Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Mechanical and Industrial Engineering

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A Propositon for Strategies and Decisionmaking in the Construction Of Complex Shipbuilding Modules in Norway

Master's thesis in Global Manufacturing Management
Supervisor: Marco G. Semini
Co-supervisor: Arnulf Hagen

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1 Preface

In the final midterm of the two-year study programme *Global Manufacturing Management,* the students are to research and write a master's Thesis to demonstrate that they have the skills and abilities required to pass the master's programme.

I would like to take the opportunity to thank my two supervisors: Marco G. Semini and Arnulf Hagen for their valuable insight and contribution to this thesis. I would also like to thank Per Olaf Brett for his assistance, particularly with improvement of the thesis structure. Without their assistance, this task would have been significantly more difficult. I would also use the opportunity to thank for the patience and understanding as personal events have stolen from the study time and is likely to have caused the supervisors some headaches along the way. Due to unfortunate events the delivery time for the study was cut short. The study has been conducted in a manner that utilized the time and occasion as best as possible, though not all the processes that was intended for the study could be completed and has thus not been presented in the study.

My hope is that this study can be a contribution to the field of shipbuilding, and particularly for the use of complex modules in Norwegian ship construction. It is an area within shipbuilding that I personally consider to have large and unused potential, and I hope that this study can contribute with additions to strategic thinking that can show this.

Bergen, June 2022.

Reidar Andreas Brandsrud

2 Summary

For the last several years, the development in the Norwegian shipbuilding sector has seen a downturn in profits for large and medium sized shipyards. An increase in offshoring strategies have been used, and less production is taking place in Norway. This means that orders for new ships are increasingly going to foreign shipyards. As a consequence, foreign shipyards in other European countries previously used as offshoring destinations have started to catch up to the Norwegian shipyards and are now able to compete in many of the same customer segments, but at lower prices. This is especially true for countries such as Turkey which is now Norway's biggest competitor (Haugland et al, 2021)

One of the solutions used at Norwegian shipyards have been to try other strategic solutions where the Norwegian competitive advantages could be used while the relative disadvantages were mediated. One of these solutions were an increased production of modules in shipbuilding, though it was not an idea that was used or tested to a large extent.

Though module construction is not a new concept for Norwegian shipyards, there seemed to be a lack of research that described, targeted, or offered specific strategies or strategic considerations for module construction in Norwegian shipbuilding. Though there were studies such as Longva et al (2007) that research and speculated in the use of modules within ship construction, it was highly conceptual and did not offer an insight into a more holistic manufacturing strategy for modules. This is especially true for shipyards that would only focus on building complex modules, and there are no studies that discuss or present different strategies, decision areas, or manufacturing strategies for such a production. As there was evidently a gap in the research, this study set out to explore this topic, in hopes of being able to fill that gap at least partly. For this, three research objectives were developed:

RO1: *Identify characteristics with module construction in shipbuilding and propose three different module construction strategies for Norwegian shipyards based on a relevant theoretical framework.*

RO2: *Perform an analysis of the module construction strategies using the results from RO1 to make a relevant comparison highlighting the similarities and differences, as well as identifying relevant challenges for decisionmakers.*

RO3: Identify key decision areas to be addressed when a yard develops a module construction strategy based on Norwegian competitive advantages and disadvantages. Combine the

discussion on module construction strategies and the identified decision areas to form a holistic perspective for decisionmakers.

In this study, modules were proposed as an alternative to traditional shipbuilding, where *module yards* would specialize in building complex modules containing complete subsystems for vessels, according to the module yards manufacturing strategy. This is conceptually different from other types of modular construction utilized by Norwegian shipyards, as both Ulstein and Kleven have used modules as a part of their complete shipbuilding programmes. The module yards addressed in this study would only focus on building modules, and this study was dedicated to developing parts of the manufacturing strategy. In this study, two strategic approaches for modules were investigated, discussed, and combined into one combined manufacturing strategy. In the literature review, several definitions of manufacturing strategy were used, and combined into a new definition for this study.

Manufacturing strategy in shipbuilding can be defined as coordination, planning, and execution of projects using the companies' facilities, capabilities, resources, and competitive advantage in a way consistent with project specifications and the companies' business plan.[1]

The definition was wide, and in this study the focus was on developing module construction strategies that specifically targeted possible offshoring solutions and their performance, and to combine this with relevant decision criteria that could facilitate for a manufacturing strategy according to the definition. The main focus of this study was on facilities, capabilities, resources, and competitive advantages, though coordination, planning, and execution were also added to the discussions as general subjects because they were highly relevant to both the identified decision criteria and the performance of the module construction strategies.

The study was separated into three sections, each dedicated to work with one research objective. The results chapter addressed research objective one and proposed three module strategies based on offshoring strategies given by Semini et al (2018). These strategies were then evaluated using Beckman & Rosenfield's (2014) competitive priorities framework to estimate their performance separately and in accordance with information from the literature study. Module strategy I was a module yard that had facilities for a complete module construction in Norway. This involved all parts of the production, including all the stages in the steelwork process. This strategy had a high score in flexibility, quality, delivery

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[1] This is not an official definition, but a definition made for this study by the author as shipbuilding manufacturing strategies are often difficult to define clearly.

dependability, and lead times as it allowed for the best control of the entire construction process. It also had advantages in terms of quality control, innovation, and rapid problem solving. Module strategy II used offshoring for the steelwork, but retained in-house production of the outfitting, and in cases where it was suitable allowed for possible testing and installation. This allowed the module yard to offshore labour-intensive operations with competitive disadvantages, while retaining parts of the manufacturing operation where it was crucial to deliver with high quality, flexibility, and innovation. This would typically allow the yard to retain the value-added from the outfitting, while it would have to procure the services in the steelwork, which would be beneficial in operations where the outfitting was the dominating value-driver. The final module strategy would use complete offshoring both in steelwork and in outfitting, and would have the least value-added in Norway, while at the same time allowing for the lowest costs in terms of labour. In this module strategy, the Norwegian yard would for the most part be a facilitator involved in planning, coordination, and engineering, and even the expert of the particular module installation method. This solution would generally score the lowest on the competitive priorities that were improved by increased production control such as delivery times, flexibility, and quality.

In the first chapter of the discussion, the module strategies were discussed and compared in accordance with the competitive priorities that were identified in the results. The discussion showed that the module strategies have different areas where they perform well, and that other criteria and decisions would need to be included to consider the usability of each strategy.

In the second chapter of the discussion, eight relevant decision areas to be addressed when developing a module construction strategy, based on Norwegian competitive advantages and disadvantages, were identified and added to the discussion on module strategies. The discussions revealed that based on the strategic choices made by the module yard, the most fitting module strategy would vary, and it would have a significant impact on the total manufacturing strategy. This could be exemplified by the chosen product mix for the manufacturing strategy where the type of module had a large impact on the other strategic decisions and on the degree of offshoring. It clearly showed that there needed to be congruency between the module strategies and the strategic decision areas in order to create a well-functioning manufacturing strategy.

In this study, an attempt at identifying, describing, and discussing important strategic decision areas and considerations that goes into making a complex module manufacturing strategy has been made. This study has contributed to the research on the field of complex module construction in shipbuilding by proposing three different module construction strategies with different performance according to degree of offshoring. It has also contributed by identifying decision areas that are critical for the performance and viability of the manufacturing strategy, and that needs to be considered in combination with the offshoring strategies to make a holistic manufacturing strategy. This study shows that there is a place for module yards as long as there can be established a demand for complex modules designed independently from regular ship construction. There are many potential advantages to gain, as it would allow customers to split the production into complex module(s) and hull construction, each built where the competitive advantages are favourable.

The study has limitations, as the research on the field is still rather unexplored. The study is also almost purely based on qualitative data which could be misinterpreted or taken out of context. Limitations also had to be made in terms of scope, because the topics that went into the study had potential of reaching out too much. Manufacturing strategy was chosen as the overall strategic approach and divided into two strategic fields. However, the definition chosen for manufacturing strategy shows that there would be several other topics that would also be a part of the manufacturing strategy that has not been included in the study. The use of personal communication as a source of information in the study also opens for assumptions, personal meanings, and inaccurate information, however these sources have only been used to support or add to already established discussions. In this study, the main focus has been on the Norwegian shipbuilding sector, and many of the sources used have not directly been tied to module construction as these studies were more difficult to find. This might be a cause for inaccuracy or error as there are differences between module construction and more traditional shipbuilding, in which some of the points were identified in this study. It might also make the study less relevant for potential module yards in foreign countries.

To add to the field of study, there are several potential avenues for further research. A study that targeted costs for each of the proposed module strategies with a fixed set of decision areas would definitely add to the field, as decisionmakers would be able to make proper cost-benefit decisions on specific module yard scenarios. Studies that went more into depth on the different manufacturing strategy components in the proposed definition from this study would also add to the discussion, as the main focus of this study was more on the attributes directly tied to the physical construction. More in-depth studies regarding coordination, planning, engineering, resource management, and business plans would be a valuable addition to the field of module construction in Norwegian shipbuilding. These are studies that in many cases already exist in the field of shipbuilding, so a clear potential to adept and make them for module construction should be possible.

3 Content

4 Introduction

Throughout the 21st century, the Norwegian shipbuilding industry has experienced a negative development in terms of diminished competitive prowess when compared to other European shipbuilding nations (Haugland et al, 2021; Semini et al, 2018). In a report from 2021, Menon economics in cooperation with Boston Consulting Group carried out a research project that investigated the competitive environment and the state of the Norwegian shipbuilding industry. The report was based on previous reports carried out on the same field, interviews with relevant actors on the field, and available economic data (Haugland et al, 2021).

The Menon report revealed that through several economic conjectures since the worldwide financial crises in 2008/09, and the fluctuations on oil prices following the years after 2010, the market for offshore vessels (OSVs) have cooled off, and the demand for such vessels have diminished (Haugland et al, 2021). There have been several reasons for this such as increased competition from Asian competitors, increased competition from European actors, and overfilled orderbooks for OSVs prior to 2015 which have now saturated the market (Haugland et al, 2021) Prior to these events, the Norwegian yards had a very strong position in the OSV market, but the last years have been difficult in particular for the large Norwegian yards who have struggled with low profits, reduced liquidity, and poor solvency (Haugland et al, 2021).

The challenges for the Norwegian shipbuilding industry does not solely rely on one specific problem but involves several challenges where the competitive power has been reduced over time, while the competitive power of relevant actors such as shipyards in Turkey, Romania, and Spain have increased relative to Norway (Haugland et al, 2021). The source of the competitive advantage for Norwegian yards have been the ability to create vessels tailored according to the specific needs and demands of the customers, as well as a high level of flexibility and innovation (Haugland et al, 2021; Semini et al 2018). This meant that for a long time, the Norwegian yards had a competitive advantage when the customers had a large willingness to pay for quality and technology, especially when the ships were used in an industry that would pay of the costs quickly (Haugland et al, 2021). The proximity to suppliers, other yards, and the sea also gave Norwegian yards synergy effects that caused a competitive advantage and mutual learning effects, further enhancing the competitive advantage (Semini et al, 2016; Haugland et al, 2021). Though the competitive factors are still relevant and gives Norwegian yards a competitive advantage, the results from the Norwegian shipbuilding sector have lately shown that the competitive advantages have not been enough to create a profitable environment, thus causing difficult times for the yards.

