of the three distinct areas, standardization is assessed to be the area with most associated benefits, and examples include shorter design and production lead time and lower cost per unit. Further, modularization is the area with most challenges yet to be overcome, such as mapping of complex system interactions, definition of modules and mapping between form and performance. Lastly, relevant benefits of CBD include rapid response during tendering, designer friendly and a flexible design process, but requires a solid foundation of design and engineering in standardization and/or modularization.

Thus, it can be concluded that the chosen solution may act as a value robust solution. However, there are various obstacles along the path towards this solution, which science is yet to overcome.

# SAMMENDRAG


Den nylige nedgangen i oljeprisen har forårsaket en nedgang blant aktivitetene i den maritime næringen, noe som har resultert i økt konkurranse blant selskapene, noe som krever at de samtidig må øke posisjonen i markedet og redusere kostnadsnivåer for å oppnå et konkurransefortrinn. For mange bedrifter er det problematisk å opprettholde et tilstrekkelig profittnivå, eller unngå konkurs, i en nedgang som oljeprisfallet i 2014. Kortsiktige løsninger inkluderer å oppsi overflødige ansatte. Dette er imidlertid ikke en bærekraftig løsning for selskaper med langsiktige mål. I et marked med høy konkurranse kreves andre løsninger. *De mulige løsningene* representeres av løsninger som over tid øker robustheten til designfirmaet, det vil si, evnen til firmaet til å levere verdi til interessentene gjennom endrende kontekst (Ross and Rhodes, 2008).

Å utnytte konsepter og løsninger fra andre næringer mot skip og maritime systemer kan vise seg å være effektivt, og dette er løsningen som er valgt til videre undersøkelser. Det overordnede målet med avhandlingen er å undersøke de potensielle fordelene med en konfigurasjonsbasert design (KBD) strategi, inkludert standardisering og modularisering. I tillegg skal følgende spørsmål besvares: (1) Hva er de viktigste grunnene til at KBD ikke er en standard i skipsdesign, som det er i bransjer som bilindustrien og dataindustrien? (2) Hvorfor skal skipskunden ha stor innflytelse over design- og ingeniøravslutninger? (3) I konteksten av emnene i denne avhandlingen, hva forventes av fremtiden til skipsdesign?

Et case-studie er inkludert som en måte å oppnå målet i avhandlingen. Case-studiet kombinerer de tre distinkte forskningsområdene i én enkelt, praktisk case. Case-studiet bruker et forsyningsskip (engelsk: platform supply vessel (PSV)) som studieobjekt. Resultatet av casen er en skipskonfigurator, det vil si et grensesnitt som en designer kan bruke til å tilpasse et skip etter et sett med gitte kundekrav. Samtidig utvikles en 3D-modell, og etter konfigurasjon eksporteres modellen til AutoCAD for utvikling av et generalarrangement.

Hovedresultatene viser at av de tre distinkte områdene, så er standardisering området med flest tilknyttede fordeler. Dette inkluderer blant annet kortere design- og produksjonstid og lavere kostnad per enhet. Videre er modularisering det området med de fleste utfordringene som må overkommes. Dette inkluderer utfordringer som kartlegging av komplekse systeminteraksjoner, definisjon av moduler og kartlegging mellom form og ytelse. Til slutt, interessante fordeler med KBD inkluderer rask respons under forespørsel, intuitivt design grensesnitt og en fleksibel designprosess, men KBD kreves et solid grunnlag i design- og ingeniørarbeid i standardisering og/eller modularisering.

Til slutt kan det bli konkludert med at den valgte løsningen kan over tid øke robustheten til designfirmaet. Imidlertid er det ulike utfordringer langs veien mot denne løsningen, som vitenskapen har til gode å løse.

# TABLE OF CONTENTS

# List of Captions

# LIST OF TABLES

# Part I BACKGROUND

# 1 INTRODUCTION

## 1.1 Problem description

Recent low oil prices have caused a downturn of activities (contracts) in several maritime industries, resulting in increased competition and pushing companies to simultaneously increase their position in the market and reduce cost levels to gain a competitive edge.

For many companies, it is problematic to maintain a sufficient level of profit, even avoiding bankruptcy, during a downturn of such magnitude as the oil price drop in 2014. A short-term solution is to lay off employees who are deemed excessive due to the downturn of contracts. However, this is presumably not a sustainable solution for companies with long term goals and stakeholders expecting return on investment (ROI). In a tough and competitive market, other solutions are required.

## 1.2 The solution space

The *solution space* is represented by the solutions which in return increases value robustness, which is defined as the ability of a system to continue to deliver stakeholder value in the face of changing contexts and needs (Ross and Rhodes, 2008). The system in this context is a ship design company. Changing contexts and needs implies temporal changes both downstream (the customer: oil price, demand fluctuations, etc.) and upstream (the yard: building strategy, technology, classification, etc.).

This forces ship design companies to invest internally and/or externally to find such value robust solutions which, in the business end, leads to an increase in contracts. The following sub-chapters include a brief outlook on some relevant solutions to the problem described in the sub-chapter 1.1.

### 1.2.1 Investing in employees

A solution is to invest internally in the company's employees. This can be done by arranging courses, lectures or seminars, even send employees to universities for further education. The goal is that the employees find new solutions and innovations by having a refreshed, wider and deeper view on the current technology. An example in the industry is from 2016, when Ulstein arranged an extensive course in systems engineering for their employees, to be better prepared for the future (Ulstein, 2016). However, the main risk related to this solution is that there is a requirement for a capital investment, which in time, might not pay off as there are no guarantees for new discoveries.

### 1.2.2 Explore other market segments

Another solution is to explore other market segments. For example, there is a drive for both inshore and offshore aquaculture (fish farms), which requires new offshore certified well boats. Design companies with previous offshore designs may utilize their experience with offshore conditions, thus gaining a competitive edge in this segment. This may also apply for offshore wind construction and maintenance, which is another interesting market segment gaining both interest and investments. A turnaround to a new market segment presumably requires skilled employees across disciplines and well as financial investments, to handle all aspects of the turnaround. In addition, challenges with turnarounds include: risks connected to entering a new segment, company reputation and position in the new segment, establishing new customer and supplier relations and having order-winning design solutions. However, if the turnaround is timed and executed correctly, there presumably exists large financial benefits. One example is Ulstein. They have launched new ship design series and are building the world's largest hybrid vessel (Ulstein, 2017).

#### 1.2.3 Collaborating with academia

Companies may turn to academia and research to seek out new ways on how to reduce cost levels in e.g. design and construction or to find new and innovative solutions. There might exist untapped knowledge or methodologies to apply on an industrial basis. Examples here can be to engage students in projects or collaborating with dissertations, and to sponsor research work. This is presumably a medium-term investment, which implies that if the company is in immediate risk of going bankrupt, it is not most robust best solution.

#### 1.2.4 Inspiration from other industries

The ship design companies can find solutions by looking to other industries such as the automotive, computer, furniture and aerospace industry for inspiration. Utilizing proven concepts and solutions from such industries towards ships and maritime systems, can prove to be efficient. Especially interesting are some of the design strategies, utilized by the mentioned industries. Key terms associated with this strategy are standardization, modularization and CBD (CBD).

An example is found in the automotive industry, where several car manufacturers such as Mercedes-Benz, BMW, Volkswagen, Tesla and Toyota, offer configurable cars. That is, the customer can add, remove or scale pre-defined systems to customize the car to their preferences. This service is usually accessible through the companies' websites, and requires no special skills from the customer.

The key point with this solution is that the point in the value chain where the customer interacts with the product, is shifted downstream. This implies that design and engineering decisions are pre-defined and less influenced by the customers, and that the customers are presented with a set of limited design choices. This opens for the possibility of a higher degree of standardization throughout the value chain, more effective production and eventually cost reductions.

This solution is from this point on to be considered as the chosen solutions in this thesis. In the next sub-chapters, previous research on the chosen topic is presented, the goals of the thesis are addressed and the scope of the thesis is delimited.

## 1.3 Previous research and the current frontiers

The key terms mentioned in the previous sub-chapter (standardization, modularization, and CBD) are familiar terms in design and engineering theory, and is utilized by several industries. In the specialised tonnage segment in the maritime industry, there has been research projects on these terms towards ship design and construction as well. However, if one considers the recent high oil prices and looser requirements regarding expenditure from the customers, the focus has to a certain degree shifted towards customized, 'one-off' ship designs. In addition, the influence possessed by the ship customer on design and engineering decisions has made it difficult for designers to standardize their design solutions. As it was possible to maintain a profit by designing and building customized ships, the presumption is that other design strategies such as CBD, standardization and modularization were partly put away or postponed.

Some of the research contributions are Master's theses from NTNU, and some recent relevant examples are Vestbøstad (2011), Tvedt (2012), Kristiansen (2014) and Brekke (2012). The three former authors utilize modularity to a certain degree to assist the designer, in a preliminary design phase, in a design spiral strategy. In this phase, the modules are scaled according to customer preferences as a 'starting point' for the design spiral strategy. Further, they acknowledged that visualizing the design in 3D was especially helpful.

Vestbøstad (2011) concluded that correct utilization of software is an asset to a designer, enabling higher creativity and efficiency, however, the author identifies some challenges related to industrial applicability due to real life system complexity. Kristiansen (2014) uses statistical data and seasonal profiles to identify the required systems needed on fishing vessels, and designs a modular fishing vessel that can operate in two distinct segments, depending on the season. Lastly, Brekke (2012) handles modularity in the operational phase, and presents a case study on OSVs. In this case, the author concludes that the main challenges lie in the interfaces between modules due to their complexity. A similarity in all four theses is the complexity of the structural elements and interfaces between systems in a ship.

In addition, there are some other contributions from NTNU. Erikstad (2009) provides a theoretical overview of modularization related to shipbuilding, with focus on modularization and product platforms in the product development and tendering phase. Further, some contribution in research related to modularization and CBD has come from the Ship Design and Operation Lab at NTNU, Aalesund. For instance, Chaves et al. (2015) concluded virtual prototyping combined with modularization has several benefits regarding ship design: reduced time in the ship's conceptual design phase, less effort in comparison of ships, quicker and simpler redesign, and a more visual approach. They also found that some behaviours/properties can follow each module and others must be simulated/calculated after the total assembly. However, the authors found that a challenge is to define the modules of a ship, and to define the behaviour of each module on the total performance. Further, the Ship Design and Operation Lab has developed a Ship Virtual Prototype and Parametric Motion Simulator (Ship Lab, 2016), which won the DNV-GL COMPIT Award 2016 (DNV-GL, 2016).

Regarding standardization, Semini et al. (2013) presents an interesting comparison of a custom design (CD) strategy and a standard design (SD) strategy, and links the strategies to a supply chain perspective using a customer order decoupling point (CODP). Here, the main attributes of a CD strategy and SD strategy are assessed and compared.

These are examples of previous research which has been conducted on the chosen topic, and a more extensive literature review is presented in chapter 4 on page 17.

### 1.3.1 The current frontiers

It seems that regarding modularization of a ship design, the key challenges lie in the complexity of a ship design due to the extensive interactions between systems in the ship. The mapping of behaviour and the individual module's effect on the total ship performance is a challenge, causing case studies (such as the Master theses mentioned) to be simplified, instead of addressing the challenge in its depth. Chaves et al. (2015) reached the same conclusion as the theses mentioned regarding complexity, and there is no surprise to a marine engineer that the complexity of a ship design and the interaction between the systems in the ship is a challenge.

Regarding CBD, some work is done by e.g. the Ship Design and Operation Lab, however their design object is relatively simplified and the applicability is mainly on an educational scale. Further, given that CBD is a standard in the automotive and computer industry, one should assume that a CBD strategy is applicable, in some degree, in the maritime industry.

The benefits, drawbacks and challenges of standardization in product design and production is relatively established, and to some degree for ship design and production as well, as discussed by Semini et al. (2013). However, when CBD and modularization is combined with standardization, and applied towards ship design, some new benefits, drawbacks and challenges presumably arise.

## 1.4 The goal of the thesis

The goals this thesis challenges the established ignorance defined by the findings and results of the previous research, in the context of the chosen topic.

Thus, the overall goal of this thesis is to investigate the potential benefits, drawbacks and challenges with a CBD strategy, including standardization and modularization.

Further, the following questions are to be answered during the thesis:

1. What are the key challenges to why CBD is not a standard in ship design, as it is in industries such as the automotive and computer industry?

2. Why should the ship customer be allowed heavy influence the design and engineering decisions?

3. In the context of the topics covered in this thesis, what is expected from the future of ship design?

## 1.5 Delimiting the thesis scope

As stated in the overall goal, there are three distinct areas of research which are part of the scope of the thesis. This distinction allows for a separate, primary literature research on the respective topics, for then to further merge them to fully utilize the body of knowledge in the context of this thesis. Now, the scope of the distinct areas is delimited.

The scope regarding CBD comprises firstly a study of the traditional ship design process, and its benefits and drawbacks. Then the concept of CBD is presented, along with benefits, drawbacks and challenges.

The scope regarding standardization will mainly consist of the causes and effects of standardization in the design phase of a ship. Both cause and effect ripple upstream (yard, 3rd party supplier) and downstream (customer, operator) in the value chain, relative to the design company, whereas both directions will to a certain degree be included. The considered topics within standardization are mainly the high-level aspects of design, production and finances.

For modularization, the scope includes a literature review of topics related to modularization. These topics are: modules, modular structures, product platforms, interfaces and (modular) architectures. Further, this theory will be applied towards a case study.

Lastly, the three distinct areas of research are merged together in a case study, focusing on applying the theory towards a platform supply vessel (PSV).

### 1.5.1 Definitions

This sub-chapter contains some definitions which are used throughout the thesis. This is done to remove uncertainty in how certain terms are defined, thus elevating the reading experience.

The simplified value chain in Figure 1-1 is used as reference throughout various parts of the thesis. The key actors, the customer, designer and yard, are highlighted. Upstream relative to the design company is denoted *construction* and downstream is denoted *operation*.

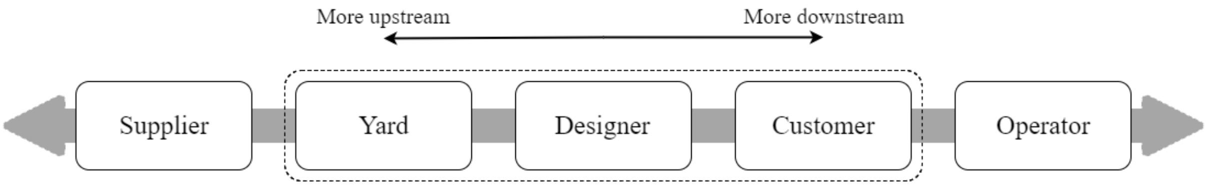



Figure 1-1: Maritime value chain

These key actors are defined below, from most downstream to most upstream:

- The ship customer, or customer, is referring to the company who is purchasing the ship. The customer is usually a shipowner, who owns a fleet of ships that provide a function in a larger logistic chain.
- The ship designer, or designer, is referring to the company that performs the majority of the design and engineering work during the development of a ship design.
- The shipyard, or yard, is referring to the company that builds the ship. The yard may outsource parts of the production to 3rd party suppliers, but the majority of the total assembly and building is done by the yard.

Further, *benefit, drawback* and *challenge* are defined as:

- Benefit is something that is advantageous, that is, any state, circumstance, opportunity, or means especially favourable to success.
- Drawback is the antonym of benefit.
- Challenge is an obstacle, something that obstructs or hinders progress.

## 1.6 The structure of the thesis

To increase readability and present the thesis in a lucid manner, the thesis is divided in parts, chapters and sub-chapters. The parts cluster the connected chapters to differentiate between the distinct parts of the thesis, of which there are four: background, case study, discussion and epilogue. The respective parts are further elaborated below.

The remaining chapter of Part I contains a market analysis on three maritime markets where specialised tonnage ship design is of interest: oil and gas, aquaculture and offshore wind.

Part II constitutes the case study. The part consists of five chapters: Case Study Introduction, Literature Review, Foundation, 3D-Modelling and Assembly and lastly, Results. In this part, the case is introduced in chapter 3 and a literature review is presented in chapter 4. Then the case is developed through chapter 5 and 6, and the case results are presented in chapter 7.

Part III contains the discussion chapters, of which there are three: Discussion of Case Study, Value Chain Perspective and The Goal of the Thesis. In chapter 8, the assessments, decisions and results from the case study are discussed. In chapter 9, the value chain (previous page) is considered in the context of the thesis, and lastly, in chapter 10, the goals of the thesis (page 6) are discussed.

Part IV contains two chapters: Conclusion and Further Research. The conclusion in chapter 11 presents the main finding of the thesis, while chapter 12 suggests areas for further research.

The structure of the chapters is shown visually in Figure 1-2.

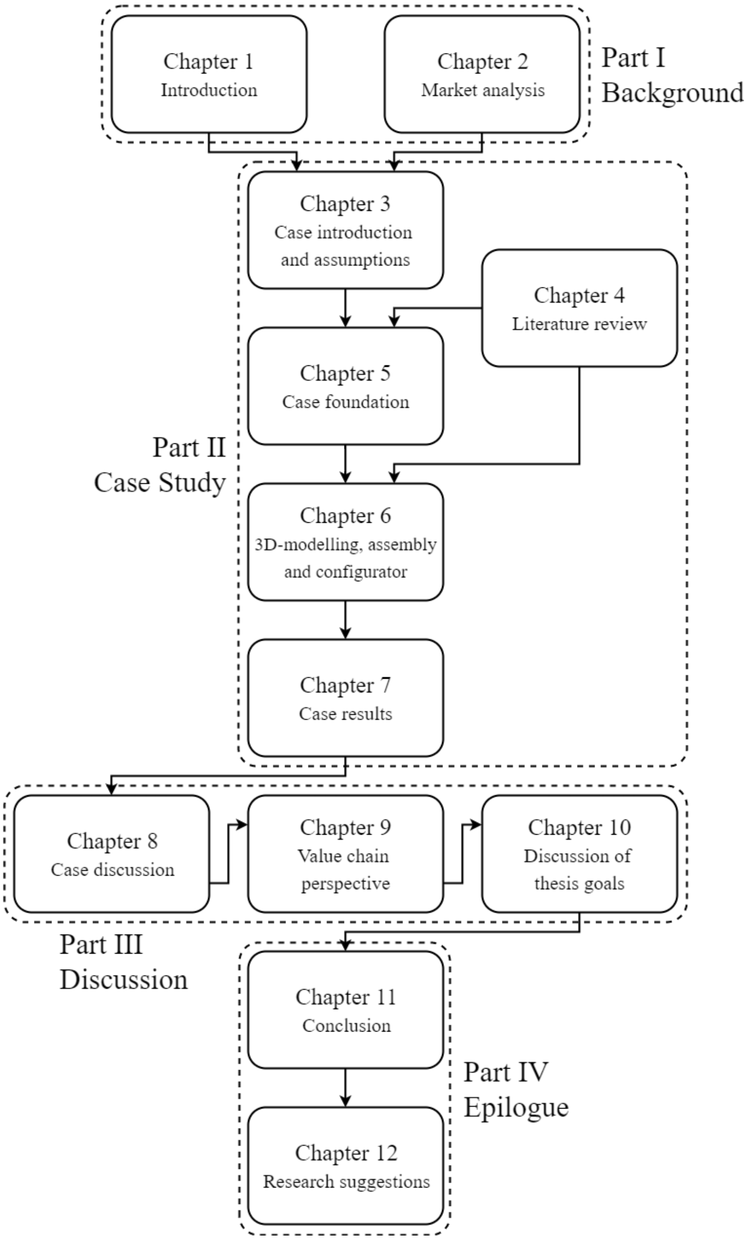



Figure 1-2: Thesis structure

# 2 MARKET ANALYSIS

In this chapter, the three relevant industry segments will be analysed and discussed: oil and gas, aquaculture, and offshore wind power. This will contribute to establish a solid foundation for the rest of the thesis, and helps increasing the total understanding of the current industrial situation and the future of the maritime industry.