In the Menon report, several factors are used to highlight the reasons for the reduced competitive power. High wages, lack of specialization, rapid changes in vessel types, outsourcing, competence, lack of integration between outfitting and hull construction, insufficient project management, change from high margin to low margin payoffs, solidity, access to capital, and offset in which actors who bears the project risk are all mentioned as reasons for a reduced competitive power (Haugland et al, 2021).

As a result of these factors, it has become difficult for Norwegian shipyards to qualify for orders, and even harder to win them, most often because of the price the yards would have to take to receive any profit. One challenge for the Norwegian yards have been the rising wages, that has made labour unsustainably expensive in comparison to countries such as Turkey, who for the time being serves as the biggest competitor for Norwegian yards according to the Menon report. Another great challenge has been the relative increase in quality and technology that can now be provided by low-cost countries, but at a lower price (Haugland et al, 2021) In general, the current competitive situation for the Norwegian yards have been very challenging for the last few years, though variations in terms of yard size can be observed. As of now, the large yards are experiencing difficulties in gaining profits, the medium sized yards are breaking even, and the small yards are doing well in terms of profits (Haugland et al, 2021).

As an answer to the challenges in the Norwegian shipbuilding industry, different Norwegian shipyards have tried to utilize different product portfolios and strategies where some specialized and narrowed their product portfolio, while other yards tried different product strategies such as modularization. Different sourcing strategies have also been used by many of the yards, and where different degrees of offshoring are utilized in accordance with demand, capabilities, and strategy (Semini et al, 2018). Unfortunately, at the time of writing it seems like though the large Norwegian yards have different strategic approaches, there are no signs of change in the economic outlook.

In shipbuilding, there is no lack of research on methods and strategies designed to either explain the current state, or to give insight into possibilities for improvement within the industry. Studies within the field includes research on different offshoring strategies utilized by Norwegian shipbuilders (Semini et al, 2018), holistic strategic approaches to shipbuilding (Clarke & Lamb, 1996), and different strategic manufacturing approaches depending on customer order decoupling points (Semini et al, 2014). All these studies address different strategic approaches that can help explain the current situation and propose possible solutions or mitigating factors. The field also contains a lot of research on different innovative solutions such as lean supply chain management (Chu et al, 2021; Emblemsvåg, 2014), and innovative industrial solutions that are likely to be highly relevant in the future such as digitalized manufacturing logistics (Strandhagen et al, 2019) and smart design, building, and operation (Ang et al, 2017). Several studies have also been carried out on industrial clusters, particularly the effect clusters can have on learning, efficiency, and quality in shipbuilding such as Halse (2014), Ruuska et al (2012), Haugland et al (2021), and Semini et al (2013).

Though there are much research tied to shipbuilding, there seem to be few studies that can propose relevant innovative solutions or that can aid in providing an alternative strategic route for struggling Norwegian shipyards. Studies such as Semini et al 2018, Semini et al 2013 provide good descriptions and diagnosis of the current situation within the industry as well as highlighting important strategic considerations. However, the studies are unspecific as to which strategic measures to take given a certain market or situation, and therefore does not provide strategic alternatives outside of the already established paradigm. In the research, there seem to be few studies that explore alternative strategic concepts that could replace traditional shipbuilding for yards where this is either hard to maintain, less profitable, or unviable. Though studies such as Liker & Lamb (2002) and Ang et al (2017) propose different ways to organize shipyards and to access different markets, most studies address alterations or explanations for already existing shipbuilding strategies such as Mello et al (2015) where measures to improve coordination is proposed.

One strategic approach that differs from traditional shipbuilding with a focus on building complete vessels could be to construct and manufacture modules for ships as an alternative. This is not a new concept as companies such as Ulstein and Vard have used modules in previous projects. Modules are used in different ways, and there is a difference between those modules used by Ulstein and Vard, and companies from other sectors. Typically, in Norwegian shipbuilding, modules were used as a part of the ship that was built at a different location because of certain characteristics such as the requirement of complex construction or outfitting (Semini et al, 2018). In this case the module could be any part of the ship and was simply built as a separate block and added to the vessel during the assembly process. In other module construction scenarios, the module can be built as a means to separate parts of the production, where the module is built as a complete subsystem, or a unit that could be customized according to the customers wishes and then later added to the ship. Though there exist studies on the use of modules in shipbuilding one of which is Baade et al (1998), no studies could be found that proposed different strategies specifically related to module construction within shipbuilding. As studies such as Semini et al (2018) divides and addresses different offshoring strategies for traditional shipbuilding, it would be interesting to investigate if different strategic approaches could be developed for module construction. This could indicate that there is a gap in the literature where most of the studies on the field are improvements or research on current topics, rather than an exploration of alternative strategies that could contribute as options for shipyards.

As shipbuilding has served as a cornerstone activity along the Norwegian west coast and has a reputation for producing innovation and quality, a big motivation for this study is the thought of being able to help rekindle the Norwegian shipbuilding industry, even if only by a little. In the coming years, there will likely be an increased demand for newbuilds as the *green revolution* sets in, which requires innovative thinking and shipbuilders who can deliver ships with the quality and technology required (Haugland et al, 2021). This could mean a new revolution for Norwegian shipyards if they are able to strategically position themselves and find solutions so that Norwegian ships become both profitable, in demand, and at a standard Norwegian yard can deliver. The author’s hope and ambition is that this thesis can serve as a small contribution to an alternative way of thinking about shipbuilding strategy, so that Norway once again can take back its position as an in-demand shipbuilder and that it becomes a flourishing Norwegian enterprise.

4.1 Problem statement and research objectives

Through the introduction, a clear theme emerges. The Norwegian yards have over a period of years experienced a significant development in business conditions, and especially for the last big yards this has resulted in a diminished ability to make profits (Haugland et al, 2021; Semini et al, 2018). Due to a strategic shift in Norwegian shipbuilding, more of the production has been offshored to low-cost countries, and with it, new strategic approaches have been put to use that heavily emphasizes the use of offshoring strategies with varying degrees of domestic production (Semini et al, 2018). Though yards use different offshoring strategies, the general trend is that the large yards are shutting down even through the use of different strategies, begging the question of whether complete shipbuilding lead from Norway at all is viable even through different sourcing solutions. Another question is if some of the factors that are contributing towards a reduced competitive advantage are changeable, or if there are other strategic solutions that could be utilized to gain a competitive edge.

In this project, a study will be conducted to investigate the possibility of using module construction as a strategic alternative to regular shipbuilding at Norwegian yards. Based on the work by Semini et al 2018, a proposition for different strategic approaches to module construction will be made and evaluated through the *competitive priorities* framework described in the literature review. Further, relevant decisions for strategic module construction will also be addressed and identified. The aim of the study is to investigate module construction as an alternative to regular shipbuilding for Norwegian yards, and to identify and discuss important strategic decisions for Norwegian module construction. In this study, a difference will be made between modular construction, with corresponding module yards and regular or traditional shipbuilding. Regular or traditional shipbuilding is in this study considered as the act of building or facilitating for the construction of complete vessels, instead of the alternative, which in this study is the focus on producing only complex modules. Shipyards that only has a focus on the construction of complex modules are in this study referred to as *module yards.*

The result and discussion part of the study will be separated into three different parts, each addressing one research objective. These research objectives will serve as guidelines for the thesis and describes the objective that is to be solved in each part. Chapter 7 will describe general module characteristics and then a general building process used in shipbuilding which is based on Hagen & Erikstad's work (2014) but adapted to module construction. In addition, a description of Norwegian competitive advantages and disadvantages will be added, which will be used in chapter 10. This is followed by three general strategic propositions for module construction at Norwegian yards and is based on characteristics typical for the Norwegian maritime industry which will be presented in chapter 8. Each of these strategies will be considered in light of the studies from the literature review and will be more specifically addressed in terms of how they score according to the competitive priorities.

RO1: *Identify characteristics with module construction in shipbuilding and propose three different module strategies for Norwegian shipyards based on a relevant theoretical framework.*

Chapter 9 will be a discussion of the results from the previous chapters. In this chapter, each of the competitive priorities will be discussed in comparison to each other. In this chapter, the competitive priorities for each module strategy will be compared and discussed, so that the similarities and differences can be identified. The comparison will add to the discussion on strategic choices for decisionmakers involved in module construction.

RO2: *Analyse the module strategies developed in the previous chapters and make a relevant comparison highlighting similarities and differences, as well as relevant challenges for decisionmakers discovered through the results.*

In chapter 10 another layer will be added to the discussion on module strategies as additional decision areas for module strategies will be identified and discussed based on Norwegian competitive advantages and disadvantages. Important decision areas crucial for a match between the module yard's resources, business plan, module building policy, and offshoring strategy will be identified, and used in a practical case.

RO3: Identify relevant decision areas that are of importance for a module building policy based on Norwegian competitive advantages and disadvantages. Combine the discussion on module strategies and the identified decision areas to form a holistic perspective for decisionmakers.

4.2 Research scope

To develop different alternatives for module strategies at Norwegian shipyards, relevant theoretical frameworks and models must be identified. Though the study might contain references and touch on concepts from these fields of study, the scope of the study will be on ship manufacturing strategies and relevant strategic decisions. For this reason, the study will use concepts from mainly three academic fields: production theory, business management, and shipbuilding. In addition, some simple economic theory will be used as a means to define expressions that is required in the study. This project is not a study in naval engineering, design, or architecture, thus will not address these topics. Though some of the topics are of relevance and can be mentioned in short (such as engineering), no thorough discussions will be conducted on these topics.

This study will specifically focus on module construction, but as few studies target specific module construction strategies, a lot of research from the field of traditional shipbuilding will be used, as there can be expected to be a great overlap. For this reason, several regular shipbuilding concepts and studies will be used and adapted throughout the study. The purpose of the study is to capture, identify, and use general concepts to develop and analyse strategic aspects of module construction to create a basis for a manufacturing strategy for module yards.

4.3 Thesis structure

In this study, the reader can expect to find a structured scientific report that contains the following parts: introduction, methodology, theory, results, analysis/discussion, and conclusion. Each part of the study is divided into several chapters and subchapters, according to the scientific standard expected at a masters' programme.

Introduction – Chapter 4 introduces the theme for the thesis. Problem statement, research objectives, and research scope containing the boundaries and limitations of the study will be described.

Methodology – The methodology chapter contains a description of the methods that have been used to find relevant information to work towards the research objectives. The sum of the methods is the methodology used for the thesis, and this chapter should serve as a recipe for those who wish to dive into or replicate the study. The methodology is found in chapter 5.

Theory – In the theory chapter, relevant studies and frameworks identified through the methods are selected, thoroughly studied, and added to the theory chapter as they will form the basis for the results and the analysis of the thesis. The theories and literature studies selected to form the basis of the study are found in chapter 6.

Results – The results are the interpretation and use of the theories selected in the theory chapter (chapter 6) and the data that has been gathered for the study. As this study is exploratory and requires the theory to be combined in a new way, some assumptions will be made. In the first part of the results, an explanation of the stages in the construction of a complex module is described. This will be done in chapter 7. In chapter 8, three propositions for module construction strategies will be given, based on the process in chapter 7, and evaluated using the competitive priorities framework.

The results chapter is dedicated to answer research objective one. The results will be an extensive part of this thesis and makes up chapter 7 and 8.

Analysis/discussion – The analysis and discussion part are divided into two chapters, each answering one research objective. Chapter 9 is a discussion on the proposed module strategies and is connected to research objective 2. Chapter 10 adds a discussion on relevant strategic decision areas that must be added to the proposed module strategies to form a holistic basis for strategic decision making, and also combines and discusses the usability and correlation between the findings in chapter 9 and 10. Chapter 10 is tasked with answering research objective 3.

Conclusion – In the final chapter of the thesis, the study is summarized, and final conclusions are reached. Limitations to the study as well as avenues for further research will also be identified and briefly discussed. The conclusion is found in chapter 11.

References and appendix – After the conclusion of the study, references, appendix, and a list of graphs/models/drawings/tables will be added.

5 Methodology

5.1 Literature study

With the intention of gaining better understanding of the Norwegian shipbuilding sector, modular design and construction, and the latter in shipbuilding, this study will mainly be based on a literature study. Most of the studies in the field of shipbuilding are research and studies regarding analysis of current shipbuilding strategies, methods for improvement of these, and analysis of the current state in the Norwegian shipbuilding industry. Little attention has been given to different strategies for module construction in shipbuilding, though module construction has been used both in shipbuilding and in other industries. In particular, few studies that address different module building strategies in Norwegian shipbuilding have been found.

For this study, no particular scientific journals have been prioritized. Initially, a wide search using search engines such as Oria, Scopus, and Google Scholar were used to find studies, papers, and articles that could give a better understanding of the problem scope and the relevance of the study. Initially, a broad approach was used for literature searches with relatively open search blocks such as "shipbuilding" to gain an overview of the available literature within the field of study. Once an overview of the available literature was gained, search blocks were added to narrow the scope of the search, and to make the searches more specific to the field of modules in shipbuilding. Second, a literature search was done for "modules" to discover a broad sense of modules were used in different study disciplines. The same approach was used for modules, as additional search blocks were added to narrow the search to relevant fields of study. Most preference were given to peer-reviewed articles to make sure that the papers used in the study were of a reasonable quality and trustworthy. An overview of the search blocks used are given in the table below.

The initial stages of the study required a more thorough reading of the identified studies from the "shipbuilding" and "module" blocks. After narrowing through addition of search blocks, a content check was used to consider relevant studies where the abstract, the introduction, keywords, findings, and conclusions were usually read to consider if the study have value additions to the research. This made it easier to identify the most relevant papers, and to increase the knowledge base. This also revealed that relevant qualitative information that could be used in the study did not only have to be taken from studies about modules within shipbuilding, but there were also interesting and relevant studies from other fields such as house construction.

After the initial stages of the study, the reference lists from the most relevant studies were used to find more relevant literature. This was a method that was used often, and it can be expected that a large portion of the studies used in the research have been found this way.

The tools used for writing and editing the study has mainly been Microsoft Word, Microsoft Power Point, and Microsoft Excel.

Main segment	**Keyword**	**Secondary keyword**
Shipbuilding	• Norwegian • Strategy • Offshoring • Modules • Performance	• Module construction • Modular design
Module	• Definition • Construction • Manufacturing • Performance • Shipbuilding • Ship • Strategy • Building • Offshoring	• Type • Architecture • Sucess • Benefits

5.2 Secondary data

Secondary data was used extensively in this study as a source of case-specific information both regarding the Norwegian shipbuilding sector, and for cases where insight into strategic considerations were carried out in practise. To increase the trustworthiness, studies that were developed or approved by the Norwegian scientific community, and that used multiple sources of information were favoured. The Menon report (2021) served as a qualitative empirical study of the state of the Norwegian shipbuilding industry, with many useful inputs for this study, while the Modnet report by Longva et al (2007) served as a practical strategic consideration about the use of modules by a Norwegian shipyard. The latter study was a combined study effort by many relevant actors within the Norwegian shipbuilding community in combination with the scientific community.

5.3 Personal correspondence

This study has been carried out in collaboration with several experts and actors in the Norwegian shipbuilding community. A part of the empirical background, as well as important additions to both results and discussion has been from personal correspondence with these actors. This correspondence was conducted through emails, but also through several digital meetings, where topics directly relevant to the study was the agenda. Open-ended questions often lead to discussions and conversations that revealed both useful and important information from the shipbuilding sector, but also about modular design and construction. This had a valuable effect, as it revealed relevant topics, strategic decisions, and information that otherwise would have been left out of the study.

Second, the conversations with these actors at times went from informative meetings to sessions where interview-like questions were asked by the author, and thus served as unanticipated interviews.

As the conversations most often did not follow a specific interview script (though this was developed and sporadically used), it cannot be considered as formal interviews, though the information has been used as additions or thoughts on introduced topics in the study. They do, however, not make up the basis for any of the topics in the study, as it would be partly based on personal opinions and not referenced and traceable facts. In appendix A the original interview guide is added. Though this was not fully used, the questions were discussed with several of the actors in a more open and sporadic manner.

6 Theory and literature study

This chapter presents theory, frameworks, and concepts required to work towards solving the research objectives. The chapter is divided into two sections. The first subchapter contains data on how a shipbuilding strategy can be defined, what it implies, and what it involves. It will also contain a description on how modular construction can be defined, and how it can be connected to shipbuilding. The second subchapter contains frameworks that are required develop module strategies, and that allows for a structured comparison and later discussion.

6.1 Shipbuilding, modules, and strategy

To develop alternative strategic propositions for module construction, a clear definition of shipbuilding strategy and modular construction is needed.

6.1.1 Shipbuilding

Shipbuilding is a complex process integrating different disciplines to produce a final product (Hagen & Erikstad, 2014; Clark & Lamb, 1996). Ships are in production often defined as being complex, spatially confined structures that are often produced as one-of-a-kind constructions and usually through project structures, especially in Europe (Hagen & Erikstad, 2014). As ships are often large structures with long lifetimes, built over long periods of time and at relatively high costs, different countries and yards have different approaches to shipbuilding strategies exemplified by Norwegian yards using offshoring strategies and countries such as Turkey and China using complete in-house production (Semini et al, 2018; Haugland et al, 2021; Clark & Lamb, 1996; Platts & Song, 2010). Studies such as Semini et al (2018) and Clark & Lamb (1996) show that depending on the yards' capabilities, starting point, facilities, and competitive advantages different strategies might be considered for use. Shipbuilding is an industrial process and consists of a vertical value-chain where the ship is the final output (Hagen & Erikstad, 2014). This implies that the final construction of the ship is made up of a web of different inputs, and that a shipbuilding strategy also would benefit from an overall coordination and planning process. The importance of a thorough planning process and a methodical approach to strategy that allows for good coordination, cost savings, predictability, good utilization of facilities, reduced delay, and the ability to gain from the competitive advantage are all factors that are emphasized in studies such as Mello et al (2017), Semini et al (2016), Semini et al (2018). However, the studies show that shipbuilding strategies are complex, multifaceted, and that strategies are often limited to certain areas of the production, making the project a conglomerate of different strategies. Examples of such strategies as manufacturing strategies, financial strategy, business strategy, etc.

As a ship is a large and complex project, it is not uncommon that each ship has its own product structure and strategies specific for that one product (Hagen & Erikstad, 2014). Clark and Lamb (1996) show that many yards share similarities in their separation of the strategic process, and that though the starting point and endpoint for the strategies vary for different shipbuilders, most of these projects contain a lot of the same elements and decisions. Typically, the shipbuilder needs to make decisions tied to cost structure and organization, delivery times, what and where to build, required facilities, degree of customer and producer flexibility (Semini et al, 2018). Many of these decisions falls within the sphere of manufacturing management, which is one part of the total build strategy according to Clark & Lamb (1996).

For this study, the emphasis will be on manufacturing strategy in shipbuilding, and more specifically tied to the manufacturing of modules to be used in shipbuilding projects as an alternative to regular shipbuilding.

6.1.2 Strategy

Before moving on to frameworks and models relevant for the study, some definitions and precisions must be made. As this study is about shipbuilding manufacturing strategies, a closer look must be taken at what it implies. A clear definition of strategy is difficult, as academic opinions about what *a strategy* includes, does not include, differs depending on context and situation (De Wit, 2020; Freedman, 2013). Strategies also differ in scope as some strategies address specific topics or parts of a business on a functional or business level, while other strategies are made to handle situations at a corporate or network level (De Wit, 2020; Beckman & Rosenfield, 2014). Strategy is often defined as a plan or a way to organize the resources so that a specific goal can be reached (Freedman, 2013), and are often divided into three levels according to timeframe and scope; strategic level, tactical level, and operational level, each with its own procedures and goals (De Wit, 2020; Chopra, 2019; Christopher, 2016).

Using these descriptions, a strategy can loosely be defined as a plan that evaluates and puts to use the organizations resources so that it can move from one state to another given a plan of procedure at three different levels. These states can be considered as a predefined starting point where a plan for the use of resources strives to take the organization to its predetermined destination. The description also states that a strategy can be a sub-part of an organizations plans and interact with other strategies to reach the organizations' overreaching goal. Though this is not an official definition of strategy, it is the foundation for the understanding of what a strategy is that will be used in this study.

In this study, the scope will primarily be on manufacturing strategy which also requires a definition. As with other strategies, manufacturing strategy can be complex to define. Definitions range from it being a description of how a shipyard carries out its production activities (Bruce & Garrard, 2013) to it being a pattern of decisions specifying how a shipyard will operate considering its capabilities, to meet manufacturing objectives, which are a part of the overall business objectives (Platts et al, 1998). The latter definition shares great resemblance to what Clark & Lamb (1996) refers to as a *shipbuilding policy* which is the optimal organization and build methods that is required to produce the product portfolio aspired by the shipbuilder (Clark & Lamb, 1996). The shipbuilding policy is the connection between the companies' business strategy and specific vessel strategies and addresses subjects such as aspired product range, shipyard capacity and output, cost targets (or cost plan), and pricing policy (Clark & Lamb, 1996). Thus, a shipbuilding policy can contain categories such as ship definition, plan for ship production (or sub-strategy), strategy for production facilities, and a strategy for planning and control (Clark & Lamb, 1996). The model shows the relationship between the company business plan and its policies for a shipyard. It is often common for each department to often employ its own sub-strategy in many businesses (Erichsen et al, 2019; Beckman & Rosenfield, 2014). In this sense the shipbuilding policy becomes a strategy for managing the specific vessel strategies or projects that each type of vessel represents. Though close to the definition used by Platts et al (1998) there are differences as Platts et al (1998) has a looser definition. Using these definitions along with shipbuilding policy, a new definition of manufacturing strategy can be defined as will be used in this study, containing elements from Clark & Lamb (1996), Platts et al (1998), and Bruce & Garrard (2013).

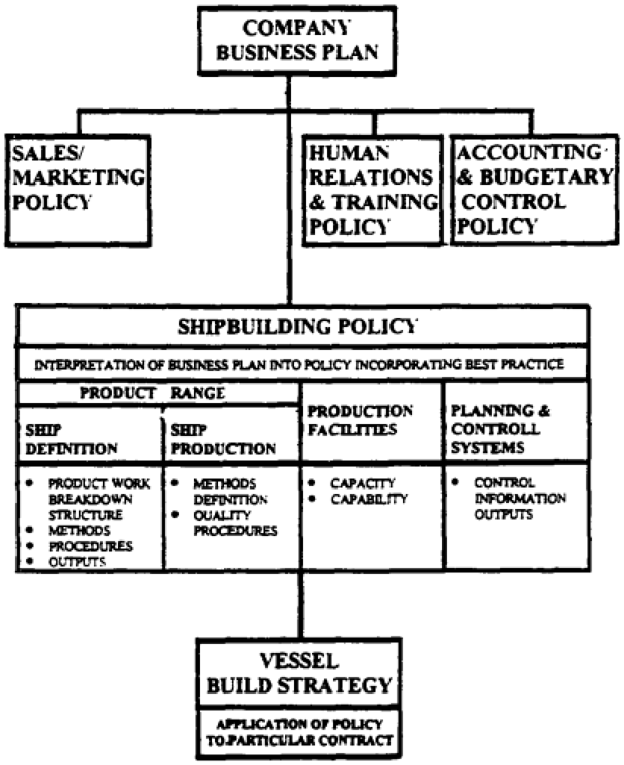

Figure 1: Build strategy and shipbuilding policy (Clark & Lamb, 1996)

Manufacturing strategy in shipbuilding can be defined as coordination, planning, and execution of projects using the companies' facilities, capabilities, resources, and competitive advantage in a way consistent with project specifications and the companies' business plan.[2]

This definition is well within the definitions given in the studies, but it also allows for a more open interpretation than the shipbuilding policy given by Clark & Lamb. This definition includes activities carried out by external actors, but that is governed by the shipbuilder, meaning the company that originally received and owns the order. This definition allows for external sourcing solutions and would still consider the outsourced/offshored work as within the companies' manufacturing strategy.