## 2.1 Oil and gas industries

The last 20-30 years, the main part of the customers for the Norwegian maritime actors has been in the oil and gas industry (or related). During recent years, from 2000 until 2014, the industry has been very lucrative due to high oil prices. From year 2000, the oil and gas industry has been responsible for over 50% of the total value of exports from Norway. This is shown in Figure 2-1 (Norsk Petroleum, 2017). During this period, some ship customers spent large amounts of money on custom made, Norwegian prototype offshore ships, to have the most competitive ships in their fleet.ez

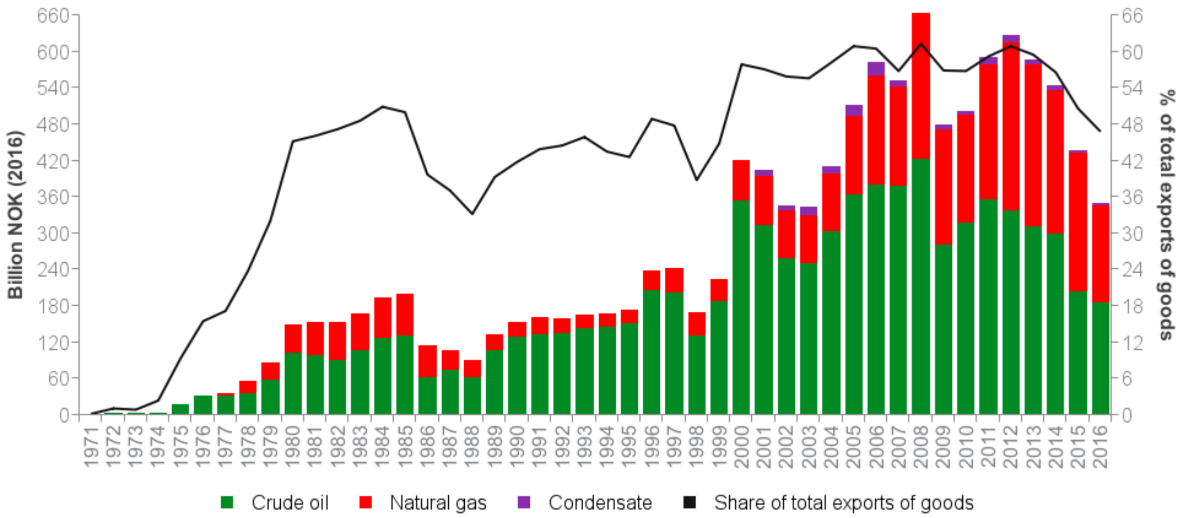



Figure 2-1: Export of oil and gas in Norway 1971-2016 (Norsk Petroleum, 2017).

In June 2014, everything changed. The price for Brent Crude Oil dropped from approx. 110$ down to 45$ per barrel (Macrotrends, 2016) in a few months. This was a result of various factors which occurred in a relatively short period of time. A major factor was the rapidly growing demand for oil in developing countries such as China, Russia, India and Brazil but also USA and Canada during the 1990s and 2000s, which decreased drastically around 2010 (Investopedia, 2015). Prior to the demand decrease, oil producing nations increased production to fulfil the rapidly growing demand of the mentioned countries.

The increase in oil production and decrease in demand in 2010 started to drive the oil prices down. When the Organization of the Petroleum Exporting Countries (OPEC) was faced with the decision of continuing production and allow the oil price to drop or ceding market share (by cutting production thus increase the oil price), they chose the former option (Investopedia, 2015). This was sustainable for several OPEC members due to the relatively low production costs in e.g. the Middle East, compared higher production costs in e.g. USA, Canada or Norway.

The result was an industry changing oil price drop from June, 2014 to January, 2015, as shown in Figure 2-2.


Figure 2-2: Brent Crude Oil prices in June, 2014 and January, 2015.

As of today, Brent Crude Oil trades for around 50$ per barrel (EIA, 2017) and there seems to be a consensus in the industry that the oil price will increase in the future, but no one knows when and to how rapidly. For example, the U.S. Energy Information Administration (EIA) operates with a forecast between 28$ and 100$ per barrel (95% confidence interval) by the end of 2017 for WTI crude oil (EIA, 2016) and Goldman Sachs forecasts that the WTI will be approx. 60$ by the end of 2018 (Goldman Sachs, 2016). As the oil price is affected by various global factors, such as politics, OPEC's behaviour, more focus on green initiatives and demand fluctuations, it seems impossible to forecast with high accuracy. Meanwhile, it looks like the Norwegian maritime actors should turn parts of their production in to other market segments.

## 2.2 Aquaculture industry

In this market segment, there are a lot of interesting opportunities and for Norwegian shipbuilders it would be wise to show their interest in this segment as early as possible. Aquaculture, especially in Norway, has shown a lot of promise in recent years and it is forecasted that the production levels will continue to increase in the years to come. In 2015, Norway exported seafood for approx. 75 billion NOK (approx. 9 billion $) (E24, 2016) where approx. 50 billion NOK were directly from farmed salmon (Statistics Norway, 2017a). In Figure 2-3, the left graph (Statistics Norway, 2017a) shows that the value of salmon and export quantity has increased considerably the last 20 years. The right graph (Statistics Norway, 2017b) shows the development of price per kilo for salmon from 2015 to 2016, and the first months of 2017.

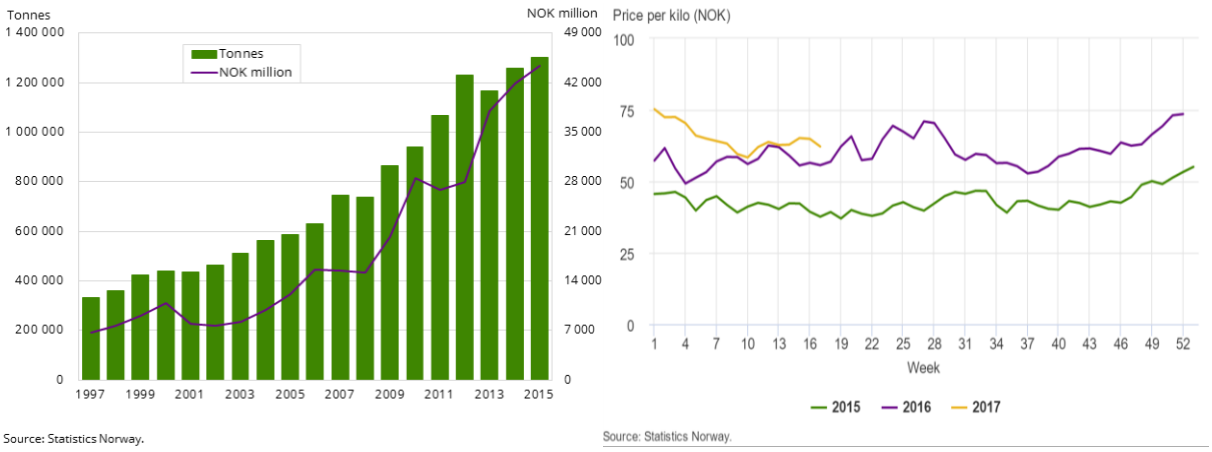



Figure 2-3: Left: Sales of salmon. Right: Export price of fresh or chilled, farmed salmon.

Norway have their own Minister of Fisheries, and both the current and previous ministers are positive to an increase in production of farmed salmon. The previous minister, Elisabeth Aspaker, said in 2015 that she encourages and welcomes development and increase in fish farms, both inshore and offshore, and that she aims towards a fivefold of farmed salmon by 2050 (iLaks, 2015b). The current Minister of Fisheries, Per Sandberg, agrees with Aspaker's aim and he has also been travelling to other countries, such as Sweden and Iran to promote Norwegian farmed salmon and to develop collaborations (VG, 2016). At the same time, he emphasises that the Norwegian fish farmers has to behave and follow the current and future rules and regulations for fish farms, vessels, delousing and other equipment related to fish farming (Dagbladet, 2016).

The existing fleet of well boats in Norway, which are the boats that carry the live salmon between fish farms and production facilities, is relatively old and barely manages to keep up with the increase in activities in the industry. Roger Halsbakk, The CEO of Sølvtrans, which is the world's largest well boat company, warns the industry that to keep up with the increasing activities, new rules and new regulations, there has to be built more well boats (iLaks, 2015a, Sølvtrans, 2016).

Current challenges for Norwegian fish farmers today includes salmon lice, space restrictions in narrow fjords and coastal areas, escaping salmon and complications with local coastal societies. Considering these challenges, there is a drive for offshore fish farms, and new highly technological 'closed' aquaculture systems. This drive is also contributing to an increase in the industry activities.

The aquaculture industry is potentially highly profitable, considering the current market situation and future prospects. In addition to new builds such as well boats, there might also be a market in re-building PSV in cold lay up to well boats or other demanded vessel types.

## 2.3 Offshore wind energy industry

The wind energy industry does not have the same profile in the media in Norway as the oil, offshore and aquaculture industries, but is a rapidly expanding industry. Wind energy is produced by windmills which are placed either onshore or offshore. The global wind power market has increased drastically in recent years, due to more focus on green initiatives. In 2014, a new record was set with annual windmill installations with a total capacity of 51.7 gigawatts

(GW) globally. This record was again broken in 2015, and the new record now is 63 GW of annual installation capacity (GWEC, 2017b).

The biggest actors of the offshore wind power industry are UK and Germany, followed by PR China, Denmark, the Netherlands and Belgium, as presented in Figure 2-4 (GWEC, 2017a). Further, the figure shows that especially Germany, PR China and the Netherlands have had a significant increase in offshore wind power from 2015 to 2016, confirming that this is a market segment with increasing activity and investment.

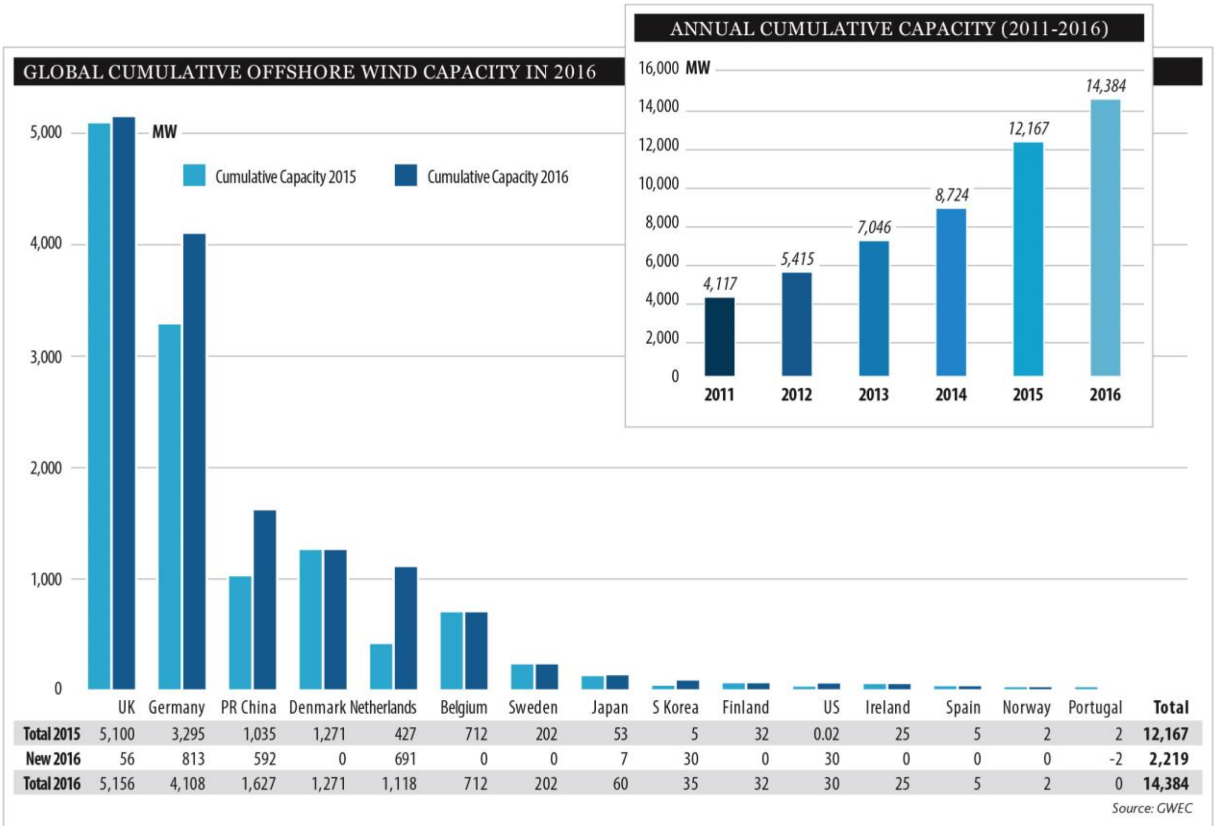



Figure 2-4: Global cumulative offshore wind capacity 2015 and annual cumulative capacity 2011-2015.

Offshore windmills are inspected and maintained by offshore wind power service vessels. These vessels require high levels of safety and advanced technology, especially if the weather conditions are rough. As more than 90% of the world’s offshore wind power is located off the coasts of Northern Europe (GWEC, 2017c), this seems to be a good match considering the Norwegian shipbuilders’ relationship and experience with rough weather conditions, so this market segment is very interesting

.

# Part II CASE STUDY

# 3 CASE STUDY INTRODUCTION

The case study is constructed as a tool to help achieve the goal of the thesis. It will combine the three distinct areas of research (see sub-chapter 1.5) in a single, practical case. The case will use a PSV as the study object.

The case study consists of four parts:

- Literature review
  - There are three distinct theoretical areas of interest: standardization, modularization and CBD. The literature review is presented in Chapter 4.
- Foundation
  - Work which is performed before entering the 3D-modelling environment. The foundation work is presented in Chapter 0.
- 3D-modelling and assembly
  - Form is given in a 3D-modelling environment. This is presented in Chapter 6.
- The ship configurator
  - An intuitive graphical user interface (GUI) is developed to simplify the interaction between the designer and the ship. This is shown in Chapter 0.

The case study is conducted using mainly two software programs, shown in Table 3-1.

Table 3-1: Software used in case study

| **Software** | **Owned by** | **Used for** |
|---|---|---|
| NX 11.0 | Siemens | 3D-modelling, assembly and GUI |
| AutoCAD | Autodesk | 2D technical drawings |
| DelftShip$^{TMFree}$ | DelftShip, Marine Software | 3D-modelling of hull |

## 3.1 Assumptions

To delimit the scope of the case study, some assumptions and simplifications are given.

- The description of the PSV is assumed generic, and is given by Levander (2012).
- The deadweight of the PSV is assumed divided in two categories: tank cargo weight and deck cargo weight.
- The gross tonnage (GT) of the PSV is assumed fixed at 3500.
- The functions of a PSV can be connected to high-level systems, which is divided in two categories: task related systems and ship systems.

# 4 LITERATURE REVIEW

This chapter will give a thorough presentation of the theory considered in this thesis. The theory will be applied towards a practical case in chapter 0 and 6. The chapter is divided in sub-chapters to structure the theory and increase the readability. The theory considered is the ship design process, modularization, modules, modular structures, motivations/drawbacks with modularization, product platforms, interfaces, architectures and CBD. At the end, there will be a sub-chapter with a summary and discussion of the theory.

## 4.1 Ship design process

After an initiation process, the following steps of the ship design process varies, as described by Hagen and Erikstad (2014):

> *"In commercial shipbuilding, the process through which an owner requests tenders varies. It depends on the size and proficiency of the owner, whether the owner does business in industrial shipping with specialised tonnage, such as car carriers or offshore service vessels, or is in a more standardised segment, such as trading crude oil."*

This implies that the specification level in a tender invitation delivered by the customer varies, however it can usually be categorized in one of three levels: brief, outline or detailed (contract). A summary of the specification levels is found in Table 4-1 (Hagen and Erikstad, 2014).

Table 4-1: Specification level and content

| Specification level | General content | Typical level of detail | Typical size |
|---|---|---|---|
| Brief | Describes main functions, main characteristics and key performance parameters. | Uppermost level in the group system (SFI main group) or not connected to a specific group system. 10-15 chapters. | 1-10 pages |
| Outline | Describes functions, main performance and main technical solutions. | Medium level in the group system (SFI group). 30-50 chapters. | 10-30 pages |
| Detail (contract) | Describes detailed performance and technical solutions, often including individual choices on material and equipment. | Lower level in group system (SFI sub-group). Typically, 150-400 chapters and sub-chapters. | 30-300 pages |

These three levels of specification can be merged with the design activities in the general design process, described by Pahl et al. (2007). This is done in Erikstad (1996), which Figure 4-1 is based upon. From the figure, one can see that depending on the specification level from the customer, it is possible to enter the design time line at different points in time. However, the designer or yard will usually engage in a discussion with the customer, and add some comments or suggestions to the specification.

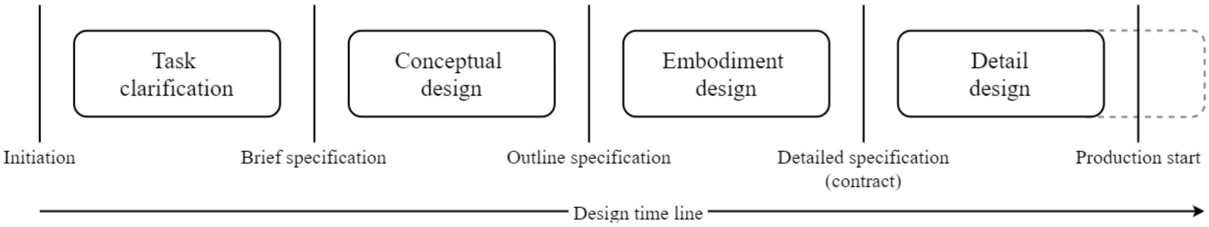



Figure 4-1: Design activities and specification levels

## 4.2 Ship design problem

A ship design is usually based on a set of performance functions that the final ship design must satisfy. Erikstad (1996) further provides a good description of the ship design problem:

> *"At the top level, the design problem is specified by a set of performance functions that the design artefact is expected to deliver. In addition, a number of constraints and bounds may be given. The outcome of the process consists of a description of a design object that both satisfies the given constrains and bounds, and is preferable to other design objects by some measure. Thus, we operate mainly on two different representations of the design object, as illustrated in Figure 4-2: A decision space that consists of the descriptions of potential design solutions, and a performance space specifying the functions to be delivered by the design object."*

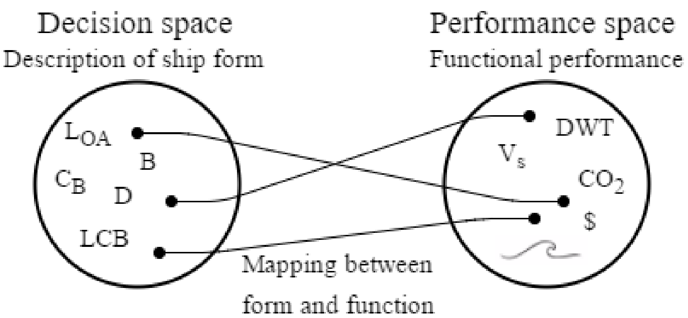



Figure 4-2: The top-level design process as a mapping between a decision space and a performance space (adapted from (Erikstad, 1996)).

This concept of mapping between form and function is taken a step further in the ship design spiral. Here a set of requirements (mission, function, performance, etc.) is given as a starting point, and the final design is achieved by performing several iterations between form and function. This is shown in Figure 4-3 (Evans, 1959). Here, the design time line will follow the spiral inwards.

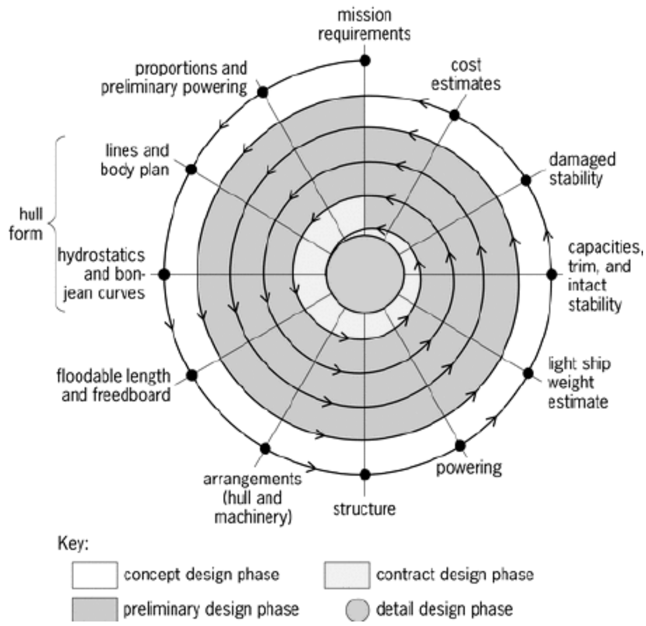



Figure 4-3: Ship design spiral, including design phases (Evans, 1959).

In the early stages of the ship design process, that is, the part of the total ship design process in which the main features of the ship are determined, the design is characterized by a high degree of freedom (Erikstad, 1996). This is due to little design knowledge, that is, the facts, bounds and constraints given by a decision. As time progresses and decisions are made, the design knowledge will increase, and thus, the freedom to make changes will decrease. This is shown visually in Figure 4-4 (Erikstad, 1996).

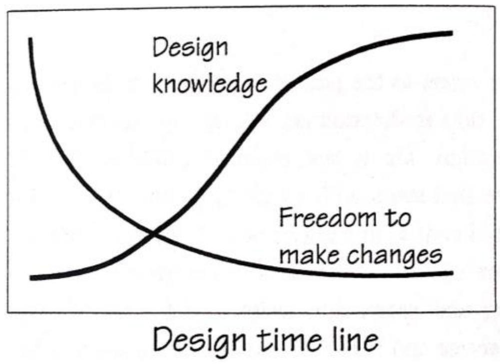



Figure 4-4: Design knowledge and design freedom in a design time line (Erikstad, 1996).