The definition also allows for strategic involvement on several levels of the building process, everything from the planning and coordination stages to the physical execution of the building process, this being engineering, mechanical, or offshoring, but also on different operational levels such as strategic, tactical, and operational.

6.1.3 Modules and standardization

This is a study about module strategies, thus a clear understanding of how modules fit into shipbuilding is needed. Studies approach modules in different ways and involve different concepts such as product architecture (Ulrich, 1994), configuration-based design (Brathaug et al, 2008), and product-platform technologies (Simpson, 2005). In literature, modularity and modularization are often seen in a wide range of academic fields such as biology, mathematics, computer science, and engineering. There are variations as to their meaning and relevancy in the different fields, but some commonalities that often reoccurs are: the division of larger systems into smaller parts, the smaller parts being relatively self-sufficient, a holistic system architecture that allows the parts to be put back together into multiple products based on a set of overall rules (Hagen & Erikstad, 2014). Modularity can also be used to describe a system characteristic that says something about the systems ability to be separated and recombined (Schilling, 2000).

A simple definition of modularization relevant to shipbuilding would be that it is a concept that simply builds on objects serving different functions that can be connected to a common hub or interface (Beckman & Rosenfield, 2014). If a strategy is based on this way of thinking, it can be referred to as *modular architecture*, where individual units are built or designed

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[2] This is not an official definition, but a definition made for this study by the author as shipbuilding manufacturing strategies are often difficult to define clearly.

independent of each other, while being part of the same final product (Hagen & Erikstad, 2014; Beckman & Rosenfield, 2014). There are several ways to arrange strategies based on module construction, and they are dependent on type of product. Ulrich & Eppinger (2008) defines three types of modularizations: slot modularity, bus modularity, sectional modularity. Slot modularity is where a common hub serves as the baseline for the product, and where each equipment "slot" is interchangeable, but only by products that fits into that slot (Jolliff, 1974; Ulrich & Eppinger, 2008). Bus modularity is a version where the interfaces fit to a wider range of products, and where the modules usually come as larger packages (Jolliff, 1974; Hagen & Erikstad, 2014; Ulrich & Eppinger 2008). Sectional modularity are modules where there is no hub, but all the units are built with interfaces that allows for a wide degree of customization, such as pipes with standard connections (Hagen & Erikstad, 2014; Ulrich & Eppinger 2008). Hagen & Erikstad (2014) also shows a wide range of other modularization possibilities summarized from other studies such as Christiansen et al (2003).

Modularization can be further divided into two subcategories. The first is *integral architecture* which is modular design where different modules are dependent on each other, such as a cargo platform and a propulsion unit if the customer has demands for both carrying capacity and speed. This can be categorized by a high level of complexity between the module units, and that there is more than one required to perform the function (Ulrich & Eppinger; Hagen & Erikstad, 2014). This serves as the opposite of the aforementioned *modular architecture* where each module serves its own separate function and is therefore more independent (Ulrich & Eppinger; Ulrich, 1995).

Modularization is not a new concept for Norwegian shipbuilders. Several shipyards have tried some form of modularization, and though the extent of modules within Norwegian shipbuilding is limited there have been several studies, projects, and initiatives that may serve as a base for knowledge for more use of modules in the industry (Hagen & Erikstad, 2014). One of these studies were the Modnet study which tested out production, design, operation, and sales of module-based ship solutions in a global industrial resource network (Hagen & Erikstad, 2014; Longva, 2007). Since the Modnet report, many changes have occurred in the Norwegian shipbuilding industry as described in the introduction, effectively reducing the shipyards' ability to innovate and develop new concepts, thus limiting the extent of the module construction solutions.

Depending on the products architecture there are different ways to organize the supply chain for the project and project specific supply chains are common for one-of-a-kind production

(Hagen & Erikstad, 2014). With a modular architecture, parts of the production could be outsourced or offshored providing the shipbuilder with an increased range of options for the final product (Hagen & Erikstad, 2014). It is also possible to use a modular architecture to allow for a set of prefixed solutions that the customer can choose from, which is sometimes called *product-configuration* and is a part of the configuration-based design (Brathaug et al, 2008; Longva et al, 2007).

An important topic thereof is whether modules must be physical constructions, or if modules can be structural elements in a product-platform structure. The Modnet report suggests that modules can be "documentary modules" and is a classification of a certain systems that are reusable across several projects (Longva et al, 2007).

6.1.4 Adding value in the production

Value adding or *value-adding activity* is an economic expression that is used to describe how a certain process makes an object more valuable as it flows through the value chain (Christopher, 2016; Hoff & Helbæk, 2018; Chopra, 2019). This is done by enhancing the quality of the product at each step of the value chain, where each step is a value-adding activity, and can be considered as the value the customer is willing to pay for the product, minus the costs incurred through the supply chain. This is called a *supply chain surplus* (Chopra, 2019)

The cost of the product does not necessarily have to follow a fixed system, and though there is often a correlation between input value and output value, the value of the output part is ultimately governed by a term called *willingness-to-pay*[3] (Riis & Moen, 2017; Hoff & Helbæk, 2018; Frank, 2015). In simple terms, if enhancing the product is very expensive, the value placed on the product by the producer might be higher than the price customers are willing to pay for it. Ultimately, this might mean that the product is so expensive to make with use of the current input factors that it is unviable, no matter the quality. Usually this would lead the customers to search for alternatives to replace the product with a substitute (substitution) or a completely different product (product differentiation) (Riis & Moen, 2017; Hoff & Helbæk, 2018). The opposite can also happen where the willingness-to-pay is

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[3] A microeconomic expression that is tied to supply and demand and shows the highest price customers are willing to pay for a product, often depicted as a graph showing the correlation between demand and price (Riis & Moen, 2017).

significantly higher than the input factors, leading to a profitable establishment for the producer.

Accompanying added value is the expression added cost or for supply chains, *supply chain cost.* These are the costs incurred while producing the final product and can be related to procurement, labour, facilities, inventory, transportation or anything else that adds a cost premium to the final product (Chopra, 2019; Hagen & Erikstad, 2014; Semini et al, 2018).

Eventually the single most important value for the yard or the company who facilitates the building process is profit. Without profit the company cannot grow, and it will be unable to absorb negative economic changes. Simply stated, the profit is revenue minus the costs, and as have been shown revenue and costs are contingent on several factors, some within the control of the company and some that are externally given. A way to increase profits is to retain more of the value-added as profits, while reducing costs, which as is shown here can be done by sustaining a high willingness-to-pay for the products while spending as little resources doing so as possible (Chopra, 2019).

6.2 Frameworks and models

Before reviewing important aspects of the ship manufacturing process, a framework or model is needed to measure and compare the performance of the different strategies, or at least in a qualitative way provide categories for comparison. Several frameworks have been considered as manufacturing strategy is a wide subject. Studies such as Semini et al (2016) provides strategies and a framework that could be used to differentiate between types of manufacturing strategies within shipbuilding. There are models that are less specific to shipbuilding, but that could also help systematically differentiate between different strategic approaches such as Hayes and Wheelwright (1984) and Fisher (1997), where the focus is mainly on having the right approach between supply chains and manufacturing processes. However, for this study, a more general approach to describe strategic performance is required, as many of the mentioned models are more subject specific and therefore somewhat more restricted. Beckman & Rosenfield (2014) presents a framework that has a more general approach, and allows for a qualitative evaluation of an organization, project, strategy, or any sort of execution within five business dimensions (Beckman & Rosenfield, 2014). Different versions of the framework exist, where different categories are added or subtracted depending on their relevancy in terms of field, and type of strategy (Beckman & Rosenfield, 2014). For this study, a framework consisting of five categories presented in Beckman & Rosenfield (2014) and used in Semini et al 2018 to consider the performance of different shipbuilding offshoring strategies will be used.

6.2.1 Competitive priorities

The framework of choice consists of five performance dimensions: cost, quality, delivery dependability, delivery speed, and flexibility (Beckman & Rosenfield, 2014; Semini et al, 2018; Spring & Boaden, 1997). Each dimension will be described in its own subsection where it will also be connected to an underlying strategic choice, highlighting how practical strategic choices will be reflected through the business performance dimensions. Different actors within the shipbuilding field put to use different strategies, even within the same market as can be seen in studies such as Clark & Lamb (1996) and Semini et al (2018). The competitive priorities framework will allow these strategies to be compared and scored according to the same categories, giving a reasonable ground for comparability. Granted, there are other categories that could also provide useful additions to the framework, several of which are presented by Beckman & Rosenfield, but as a baseline for strategic comparison the chosen categories are assumed to be sufficient. Often accompanying the competitive priorities are the expressions *order qualifiers* and *order winners. Order qualifiers* are requirements that needs to be checked off to even be considered by the customer, while *order winners* are the determining factors that makes the customer choose a certain product or contractor (Beckman & Rosenfield, 2014). Competitive priorities can often be seen as both order qualifiers and order winners, one of which in the contemporary market is often price and heavily tied to costs (Semini et al, 2018; Hagen & Erikstad, 2014)

Cost

Cost is defined as the ability to produce and deliver at low cost (Beckman & Rosenfield, 2014). Cost is a multifaceted performance measurement as there are many factors that goes into the category. For manufacturing, elements such as logistics, supply chain management, and production are all cost drivers (Chopra, 2019), while for most industrial companies' procurement also makes up a large portion of the costs (Van Weele, 2018). It is a crucial factor to control and that has a vital impact on strategic choices, because eventually the livelihood of any business will be determined by its ability to maintain a lower cost than revenue level. It goes without saying that a company that maintains a higher cost level than revenue level will need to make decisions that address and corrects this. Costs can be impacted at different levels of the organization such as operational, tactical, or strategic levels and through different facets of the organization, but to choose a strategy that is based on flawed cost estimates will almost always in the best of cases leave it up to chance whether a production is sustainable or not. It goes without saying that companies with an uncontrolled, unviable, or poorly regulated cost level is destined to fail as the costs will eat up the revenue, leaving no profits.

The cost category is influenced by many different decisions, from market factors, political factors, production methods, domestic cost level, alternative cost level, and so on. Thus, costs make up a complex picture that can be influenced by making decisions on many different levels and areas but is also influenced by factors outside of the companies' own control. Some facets of the cost estimate will be given, while other factors are to a certain degree controllable, such as how to arrange the production, or which building strategy to use.

Costs can be complex, and there can be big differences in the cost picture between actors, and especially states as shown by the Menon report (2021). Costs can be affected by internal factors, usually financial or structural decisions (Hoff & Helbæk, 2018), external factors such as given macroeconomic, environmental, or judicial conditions (Haugland et al, 2021; Krugman et al, 2015), or by the interrelations between companies. The latter category would typically be decisions related to cooperation between actors such as value-chain costs, procurement, or sourcing where the relationship between the actors can have a direct impact on the outcome (Chopra, 2019; Van Weele, 2018; Håkansson & Snehota, 1995)

Increased costs (or a cost premium) are reflected in one of two ways from a company's perspective: An increase in price for the consumer, or a decrease in company profits (it could technically also be both) (Hoff & Helbæk, 2018). This means that for a company that experiences increased costs, everything else considered equal (product value, price, etc) this could result in reduced demand due to a more expensive product for the customer, or less profits for the company (Riis & Moen, 2017). Considering the development of the Norwegian cost level the last couple of years, this is an important consideration when making decisions tied to building strategy and viability (Haugland et al, 2021).

Quality

Quality is defined as a company's ability to deliver high quality or performance standards (Beckman & Rosenfield, 2014). In the maritime industry, high quality is usually resembled by better durability, better system integration, higher level of usability, and a longer lifespan.

Yards focused on quality would often build products at a price premium, but with better steel alloys, more technologically advanced, better service, better design and engineering, to mention some qualities. In shipbuilding a products quality can be defined as the degree of durability, reliability, safety, and serviceability (Semini et al, 2016). Within the field of manufacturing management, several studies and models depict quality, innovation, and variability as oppositions to costs, thus meaning that there is a dichotomy between the three categories and cost-efficiency (Beckman & Rosenfield, 2014; Fisher, 1997; Stavrulaki & Davis, 2010; Hayes & Wheelwright, 1984), especially in terms of production methods and supply chain arrangements.

These studies show that there is a complex correlation between managing costs, quality, and other factors, and that the demand for the products and the companies' possibilities must be arranged in a way that allows for a maximization of the companies' capabilities. It also shows that from a holistic manufacturing perspective there are many decisions that needs to be constantly weighed against each other, that being supply chain decisions, logistical decisions, make-or-buy, sourcing, amongst many other things.

Delivery dependability

Delivery dependability is defined as the company's ability to meet delivery schedules (Beckman & Rosenfield, 2014). A yard that cannot deliver products on time will very quickly be considered unreliable which can significantly damage its reputation (Hagen & Erikstad, 2014). In a highly competitive market this can have a major impact on whether or not certain yards are able to win orders. Delivery dependability is both important and a difficult factor to manage as the construction of ships is usually a project that stretches over many years and depending on the choice of building strategy can have many different actors involved in the same project spread out both in geography and time (Hagen & Erikstad, 2014)

Because of the enormous amount of value put into building a ship, delays can be incredibly costly. There are several sources for this, one being that most of the materials and equipment that goes into the construction is bought using loaned money which because of the high value can cost a lot of money over time, and the second being that delays are most often fined using day-fines (Haugland et al, 2021; Hagen & Erikstad, 2014; Semini et al, 2018). Not considering the damage that being late causes for the yard's reputation as a reliable actor, the pure economic consequences of postponements can quickly eat up the small profit margin that most often exist within shipbuilding (Haugland et al, 2021).

Based on this, strategic factors that could affect delivery dependability are for example varying degree of control and coordination, reliability on partners or suppliers, transportation and logistics, and the availability of goods and materials. A factor that could also have an impact on delivery dependability is disruptions in the supply chain such as supply chain ripples of different kinds. These are low volume, high effect events that causes ripples through entire supply chains, and that can have massive negative effects on actors in the supply chain such as the corona-pandemic or the financial crisis of 2008/09 (Dolgui et al, 2018; Ivanov, 2020).

Delivery time

Delivery time as a performance measurement can be defined as the ability to keep the delivery time as short as possible (Beckman & Rosenfield, 2014). Clearly correlated with delivery dependability, delivery time adds another important measurement as to how quickly a potential customer can expect to receive their product when putting in the order. In production theory this is also called *lead time* and refers to the time it takes from a customer place an order until the customer receives the finished product (Chopra, 2019). If the project can be finished in for example half the time, the cost of interest on the loans will be less, and the yard will be able to cycle through more projects in a shorter time. A short lead time is also beneficial for the customer, as the vessel does not generate income before it is delivered and operating (Hagen & Erikstad, 2014). This shows that a reduced lead time could be mutually beneficial for both buyer and supplier, and that it could serve as a competitive advantage.

A reduced lead time could reduce the cost of inventory, interest, while it could increase costs tied to for example staff and overtime work.

Flexibility

In operations management theory, flexibility refers to a business's ability to react to changes in the product mix, change in sequence, fluctuations in materials, and modifications to design (Beckman & Rosenfield, 2014). Another definition of flexibility is to which degree a business can handle changes in delivery dates, level of output, product differentiation or range, and the ability to find new solutions (Slack et al, 2010).

Flexibility is the competitive priority parameter that measures a company's ability to handle unforeseen happenings, but also its ability to adjust its production according to the customers' requirements (Beckman & Rosenfield, 2014). Flexibility is also a measurement of an organizations ability to innovate (Semini et al, 2018). In supply chain and manufacturing theory, there is often a correlation between cost-efficiency and standardized production on one side, and high volumes, low variety on the other (Hayes & Wheelwright, 1984). This implies that a low variety often is considered as a cost-efficient solution, thus meaning that an increased variety either through more products or product flexibility is less cost efficient.

In shipbuilding, many yards offer complete flexibility where the solution is tailored specifically for the customer, especially in Norway (Haugland et al, 2021). On the other end of the scale there are large Asian yards who mass produce standardized types of vessels that are more cost-efficient and therefore cheaper, but that offers less flexibility for the customer (Haugland et al, 2021; Clark & Lamb, 1996; Platts & Song, 2010).

As a framework for measuring performance between different strategies are in place, a framework for understanding the ship and module construction process must be added.

To understand the manufacturing process for a complete vessel, and therefore also how a module could be built at a given shipyard, a general framework for vessel manufacturing at a shipyard will be presented. The framework is developed by Hagen & Erikstad (2014) and is a part of their book *Compendium in Shipbuilding.* The book is recognized as a good source for information in shipbuilding and is used as part of the course material at NTNU.

The framework from *Compendium in Shipbuilding* considers the building process of a ship from the perspective of an integrated yard that facilitates the building of a vessel from start to finish. Though this approach is less relevant now than before as few Norwegian yards builds ships through an integrated approach, it gives a good illustration of the facilities, decisions, and requirements that goes into the construction of a ship (Semini, 2021), and probably also a module. The stages have been described and adapted according to Hagen & Erikstad (2014).

6.2.2 Stages in Shipbuilding

Before moving on to the stages, two expressions will be introduced: *Early outfitting,* and *postponed outfitting. Outfitting* is simply the process of installing equipment into the hull or adding equipment to the vessel (Hagen & Erikstad, 2014). Typically, outfitting can be performed at different stages, depending on the type of equipment, type of vessel, and building strategy. Outfitting can happen according to a zone-based strategy where specific zones are prioritized before moving on to the next (for example a complete outfitting of the engine room, before even starting at the cargo room), or the building strategy can include a *stage-based* strategy where outfitting happens in stages (for example doing the pipe work in all of the zones at one stage of the vessel, before doing the electric work in all of the zones etc) depending on the practice of the yard (Hagen & Erikstad, 2014). *Early outfitting* is a technique that is used when outfitting starts before that stage of the building process is complete. Typically, this would be items that are so heavy or difficult to work with that it would be difficult or require a lot of extra work to install them after completing the stage. An example could be an engine or a gearbox that the yard could consider adding into the vessel before sealing the hull as it would allow the use of cranes, and there would be no need to cut the hull open after sealing it. *Postponed outfitting* is the opposite, and is a process where outfitting is carried out later than other similar tasks. An example would be electric work that should had been done at a certain stage, but limitations due to working space or conditions only allowed for installation at a later stage (Hagen & Erikstad, 2014).

Stage 1 – Design

Design is a very important stage in the shipbuilding process as it lays the foundation and the limitations for both the building process, but also the result. The design is based on an agreement with the buyer and are agreed upon in complex contracts that states very clearly what the yard is supposed to deliver (Hagen & Erikstad, 2014). The design includes engineering, naval architecture, production planning, finance, to mention some. What is crucial is that the decisions taken at this stage affects the entire production, and the estimates made are based on negotiations taken often years in advance. There have been cases where buyers have been specialized in making vague or devious contractual agreements where the gain and the yards lose on the deal. These buyers are often referred to as *yard killers,* because in the example of the Norwegian yards where the profits are already low, small changes or unforeseen details in the contracts can remove the little profit that existed, making the project become more of a liability than a mutually profitable project (Hagen & Erikstad, 2014).

The design stage is so complex that it would be suitable for a study of its own. It is therefore not within the scope of this study. Though, it is possible to imagine how the design stage can have an impact on the competitive priorities. The costs tied to design as a share of the total project costs (for offshore vessels) are given as approximately 6% (Hagen & Erikstad, 2014). Though this does not sound like a significant number, it is approximately the same as the cost of steel, and in a project that has a project value of several hundred million kroners, it does add up. However, the problem with the design is not only that the cost directly affects the final outcome, but the potential it has to indirectly affect the outcome of the rest of the production. Drawings, coordination, and choices in terms of production all significantly affects the costs incurred in the project, but also the quality of the product, the lead times, and that allowed degree of flexibility (Hagen & Erikstad, 2014; Semini et al, 2018).

Stage 2 – Prefabrication

Prefabrication is a stage where the focus in on producing the basic parts that makes up the hull. For the most part this will be steelwork, but other necessary parts that goes into the ship's foundation such as rubber or parts made out of other metals can also be produced. Typical parts that are being made at this stage are pipes, spools, different cuts, and it is also common to mark up the plates that are to be cut, bended, or formed at a later stage (Hagen & Erikstad, 2014). Generally, the prefabrication is a stage where preparations are made for the later stages by manufacturing the simplest of necessary parts, stocking up on parts that are needed for later, and by preparing the parts that are not yet to be produced.

As ships are large constructions and mostly made up of steel, it is clear that to make all the parts there is a large need for both labour and capital. Shipbuilding, and in particular the initial stages of the building process is very labour-intensive as most of these parts are produced manually or semi-manually (machines that requires operators), but it also requires heavy-duty machinery, cutting or burning tools, rollers, plate cutters, and so on. What is also of critical importance is proper drawings. Isometric and foundation drawings[4] are of utmost importance at this stage, and it is also important to make sure that precision is maintained. Parts or markings that are unprecise are as good as useless, and can in many cases delay the project, even sometimes requiring a complete rework. If the drawings are incomplete, non-intuitive, or wrong, the prefabrication stage can serve as a bottleneck in the production, causing delays or expensive corrective action.

The prefabrication stage is one of those stages where many yards choose to limit their costs by either *offshoring* or *outsourcing* parts of their production (Semini et al, 2018). Offshoring will be described in the next subchapter, but the point is that because of the high labour costs and the hours spent on the prefabrication stage, this is a challenge for yards struggling with expensive labour which is common in high-cost countries. Besides just the labour costs (wages), to maintain in-house prefabrication the yard would also have to invest in machinery, workshops, indoor area, storage, all of which costs money and that depreciates over time so that it needs to be replaced/repaired/upgraded.

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[4] Isometric drawings are drawings that represents a 3D objective in a 2D format, and that therefore can give representation of certain facets of the vessel prior to construction (Hagen & Erikstad, 2014).