Levander (2012) proposes another approach towards ship design, as an option to the traditional design spiral: system based ship design (SBSD). The key difference between the two approaches is that SBSD comprises a statistical analysis before the design iterations begin. Based on statistical data of previous designs, mission statements and functional requirements are used to calculate internal volumes and areas of the ship. These volumes and areas are then used to estimate the main dimensions and characteristics of the ship. This will presumably decrease the number of iterations required. The system based ship design process is shown in Figure 4-3.

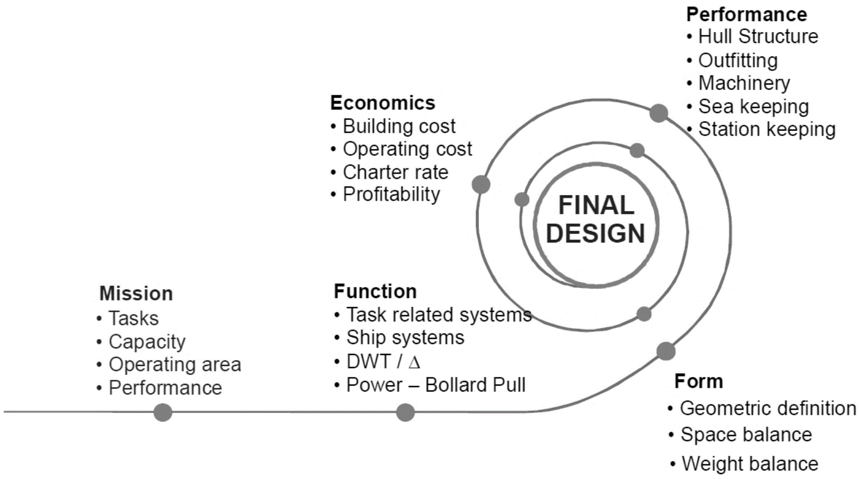



Figure 4-5: System based ship design process (Levander, 2012)

As a part of the SBSD design process, systems are divided in *task related systems* and *ship systems.* The former are the payload functions and the latter are the systems required for the ship to have a safe and efficient voyage.

## 4.3 Modularization

Modularization is a commonly used term, and is utilized in various research areas and industries. The meaning and application of the term varies, however, there are some key similarities (Erikstad, 2009):

1. The division of a larger system into smaller systems or components
2. The principle of (relative) self-sufficiency of the individual smaller systems or components
3. The recombination of the systems or components into multiple end products, according to a set of “rules” given by an overall systems architecture

A comment to point 3, is that splitting a system or component to simply assemble it later is not considered a modular approach. As point 3 states, the systems or components must have the attributes to be recombined into multiple end products.

Schilling (2000) describes modularization as a continuum, which is an interesting perspective:

> *“a general systems concept: it is a continuum describing the degree to which a system’s components can be separated and recombined.”*

By defining modularization as a continuum, the author allows for only parts of the system to be modular.

Further, Tvedt (2012) proposes a relatively short, yet precise definition:

*“Decomposition of a system into self-sufficient blocks.”*

All three authors capture the *decomposition* of a system, however, the principle of *self-sufficiency*, an overall *architecture* and the *recombination* of the decomposed systems to a *variety* of products are assessed to be important if modularization of a system is to serve a practical and industrial purpose.

## 4.4 Module as a functional building block

There seems to be a diversity in the industries on how a module is defined. As mentioned, the term modularization is used in relatively different industries. According to Hildre et al. (2010), a module shall have a clearly defined function and well-defined interfaces to other units or systems:

*"A module is a functional building block with clearly defined interfaces."*

Further, the authors emphasize that a section or block, which are commonly used terms in shipbuilding, should not be confused with a module. A section or block is usually defined by crane capacity or production constraints, and are not (usually) functioning units and should not be considered as modules.

## 4.5 Modular structures

Before defining modular structures, it is beneficial to define what is considered the opposite: integral structures. In an integral structure, each designed *element* in a system is highly dependent on other designed elements in the same system. If change is applied to one element, one or more other elements in the system will be affected, and new assessments are required. Therefore, a structure which is considered integral is often designed by using an iterative approach, e.g. a design spiral. Integral structures are often characterized by: Product functions are implemented using more than one element, a single element or module implements many product functions, and there is a high degree of (complex) interaction between the product modules (Ulrich, 2008).

A modular structure is considered the opposite, and is therefore characterized by: A single element (or module) implements one or a few functions and the interaction between the elements (or modules) is limited and well defined (Ulrich, 2008). Further, if a module malfunctions, it does not affect the rest of the system. The function (or functions) the module provides is lost, but the rest of the system can continue operation.

## 4.6 Product platform

Before defining product platforms, it is beneficial to define the term *platform*. As platform is a relatively common term and is used in different situations, outside of industries as well, there exist a variety of definitions. Although the definition varies, the core value is that a platform describes something stable and solid that one may build upon (Hildre et al., 2010). Further, there is not a requirement for a platform to be a visible or physical object, and a platform can be defined as is a strategic value that is intended to be kept over a long time (Hildre et al., 2010).

A product platform has the same core value as a platform, and is targeted towards products. It is a relatively familiar term used by many industries, but the definition of 'product platform' varies somewhat. In the context of this thesis, the two following definitions are suitable:

> *"a product platform is a set of subsystems and interfaces that form a common structure shared by many products" (Hildre et al., 2010),*

and

*"a product platform is a structured, coherent collection of resources, including systems and template hierarchies, textual components, variants, rules and interface definitions, from which a range of customized product definitions can be derived" (Erikstad, 2009).*

## 4.7 Interfaces

A given interface is a pre-defined system of interaction between two other systems. There exist several different types of interfaces but according to Ulrich (2008), modular architectures comprise in general three types of interfaces: slot, bus and sectional.

- **Slot modularity:** Modules are categorized into different module types, and the respective module type share the same interface. Example: On a modular navy vessel, there are two different module types (i.e. two types of interfaces): cargo modules and weapon modules. In the case of slot modularity, the cargo modules are not compatible with the weapon interface, and vice versa.
- **Bus modularity:** Modules are not categorized into different module types, and all modules share the same interface. A good example is the USB-port interface on electronics.
- **Sectional modularity:** There is no physical object (or platform) on which the modules are placed, but all modules share the same interface (or a few). The assembly is built by connecting the modules to each other (Hildre et al., 2010), in this way the modules can be combined in different ways into a range of products. Examples are LEGO, pipes with flanges, or a kitchen assembled from modules.

The three interface types are visually illustrated in Figure 4-6. The interfaces are represented through the different shapes.

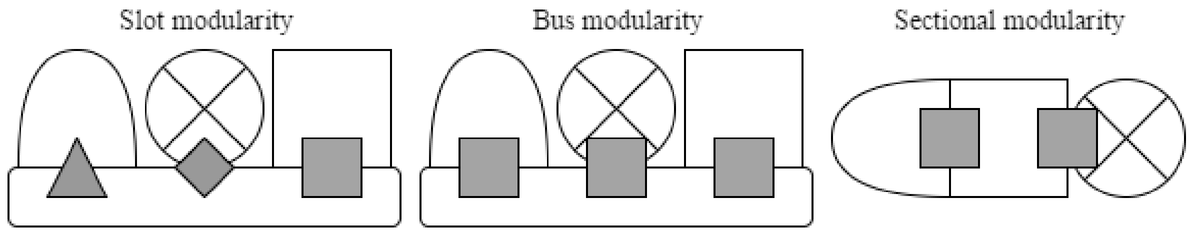



Figure 4-6: An illustration of slot, bus and sectional modularity

## 4.8 Architectures

The word architect comes from the Latin word *architura* and the Greek word *architectu* which means *master builder*. The word architecture is used in many industries, and is usually used when talking about architects, and how they design the most beautiful buildings in the world. However, in the context of this thesis, the word architect has another meaning. The following definition applies (Hildre et al., 2010):

*"architecture is creating an actual plan of any complex object or system, and it is used to describe the system structure and how elements in the structure can be combined and their interfaces."*

Further, other definitions in the literature, such as Erikstad (2009) and Tvedt (2012), are also applicable as they both state the same as Hildre et al. (2010). This implies that the architecture is not only a list of all elements, but also the compatibility and interaction between them, where the two latter often are referred to as *rules.* For instance, the rules define how modules can be combined and how they interact. By extending this, one can assume that at least one architecture is required for a given modular system, if exists to serve a practical purpose.

Architecture can be used to represent different orientations of the system, e.g. physical, component, functional and modular architecture, or a combination such as the SFI system. A modular architecture is of special relevance in this thesis, and is defined by Hildre et al. (2010):

> *"the overall scheme describing how variants can be put together by parts/modules and corresponding interfaces. A modular architecture allows you to replace or add any components/modules without affecting the rest of the system."*

## 4.9 Product families

Product platforms and modules are related in the sense that modules can be added to the product platform in various combinations, creating a range of end products. The end product can thus be designed to fulfil performance expectations, requirements and other goals, in a range of market segments by combining product platforms with modules. The architecture of a given product platform defines the rules for which modules that are allowed to be added to the product platform and how they can be arranged. Further, Hildre et al. (2010) defines a product family:

> *"If a group of related or similar products are derived from the same product platform, this group is often defined as a product family."*

The relationship between parts, modules, architectures and product family is presented in Figure 4-7 (Hildre et al., 2010).

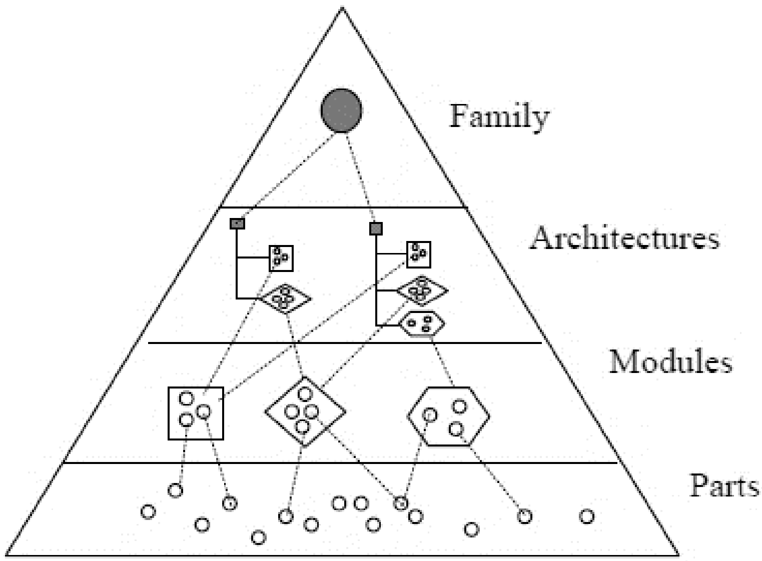



Figure 4-7: Relationship between modules, architectures and product family

## 4.10 Configuration based design

Mittal and Frayman (1989) defines configuration as:

> *"a special type of design activity, with the key feature that the artefact being designed is assembled from a set of pre-defined components that can only be connected together in certain ways."*

*Pre-defined components* allow for design standardizations and *in certain ways* implies that there is an architecture involved in the design process. Further, Mittal and Frayman (1989) define a configuration task by defining two steps:

- **Given:** (A) a fixed, pre-defined set of components and an architecture describing the rules; (B) some description of the desired configuration; and (C) possibly some criteria for making optimal solutions.
- **To be designed:** One or more configurations that satisfy all the requirements.

Brathaug et al. (2008) further defines a ship design configuration system as:

> *"a (software) system that enables a structured definition of a valid design solution from a given set of customer requirements, by applying pre-defined rules and templates to select, scale and synthesize a collection of modules."*

Erikstad (2009) recognizes that in ship design, the application of configuration-based design has been relatively limited, particularly in segments other than low-complexity, standardized vessels. Further, the author argues that compared to many other industries facing a similar complexity level (e.g. automotive or computers), the typical length of a series in particularly European shipbuilding is short. This implies fewer projects to share the costs of developing a configurable product platform (Erikstad, 2009).

## 4.11 Customer order decoupling point

The customer order decoupling point (CODP) is defined by Semini et al. (2013) as:

> *"The CODP is the point in the manufacturing value chain of a product, where the product is linked to a specific customer order."*

There are four basic strategies linked with the CODP, listed from most upstream to most downstream: engineer-to-order (ETO), make-to-order (MTO), assembler-to-order (ATO) and make-to-stock (MTS). Table 4-2 (continues on the next page) presents a summary of the four strategies (Arnold et al., 2001).

Table 4-2: CODP strategies and their effects

| Strategy | Effects of strategy |
|---|---|
| ETO | The customer's specification requires unique engineer design or significant customization. Usually the customer is highly involved in the product design. Delivery lead time is long because it includes not only purchase lead time, but design lead time as well. |

| Strategy | Effects of strategy |
|---|---|
| MTO | The manufacturer does not start to make products until a customer's order is received. The final product is usually made from standard items, but may include custom components. Delivery lead time is reduced due to little design time and inventory held as raw material. |
| ATO | Product is made from standard components that the manufacturer can inventory. Delivery lead time is reduced further due to no design time and components are held ready for assembly. Customer involvement in the design of the product is limited to selection of the offered component options. |
| MTS | The products are manufactured completely, and are sold from stock. Delivery lead time is shortest and the customer has little involvement in the product design. |

Semini et al. (2013) emphasizes that many high-volume manufacturing companies has benefited from strategically positioning the CODP, as it has enabled them to define and implement manufacturing and supply chain strategies that match the characteristics of their products and markets. Further, Semini et al. (2013) and Olhager (2003) describes shifts in the COPD:

> *"Typically, a downstream shift of the CODP can lead to shorter lead times, higher delivery reliability and lower cost. In contrast, an upstream shift allows a higher degree of customization, reduced reliance on forecasts and reduced inventories."*

Martinez-Olvera and Shunk (2006) shows a link between CODP and various attributes of a supply chain strategy. Semini et al. (2013) captures this and presents a comparison of product and market attributes of a custom ship design strategy versus a standard ship design strategy. The resulting comparison is shown in Table 4-3.

Table 4-3: A comparison of design strategies and product/market attributes

| Product/market attributes | Custom design strategy | Standard design strategy |
|---|---|---|
| Cost/price | Higher | The more ships produced, the lower the unit cost and price |
| Lead time | Longer | Shorter (if production can start quickly) |
| Delivery precision | More difficult to achieve | Easier to achieve |
| Level of customization | Higher | Lower |
| Variety | Higher | Lower |
| Modularity and standardization | Desirable, but difficult | A must |
| Customer influence | Part of the value offered | Must be kept low |
| Number of components | Very high | High |
| Minimum volume requirements | One or two | Typically, three or more |
| Order qualifiers | Quality, lead time, on-time delivery, price | Quality, lead time, on-time delivery |
| Order winners | Flexibility, customization, product design/features | Price, product design/features |

# 5 FOUNDATION

The foundation is the work, decisions and constraints on which the 3D-model is based upon. To assure for a streamlined 3D-modelling process, the foundation should be performed in a correct manner. The following sub-chapter comprise the foundation work.

## 5.1 Methodology

The methodology allows for the foundation work to be performed correctly in a structured manner. It is divided in three main steps, which are defined in Methodology 5-1 and executed in the following sub-chapters.

Methodology 5-1: Study case foundation methodology

Identification of operations and systems.

- Identify the high-level operations/functions performed by a PSV.
- For each of the operations identified, map the corresponding high-level task related systems and ship systems required for performing the operations

Database and Modules

- Define modules for all the task related systems and ship systems identified in step 1.
- Establish a database for the PSV. The database should contain a sufficient amount of ships and corresponding data.
- Filter the database to exlude non-relevant ships and clean the database for a more uniform dataset
- Categorize the database by the modules
- Use normal distribution and standard deviation to establish the range for the respective modules
- Divide the range in logical, standard steps, to establish module sizes

Architecture

- Establish each module's affect on the ship's performance (performance connections)
- Map the compatibility by setting limits on performance criteria
- Establish design interfaces between the modules

Parallel to the methodology, there is also the process of documenting all the preliminary results which are obtained. In this way, one should be able to present the development of the case study as it progresses. By the end of the foundation methodology, one should end up with a set of modules, as well as their architecture.

## 5.2 Identification

This sub-chapter corresponds to the first step of the methodology. The purpose for the identification is to map the link form ship type, through operations, to task related systems and ship systems. The case will consider a PSV. However, sub-chapter 5.2.1 includes an example for several ship types, to show that the methodology is not locked to PSVs.

By the end of Step 1, the results should be the operations of a PSV mapped with the corresponding task related systems and ship systems.

### 5.2.1 Identification of operations

Table 5-1 describes the typical operations performed by the listed ship types. The case will further only consider PSVs. The table continues on the next page.

Table 5-1: Vessel types and corresponding typical operations

| **Ship type** | **Description of typical operations** | **Summary** |
|---|---|---|
| Platform Supply Vessel (PSV) | Provide supplies, often divided in tank cargo and deck cargo, for offshore platforms and other vessels. The vessels normally have an open cargo deck aft, with storage tanks for liquid and dry bulk cargo below the deck (Levander, 2012). The PSV needs to stay relatively in the same position when cargo is loaded/unloaded and to have good manoeuvrability close to platforms, as well as good crew comfort during transit. | Tank cargo supply and deck cargo supply. |
| Multipurpose PSV (MPSV) | Same as PSV, but usually with a larger hull which allows for an offshore/knuckle boom crane and/or a ROV hangar/ ROV mezzanine deck. Typically has more accommodation than a PSV due to the extra systems, as well as a helideck. | Tank cargo supply, deck cargo supply, heavy lifting, ROV operations. |
| Offshore Well Boat (OWB) | Transports live fish, in wells, between shore base and fish farm. Due to problems with sea lice, the newer well boats usually have systems for fish cleaning. In the close future, offshore certification and DP will presumably be required for operating with offshore fish farms. | Transport of live fish, fish cleaning |
| Anchor Handling and Tug Supply (AHTS) | Used for placing platform anchors in the right positions, recovering anchors and relocating anchors. Some AHTS are also used for towing platforms and other vessels. Requires high winch capacity and bollard pull. | Anchor handling and deck cargo supply. |
| Cable lay | Ships used to lay cables for e.g. telecommunications or power cables, on the seabed. | S-lay cable lay and J-lay cable lay |

| Ship type | Description of typical operations | Summary |
|---|---|---|
| Pipe lay | Lays pipe on or below the seabed, usually for connecting subsea infrastructures. Two distinct methods: S-lay and J-lay, which depends on the properties of the pipe. S-lay requires a construction/welding deck, while J-lay requires a construction/welding tower and usually a moon pool. | S-lay pipelay and J-lay pipelay |
| Inspection, Maintenance and Repair (IMR) | IMR ships are used for inspection, maintenance and repair of subsea facilities and infrastructure. Usual equipment on IMR ships are ROVs (of various kinds), diving systems, offshore/knuckle boom crane. Extra accommodation and a helideck is typically found on IMR ships due to the high number of POB. | ROV operations, crane operations, deep sea diving |
| Emergency Rescue and Response Vessel (ERRV) | ERRVs are used for safety standby, emergency response and rescuing for offshore installations. An ERRV typically has good manoeuvrability, high-speed capacity, hospital, daughter ships (for rescue), FIFI-systems and sometimes supply tanks. | Safety standby, emergency response, rescuing, fire fighting |

### 5.2.2 Link between operations and systems

With the operations identified, the next step is now to identify the corresponding task related systems and ship systems required to perform the operations. In Table 5-2, the typical PSV operations identified in sub-chapter 5.2.1 are mapped with the corresponding task related systems. The customer requirements for the respective systems are also included.

Table 5-2: Mapping operations to task related systems

| Operations | Task related systems | Summary |
|---|---|---|
| Tank cargo supply | Requires cargo tanks, which are usually located below the main deck, around the longitudinal centre of the ship, due to the relative high weight of the tank content. Tank cargo can be further divided in liquid and dry bulk cargo, and even further in cargo types. The requirement from the ship buyer is usually capacity of each cargo type, in either $m^3$ or sometimes tonne. | Cargo tanks |
| Deck cargo supply | Requires free space on a cargo deck, which is typically stronger than a usual outside deck. The requirement from the ship buyer is usually the available area ($m^2$) and strength (tonne/$m^2$). | Free cargo deck |

The next step is to identify the corresponding ship systems for deck cargo and tank cargo supply operations. This is presented in Table 5-3 on the next page.