Stage 3 – Part production

Stage 3 is for the most part a continuation of stage 2. Many of the same tools and machines are in use, which means that the requirements in terms of both labour and capital are also high at this stage. In stage three, the small parts from the prefabrication is put together into larger parts that are to be used in the construction of the hull. Plates that were marked up are to be cut into the correct shapes. This can be done by hand, but because of the requirements for precision many yards use robots or burning tables to cut the metal plates into the correct shapes and pieces.

At this stage, a part of the job is also to weld together plates or pieces of metal into larger structures. Welding is especially labour-intensive as the requirements for welders are very high. Because of the criticality, welders must deliver to perfection every time they perform a job, and though research has been done on robot welding it is still a technique that is less developed in shipbuilding, because of the complex curvatures of the ship[5]. Welding is also *hot work* which means that it exerts temperatures that can affect other things in near proximity, causing damage or unintended reactions if not handled correctly (Hagen & Erikstad, 2014). Welding and hot work can change the characteristics of the steel, so knowledge and control of the welding process is important[6]. Granted, many of the profiles should be eligible for robot welding, but seemingly this technique is not being extensively used, nor is it within the scope of this study. The point is that even though research and experimentation is being carried out within the world of welding, the current paradigm still requires shipbuilders to use manual welding which has a significant impact on the costs.

Stage 4 – Section building

Because of the sheer size of the ship, it is uncommon to build the ship from the foundation up in one complete construction (Hagen & Erikstad, 2014; Semini et al, 2018). What is more common is to construct the ship in several smaller pieces, usually *blocks* or *modules* (Hagen & Erikstad, 2014). One method is to separate the ship into *blocks* where each block is a portion of the total ship, for example separating the hull into 5-10 somewhat similar sections. The ship can also be constructed using *modules,* which means that some sections of the vessel are prebuilt sections that can simply be added to the vessel (Hagen & Erikstad, 2014). There is a difference between the modules used in this sense and the ones focused in this study. Modules in regular ship construction can be considered portions of the ship that is built at the

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[5] This is from an informal interview per mail correspondence with contact no. 2.

[6] Based on personal experience with welding and steelwork onboard and at the shipyard.

yard and can be seen as advanced blocks. These are often just made of steel and makes up a part of the ship through the hull assembly process. It is often used as a means to simplify hull construction. Modules built at the module yards in this study are complex modules that are built individually from the ship and contains complex subsystems. That means that the complex modules are often complete subsystems, which are not just a part of the steel construction, but are outfitted, finished, and ready for installation directly after production.

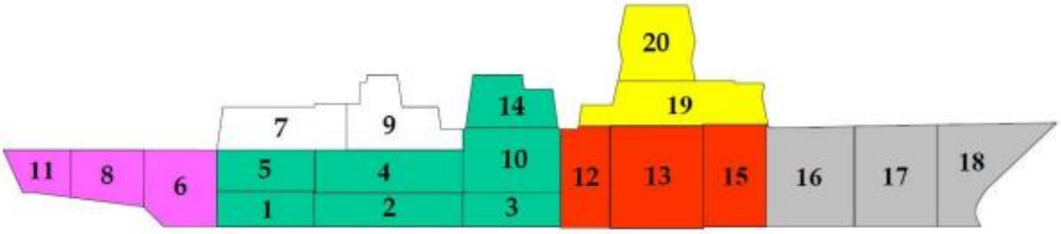

Figure 2: The Nansen Frigate class (Hagen & Erikstad, 2014)

The drawing shows a ship that is separated into sections, and where each number shows the order in which each section is to be added. In this drawing, sections 11,8,6,1,2,3,12,13,15,16,17,18 could for example be built as different blocks at the yard, while 7,9,14,19,20 could be built at a yard as complete modules that simply could be added to the rest of the hull after the hull had been assembled.

Construction of blocks consist of a lot of hot work. At this stage, the parts from the part construction are put together according to drawings and welded. Because of the size and weight of the blocks (or modules), a plan needs to be made as to where, how, when, each block is supposed to be built. Platforms, reinforced floor, and routes need to be prepared so that once the section building has been started it can be completed without causing logistical or technical problems. In addition, the yard needs to prepare jigs and lifting gear so that the sections are accessible for the workers, in particular the welders. The yard also needs to make decisions about if these blocks are to be constructed indoors or outdoors. Because of the weight and size, it will require large facilities to do the construction indoors but completing the construction outdoors before the blocks have been treated can cause damage due to heat, weather, and humidity.

Stage 5 – Painting and blasting

Painting and blasting are important, as ships are to endure rough weather and harsh conditions throughout their lifetime. The paint has several qualities that enhances the steels' ability to resist corrosion, and it reduces drag. Painting and blasting are rather straight forward, but it is complicated by the fact that the sections are heavy and rather immobile. This means that previous to the section building, this must be taken into consideration so that the blocks can either easily be transported to a suitable location, or so that the painting and blasting can be performed on site. It is also important that the jigs are set up so that every spot and location on the section can be reached.

Stage 6 – Block outfitting

At this stage the individual blocks (or modules) are to be outfitted, before being assembled. At this time the blocks are still open structures which allows for easier accessibility, which means that it is a good time to start with early outfitting. Depending on the size of the blocks, it is important to keep in mind that the blocks are supposed to be welded together at a later stage which generates a lot of heat that can change the structure of the steel and perhaps damage early outfitted equipment. However, many of the parts that can be installed early such as pipes, spools, and other basic materials are made from steel and can tolerate the heat. The blocks can also be large and because of the distance they might be out of danger. When outfitting it is critical to have good drawings and a solid plan. As several workers might be working in the same area or across from each other, it is important to do things in the correct order so that work does not have to be redone, or so that it does not cause bottlenecks in the operation.

When outfitting the blocks, equipment from the prefabrication stage such as pipes and spools are being installed into blocks where it is convenient. In addition, the yard can start installing technical equipment, which requires that they have been bought and delivered so that it does not cause a delay.

Stage 7 – Hull assembly

When the blocks or sections have been constructed and outfitted according to plan, it is time to assemble the blocks into a complete hull. Normally this is done by moving the sections to a slipway or a drydock where they are welded together (Hagen & Erikstad, 2014). As mentioned in the part about section building, it is important to have a plan as to which order the ship is to be assembled. The sections are very heavy objects, and once put into place it is difficult to move them again. Sections can be moved and put into place by several means, such as skids, or cranes. Once the sections are put into order, they can be welded together, and the hull can be completed. During the assembly it is of the utmost importance that the hull is inspected and checked continuously so that it is within the required tolerances. If the operation is done without inspections and the job (or the plan) is poorly executed, the yard risk building what is referred to as a *banana boat* where the keel is uneven (Hagen & Erikstad, 2014). Because of the large amount of hot work, it is even more critical to inspect regularly, because the structure of the steel changes during welding while the heat and the stress can cause structural changes both locally and far away from the actual source. Moore & Booth (2014) describes the criticality of proper welding with a reference to several of the American Liberty Ships that sunk due to poor welding (Moore & Booth, 2014).

As many of the previous stages, the hull assembly is a rather labour-intensive stage due to all the welding, but it also requires inspectors, operators (cranes, trucks, etc), and other support personnel. However, this stage also requires a lot of capital investments as there is a wide range of equipment and facilities needed to facilitate for the job.

Stage 8 – Dock outfitting

As of this point, the hull is assembled and the outfitting that could not be performed at an earlier stage can be installed. Typically, parts that needs to be installed prior to raising the water level must be done at this point such as bottom valves, sea chests, sea water pumps, shaft sealings, and propellers to mention some. It is important to install all the equipment that need to go into the vessel before putting it at sea, because to fail this would mean that the ship needs to be taken out of the water to redo these operations. At this stage of the building process, it is common to work on a zone-by-zone basis, meaning that each zone will be finished before moving on to the next one (Hagen & Erikstad, 2014).

Stage 9 – Quay outfitting

After the dock outfitting the vessel is submerged into the water and tested to see if there is any leakage. If there are no leakages, the vessel can be transported to a quay where the last parts of the outfitting can be completed. At this stage the systems onboard will also be tested and tuned, such as HVAC, propulsion, sea water pumps, manoeuvre systems, etc. After the systems have been tested, it is common for the yard to perform certain functionality tests for the vessel to clear it for operational duty[7] (Hagen & Erikstad, 2014). Once these tests are passed, the vessel is ready to be delivered to the buyer.

6.2.3 Strategic approaches

In the final part of this literature review, some strategies for shipbuilding and some common concepts for supply chain arrangements will be introduced. A *supply chain* are all the actors involved in fulfilling a customer request and can involve transportation, suppliers, warehouses, retailers, and in some cases even the customers themselves (Chopra, 2019). The latter is common in shipbuilding projects as the customer is often involved in developing the specifications for the final product (Hagen & Erikstad, 2014; Semini et al, 2018). Supply chains can be linear or highly complex with a large range of suppliers (Ruuska et al, 2012; Mello et al, 2015). Supply chain solutions are highly relevant for manufacturing strategies and will be revisited after a review of important offshoring strategies for shipbuilding.

Lately, the development in the Norwegian shipbuilding have been a transition from more integrated yards to increased use of offshoring and outsourcing solutions (Semini, 2021). *Offshoring* is a sourcing strategy that can be defined as establishing a production in a low-cost country that previously used to be in a high-cost country, and is referred to as work across geographical borders (Hogan, 2004; Semini et al, 2018; Chakrabarty, 2006). It is more common for Norwegian shipbuilders to utilize at least some sort of offshoring, especially the larger shipyards (Haugland et al, 2021). Semini et al (2018) describes four different offshoring strategies used by Norwegian yards depending on how much of the production that is being offshored. In this subchapter, each of these four strategies will be presented and connected to the building stages in the previous subchapter.

According to a study by Semini et al (2018) there are commonalities between the four different offshoring strategies, though the degree of offshoring differs significantly. In the study, build elements where there was a difference between the strategies were highlighted. Both commonalities and differences could be highlighted in strategic evaluations as they could both be relevant for decision-makers. The most important differences between the strategies according to Semini et al (2018) were the level of structural steelwork performed abroad, outfitting performed abroad, degree of work-in-progress transported [from the foreign yard] to the Norwegian yard, degree of early outfitting, concurrent execution of engineering and production, engineering and production interfaces, yard capabilities, infrastructure, and

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[7] Harbour acceptance test (HAT) and Sea acceptance test (SAT).

equipment, value creation and degree of vertical integration (Semini et al, 2018). Many of these subjects were addressed in the framework from Hagen & Erikstad (2014), and the offshoring strategies allow a systematic differentiation between strategies according to the degree of offshoring. Though there are other methods for strategic differentiation such as internal modifications of the manufacturing process (Semini et al, 2014), sale of complex integrated solutions tailored for the customer (Brady et al, 2005), or enhanced manufacturing through different process methods such as lean (Chu et al, 2021; Emblemsvåg, 2014), solutions that could enhance domestic production, offshoring seems to be a trend that is likely to stay relevant.

Offshoring strategy I – Integrated yard

The first offshoring strategy is defined as a complete in-house production where all the yards functions are vertically integrated, and the yard has all the capabilities needed to facilitate for a complete shipbuilding process (Semini et al, 2018). Traditionally, this would mean that all the stages in the previous subchapter were carried out at the same yard, though certain tasks could be *outsourced*, meaning that they were procured services from a third party (Chopra, 2019).

Integrated yards build integrated solutions, which traditionally meant complete ships. This required the yard to have all the necessary facilities for a complete ship production illustrated by the tools and resources described in the *stages in shipbuilding* section (Hagen & Erikstad, 2014; Semini et al, 2018). Integrated yards are usually vertically integrated, meaning that the organization has ownership of the complete production process, though it might procure some services such as raw materials (Semini et al, 2018). Since the shipyard has the facilities required to build complete vessels in-house, it limits the required interaction with other suppliers and actors, which has an effect on coordination and planning. The shipyard might perform its own engineering and does not require transportation of work-in-progress from other companies as the entire production takes place at the yard. The shipbuilding process is commonly highly labour and steel-intensive at the initial building stages which must be absorbed by the shipyard and will for Norwegian yards usually imply a higher cost level (Hagen & Erikstad, 2014; Semini et al, 2018). Since all of the stages in the production is carried out by the shipyard that builds the vessel, a closer proximity between the departments can be expected that can lead to positive effects (Semini et al, 2016). Studies such as Clark & Lamb (1996) states that this is not necessarily true as some shipyards can be large and contain so much personnel that the degree of interpersonal relationships are not at a level where synergy effects can be expected.

Offshoring strategy I is a strategy that limits the use of offshoring, and that maintains as much of the production as possible in-house (Semini et al, 2018). It has the highest degree of domestic steelwork, has a complete freedom to outfit the vessel at their time of choosing, has the closest proximity between the different actors involved in the process, and potentially allows for simpler drawings and instructions. Though, it is considered as the strategy that requires the most facilities, equipment, and infrastructure (Semini et al, 2018).

Offshoring strategy II – Norwegian block outfitting

Offshoring strategy II is based on offshoring most of the steel related construction to foreign actors who can benefit from lower labour costs (Semini et al, 2018). A high degree of the steelwork in complete vessel construction is normally offshored, and it is expected that the simple structures that makes of the foundation of the hull can be built at a significantly lower price, yet at a sufficient quality abroad (Semini et al, 2018; Haugland et al, 2021). For the Norwegian shipyard this would reduce steelwork related costs, and it would also mitigate the costs tied to equipment, facilities, and infrastructure required at the yard. As the foreign yard is expected to perform little or no engineering themselves, this responsibility would be on the Norwegian yard as well as to handle the complete process coordination (Semini et al, 2018).

Usually, the project would be owned by the Norwegian yard who engineers, plans, and coordinates the complete construction of the vessel. Drawings and plans would be prepared, and an agreement with a foreign contractor would be made to construct the steel blocks that makes up the hull. These steel blocks would be transported to Norway, where the outfitting, assembly, completion, and testing would take place (Semini et al, 2018). While most of the block outfitting would take place in Norway, some outfitting could be offshored to the foreign contractor such as steel outfitting and outfitting that would be difficult to do after completing the blocks. As steelwork is considered as an uncomplicated process, a wide range of available workshops could be used, and it does not necessarily have to be a shipyard (Semini et al, 2018). Though the block construction mainly takes place abroad, complex blocks could be built in Norway as it could increase the quality of the total product (Semini et al, 2018)

Though the block construction is offshored, the Norwegian shipyard still needs the facilities required to handle the blocks, perform outfitting, assemble the blocks, and the rest of the steps described in *stages in shipbuilding.* This means that much of the solutions from the integrated yard still needs to be in place for the utilization of offshoring strategy II.

Offshoring strategy III – Norwegian dock outfitting

In offshoring strategy III the degree of offshored operations are advanced even further than in strategic alternative II. In this strategy the hull is completed abroad, and the foreign yards are in these cases usually referred to as *hull yards* (Semini et al, 2018; Haugland et al, 2021). In difference to strategy II the hull is completed and launched at the foreign yard before it is towed to the Norwegian yard. This implies that the hull structure must be completed and sealed and means that it must be built at a foreign shipyard. For the Norwegian shipbuilder this marks a change in the building process tied to several manufacturing areas. Receiving the vessel as a complete structure requires the hull yard to perform some of the outfitting, unless the Norwegian yard wants to reopen the steel structure to perform the job. This requires an increased level of detail in terms of drawings, plans, and engineering, and it reduces the time available for making these plans as these can often be made in parallel to the outfitting process while using strategy I or II (Semini et al, 2018). For the Norwegian yard to work on a closed steel structure is often costly and can require expensive equipment. Another perceived challenge that has become prominent over the last couple of years is the challenge tied to intellectual property. If offshoring strategy II is used, smaller workshops that does not have the facilities required to run as shipyards can be used where sharing information pose little risk. In strategy III the hull must be finished at a shipyard who can learn and adapt from the work it does for the Norwegian yard, eventually initiating its own shipbuilding operations following the same model and know-how. This poses a risk for Norwegian yards as it over time allows foreign yards to close the gap in innovation and quality while still producing at significantly lower prices, becoming a competitor (Haugland et al, 2021; Semini et al, 2018).

Offshoring strategy III presents the sharpest split between steelwork and outfitting. With the use of this strategy, the steelwork is performed at a location where it can be provided at a low cost, while the outfitting is carried out where the capabilities are available to deliver according to demand (Semini et al, 2018).

Offshoring strategy IV – Norwegian quay outfitting

In the final offshoring strategy, the total construction of the hull and most of the outfitting is performed by a foreign shipyard. This would also include dock outfitting, meaning that the ship could be launched after completion, and only requires outfitting that can be done from the quayside in Norway (Semini et al, 2018). The most significant difference between offshoring strategy IV and the previous three is the degree of complex outfitting that is done abroad. Because of the positioning of the equipment, some parts such as sea water pumps and engines might be installed abroad as they are difficult to access once the ship has been sealed. This strategy requires a strong mutual understanding between the Norwegian shipbuilder and the foreign yard, as both simple and complex outfitting is to be performed. Differences in culture, language, work practices, and competence are complicating factors that increases the potential for failure, thus effective coordination, communication and planning are of great importance (Semini et al, 2018).

As with offshoring strategy III, knowledge transfer and intellectual property are challenging subjects when such a large portion of the production is offshored. As the details on drawings, coordination, planning, and practises have to be transferred to increase the likelihood of a successful operation, more of this information will be absorbed by the foreign actors. A solution is vertical integration between the foreign yard and the Norwegian shipbuilder, though it represents risks such as changing partners in case of problems, foreign national problems, or economic challenges.

Offshoring strategy IV requires significantly less facilities, equipment, and infrastructure than the other strategies, but would still require a quay, tools, and equipment to carry out the final outfitting. The foreign yard on the other hand would require all the facilities required to build the ship, as an integrated shipyard.

7 Results

This chapter will be devoted to solving research objective one. To identify characteristics with module construction in shipbuilding, and to develop module construction strategies for Norwegian yards, the research from the theory chapter must be used. As a clarification, though modules can be planned and used as documentary modules (Longva et al, 2007) this study will only be concerned with construction of physical modules. Before addressing module characteristics, a study of Norwegian competitive advantages and disadvantages will be done, as these are important for strategic propositions and evaluations also in module construction.

7.1 Competitive advantages and disadvantages for Norwegian shipbuilding

Though the strategies that are proposed in this study are mainly concerned with degree of offshoring, strategic decisions regarding manufacturing strategy and business plan must also address issues such as product mix, volumes, capacity, and other criteria that specializes the production. These decisions should correlate with the module yards' and Norwegian competitive advantages, and hopefully reduce the extent of the competitive disadvantages. To increase the likelihood of a successful strategy, decision-makers need to choose and develop a module strategy that unifies the offshoring strategies with the relevant competitive advantages. In this subchapter, Norwegian competitive advantages and disadvantages will be described, and are related to the topics from the literature review. These topics will be revisited in chapter 10 where an elaboration on important points for decision-makers will be addressed.

7.1.1 Norwegian competitive disadvantages

In the Menon report (2021), a study was carried out to analyse the state of the shipbuilding sector in Norway. A part of the study was to identify Norwegian competitive advantages and disadvantages in comparison to relevant competition, primarily other European shipyards. Nine categories were identified as competitive disadvantages, while three categories of points were identified as competitive advantages. Several of these points are confirmed and elaborated on further in other studies. In the following sections, sources for competitive disadvantages that could be relevant for strategic decision-making at a module yard are described. The identified advantages and disadvantages are based on construction of complete newbuild vessels and not on modules. No studies describing this specifically for module construction in Norway was found, but it can be expected that the competitive environment is very similar in nature, though some differences might occur.

High cost level

A widely accepted truth in the Norwegian shipbuilding community is that Norway produces or facilitates to produce vessels with high quality and a high degree of flexibility so that the customer can tailor the vessel after wanted specifications (Haugland et al, 2021; Semini et al, 2018). This is typically done through one-of-a-kind production of vessels, where the customer dictates the specifications of the vessel for a price premium (Hagen & Erikstad, 2014). It is also a common accepted truth that the cost level in Norway is too high to sustain a high degree of labour hours, typically corresponding to steelwork within shipbuilding, but also other parts of the production (Semini et al, 2018; Hagen & Erikstad, 2014; Haugland et al, 2021). For this reason, extensive outsourcing and offshoring have been used, as increased globalization and competition have pushed production towards solutions where the price level is lower (Halse, 2014). Studies such as Halse (2014), Semini et al (2018), Semini et al (2013), Longva et al (2007) and more emphasize that costs are a competitive disadvantage for Norwegian shipyards, however it is also important to be precise as to what drives the costs, and what defines the costs as being so high that it makes it a competitive disadvantage. In some studies, it is argued that the high cost level stems from primarily two interrelated factors; steelwork, and labour. Granted, labour per hour at Norwegian yards has historically been higher than at comparable foreign shipyards, even when adjusted for increased productivity at the Norwegian yards (Haugland et al, 2021; Semini et al, 2018; Semini et al, 2016), but this is more accurate for shop floor work, than for example engineering where the cost level is much more similar.

Steelwork is according to Semini et al (2018) a part of the production where Norwegian shipyards is at a major disadvantage in terms of costs. To assess why steelwork is such an expensive activity for Norwegian shipyards it is useful to separate steelwork into lesser components such as labour, logistics, and steel manufacturing.

Labour is by most sources considered relatively expensive in Norway, in particular for simple tasks such as work done by plumbers, welders, electricians, painters, and other carpenters. Rules and regulations in Norway even out the pay gap between workers of different professions, increasing the wages for industrial workers (Haugland et al, 2021). In addition, due to varying demand at Norwegian shipyards and varying project size, extensive use of part-time hire is utilized as exemplified in the Menon report (2021). The cost of labour is heavily amplified when extensive use of part-time hire is utilized, which makes part-time hire a cost driver. The logic is that the average payment for an industrial worker is much less then what the yard pays as there are additional costs on top the wages for the employer (Hoff & Helbæk, 2018). For part-time hire, an extra premium must be expected on top of these costs, so that the company that governs and pays the workers also can make money from the transition. On average the interview-objects used in the Menon report reported that 33% of the total costs in a shipbuilding project could be traced back to labour (Haugland et al, 2021).

For steelwork, logistics also serve as a cost-driver. For Norwegian shipyards or in this case module yards the steel needs to be procured from steel plants abroad and transported to Norway for part production. Transportation adds both time and a price premium to the project, even before the manufacturing process has started. As the amount of steel in modules can be expected to be relatively low, there are low chances of receiving price reductions for increased volumes.

Steel manufacturing is the process of the steelwork where steel chunks or plates are manufactured into parts that can be used to build the module steel structure. This process is anticipated to be very labour-intensive under the current manufacturing paradigm where most of the steel manufacturing is manual work (Hagen & Erikstad, 2014). Equipment for steel manufacturing is also a cost driver. Variation in orders also makes it difficult to achieve economies of scale, and the one-of-a-kind policy used by many Norwegian shipbuilders makes replication challenging.