Table 5-3: Mapping operations to ship systems

| Operations | Ship systems | Summary |
|---|---|---|
| Tank cargo supply | A PSV requires an offshore hull structure to handle the rough conditions in the offshore environment. Further, the superstructure and accommodation areas must be large enough to accommodate the personnel on board (POB), and a bridge is required for officers. For a PSV, the superstructure is typically located towards the front of the ship. A small crane for provisions and light cargo is usually placed right aft of the superstructure or on top of the cargo rails. The machinery and the related systems must be sufficiently large to sail the ship at the required speed and meet the class requirements for the selected dynamic positioning (DP). This is required to due restrictions regarding ship motion during loading/unloading and manoeuvring close to the offshore platforms. | Offshore hull<br>Accommodation<br>Bridge<br>Small crane<br>Main Engine<br>DP |
| Deck cargo supply | Same as tank cargo supply. | Same as tank cargo supply |

### 5.2.3 Mapping results

A method for presenting the link between operation and system (for the ship types exemplified in sub-chapter 5.2.1) in shown in Figure 5-1 on the next page. This method allows a designer to enter a spreadsheet and to recognize corresponding operations and systems in an efficient manner.

The strength of the relationship between operation and system is classified as 1 or 2, where 1 is “usually found on ship type” and 2 is “crucial for performing operation”. Disclaimer: may deviate from reality, but effort is put in to make it sufficiently accurate.

| | |
|---|---|
| 1 | Usually found on ship type |
| 2 | Crucial for performing operation |
| ■ (grey) | Typical operation |

| NAME | OPERATIONS | PSV | MPSV | OWB | AHTS | Cable lay | Pipe lay | Wind | IMR | ERRV |
|---|---|---|---|---|---|---|---|---|---|---|
| OP-001 | Deck cargo supply | ■ | ■ | | ■ | | | | | |
| OP-002 | Tank cargo supply | ■ | ■ | | | | | | | |
| OP-003 | ROV operations | | ■ | | | | | | ■ | |
| OP-004 | Crane operations | | ■ | | | | | | ■ | |
| OP-005 | Transport of live fish | | | ■ | | | | | | |
| OP-006 | Fish cleaning (lice) | | | ■ | | | | | | |
| OP-007 | Anchor handling | | | | ■ | | | | | |
| OP-008 | S-lay, cable | | | | | ■ | | | | |
| OP-009 | J-lay, cable | | | | | ■ | | | | |
| OP-010 | S-lay, pipe | | | | | | ■ | | | |
| OP-011 | J-lay, pipe | | | | | | ■ | | | |
| OP-012 | Maintanance of windmills | | | | | | | ■ | | |
| OP-013 | Safety standby and rescue | | | | | | | | | ■ |
| OP-014 | Deep sea diving | | | | | | | | ■ | |
| OP-015 | Fire fighting | | | | | | | | | ■ |

| | | | OP-001 | OP-002 | OP-003 | OP-004 | OP-005 | OP-006 | OP-007 | OP-008 | OP-009 | OP-010 | OP-011 | OP-012 | OP-013 | OP-014 | OP-015 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TASK RELATED SYSTEMS | SYS-001 | Supply tanks | | 2 | | | | | | | | | | | 1 | | |
| | SYS-002 | Free cargo deck | 2 | | | | | | | | | | | | | | |
| | SYS-003 | ROV hangar | | | 2 | | | | | | | | | | | | |
| | SYS-004 | Mezzanine deck (ROV) | | | 2 | | | | | | | | | | | | |
| | SYS-005 | Offshore crane | | | 1 | 2 | | | | 1 | 1 | 1 | 1 | 1 | | | |
| | SYS-006 | Fish well(s) | | | | | 2 | 2 | | | | | | | | | |
| | SYS-007 | Fish cleaning systems | | | | | | 2 | | | | | | | | | |
| | SYS-008 | Main winches | | | | | | | 2 | | | | | | | | |
| | SYS-009 | A-frame | | | 1 | | | | 1 | | | | | | | | |
| | SYS-010 | Rope and chain storage | | | | | | | 2 | | | | | | | | |
| | SYS-011 | Cable drum | | | | | | | | 2 | 2 | | | | | | |
| | SYS-012 | Helideck | | | 1 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | | |
| | SYS-013 | Xmas tree | | | | | | | | | 2 | | 2 | | | | |
| | SYS-014 | Moonpool | | | 1 | | | | | | 1 | | 2 | | | 1 | |
| | SYS-015 | Stabilised gangway | | | | | | | | | | | | 2 | | | |
| | SYS-016 | MOB boats | | | | | | | | | | | | 1 | 2 | 1 | 1 |
| | SYS-017 | Construction deck | | | | | | | | 2 | | 2 | | | | | |
| | SYS-018 | Pipe drum | | | | | | | | | | 2 | 2 | | | | |
| | SYS-019 | Saturation bell systems | | | | | | | | | | | | | | 2 | |
| | SYS-020 | Hyperbaric life boat | | | | | | | | | | | | | | 2 | |
| | SYS-021 | Hospital | | | | | | | | | | | | | 2 | | |
| SHIP SYSTEMS | CSYS-001 | Hull | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | CSYS-002 | Bridge | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | CSYS-003 | Accomodation decks | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| | CSYS-004 | Machinery | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 |
| | CSYS-005 | Provisions crane | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | CSYS-006 | FIFI | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| | CSYS-007 | DYN POS | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |

Figure 5-1: Mapping between operations and systems

## 5.3 Database and Modules

As stated in the methodology, the next step is to a define modules for the systems identified in sub-chapter 5.2. Per the definition of a module presented in sub-chapter 4.4, there are two aspects which are captured: function and interface. As the systems identified in sub-chapter 5.2 are high-level, the assumption is that they respectively provide one or a few functions, as shown in Table 5-4. Further, they have established interfaces, which are defined in sub-chapter 5.4.3 on page 37. Id est, the systems are from this point on considered as modules.

Table 5-4: Systems and their function

| System | Function |
|---|---|
| Cargo tanks | Transport of liquid and bulk cargo |
| Cargo deck | Transport of deck cargo |
| Offshore hull | Buoyancy |
| Accommodation | Accommodate the POB |
| Bridge | Control centre of ship |
| Small crane | Lift provisions on/off |
| Main Engine | Generate power for propulsion |
| DP | Station keeping/manoeuvring |

The goal of this sub-chapter is then to the determine the range and size of each module, based on the market demand. The latter is assured by analysing a representative fleet of existing ships in a database, with the assumption that the fleet represents demand. The database is provided by Ulstein Group ASA, and can be assumed to be a world-wide representative fleet of PSVs.

### 5.3.1 Database filtering

The goal with filtering the database is to exclude PSVs which are considered not relevant for further analysis, and to keep focus on the relevant market demand. The filters applied are shown in Table 5-5.

Table 5-5: Filters applied to exclude non-relevant PSVs

| Parameter | Filter applied | Comment |
|---|---|---|
| Service year | 2000 – present | Keeping focus on more recently built PSVs and current market demand |
| DWT | > 2000 tonnes | Excluding small PSVs |
| Status | In service and under construction | Cancellations, conversions and other categories are excluded to keep focus on the market demand. |
| Has DP | Yes | DP is a requirement to operate in most environments, especially close to platforms etc. |
| L*B*T (LBT) | Zeros removed | Some of the ships are missing data for either L, B and/or T, leaving LBT as zero. To decrease missing data, these are removed. |

### 5.3.2 Database cleaning

The database is now to be cleaned for outliners and extremes from the standard deviation, as proposed in Ebrahimi et al. (2015), to create a more uniform dataset. This is done by drawing trendlines (regression line) for ± 1 standard deviation, and further, to remove all ships outside of the ± 1 standard deviation. The plots in Table 5-6 are included in the data cleaning due to the relation between the respective parameters. PSVs with abnormal relations (outside of ± 1 standard deviation) between these parameters are assumed designed with special requirements (or related), and are therefore excluded from further analysis. Figures related to database cleaning and determining of module range and size is attached in Appendix B.

Table 5-6: Plots used for data cleaning

| # | Plot | Comment |
|---|---|---|
| 1 | Deadweight vs LBT. | Relationship between deadweight and the submerged box spanned by L, B and T. |
| 2 | Deck area vs. L*B (LB). | Deck area is dependent on more than LB, but there is a clear trend between the two parameters. |
| 3 | Deadweight vs. Accommodation | Included to clean out ships with special requirements (and related) for accommodation. |
| 4 | Deadweight * Speed vs. engine | Handles the relation between ship size, speed and engine power. |

### 5.3.3 Determine module range and size

The next step is to determine the range and size of the modules. This is done by analysing the dataset using normal distributions, and using ± 1.5 standard deviation from the mean to establish the range for the respective modules. That is equivalent to 86% of the area under the curve, or approx. 6 out of 7.

As shown in Table 5-7, there are assumptions regarding the hull and bridge module. For the former, it is assumed that in this case, the hull is a separately designed module, and added to the remaining modules in the final stages of the design. For the latter, it is assumed that the bridge is scaled separately, and is therefore not given any specific values. In addition, the crane is given a binary value and the DP class has the options of DP-1, DP-2 or DP-3.

Table 5-7: Module size and range

| Module | Unit | Module range | | | | | Module size |
|---|---|---|---|---|---|---|---|
| Cargo tanks | [$m^3$] | See Table 5-8 | | | | | |
| Hull | | Assumed designed separately | | | | | |
| Bridge | | Assumed scalable | | | | | |
| Crane | [Binary] | 0 | 1 | | | | |
| Accommodation | [POB] | 15 | 20 | 25 | 30 | | 5 |
| Deck area | [$m^2$] | 550 | 700 | 850 | 1000 | | 150 |
| Main engine | [kW] | 1500 | 1700 | 1900 | 2100 | 2300 | 200 |
| DP class | [Integer] | 1 | 2 | 3 | | | - |

The tank capacities are split in five different tank contents: bulk, oil, ballast/drill water, brine and mud. They have each their own range and size, as presented in Table 5-8.

Table 5-8: Tank modules and their capacity

| # | Tank content | Density [t/m$^3$] | Product range [m$^3$] | | | | | Module size [m$^3$] |
|---|---|---|---|---|---|---|---|---|
| 1 | Bulk (cement) | 2.4 | 200 | 250 | 300 | 350 | 400 | 50 |
| 2 | Gasoil | 0.85 | 400 | 600 | 800 | 1000 | 1200 | 200 |
| 3 | Ballast/drill water | 1.025 | 1000 | 1500 | 2000 | 2500 | 3000 | 500 |
| 4 | Brine | 2.3 | 500 | 1000 | 1500 | 2000 | - | 500 |
| 5 | Mud | 2.8 | 500 | 1000 | 1500 | 2000 | 2500 | 500 |

## 5.4 Architecture

The goal of this sub-chapter is to define the architecture of the modules, according to the definition in sub-chapter 4.8 on page 22. The overall scheme can be translated into two kind of constraints: compatibility and interfaces.

### 5.4.1 Compatibility mapping

The goal of the compatibility mapping is to identify which of the configurations that are compatible and not compatible, and to present this in a structured manner. A usual reason for non-compatibility is when a combination modules exceed volume, weight or performance requirements.

The identification of compatible and non-compatible modules is done by setting limits for e.g. a performance criteria, and further, to establish the link between the module and that performance. For example, a combination of bigger main engine and accommodation may cause too high trim towards the bow. This kind of calculations require a structured mapping of all module characteristics and the affect they have on the total performance of the ship.

Only one kind of these calculations is included in the case study, weight calculations, and is presented in sub-chapter 5.4.2. The remaining calculations are excluded from the case, due to their complexity. However, a method for presenting the compatibility in a structured manner is presented. This method lists the compatibility directly between two modules in a two-dimensional matrix, and all combinations are considered. A limitation is that the method is limited to the combination of two modules, i.e. additional constraints/limitations are presumably required.

Before presenting this method, some assumptions regarding the modules are required. This is presented in Table 5-9 on page 35.

Table 5-9: Compatibility assumptions

| Module | Assumption |
|---|---|
| Cargo | Assumed compatible with all other modules, given the weight constraints defined in sub-chapter 5.4.2 are satisfied. It is therefore excluded from the method. |
| Hull | The hull is generated after the modules are scaled, and is not included in the method. |
| Bridge | The bridge has a fixed size, and is compatible with all modules, and is thus not included. |
| Provisions crane | The provisions crane is a binary variable, i.e. only one capacity, and is either in/out. This is also excluded. |
| DP | The DP class does not affect the design or the performance in the case study, and is therefore excluded from the method. |

Given these assumptions, the remaining modules are included in the method: deck area, main engine and accommodation. Further, as the calculations between modules and performance are excluded, all modular combinations in this case are compatible. The final presentation is shown in Figure 5-2. In the upper-right half of the matrix, the compatibility is represented by colours, while in the bottom-left half, comments are added on the combinations.

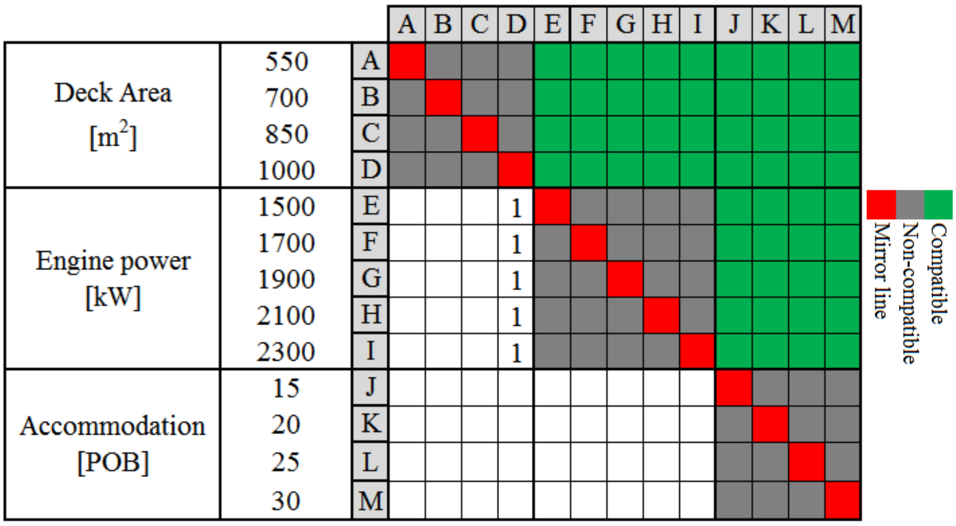



Figure 5-2: Compatibility matrix

Examples on comments are shown in Table 5-10.

Table 5-10: Comments to the compatibility matrix

| Symbol | Comment |
|---|---|
| A, B, C, D | Smaller deck area limits the deck cargo capacity, larger deck area allows for an increase of deck cargo capacity, but requires a longer ship. |
| E, F, G, H, I | Less engine power tends to lead to a slower ship, and more engine power allows for faster sailing speed |
| J, K, L, M | More accommodation space allows for more personnel, but gives extra weight. Less space may restrict personnel flexibility |
| 1 | More deck area requires a longer ship and thus more weight, so to allows for higher cruising speeds, a bigger main engine is required. |

### 5.4.2 Weight compatibility

In this case study, the deadweight is assumed divided in two categories: tank cargo weight and deck cargo weight. Due to the variety of tank cargo types, the number of possible configurations between them is relatively high, which makes it challenging to map them correctly. However, a common constraint is that the deadweight affects the draft (T) of the ship. Further, one can add min and max limits to T, to differentiate between configurations which are compatible and non-compatible.

Firstly, the relationship between deadweight, lightweight and displacement (Δ) is shown in Equation (5.1).

$$W^{DW} + W^{LW} = \Delta \tag{5.1}$$

where

- $W^{DW}$ and $W^{LW}$ is the deadweight and lightweight, respectively
- $\Delta = L\ B\ T\ C_B\ \rho_{sw}$

Secondly, calculations for $W^{DW}$ and $W^{LW}$ are required. The calculation of deadweight is shown in Equation (5.2).

$$W^{DW} = W^{TC} + W^{DC} = \left( \sum_{i=1}^{5} V_i^{TC} * \rho_i^{TC} \right) + \left( \sum_{j=1}^{M} W_j^{DC} * x_j^{DC} \right) \tag{5.2}$$

where

- $W^{TC}$ and $W^{DC}$ is the tank cargo weight and deck cargo weight, respectively
- $V_i^{TC}$ is the volume of tank cargo $i$
- $\rho_i^{TC}$ is the density of tank cargo $i$
- $W_j^{DC}$ is the weight of the deck cargo j
- $x_j^{DC}$ is the quantity of deck cargo j
- M is the set of different deck cargo

Further, $W^{LW}$ is estimated based on $W^{DW}$, Δ and statistical data from Levander (2012). This relationship is given in Equation (5.3).

$$\frac{W^{DW}}{\Delta} = 0.65 \tag{5.3}$$

To get the calculation for $W^{LW}$, Equation (5.1) is implemented in Equation (5.3) and solved for $W^{LW}$. The resulting relationship is shown in Equation (5.4).

$$W^{LW} = \frac{0.35}{0.65} * W^{DW} \tag{5.4}$$

Lastly, T is calculated by implementing Equation (5.4) in Equation (5.1), and solving for T. The result is shown in Equation (5.5).

$$T = \frac{20}{13} \frac{W^{DW}}{L\ B\ C_B\ \rho_{sw}} \tag{5.5}$$

To differentiate between compatible and non-compatible module configurations, the following constraint for T is then given:

$$0\,m < T < D \tag{5.6}$$

where

- D is the depth of the ship

### 5.4.3 Design interfaces

The assumption is that the modules are simplified to a point where the exchange of information and matter between the modules can be excluded from further assessments. Examples here are how piping, electrical signals, etc. are interfaced between the modules. The remaining task is then to define the location interfaces, i.e. where the modules are located and how they move in relation to one another. However, as there are no movements (no rotations or translations) between the modules neither in the design nor operational phase, only a definition of the location is required.

The definition of the modules’ location is done per the generic description of a PSV. The cargo deck is located aft, surrounded by the cargo rails. The cargo tanks are located below the cargo deck, around the longitudinal centre of the ship. The main engine is located towards the bow, below the superstructure, which is in front of the cargo rails. The bridge is placed on top of the superstructure. The provisions crane is placed right aft of the superstructure. These relative descriptions are summarized in Table 5-11.

Table 5-11: Relative location of the modules

| Module | Relative location |
|---|---|
| Cargo tanks | Right aft of the main engine module |
| Bridge | On top of the superstructure |
| Crane | Right aft of the superstructure |
| Accommodation | On top of the main engine module |
| Deck area | On top of the cargo tanks module |
| Main engine | In front of cargo module, and below the superstructure |

# 6 3D-MODELLING AND ASSEMBLY

In this chapter, form is given to the modules. First, some simplifications are given before each module is explained individually, and finally assembled into a ship.

## 6.1 Simplifications and deviations

The modules are mainly boxes with simple geometry added (more is specified in the following sub-chapters). The reason for this is to direct focus towards the methodology and to delimit the scope of the 3D-modelling.

### 6.1.1 Cargo module

There are some simplifications from the foundation work, where the most visible simplifications regard the cargo module. To simplify the cargo module, the cargo types are reduced from five types to two categories: dry cargo and liquid cargo. Dry cargo is the bulk cargo, while the liquid cargo is the remaining 4 cargoes listed in Table 5-8 on page 34. The deadweight is then calculated based on these two types of cargo.

The bulk tanks are circular, while the liquid tanks are cubical. There are also deviations in capacity per tank. Table 5-8 on page 34 gives the intended capacities, but these are adjusted in the 3D-modelling due to the decrease from five tank cargo types to two. The bulk cargo tank capacity is 75 $m^3$ and the liquid cargo tank capacity is 300 $m^3$.

### 6.1.2 Hull module

Another simplification is regarding the hull module. The assumption is that designing the hull is an entirely separate exercise with includes other design disciplines such as hydrodynamics. Further, it is assumed that the hull is developed after the configuration of the other modules is complete, and will act as a “skin” in which the other modules are placed. Therefore, the hull is not part of the configurator. However, an example is of a hull is included. This is shown in sub-chapter 6.6.

## 6.2 Cargo module

The cargo module is the most central part of the ship. It has double sides and a double bottom, where the latter has capacity for ballast and/or drill water, and the exact capacity is accessible for the designer in the ship configurator. In this way, there is more free tank space for other cargo.

The cargo module consists of three decks: tank top, tween deck and main deck. However, the two latter are transparent due to better visuals, as seen in Figure 6-1. The length of the cargo module scales automatically. The designer adds or subtracts cargo tanks according to the customer’s requirements, and the module scales automatically in pre-defined steps, due to pre-defined tank dimensions, and in real time.

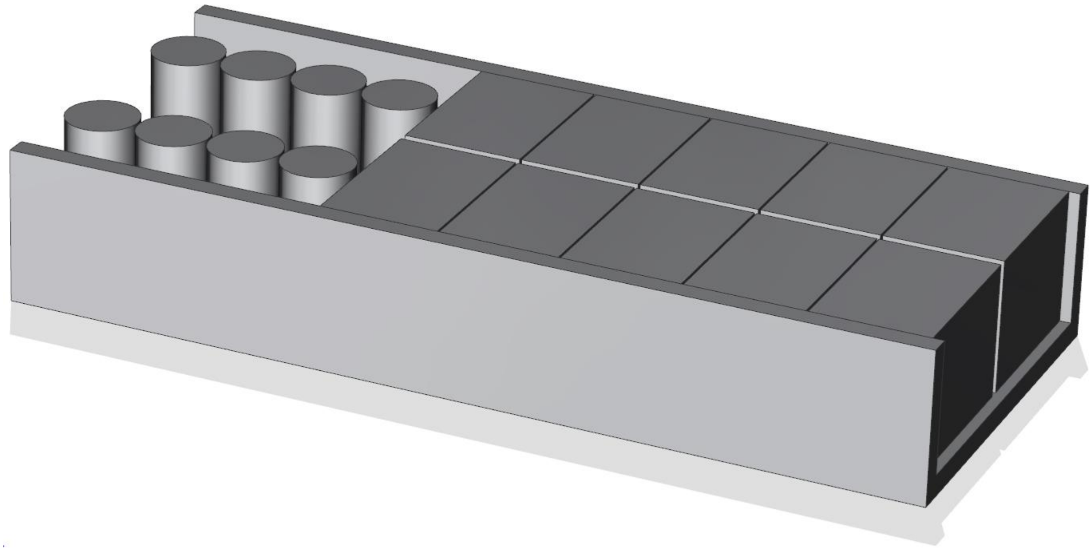


Figure 6-1: Tank module, including dry and liquid tanks

## 6.3 Main engine module

The assumption is that the main engine is located in the lower part of the bow, and that the volume of this part depends on the size of the engine. The designer chooses the main engine power according to customer requirements, and the module scales automatically. The beam and height is fixed, i.e. it scales in the longitudinal direction. Given this, the engine module is located directly in front of the cargo module, with the same height as the cargo module. The height is then from the keel to the main deck. Further, some geometric adjustments have been added to account for the narrowing of the hull in the bow. The main engine module is shown in Figure 6-2.

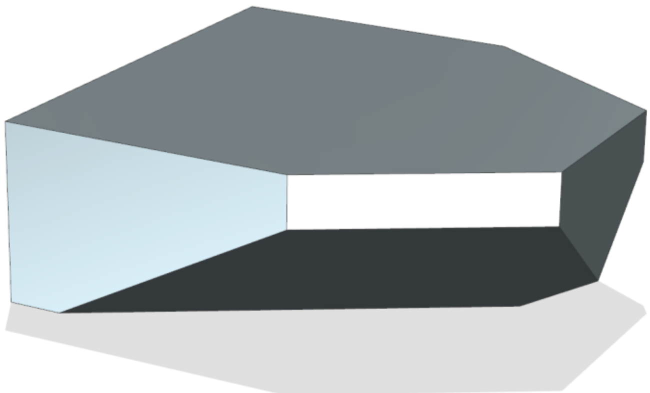


Figure 6-2: Main engine module

## 6.4 Accommodation module, bridge and crane

The assumptions are that accommodation module is located above the main engine module, in the upper part of the bow, and that the volume depends on the number of personnel on board (POB). Further, the beam and length are fixed, i.e. the scaling happens vertically. The designer selects the number of POB, and the module scales automatically, in real time. The module is given some geometric adjustments as well, to account for the narrowing of the hull, which is shown in Figure 6-3. The bridge is added on top of the accommodation module and the provisions crane in located right aft of the superstructure, as seen to the right in Figure 6-3.

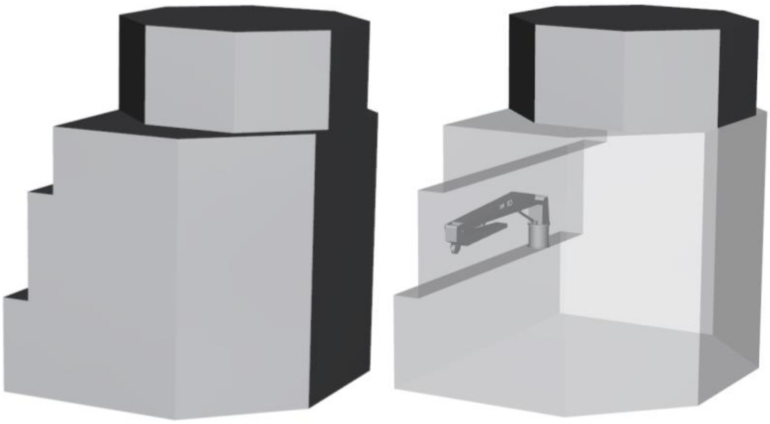


Figure 6-3: Accommodation module and crane location

## 6.5 Deck area and cargo rails

The deck area is the area bound by the superstructure and the cargo rails, above the cargo module. As the beam of the ship is fixed, the area depends exclusively on the length of the cargo module, which again depends on two factors: the number of tanks (as described in sub-chapter 6.2 on page 39) and a parameter called "extra deck area". The latter adds 50 $m^2$ by extending the cargo module. The designer is presented with the current free deck area during configuration, and can scale the cargo module according to the customer requirement. Further, the designer can add the required weight of the deck cargo, and it will add to the total deadweight.

The cargo rails are located above the cargo module, and run all the way around the deck area. Aft of the cargo module and below the cargo rails, there is a block. This block is not defined as a module, as it adds no function to the ship's performance. It is added to handle the elevation of the hull in the aft, i.e. make the transition a bit smoother, in the area where propulsion units usually are located. The top area of the block is included in the calculation of the deck area. In Figure 6-4, the block can be seen to the left, while the cargo rails can be seen surrounding the cargo deck.

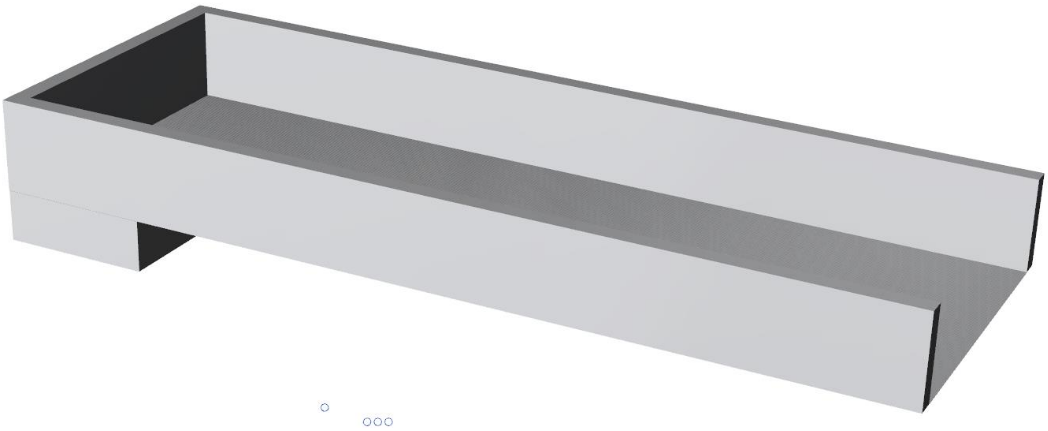


Figure 6-4: Cargo deck and cargo rails

## 6.6 Hull module

The hull shown in Figure 6-5 is created in DelftShip. In this case, the main dimensions of the ship where collected from the configurator after the scaling of the other modules was complete. Then, the main dimensions were exported to DelftShip to scale the hull. Finally, the hull was exported back to NX for assembly.

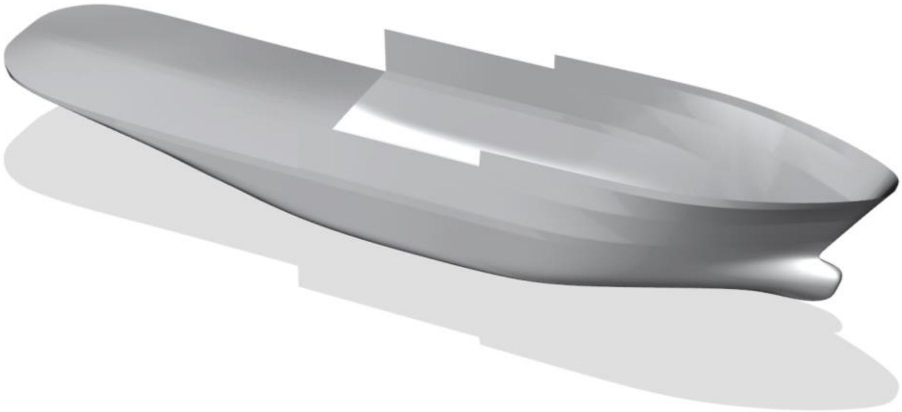


Figure 6-5: Hull module

## 6.7 Assembly

After generating all the modules, the remaining part is to assemble them according to the description presented in sub-chapter 5.4.3. An exploded view of the ship assembly is used to illustrate the location of each module and shown in Figure 6-6.

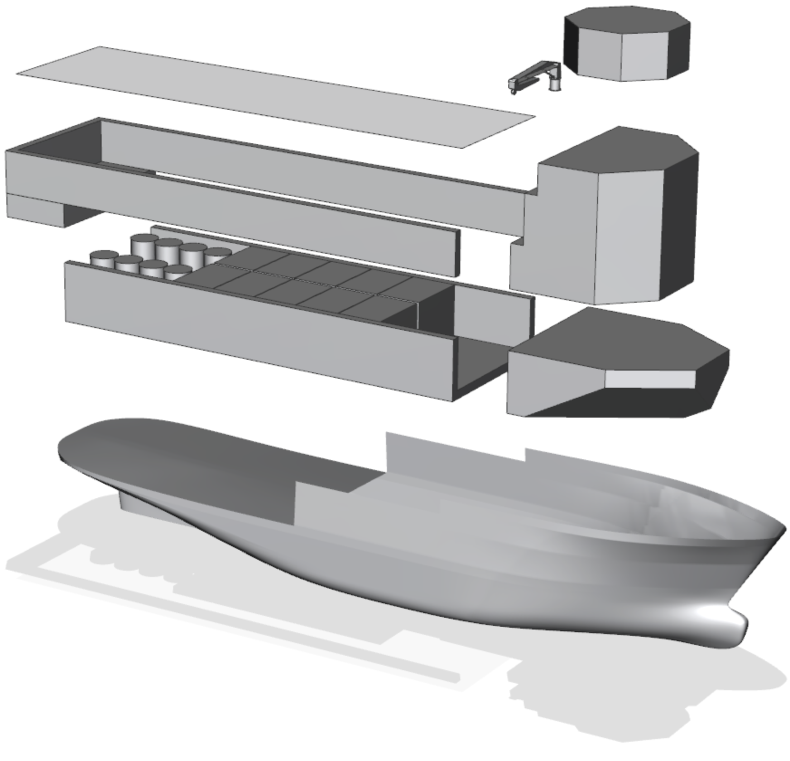


Figure 6-6: Exploded view of the ship assembly

# 7 RESULTS

The result of the case study is a ship configurator. Through the interface of the configurator, the designer can configure a design, based on customer requirements in a tender invitation. Further, the 3D-model is exported to AutoCAD, where a general arrangement (GA) is created.

The ship configurator is made in product template studio (PTS), which is an application within the NX environment.

## 7.1 Ship configurator

The final design of the configurator interface is shown in Figure 7-1. A video example is included and can be found digitally in the DAIM system or with this [link](goo.gl/r5YXsg) (URL: goo.gl/r5YXsg). The interface consists mainly of two areas: configuration and outputs. In the upper part of the interface, the designer can configure the modules, and in the lower part, various outputs are presented.

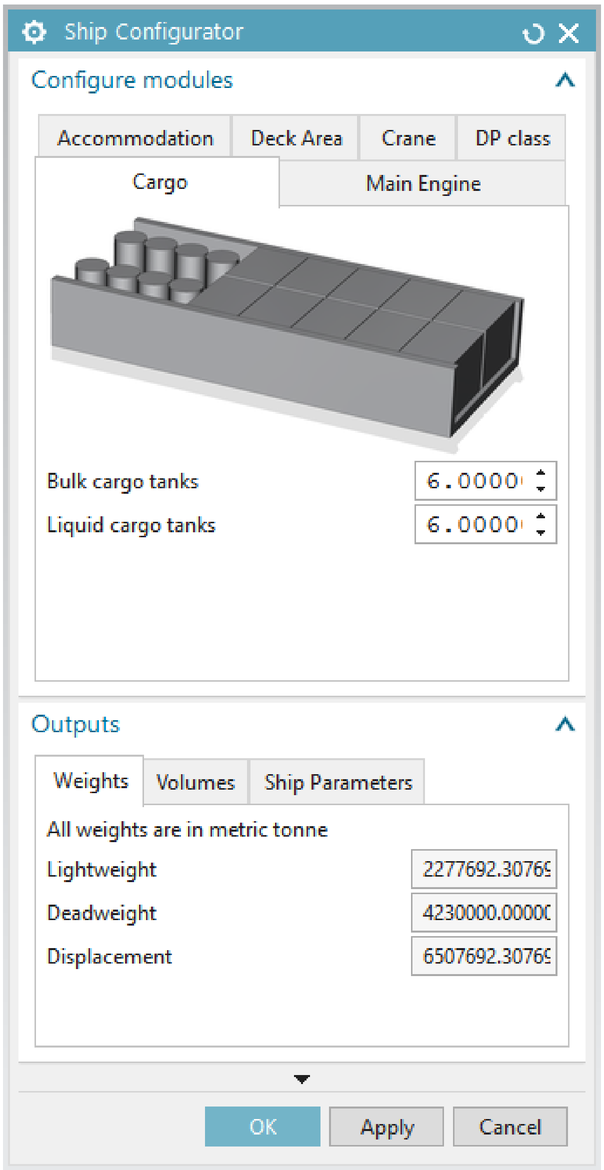



Figure 7-1: Ship configurator interface

Included are some further examples of the configuration part (Figure 7-2) and the output part (Figure 7-3). Included in the configuration interface, is a graphical presentation of each of the modules. Further, the drop-down menus contain the values obtained in sub-chapter 5.3.3 on page 33.

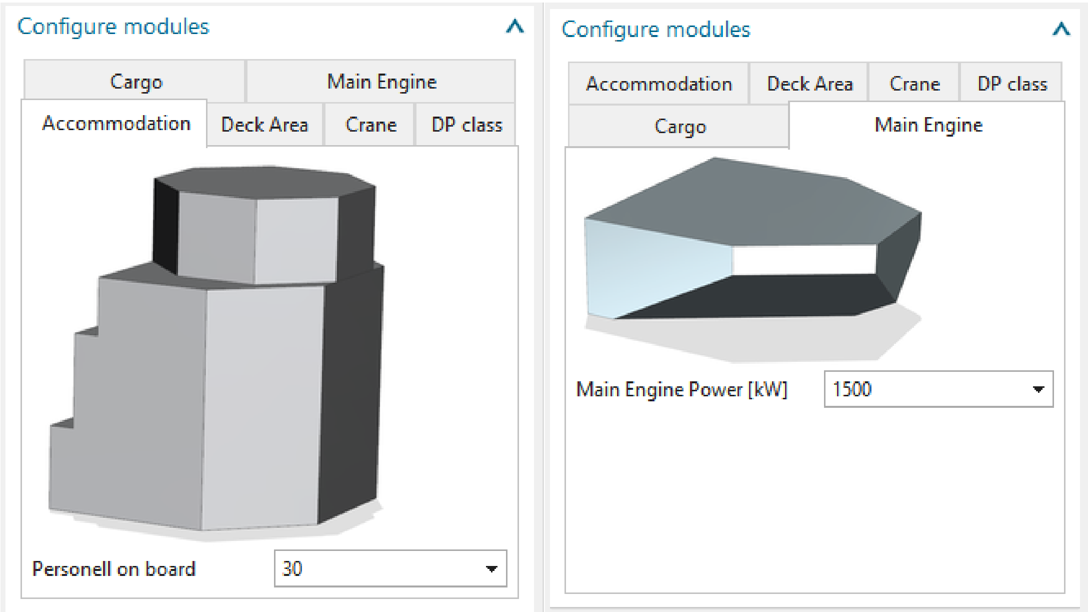



Figure 7-2: Module configuration examples

Various outputs provide the designer with necessary information, in real time. To the left in Figure 7-3, the $C_B$ is shown as in input. The assumption is that when the hull is created in a separate application, the designer can provide the $C_B$ into the configurator.

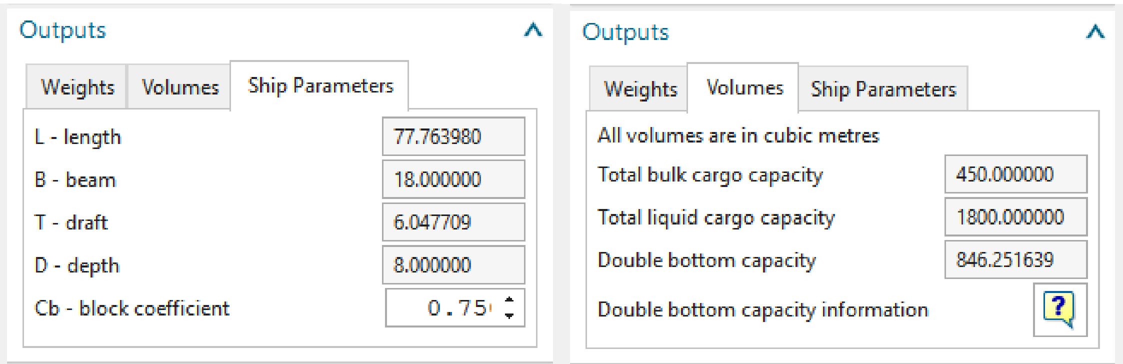



Figure 7-3: Output examples

## 7.2 General arrangement example

The general arrangement (GA) example is included to show the next step of the design process. After a configuration is complete, the designer can export the model to AutoCAD to create a GA. The simplified GA shown in Figure 7-4 should not be considered as a reference, but rather an example of the possibilities beyond the configuration environment.

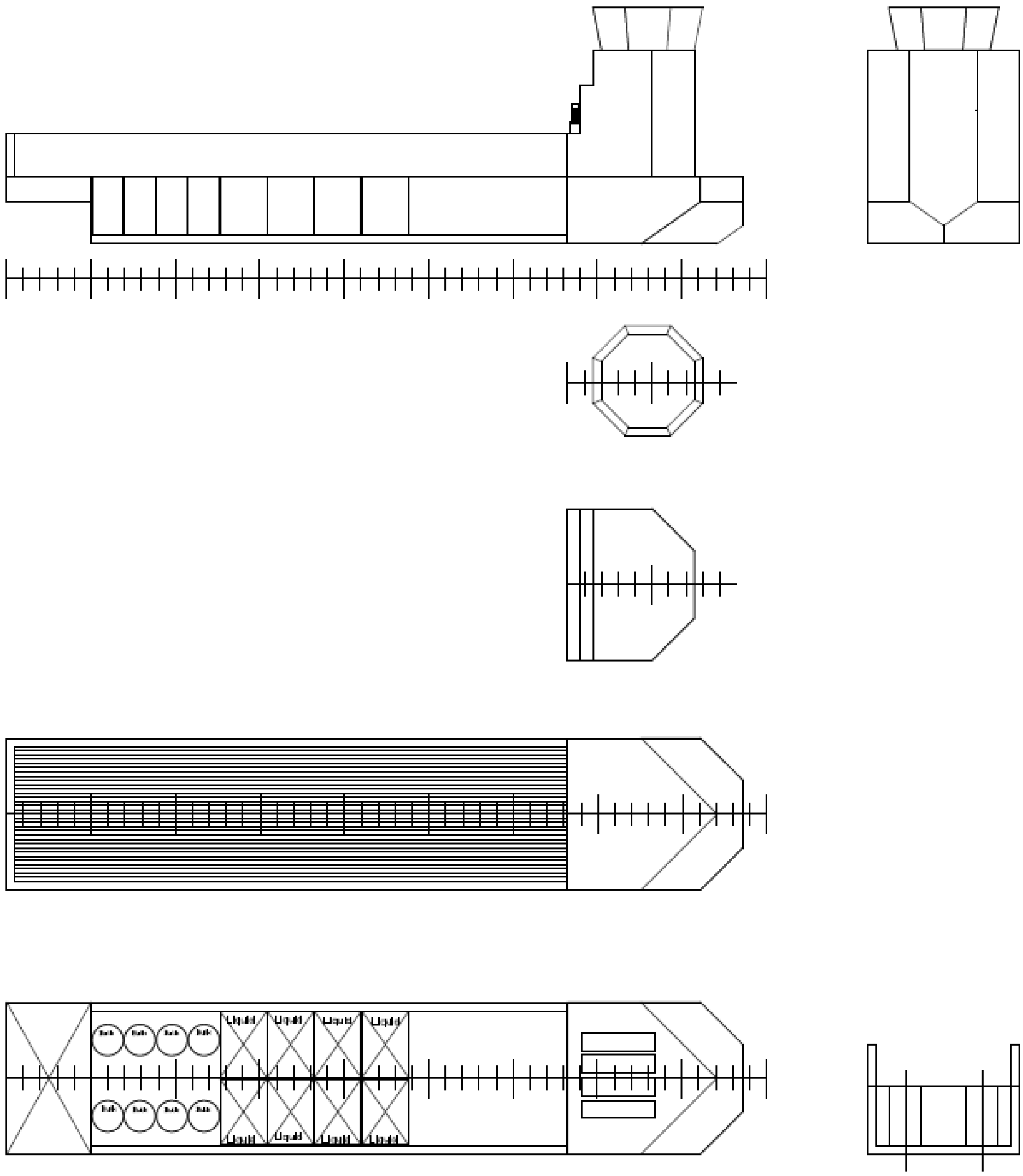


Figure 7-4: Simplified general arrangement example

# Part III DISCUSSION

# 8 DISCUSSION OF CASE STUDY

This chapter contains discussions related to the case study presented in Part II. The goal is to discuss decisions made during the case study, as well as other assessments connected to various parts of the case. The discussion will follow the same succession as the methodology presented in sub-chapter 5.1 on page 27, and will end with an additional discussion on case limitations.

## 8.1 Methodology

The methodology presented in sub-chapter 5.1 represents the working process for this thesis. The goal of the methodology is to describe the work process to the degree so that other researchers can replicate the study, to verify the results. This is one of the foundations of the scientific method. If one is to replicate the methodology presented in the case study, it is presumably unlikely that one ends up with the same set of modules, and the same architecture. This is due to insufficient precision in certain areas of the methodology. To increase the likelihood of similar results, the methodology presumably requires higher precision to reduce the variance of preliminary and final results. The areas assessed to have insufficient precision will now be discussed.

### 8.1.1 Identification of operations and system

This identification is assessed to be the part of the methodology which is most likely to produce the same (or relatively similar) results. The mapping of operations and systems for the generic description of a PSV is assessed to lead to relatively similar results. However, a difference in mapping is presumably be due to other researchers dividing the systems either to a deeper level or with another system perspective.

Further, if one presumes that a PSV is a ship with a relatively few task related systems, that implies offshore constructions vessels (OSVs) or other specialised tonnage ships with a low deadweight/displacement ratio have relatively more task related systems. When mapping operations and systems for these kinds of ships using the same methodology as in this case study, the assumption implies that the likelihood for a higher variances of mapping results are higher. This leads to the assessment that this part of the methodology requires a higher precision than presented in this case study.

### 8.1.2 Defining modules

This part of the methodology is assessed to be the part which leads to highest variance of results. The reason is due to the extensive interaction and integral structure of the ship systems. However, if one simplifies these aspects to the degree which is done in sub-chapter 5.3 and 5.4.3, and use the definition of a module in sub-chapter 4.4, one can say that the systems identified in the previous step of the methodology, may act as modules. This simplification does not allow for matter or information to be transmitted between modules, so the limitations on a detail design/production scale is obvious. However, in a conceptual design environment, these simplifications can be accepted, to a certain degree. As this design activity results in an outline specification, where the goal is to describe main functions, performance and technical solutions (see sub-chapter 4.1), a degree of simplification is presumably acceptable.

The definition of the modules, with less or even no simplifications, is an interesting research area. The main challenges will be to include all aspects of a modularization process (sub-chapter

4.3): decomposition, self-sufficiency, architecture and recombination to a variety of products, as well as the attributes of a module: one (or a few) functions and a defined interface. This requires a substantial platform of ship design and construction knowledge, before starting the modularization process. A such platform is not normally possessed by students or independent researchers. This implies that maritime companies and researchers have to collaborate, if any substantial ground is to be covered.

This is one of the drawbacks of modularization, as it requires initial investments in research and work, which may not pay off if there exists no demand for the products. Further, there are some challenges regarding the modularization process, as mentioned in the previous paragraph.

### 8.1.3 Database filtering

The next parts regard the database analysis, more precise the filtering and cleaning process. Firstly, the filtering process is discussed, where the goal is to exclude irrelevant ships from further analysis. The following paragraphs refers to the filters applied in Table 5-5 on page 32.

Service year. This filter keeps focus on newly built ships, to exclude the “last generation” ships. The filter is put to year 2000, which is chosen due to that is looks *easy on the eye*. In hindsight, more relevant filtration years could be the year of key IMO-conventions stating new design and classification requirements. An example is the MARPOL-convention and the “Prevention of Air Pollution from Ships”, which entered force 19$^{th}$ of May, 2005 (IMO, 2017).

Deadweight. This mainly excludes small PSVs, but raises the question “where goes the line between a small PSV and a regular PSV?”. Experience tells us that PSVs with less than 2000 DWT are usually relatively small, but there is no real quantitative logic behind this number. Better filters for removing small PSVs could be to exclude ships below a certain “rule length”.

Status. If a ship is not under construction or in service, it is not fulfilling any customer demand, and is thus excluded from the dataset. For example, cancellations are ships which were intentionally designed to perform a function for a customer, but due to some temporal and/or contextual complexities, there was no longer a demand for the ship.

Has DP. Today, most PSVs are constricted by regulations to have DP, especially during station keeping near platforms or other objects. PSVs without DP are assessed to have relatively small operational capabilities, and are therefore excluded from the dataset.

LBT. This filter was primarily included to reduce the number of missing data, by excluding the ships with missing values for L, B and T. But if the goal was to remove missing data, the question should be: “Why are these parameters used, and not e.g. D, speed or DWT?” L, B and T were used in the first plot (DWT vs. LBT) during the database cleaning, which resulted in many of the data points being equal to zero. This resulted in an incorrect. Therefore, “LBT = 0” were removed from the dataset. This raises the question “would the final dataset, and thus case results, differ from the current result, if other plots were used?” Presumably, yes. However, the plots were chosen based on the systems identified in the previous steps of the methodology.

### 8.1.4 Database cleaning

During the database cleaning, ± 1 standard deviation regression lines were used to remove data points form the data set. Ebrahimi et al. (2015) states that 1 or 1.5 standard deviation area in normally distributed dimensions and particulars is acceptable range for cleaning outliers.

From statistics theory, one can calculate that 1 standard deviation is equal to 68% of the area under the curve and 1.5 standard deviation is equal to 86%. There is a trade-off between 1 and 1.5 standard deviations: 1 gives a more uniform dataset, but less data points and 1.5 gives less uniform dataset, but more data points. Further, one might argue that as there are four plots which are used to clean the dataset for outliers and they are considering different parameters, it would be beneficial to include as many data points as possible, thus using 1.5 standard deviation. And further, that the number of plots will account for the uniformity of the dataset.

### 8.1.5 Determine module range and size

When the module range and size was determined, the data was firstly normal distributed respectively for each module, then, 1.5 standard deviation was used to define the range. This was done to keep focus on the relevant market demand. Another solution to define the module range would have been to list the demand from lowest to highest, and then to define the range somewhere logical. However, this would not account for the distribution, such as the normal distribution does.

The determining of the module size, which is to divide the range into equal steps, is a part which may lead to variance in results. A challenge which occurred during this process was that the 1.5 standard deviation was defined between two steps. This posed the question of whether to include the extra step or not. The assessment lead to that, in most cases, the extra step was included to allow for a higher variety on the end product. This was assessed as accepted, due to the simplifications done previous in the thesis. However, if such simplifications were not implemented, a higher variety will presumably lead to more work and higher complexity.

### 8.1.6 Architecture

As simplifications regarding most of the modules were implemented, the architecture part of the methodology is considered a part where there are several challenges. There are attributes of each module which contributes on a system level, and attributes which contributes on a ship level. E.g. additional cargo tanks contribute on a system level by adding cargo capacity, and on a ship level by adding extra length, and thus altering e.g. the trim, draft and speed. This implies that some performance criteria require calculation after the total assembly. Further, Chaves et al. (2015) captures that same aspects and states that some performance characteristics follows each module, and some has to be calculated after the final assembly of the ship.

The matrix presented in sub-chapter 5.4.1 is a visual representation of the compatibility of every combination of two modules. The main benefits are that it is intuitive and structured, and the main drawback is that it is limited to the combination of two modules. It may be utilized two identify immediate incompatibilities between modules as an initial compatibility mapping, however, as it is limited two the combination of two modules, it presumably requires more constraints/limitations.

## 8.2 3D-modelling

There were several assessments regarding the 3D-modelling, mainly with regards to simplifications relative to the previous parts of the case study. It was discovered relatively early that creating a configurable design was challenging, especially without simplifications.

### 8.2.1 Cargo module range and size simplifications

The simplifications regarding the hull module were mainly to delimit the 3D-modelling scope. The major simplification was to reduce cargo types from five down to two. Five would have been possible, but had required more time in the 3D-modelling environment and a more complex assembly process, i.e. it would have decreased focus on the other parts of the case study.

### 8.2.2 Hull module simplification

The assumption that the hull is created in a different application removes all complexity regarding the hull, in this case. However, there are some developments in hull design in the NX modelling environment. One example is Skogsfjord and Rognseth (2014). The authors of this thesis have collaborated with Wärtsilä and created an interface for hull design in NX. They have used the same application within NX, PTS, so a direct implementation of this kind of hull design is interesting.

## 8.3 Configurator

One of the most important factors of the configurator was the intuitiveness of the interface. During the interface design, several layouts were tried, assessed and deemed “unnatural” as they didn’t feel intuitive. The final interface layout allows the designer to quickly make reconfigurations and view the different outputs, and further, it feels intuitive to navigate.As the configurator is a part of the NX-environment, it allows for rapid design. When a designer e.g. increases the cargo capacity through the interface, the 3D-model and the output update in real time.

A drawback of having a pre-defined interface is that the information presented to the designer through the interface, is limited to the pre-defined information. If the designer is curious to the extent that the given information is insufficient, it requires knowledge about the 3D-modelling and assembly. However, a pre-defined interface allows for design knowledge to be re-used throughout a company, and presumably, decrease the degree of education required to operate the interface.

## 8.4 General arrangement example

After a ship is configured according to customer requirements, it can be exported to AutoCAD. In AutoCAD, the designer can develop a GA. The benefit is that the various lines and sketches required for developing a GA are directly obtained from the 3D-model.

In the example included (sub-chapter 7.2), there are some obvious simplifications regarding the details of the GA, and it should not be considered a reference in how a GA is supposed to be designed. Further, the main purpose of presenting the GA example is not to present how a GA is developed, but to show that the 3D-modelling and configuration can be included in a useful context.

## 8.5 Case limitations

Due to assumptions and simplifications, the results of the case study have several limitations. These will be further discussed in the following sub-chapters.

### 8.5.1 Description and functional performance

The main limitation in the case study presented in this thesis is the mapping between the description of the ship and the functional performance (see sub-chapter 4.2). Traditionally, this mapping is done in iterations using the design spiral strategy. In a modular design strategy, each module contributes a function, volume and weight, which affects the total performance of the ship. And due to the complex inter-relations between some systems, this mapping is a challenge. This is confirmed by the previous research, as mentioned in sub-chapter 1.3.1. For example, the cruising speed is dependent on the machinery, deadweight, hull shape, etc. Some simplified mapping could have been developed, but they would presumably be incorrect, and thus misleading to present. This mapping process is presumably an interesting research area. This limitation resulted in poor benchmarking possibilities, which in the end were assessed to be removed from the thesis.

### 8.5.2 Benchmarking

The goal with benchmarking is to review the performance of more designs than one, to find the design which better fits the requirements. In this case study, one of the most interesting things to benchmark is connected to the cargo capacities. Due to the standardization, it is possible that the customer requirement happens to be somewhere in the middle of two standardized sizes. So, the question is whether to choose the standard size below or above the customer requirement, which implies e.g. more/less deadweight, higher/lower speeds, higher/lower machinery power, and of course, cost. More cargo capacity allows for a higher income on cargo transportation, but on the other hand, higher expenses due to heavier ship, more fuel, etc. And vice versa for less cargo.

It would be interesting to develop a formula to quantify this issue. In the long-term perspective, several configurations could be compared, each with different values derived from this formula. If the formula contained factors from all the modules, the total performance and fit could be assessed to find the best design.

### 8.5.3 Ship parameters

A limitation is the assumption that B and D are fixed. Primarily, it was thought that the designer should be presented with the choice of changing B and D. However, only varying the length was deemed less complex. This also allows for the hull module to have a fixed breath, thus only scale in the longitudinal direction, which was favourable. Presumably, if the case study continued, there would be opportunities to add hulls with other values for B and/or D, e.g. to increase cargo capacity and initial stability, or increase speed by making the hull narrower.

#### 8.5.4 Tank layout

It would be interesting to add more tank layouts inside the cargo module. The current layout limits the possibility to distribute the tanks in different orders. Presumably, there would be a number of standardized layouts from which the customer could choose. These layouts will affect the performance of the ship differently, so the form-performance link also needs to be established. Some PSVs also operate with multipurpose tanks, which also would have been interesting to include.

# 9 VALUE CHAIN PERSPECTIVE

The three distinct areas of research covered in this thesis, CBD, standardization and modularization, presumably affect both upstream and downstream activities when implemented to a relatively extensive degree. With this assumption, there is a need to assess and discuss these affections. In the following chapters, the three perspectives will be further discussed: design, construction and operation.

## 9.1 Design perspective

### 9.1.1 Standardization in design

From a design perspective, standardization can be thought of as a strategy utilized by the designers to ensure re-use of design knowledge, which comes with some benefits. Re-use implies that the same design is used in different projects, thus decreasing the requirement for new designs and decreasing the design lead time. This leads to an acceleration of the design process, allowing for an increase in contracts. Further, this may affect upstream activities such as the production, as production lines can to a larger degree be optimized. This allows for price reductions, which is a key benefit in standardization.

In addition, by re-using certified designs, the risks associated with malfunction or failure of new designs will be reduced. This allows for an increase of the reputation of the company, with regards to safety and quality.

Standardization of ship design implies less customization and less customer influence on design and engineering decisions. This is an issue as for some time, one of the most heavily weighted order-winner criterion has been the level of design customization. Usually, the ship buyer gets a ship tailored to their requirements and preferences. Further, they have the power to influence design criteria and decisions during the design and construction phase of the ship. This tradition tends to eventually lead to higher design and construction costs, thus a costlier ship. Even though Cho and Porter (1986) found that the importance of price as a purchase criterion decreases as ship customization increases, recent low oil prices and less open wallets may favour standard design solutions and lower costs in favour of customization.

An example of the effects of standardization across products is the joint strike fighter (JSF) program for the US Defence. With extensive research and development regarding commonality, they managed to develop 3 fighter aircraft variants for the cost of 1.8 (Boas, 2008) resulting in huge economics savings.

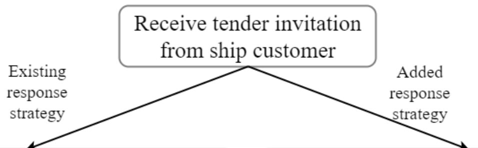
### 9.1.2 Production series and demand

Further, another aspect is the considerable difference in the length of product series between the maritime industry and e.g. the automotive industry. In the latter, the product series can be as high as millions, whereas the series of a specific ship design varies and usually depends on the ship type. The typical length of a series in particularly European shipbuilding is short, this implies fewer projects to share the costs of developing a configurable product platform (Erikstad, 2009). This is also captured by Semini et al. (2013) who states that is it critical to spread the costs of standardization of design, engineering and procurement activities over a sufficiently large number of vessels to realize expected savings.

In other industries, the standardized designed products are presumably based on forecasted demand. In this sense, it is crucial to be able to forecast the demand with sufficient accuracy. This is a challenge in the maritime industry, especially the specialised tonne segment, as the demand depends on various stochastic factors. If the demand forecast is incorrect and there is no demand for the ship type in question, there is no ROI. This, together with the criticality of spreading the cost of standardization over a sufficiently large number of vessels, are the major drawbacks of standardization in ship design.

### 9.1.3 Standardization as an added response strategy

A standardization strategy can be thought of as an addition to an existing design spiral strategy. This is shown in Figure 9-1, table is from Semini et al. (2013), based on Martinez-Olvera and Shunk (2006). This allows a design company to offer both more costly, custom designs and less costly, standard designs. Further, this may open for an increase in order winning designs, which implies an increase of contracts.




| Product/market attributes | Custom design strategy | Standard design strategy |
|---|---|---|
| Cost/price | Higher | The more ships produced, the lower the unit cost and price |
| Lead time | Longer | Shorter (if production can start quickly) |
| Delivery precision | More difficult to achieve | Easier to achieve |
| Level of customization | Higher | Lower |
| Variety | Higher | Lower |
| Modularity and standardization | Desirable, but difficult | A must |
| Customer influence | Part of the value offered | Must be kept low |
| Number of components | Very high | High |
| Minimum volume requirements | One or two | Typically, three or more |
| Order qualifiers | Quality, lead time, on-time delivery, price | Quality, lead time, on-time delivery |
| Order winners | Flexibility, customization, product design/features | Price, product design/features |

Figure 9-1: Attributes of two distinct design strategies

### 9.1.4 Modularization in design

Modularization requires a degree of design standardization, especially regarding the interfaces between modules. A great example is the USB interface found of most computers. The USB interface is similar for all external devices connecting to the computer, but the design of the external device can have almost any given form and function.

One of the characteristics of modularization is a modular structure, which allows the designer to remove or scale modules without affecting the rest of the system. According to Brekke (2012), this allows for higher creativity in the design phase. However, as the designer is limited to pre-defined modules, one might argue that modularization constrains creativity. The modular structure allows for a flexible design process, as the designer can mix and match modules to alter a product towards specific requirements. This further allows for rapid benchmarking in a virtual prototyping environment, as well as less effort in comparison of ships, quicker and simpler redesign, and a more visual approach (Chaves et al., 2015). This flexible process is assessed to be one of the key benefits of modularization. Lastly, Hagen and Erikstad (2014) argues that a modular strategy may improve the efficiency and quality of tender project development, and possibly leading to both increased handling capacity and higher hit rate.

The major challenges associated with modularization were mentioned in Chapter 1 of this thesis, but will for the purpose of the discussion be repeated. Regarding modularization of a ship design, the key challenges lie in the complexity of a ship design due to the extensive interactions between systems in the ship. As discussed earlier (see sub-chapter 8.1.2), the mapping of these interactions requires a huge platform of knowledge, usually possessed by design companies. However, they might not be interested in investing in a modularization process, so the solution requires presumably a collaboration between companies and academia or researchers.

One assumption is that modularization has, in addition to the aspects discussed previous in this sub-chapter, roughly similar benefits, drawbacks and challenges as associated with standardization. This is due to that modularization requires a degree of standardization. The benefits and drawbacks are summarized as reduced cost, reduced lead times, reduced risk, less customer influence, less design customization.

### 9.1.5 Configuration based design

The key motivation associated with CBD is a more responsive and flexible design process. Traditionally, ships are designed using a design spiral approach, which is an iterative design process, which has proven to be a good solution for handling the structural and behavioural complexity of a ship. Further, a benefit of the traditional ship design process is that it is demand based, that is, a relatively small amount of work is conducted before a ship customer invites to tender. This introduces relatively little risk in form of financial investments in design. However, the design lead time is presumably longer, relative to a CBD process, per unit designed. For the latter, a sufficient amount of design is required before the ship customer invites to tender. This allows for rapid response by the design company, when during tendering, a ship is quickly configured based on the customer's requirements.

A CBD strategy allows the designer and customer to discuss different configurations at an early stage of the design phase. If a virtual prototyping environment is included in the configurator, it allows for rapid benchmarking and assessment of various configurations. If this is extended even further by including epoch-era analysis, it is possible to identify the best possible design, including long-term assessments, for the customer.

A drawback of CBD is that it requires a degree of standardization and modularization, which has its challenges, as discussed in the previous sub-chapters. Another challenge of configurable design is that parts or modules does not have a pre-defined location, and thus can be configured in different assemblies. This is captured in Vestbøstad (2011) and is shown in Figure 9-2. The figure shows three configurations of the same volumes and functions.

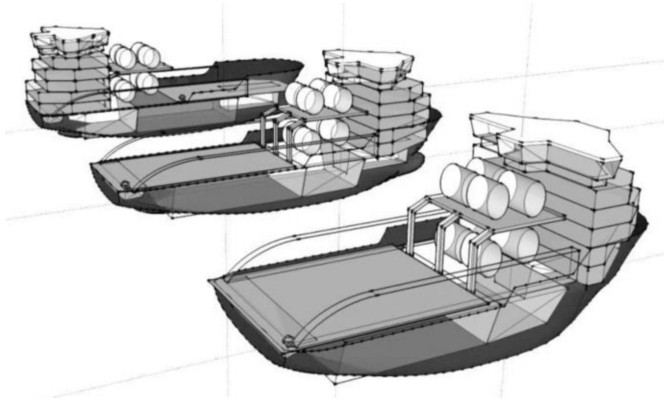


Figure 9-2: Three different configurations of the same volumes and functions (Vestbøstad, 2011).

This adds an extra dimension of challenges in the design process: "which configuration has better performance?" The benefit of implementing standardization to a sufficient extent is that this dimension is taken care of with pre-defined locations. The downside is the possibility that one misses the opportunity to compare the configurations, and further identify the design with optimal performance.

## 9.2 Construction perspective

The main benefits for the yard are associated with standardization. This allows for optimization of material flow and construction lines, and opens for new technology such as automation and industrial robots. Further, there are benefits associated with mass production and economies of scale. One example is lean manufacturing, where the underlying principle is to shorten the production flow by eliminating waste (Liker and Lamb, 2000). Lean manufacturing was famously achieved by Toyota in the middle of the 20th century, but also adopted by Japanese shipbuilders (Hagen and Erikstad, 2014).

I more recent years, robotics has entered production lines, where the most famous actor being Tesla Motors. Benefits of industrial robots are mainly efficiencies in repetitive tasks in a controlled environment. However, a drawback is that is requires a degree of an assembly line production, which is relatively rare in specialised tonnage ship construction. Nonetheless, standardization allows for assembly lines to be developed, thus the next evolutionary step is to include industrial robots.

Further, modularization allows for outsourcing of complete modules, which is associated with some benefits. A benefit is the possibility to outsource a module to a company which are considered leading on that given technology. In this way, high quality is assured throughout the construction. Outsourcing allows for parallel production as well, which leads to shorter lead time in construction. Another benefit is the self-sufficiency of the modules. This allows for quality control and extensive testing of each respective module before final assembly. So, when the final ship is assembled, there is presumably requires less time for system testing.

## 9.3 Operational perspective

From a customer perspective, standardization may be associated almost as a threat, as it removes the customer's influence on design and engineering decisions. This is presumably due to that the sums associated with investing in ships are relatively large, and when sums of this magnitude is spent, the customer wants to have an influence. This is assessed to be one of the key drawbacks of standardization from an operational perspective.

Further, the ship customers usually have their own customers, and their ships are part of a larger value chain or context. So, the question is whether this larger context will be affected by standardization of ship design, and to what degree.

Immediate benefits are associated with the familiarity of operating ships with similar systems and solutions, which implies the crew are familiar with the ship during operation. Further, presumably less time can be spent in training, as the systems are the same across a fleet.

Further, modularity in design allows for modularity in operation, if implemented through construction. This implies changing modules during the operational phase of the ship, which has some associated benefits. For example, modularity in operation allows for high mission flexibility without compromising the mission specific efficiency (Brekke, 2012).

Slot modularity in operation is utilized by naval vessels, where equipment modules are installed in different combinations, based on current mission. This allows for a high variety of missions, using the same vessel.

# 10 THE GOAL OF THE THESIS

The overall goal of the thesis was stated in the introduction, along with three questions. In this chapter, the three questions will be discussed.

## 10.1 Question 1: CBD as an industry standard

In the two industries mentioned in the question 1, the companies have made it an industry standard of providing the customers with configurable designs. This is profitable due to various factors, and presumably a combination of industrial competition and customer expectations.

The industrial competition pushes companies to always innovate, thus deliver better technology and solutions to their customers. Further, with the rapid pace of innovation in the 21st century amongst a variety of companies, new technology becomes obsolete faster than ever. This creates a drive for always possessing the newest piece of technology. This creates high expectation amongst the customers, who wants products customized to their needs. But to compete, the products need to have short lead times as well as a dimension of customization. This is where CBD is introduced.

By having a sufficiently large customer base and thus, a sufficiently large product series length, it is profitable to deliver pre-defined solutions. As discussed earlier, pre-defined solutions require a sufficient amount of design and engineering work before presented to the customers. This risk is eliminated by the size of the customer base, thus, the demand is present. This is one of the key differences when comparing the maritime industry, with the two industries previous mentioned. The demand in the maritime industry is challenging to forecast, and the work required to develop a configurable design is presumably larger for a ship, than for a car or computer. However, if implemented correctly, CBD can be beneficial. So, there is presumably required a cost-benefit calculation before CBD is implemented.

Another key difference between these industries is the cost per unit. The investment required in the maritime industry is very high, relative to e.g. the automotive industry. Whenever that level of investment is even considered, the customer expects high quality and preferably, customization. Customized ship designs have in recent years been possible due to high oil prices, but today, the situation is different. With low oil prices, the investment funding downstream has decreased as well as the demand for newbuilds. This is another challenge of CBD.

## 10.2 Question 2: Customer influence on decisions

The assumption here is that the customer's influence leads to more expensive design solutions, more challenging engineering and longer lead time. This has been the trend for some time, especially in the specialised tonnage segment. The major motivation for this from a designer's perspective is presumably the financial strength of the customer, thus the designers allow a strong influence. However, some customers may be willing to let go of this influence, with the key benefits of lower costs and shorter lead times. A decrease of customer influence implies a downstream shift of the CODP.

CODP is not only valid for describing the degree of customer influence, but is used strategically to enable companies to define and implement manufacturing and supply chain strategies to match the characteristics of their products and markets (Semini et al., 2013). This implies that a correct implementation of the CODP is beneficial from a financial perspective due to optimization of the supply chain. Thus, the link between customer influence and supply chain structure is evident. There are two CODP strategies which are relevant in the context of this thesis: ETO and MTO (see sub-chapter 4.11).

In an ETO strategy, the customers may have preferences regarding specific suppliers. This is challenging for designers and yards, as they have to collaborate with a new actor in a short period of time. This may also introduce risks such as first-time collaboration and information sharing. Further, constantly collaborating with new suppliers presumably requires more resources than having an established long-term relationship with a handful of suppliers. In an MTO strategy, the designer and yard can choose suppliers, and establish long-term relationships, according to their own preferences. This presumably reduces risk with regards to information sharing, and it allows for long term stability for the supplier.

Standard solutions may benefit the downstream operators of the ship as well. By having the same systems or solutions across a fleet of ships, presumably less time is spent in training and increases familiarity between the POB and the systems. Further, if failure occurs on a standard component or system, the probability is presumably larger for quicker repair time, relative to a custom component failure.

## 10.3 Question 3: The future of ship design

The future of ship design can be viewed from the perspectives of the three distinct research areas of this thesis: CBD, standardization and modularization. The most imminent of the three is standardization. This strategy already exists in the standard tonne segment, with e.g. bulkers or oil tankers. Considering all the associated benefits already discussed in this thesis, there is presumably only a matter of time before standard design solutions are implemented in the specialised tonnage segment. The biggest challenge is presumably *breaking the mould* on ship design and customer influence in this segment.

Further, modularization has some established challenges, such as system interaction and complexity, before the concept can be implemented on an industrial level. However, the strategy has some associated benefits, in addition to those associated with standardization, such as a modular design structure, and from a construction perspective, outsourcing and parallel workflow. It is unlikely that the ship complexity allows for total modularization, as this will presumably require extensive collaborations between companies and researchers or academia. However, cost-benefit (or other) analyses may conclude that modularization is beneficial to a certain extent, or for special parts of the ship.

CBD is presumably the least imminent of the three concepts, due to that is requires a solid foundation of standardization and/or modularization. The benefits, drawbacks and challenges of the two last strategies have been discussed earlier in this thesis. However, key motivations with CBD, such as rapid response to tenders and a flexible design process, may act as drivers for the implementation of this strategy. As for modularization, it may be beneficial to implement CBD to a certain extent, or for special design artefacts.

# Part IV EPILOGUE

# 11 CONCLUSION

The conclusion will address closing statements on the case study and the goal of the thesis. All results in this report are obtained by the author, and may not be referred to or viewed as objectively true before peer-review by other researchers.

## 11.1 Case study

The 3D-model and configurator developed in Part II have several limitations, as discussed in chapter 8, due to extensive simplification. This was done to be able to cover the main activities stated in the problem description (see Appendix A). However, it may have been more beneficial for research purposes to pivot the goal of the thesis towards the current frontiers, stated in sub-chapter 1.3.1. This would presumably push the frontiers a bit further, rather than simplify the case study, as has happened. It was mentioned in sub-chapter 1.3.1, that rather than to simplify the case studies, the challenge should be addressed in its depth. This was not recognized until too late, however, this thesis may help to understate these challenges further. The current frontiers are suggested for further research in chapter 12.

Further, the current state of 3D-model and configurator is that they work as-is and may be interesting in an academic environment, but are not applicable on an industrial level due to extensive simplifications. However, if a more precise version of the methodology is developed, this may eventually change. In addition, if a modular structure is preferred, the challenges associated with modularization of a ship design must be overcome before an industrial implementation is financially viable.

## 11.2 Goal of the thesis

For the sake of the conclusion, the goal is repeated:

> *The overall goal of this thesis is to investigate the potential benefits, drawbacks and challenges with a CBD strategy, including standardization and modularization.*

Firstly, a summary of potential benefits, drawbacks and challenges is presented. Then, a conclusion is given, based on the main finding of the thesis.

The key benefits of standardization include, but are not limited to: re-use of design knowledge, acceleration of the design process (shorter design lead time), shorter production time due to optimization of production lines (lean manufacturing, assembly lines, industrial robots), long-term relationship with suppliers (supply chain stability), familiarity in system operation, less repair time, lower costs per unit. Further, the drawbacks are mainly from the operational perspective, and include decrease of customer influence and less design customization. From a designer's perspective, the key drawback is that there is a requirement for demand/minimum production volume. The key challenges with standardization are assessed to be demand forecasting and *breaking the mould* on specialised tonnage ship design.

As modularization requires a degree of standardization (see sub-chapter 9.1.4), the benefits include to a certain degree the same benefits as in standardization. Additional benefits include: a modular structure, flexible design process and shorter construction time (outsourcing, parallel work, module testing). Drawbacks are considered the same as for standardization. However, there are some key challenges with modularization such as mapping of complex system interactions, mapping between form and performance and definition of modules.

The key benefits of CBD include: rapid response during tendering, designer friendly, flexible design process, knowledge re-use. The key drawback is that CBD requires investment in design based on forecasts and that the designer is limited to the pre-defined systems. Lastly, the key challenge with CBD is that is requires a solid foundation of standardization and/or modularization.

Thus, the main findings show that of the three distinct areas, standardization is assessed to be the area with most associated benefits, and examples include shorter design and production lead time and lower cost per unit. Further, modularization is the area with most challenges yet to be overcome, such as mapping of complex system interactions, definition of modules and mapping between form and performance. Lastly, relevant benefits of CBD include rapid response during tendering, designer friendly and a flexible design process, but requires a solid foundation of design and engineering in standardization and/or modularization.

Thus, it can be concluded that the chosen solution, utilizing proven concepts and solutions from other industries towards ships and maritime systems, may act as a value robust solution to the problem described in sub-chapter 1.1. However, there are various obstacles along the path towards this solution, which science is yet to overcome.

## 11.3 Thesis questions

For the sake of the conclusion, the three questions are repeated below. For further elaborated answers, see chapter 10.

1. What are the key challenges to why CBD is not a standard in specialised tonnage ship design, as it is in industries such as the automotive and computer industry?

The low and challenging-to-forecast demand, together with a decrease of downstream investment funding and risks connected to design and engineering work which is uncertain pay off, are the key challenges to why not CBD is a standard in the maritime industry.

2. Why should the ship customer be allowed heavy influence the design and engineering decisions?

This question is answered by listing the key motivations for why the customer should not be allowed heavy influence on design and engineering decisions, which are associated with the benefits of standardization: re-use of design knowledge, acceleration of the design process (shorter design lead time), shorter production time due to optimization of production lines (lean manufacturing, assembly lines, industrial robots), long-term relationship with suppliers (supply chain stability), familiarity in system operation, less repair time, lower costs per unit.

3. In the context of the topics covered in this thesis, what is expected from the future of ship design?

The future of ship design can be viewed from the perspectives of the three distinct research areas of this thesis: CBD, standardization and modularization. The most imminent of the three is standardization, when considering all the associated benefits already discussed in this thesis.

Further, it is unlikely that the ship complexity allows for total modularization, however, analyses may conclude that modularization is beneficial to a certain extent, or for special parts of the ship.

CBD is presumably the least imminent of the three concepts, due to that is requires a solid foundation of standardization and/or modularization. However, key motivations with CBD, such as rapid response to tenders and a flexible design process, may act as drivers for the implementation of this strategy.

# 12 FURTHER RESEARCH

The further research areas relate to the challenges presented in sub-chapter 11.2, and of the three distinct topics, modularization has the most challenges.

## 12.1 Modularization framework

The previously listed challenges of modularization are the obstacles needed to overcome if modularization is to be implemented on an industrial level in ship design. A suggestion for further research is to develop a framework for modularization. The key challenges which needs to be captured correctly if the framework is to have a practical purpose are listed below.

- Precise mapping of systems and interactions. This will allow the designers to have a platform of knowledge before defining the modules.
- The process of defining modules in a ship design. This also includes analyses of to what degree modularization is financially beneficial and how deep down the system structure it is considered viable to include in the process.
- Mapping between form and performance of each module (can be extended to include benchmarking). The mapping should include all information and data a designer requires when designing a ship.
- A more advanced architecture is presumably required when simplifications are removed from the modularization process. It should include all modular combinations. The architecture could be based on the mapping (and benchmarking).

# REFERENCES


ARNOLD, J. T., CHAPMAN, S. N. & CLIVE, L. M. 2001. Introduction to materials management.

BOAS, R. C. 2008. *Commonality in complex product families: implications of divergence and lifecycle offsets.* Massachusetts Institute of Technology.

BRATHAUG, T., HOLAN, J. & ERIKSTAD, S. Representing design knowledge in configuration-based ship design. COMPIT 7th International Conference on Computer and IT Applications in Maritime Industries, Liege, Belgium, 2008.

BREKKE, Ø. 2012. Modular Capabilities on Offshore Support Vessels.

CHAVES, O. S., NICKELSEN, M. L. & GASPAR, H. M. Enhancing Virtual Prototype In Ship Design Using Modular Techniques. ECMS, 2015. 185-191.

CHO, D. S. & PORTER, M. E. 1986. Changing global industry leadership: the case of shipbuilding. *Competition in global industries***,** 539-567.

DAGBLADET. 2016. *Sandberg lover vekst til de som oppfører seg* [Online]. Available: https://goo.gl/o79KHd.

DNV-GL. 2016. *DNV GL presents COMPIT Award 2016* [Online]. Available: https://goo.gl/frnz4X.

E24. 2016. *Redkordår for norsk sjømatnæring* [Online]. Available: https://goo.gl/Qt8U3H.

EBRAHIMI, A., BRETT, P. O., GASPAR, H. M., GARCIA, J. J. & KAMSVÅG, Ø. 2015. Parametric OSV Design Studies–precision and quality assurance via updated statistics.

EIA. 2016. *SHORT-TERM ENERGY AND WINTER FUELS OUTLOOK* [Online]. Available: https://goo.gl/5yzrLo.

EIA. 2017. *Europe Brent Spot Price FOB* [Online]. Available: https://goo.gl/i4LxiF.

ERIKSTAD, S. 2009. Modularisation in shipbuilding and modular production. *Innovation in Global Maritime Production*.

ERIKSTAD, S. O. 1996. *A Decision Support Model for Prelimenary Ship Design*.

EVANS, J. H. 1959. Basic design concepts. *Naval Engineers Journal*, 71**,** 671-678.

GOLDMAN SACHS. 2016. *Goldman Sachs WTI Forecasts Through 2018* [Online]. Available: https://goo.gl/wUgXQp.

GWEC. 2017a. *Global cumulative offshore wind capacity in 2015 and annual cumulative capacity 2011-2016* [Online]. Available: https://goo.gl/X6LeU8.

GWEC. 2017b. *Global Status of Wind Power* [Online]. Global Wind Energy Council. Available: https://goo.gl/NeYAy4.

GWEC. 2017c. *Offshore wind power* [Online]. Global Wind Energy Council. Available: https://goo.gl/HJ45SH.

HAGEN, A. & ERIKSTAD, S. O. 2014. Shipbuilding. Trondheim: Norwegian University of Science and Technology.

HILDRE, H. P., MORK, O. J. & ÆSØY, V. 2010. The Maritime Innovation Factory.

ILAKS. 2015a. *Det må bygges flere brønnbåter* [Online]. Available: https://goo.gl/w5wmTA.

ILAKS. 2015b. *Oppfordrer til økt satsning på offshore-oppdrett* [Online]. Available: https://goo.gl/yiWQah.

IMO. 2017. *International Convention for the Prevention of Pollution from Ships (MARPOL)* [Online]. Available: https://goo.gl/TLA9iL.

INVESTOPEDIA. 2015. *Why did oil prices drop so much in 2014?* [Online]. Investopedia. Available: https://goo.gl/xEe7g1.

KRISTIANSEN, V. 2014. *Modulbasert design av fiskefartøy.* Master's degree, Norwegian University of Science and Technology.
LEVANDER, K. 2012. *System Based Ship Design,* Trondheim, Norwegian University of Science and Technology.
LIKER, J. K. & LAMB, T. 2000. Lean Manufacturing Principles Guide, Version 0.5. A Guide to Lean Shipbuilding. DTIC Document.
MACROTRENDS. 2016. *Brent Crude Oil Prices - 10 Year Daily Chart* [Online]. Macrotrends. Available: https://goo.gl/eyL8Dd.
MARTINEZ-OLVERA, C. & SHUNK, D. 2006. Comprehensive framework for the development of a supply chain strategy. *International Journal of Production Research,* 44**,** 4511-4528.
MITTAL, S. & FRAYMAN, F. Towards a Generic Model of Configuraton Tasks. IJCAI, 1989. Citeseer, 1395-1401.
NORSK PETROLEUM. 2017. *Eksport av olje og gass* [Online]. Available: https://goo.gl/ehVPaU.
OLHAGER, J. 2003. Strategic positioning of the order penetration point. *International journal of production economics,* 85**,** 319-329.
PAHL, G., BEITZ, W., FELDHUSEN, J. & GROTE, K.-H. 2007. *Engineering design: a systematic approach,* London, Springer-Verlag.
ROSS, A. M. & RHODES, D. H. Architecting systems for value robustness: Research motivations and progress. Systems Conference, 2008 2nd Annual IEEE, 2008. IEEE, 1-8.
SCHILLING, M. A. 2000. Toward a general modular systems theory and its application to interfirm product modularity. *Academy of management review,* 25**,** 312-334.
SEMINI, M., HAARTVEIT, D. E. G., ALFNES, E., ARICA, E., BRETT, P. O. & STRANDHAGEN, J. O. 2013. Strategies for customized shipbuilding with different customer order decoupling points. *Engineering for the maritime environment,* 228(4) 362-372.
SHIP LAB. 2016. *Ship Virtual Simulator* [Online]. Available: https://goo.gl/ukmsP7.
SKOGSFJORD, M. B. & ROGNSETH, C. 2014. *Parametric Ship Hull Design in NX.* Master's thesis, Norwegian University of Science and Technology.
STATISTICS NORWAY. 2017a. *Aquaculture, 2015, final figures* [Online]. Available: https://goo.gl/Ur8eUJ.
STATISTICS NORWAY. 2017b. *Export of salmon* [Online]. Available: https://goo.gl/yH8H9S.
SØLVTRANS. 2016. *About Sølvtrans* [Online]. Available: https://goo.gl/7fNWRU.
TVEDT, H. 2012. Modular approach to offshore vessel design and configuration.
ULRICH, K. T. 2008. *Product design and development,* Tata McGraw-Hill Education.
ULSTEIN. 2016. *Increasing competence for future mission* [Online]. Available: https://goo.gl/h09Yxr.
ULSTEIN. 2017. *Color Line signs LOI on the world's largest hybrid vessel* [Online]. Available: https://goo.gl/VJtE8f.
VESTBØSTAD, Ø. 2011. *System Based Ship Design for Offshore Vessels.* Norwegian University of Science and Technology.
VG. 2016. *Lakse-Pers fiskeflørt i Iran: – La oss shake hands. Dere er våre venner* [Online]. Available: https://goo.gl/cRnFUJ.

# APPENDIX A

This appendix contains the problem description, in original condition, developed during the beginning of the semester.

Master's Thesis in Marine Systems Design

Student: Marcus L. Nickelsen

"Utilizing Modularization in a Configuration Based Ship Design Approach"

Spring 2017

**Background**

Low oil prices have increased the competition in the maritime industry, pushing companies to reduce cost levels and increase competitiveness, simultaneously. Ships with modular attributes may prove to be a solution for several maritime stakeholders.

**Overall aim and focus**

The overall aim is to utilize modularization and a configuration based design approach to create a portfolio of ship designs which fulfils a range of operational requirements. The customer order decoupling point will be shifted downstream, which implies that the ship buyer is limited to a finite number of designs. This presumably allows for a higher degree of standardization throughout the value chain, leading to cost reductions.

**Scope and main activities**

The candidate should presumably cover the following main points:

1) Introduction containing problem description, existing research, research questions, thesis scope, thesis structure, ++.
2) Present relevant background, theory, motivations
   a. Background, situation in the maritime industry
   b. Provide motivations for thesis relevance
   c. Present relevant theory
3) Apply a methodology for creating a modular architecture for ships
   a. Identify relevant ship types with the associated ship operations and ship systems, categorize and assign individual names.
   b. Map relationship between operations and systems.
   c. Establish functional modules based on systems.
   d. Map compatibility ("rules") between modules (exclusive, incompatible, neutral) and the influence of each module.
   e. The architecture shall also allow for operational modularity
4) Create 3D visualizations/models of each module (or a selected group of modules).
   a. Establish a graphical profile for the modules
   b. Identify and select a sufficient amount of modules which are to be created in 3D
   c. Create the selected modules in 3D
5) Use the architecture developed in 3) and the 3D models from 4) as a foundation to make an application for generating a ship design from a set of given requirements
   a. The app uses the architecture to identify the correct systems, functions and modules, based on the given requirements
   b. The app should visualize the final design by correctly assemble the 3D models representing each module

c. Finally, the app should present key data for the assembled ship

6) Implement relevant calculations such as trim, hydrostatic stability (GM), ++, and some suggestions for CapEx and OpEx (if possible)

**Modus operandi**

At Norges teknisk-naturvitenskapelige universitet (NTNU), Professor Stein Ove Erikstad is the responsible supervisor. The work follows the guidelines given for writing a Master's thesis at NTNU. The work is in accordance with 30 ECTS, corresponding to 100% of one semester.

Stein Ove Erikstad
Professor/Responsible Advisor

# APPENDIX B

This appendix contains figures obtained during the process of cleaning the database (see sub-chapter 5.3.2) and during establishment of the module range and size (see sub-chapter 5.3.3).

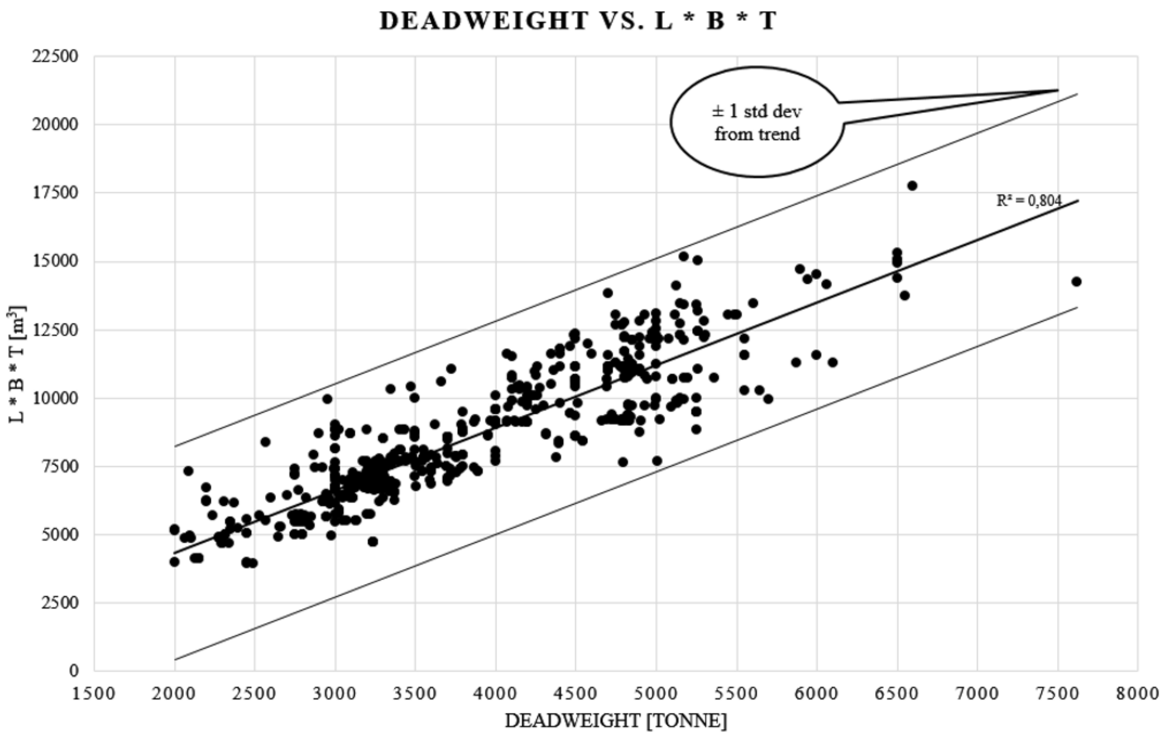



Figure 1: Result from cleaning the plot DWT vs. LBT for extremes/outliers

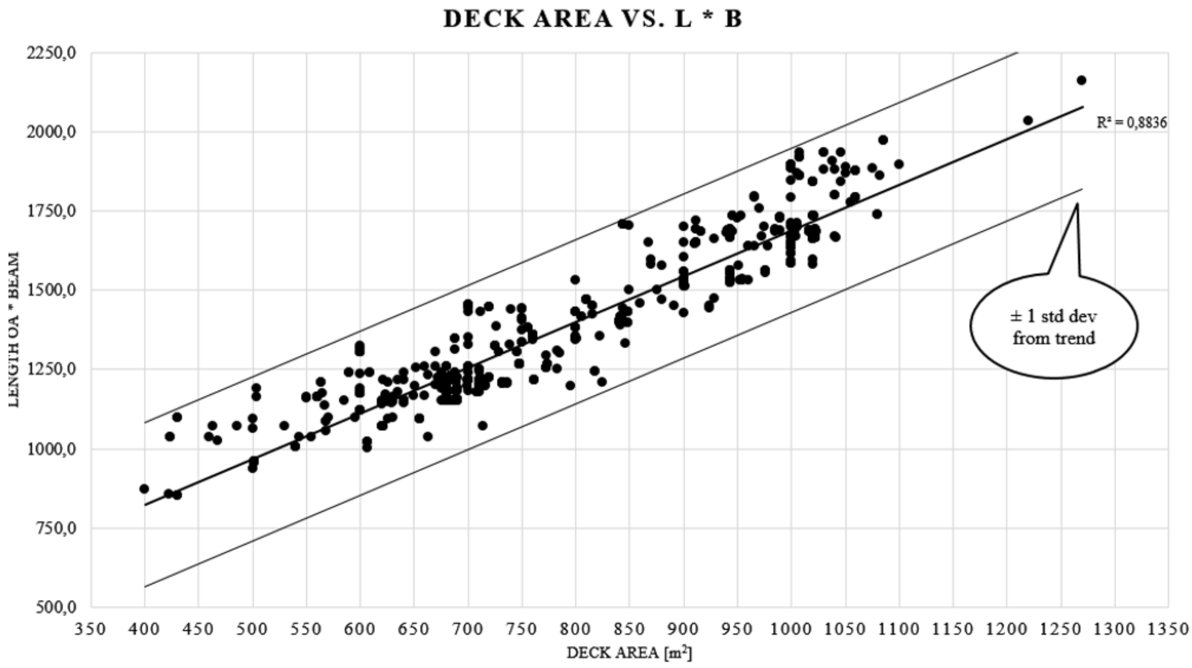



Figure 2: Result from cleaning the plot Deck area vs. LB for extremes/outliers

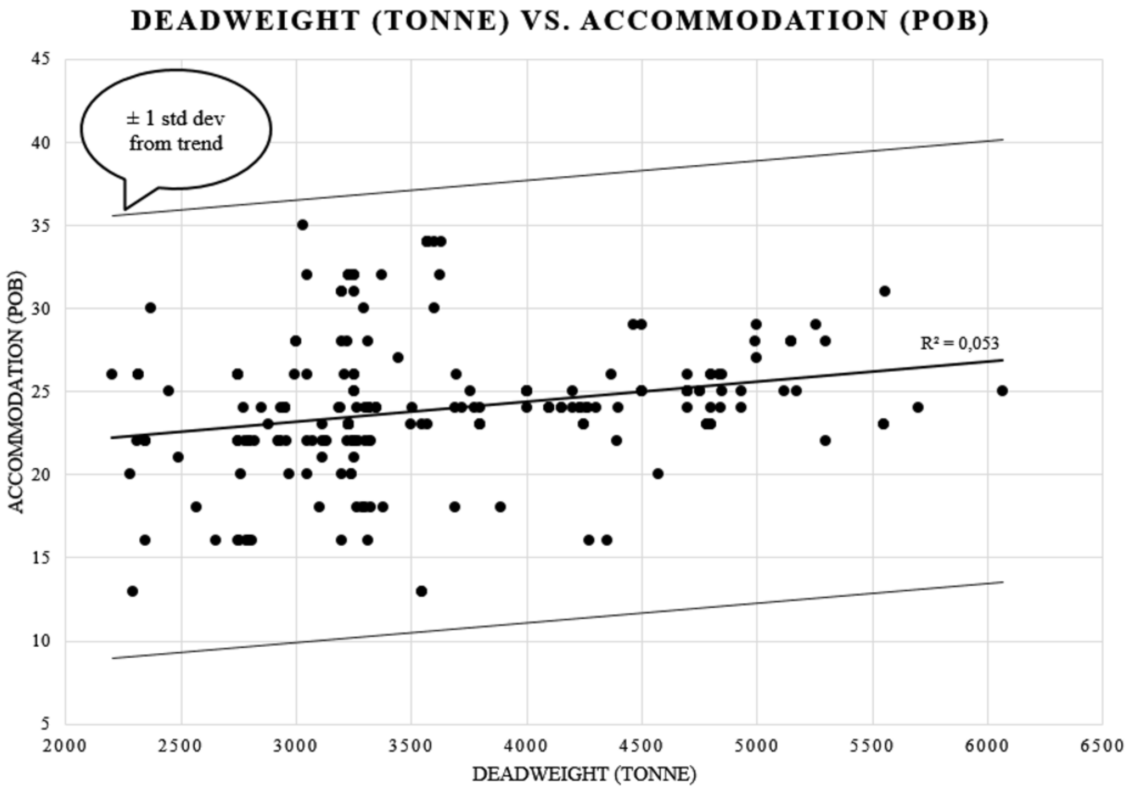



Figure 3: Result from cleaning the plot DWT vs. POB for extremes/outliers

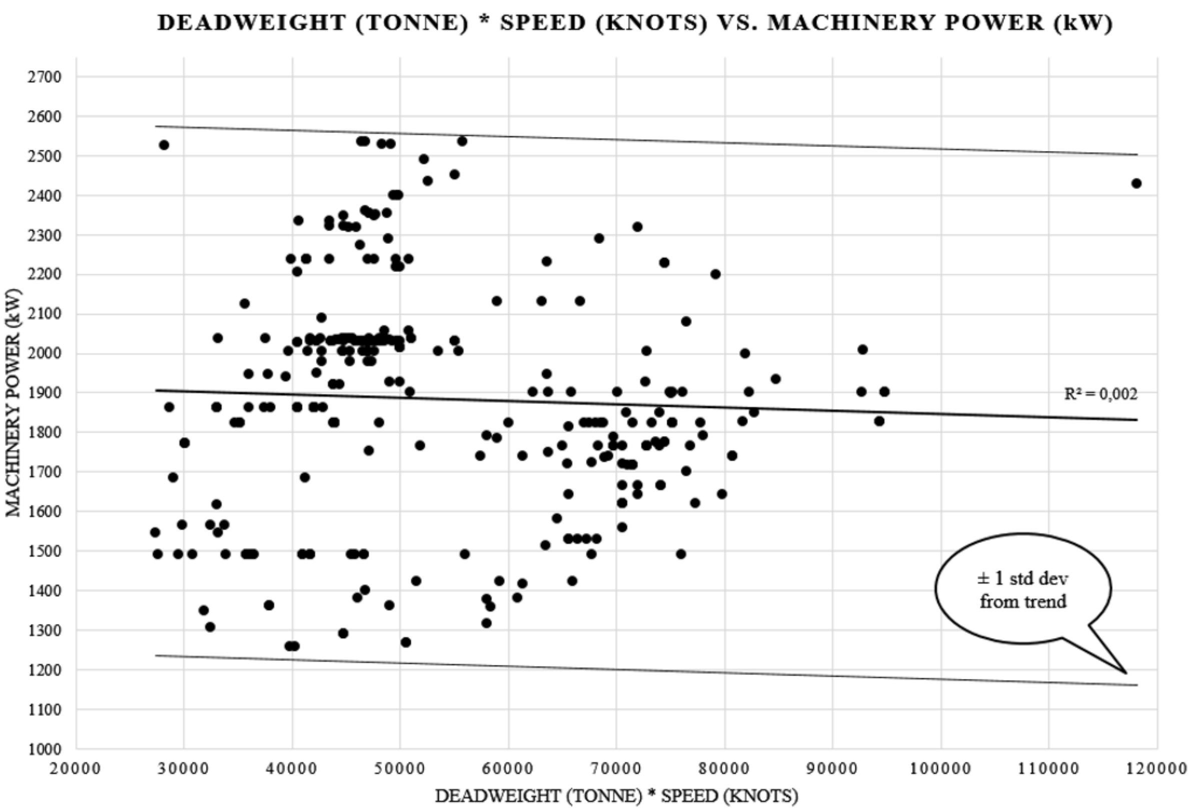



Figure 4: Result from cleaning the plot DWT * Speed vs kW for extremes/outliers

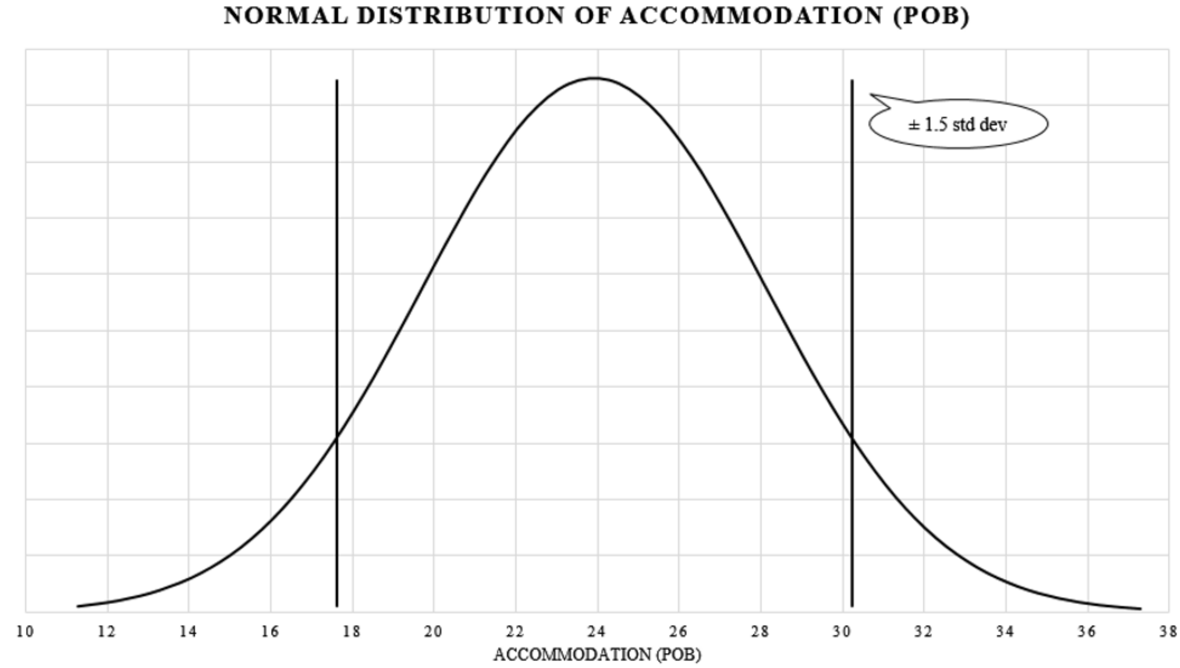



Figure 5: Normal distribution of POB and module range

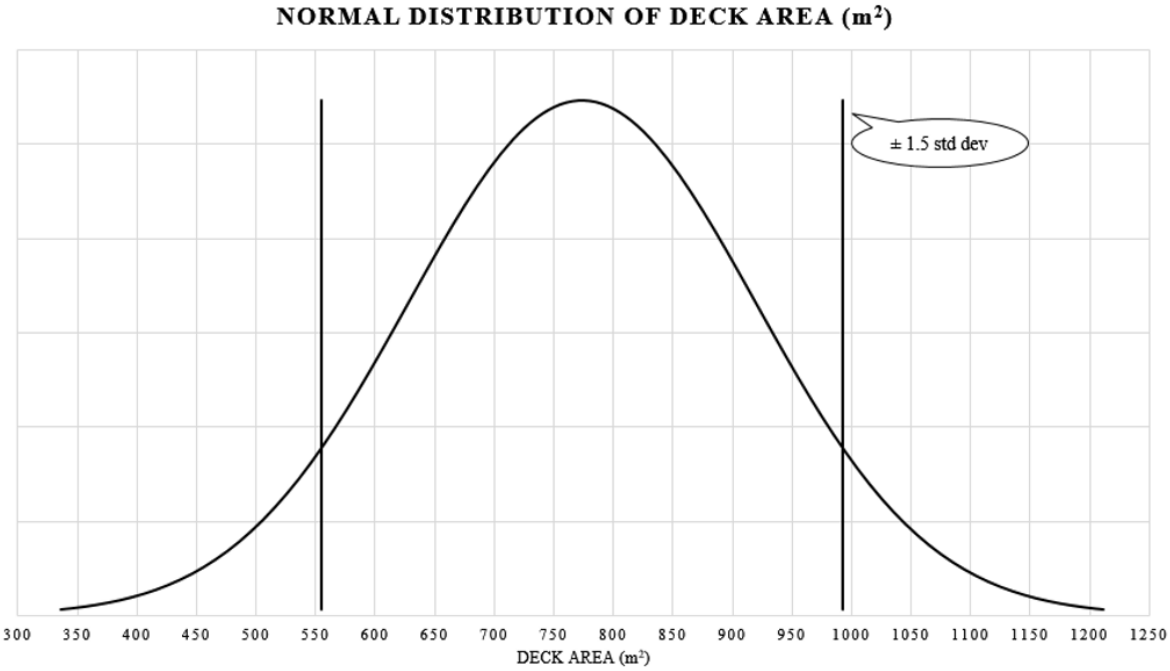



Figure 6: Normal distribution of deck area and module range

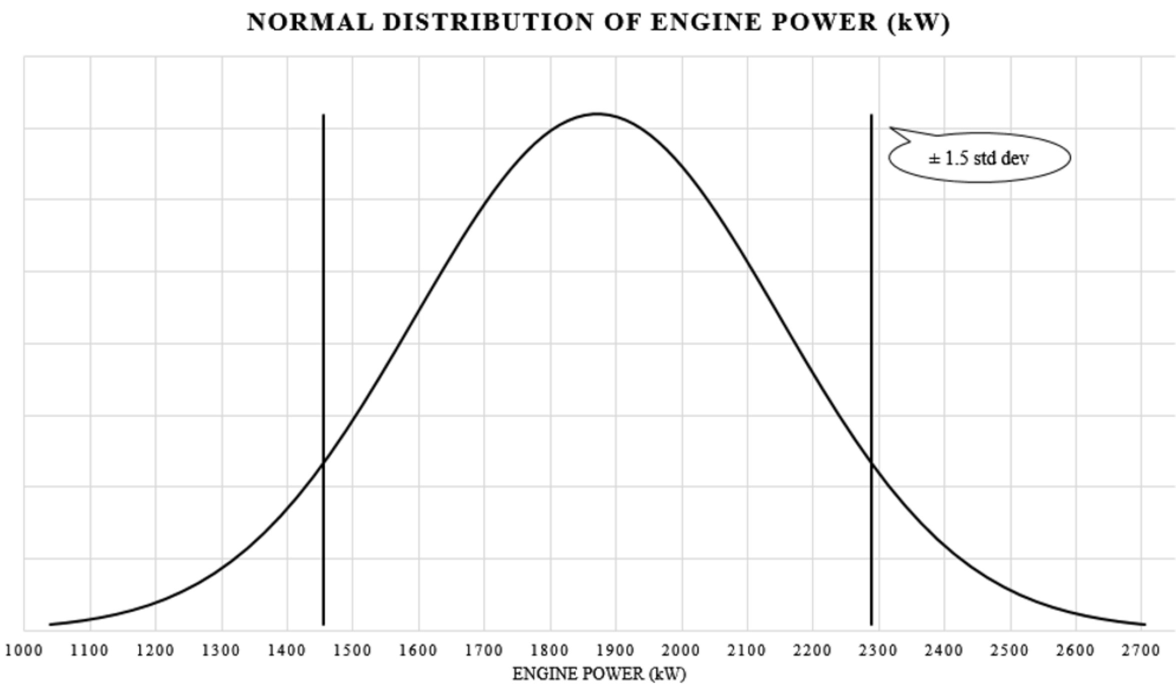



Figure 7: Normal distribution of kW and module range