Standardization

In conversations with officials from the shipbuilding community carried out for this study, several of the officials who have had or has a tight connection to the Norwegian shipbuilding industry either as intellectuals or as employees in leading positions have described standardization as a subject that does not fit with Norwegian shipbuilding. According to the Menon report (2021), the high cost level at Norwegian yards over time have led to a situation where the Norwegian shipyards and the maritime clusters built around the shipyards have specialized their production for specific market segments, and for vessels tailored at the customers request (Haugland et al, 2021). Prototypes, innovation, and a focus on technologically complex solutions are all of part of the Norwegian shipbuilding portfolio, but a focus on one-of-a-kind vessels makes Norwegian shipyards unable to benefit from economies of scale, standardization, and project replication (Haugland et al, 2021; Hagen & Erikstad, 2014).

Use of standardization in vessel construction is uncommon for Norwegian shipyards, though shipyards such as Ulstein have produced some ship series. A major challenge for the Norwegian shipbuilding industry has been that previously the shipyards often functioned as a bridge between different suppliers in the maritime clusters, and suppliers often specialized the production to match the demands of the shipyards. The shift in market demand since the 2000s have made these links weaker which have increased the transaction costs, reduced the productivity, and have made cooperation between the different actors in the shipbuilding cluster less efficient (Haugland et al, 2021). Shipyards still function as integration points between different suppliers (Haugland et al, 2021), but in one-of-a-kind production with low degrees of standardization these supply chains are more sporadic, and it must be expected that synergy effects such as mutually increased specialization, productivity, and reduced transaction costs are less prominent. A study by Ruuska et al (2012) also show that in general buyers and suppliers diverge in their view on supplier capabilities, which facilitates less mutual trust and specialization that can harm the productivity of both parties which helps confirm the findings in Haugland et al (2021).

Economic frame and terms

Norwegian shipbuilders have the last years struggled with reduced solvency and low liquidity. There are several reasons for this, amongst them failed high-risk projects that turned out to be more expensive then anticipated, and poor choices in terms of offshoring solutions where the offshoring yards have delivered insufficient products (Haugland et al, 2021). The economic situation for many Norwegian shipyards and yards that could be interested switching solely to module construction is that increased cost level combined with poor results has reduced the opportunity to innovate and experiment with new solutions (Haugland et al, 2021). Shipbuilding is expensive, and often the shipyard needs to pay for procurement up until project delivery which requires solvency and capital so that loans can be arranged.

Different national arrangements for loans and support for shipbuilders have also been a debate amongst shipbuilders as there seem to be different interpretations in terms of rules and regulations surrounding this topic. This makes it so that foreign yards might benefit from state subsidiaries that decreases Norwegian shipyards competitive edge even further (Haugland et al, 2021)

Export of equipment and knowledge

Several studies such as Semini et al (2018), Semini et al (2013), Haugland et al (2021), and Halse (2014) describe offshoring as a situation where previously competitive advantages such as technical expertise, the availability of Norwegian suppliers for ship equipment, and generally the utilization of the Norwegian maritime cluster can be transferred to foreign shipyards. When using offshoring solutions, it is common to send representatives either from the project owner or from the specific supplier to oversee the production or installation of the units. In the studies this is described as a challenge because offshoring requires knowledge transfer from the Norwegian shipbuilder to the foreign yard, or from the suppliers to the foreign yard to perform the job according to plan. This has resulted in transfer of intellectual property from the Norwegian shipbuilders to foreign yards, making them able to facilitate for this form of production themselves, eventually becoming a competitor (Haugland et al, 2021; Semini et al, 2018). In addition, this has established a connection between Norwegian maritime suppliers and the foreign yards, while weakening the link between the Norwegian yards and the suppliers in the cluster.

7.1.2 Norwegian competitive advantages

In this section, competitive advantages for Norwegian shipbuilding will be described. As with the competitive disadvantages, no studies that describe specific advantages tied to Norwegian module construction has been found.

The Norwegian maritime and shipbuilding cluster

In the Norwegian maritime clusters, the shipyards have traditionally had an integrating effect between the different suppliers in the cluster, thus working as the link that increases coordination and cooperation between the suppliers both directly and indirectly (Haugland et al, 2021). Though offshoring has served to establish links between Norwegian suppliers and foreign shipyards, and increased diversity in the supply chains due to new production concepts have in some cases weakened the link between the Norwegian yards and the suppliers, the near proximity and high trust between the actors are still prominent. According to several studies, industrial clusters can have several benefits that increases competitive advantages for the companies in the cluster. Studies such as Halse (2014) explored the knowledge transfer between offshored companies and the engineering department and found that there was a correlation between increased offshoring and reduced knowledge transfer between the units. This is also stated in a study by Gray et al (2013) where increased distance between research departments and manufacturing was expected to lower innovation and reactions to change. This implies that strong ties between the actors in the cluster such as in the Norwegian maritime clusters would serve as a competitive advantage.

Egalitarian hierarchical structure

Generally, in the Norwegian society, and also in the shipbuilding sector, there are less prominent hierarchical structures than in other countries (Haugland et al, 2021; Semini et al, 2016). This often serves as a competitive advantage as it increases the speed on decision-making, reacts to changes more rapidly, and generally makes the labour force more effective in their work (Haugland et al, 2021). Combined with a generally high level of education and competence, this makes for an effective workforce that is also adept at innovative, high quality work with a high degree of flexibility (Haugland et al, 2021; Semini et al, 2016). According to Dicken (2015), the is a large variation in labour depending on different geographical areas. This indicates that facilities for shipbuilding cannot be established at a random location and expected to succeed, especially if there is a need for competent and skilled labour. This gives Norway a competitive advantage in terms of technically complex solutions, as egalitarian regimes and a high-education level is an integrated part of the Norwegian social structure developed over many years (Semini et al, 2016).

Specialized production for tailored products and prototypes

The Norwegian maritime cluster in cooperation with the shipyards have over time specialized into specific ship segments and products where the Norwegian shipyards could remain competitive (Haugland et al, 2021). Because of the level of competence and the relatively high price level, the Norwegian yards have specialized in making innovative solutions and prototypes on request for relatively small product segments, but where Norwegian shipyards are renown to produce exactly the products the customers request (Semini et al, 2018; Haugland et al, 2021)

High degree of technical competence

As seen in some of the other competitive advantages, Norwegian maritime industry has a high level of education and competence, and are specialized in one-of-a-kind production with high quality, flexibility, and degree of innovation. This makes Norwegian shipyards able to solve challenging problems on request, and to deliver unique products exemplified with the worlds first hydrogen-driven ferry, MF Hydra and Eidesvik's pollution-free offshore vessels (Haugland et al, 2021).

With a high competence level and a well-developed maritime cluster that is primed for handling complex problems that requires innovative solutions, Norwegian maritime industry has an advantage in developing solutions for new operation paradigms.

Because of the development over time, several actors within the maritime clusters are also companies with a high degree of relevant competence in disciplines such as automation, electronics, and propulsion systems (Semini et al, 2016). A close proximity between these capabilities and ship or module yards adds to competitive advantages as mutual development in technology, research, and development, combined with possible integrated solutions allows for positive cluster synergy effects if it can be utilized as a competitive advantage.

Semini et al (2016) summarizes the competitive advantages from the locational characteristics as an advantage in delivering products with innovative features, highly customized products, products with high quality requirements, and environmentally friendly products both in production and operation (Semini et al, 2016).

7.2 Modularization characteristics

In Norwegian shipbuilding there have been examples of modular architecture, and there has been no lack of research in the possibilities of using modules more extensively in ship manufacturing (Longva et al, 2007; Hagen & Erikstad, 2014). As ships are complex systems, and the Norwegian shipbuilding industry has a reputation for delivering innovative, tailored, high-quality solutions it is difficult to imagine Norwegian shipyards that either completely standardize their solutions to a limited product catalogue or to have solutions that are based on sectional modularity (Hagen & Erikstad; Haugland et al, 2021). Though shipbuilders such as Ulstein and Brunvoll through the Modnet reports speculated in the possibility of selling somewhat standardized solutions with a configuration approach there seems to be little usage of the strategy across Europe. To develop strategic propositions, it would be useful to define modularization characteristics that might not be universal, but that can be used as a framework for this specific study. This would mean that modularization could be approached through other methods, and that these strategies are based on some specific characteristics.

One type of strategy that has been researched and speculated in has been a construction based on one or more modules placed onto a standardized hull (Buskop, 2021; Longva et al, 2007). Such as solution would allow a separation of the construction process and could be based on two different offshoring solutions in accordance with the strategies given in Semini et al (2018). As an example, most of the hull could be built using offshoring strategy III, while some of the sections could be built at a Norwegian shipyard at certain specifications. As stated in the literature review, this is sometimes already done with the use of offshoring strategy II where some of the more complex sections are being built domestically (Semini et al, 2018). The difference would be that a Norwegian shipyard could establish this as a main strategy where it specialized in building modules and where a lot of the value-added would stem from this module construction.

As described, there exists different modular architectures depending on the type of product, but for this study the scope will be on concrete functional units, meaning a complete system that makes out a distinct portion of the complete product. One such module could be a propulsion module that makes up the entire engine room, or an accommodation module that makes up all the accommodation facilities. Another criteria should also be that the module itself can be separated from the vessel, which means it would have the potential to be constructed completely separate from the rest of the production. These characteristics would incur that the module could be both planned, built, and facilitated for independent from the rest of the vessel, where some shipyards could even speculate in using two production lines, one for modules, and one for the hull. In a way this could imply that two different strategies could be used, one for the construction of the rest of the ship, and one line for production of the module.

Another characteristic is that of re-usability. If a ship was built using a modular architecture, this would make it easier to standardize parts of the vessel construction while still allowing for innovative solutions to take place. This could be done either by standardizing the module(s) and allowing the customer a choice of variability, while still customizing the rest of the ship to the buyer's preference, or by standardizing the hull and allow for customer tailored modules. If taken one step further, successful modules could go into the yard's portfolio as reusable product concepts, and the ship could be built from an array of variable premade solutions with products that are already tested. If that was the case, the customer could tailor a vessel of its liking without having to use any prototypes. This could reduce the cost of production for the yard while still allowing for a wide customer flexibility and variety. This is a type of construction that is sometimes called *configuration* and uses previously tested prototypes where price estimates and know-how is already developed (Longva et al, 2007).

As one of the main characteristics of using module construction is the ability to separate the production into two different production lines, another characteristic is that it allows a shipbuilder to benefit from two different sets of advantages. In the example of Norwegian shipyards, a clear problem is related to costs (Haugland et al, 2021; Semini et al, 2018). There is a pressure on Norwegian yards to build vessels that has a high level of innovativeness, quality, and flexibility, but at the same time, the costs are usually so high that the price to pay for maintaining the other factors often make production unprofitable (Haugland et al, 2021). As is clear from the review on offshoring strategies, if produced abroad, the cost of the production can be significantly reduced, but one of the problems is that much of the value-adding disappears as well. If the vessel could be constructed by offshoring parts of the production where the Norwegian yards have a low competitive advantage, while retaining the production where it has a higher competitive advantage such as technology and outfitting, perhaps a higher amount of profit could be retained. As one of the characteristics of module construction is that the production could be split into the use of two different strategies, this could allow for technology intensive modules that requires a high degree of human capital and productivity to be built in Norway, which would add a lot of value to the product. As shipbuilding in general is a complex process, this is also reflected in ships with modular constructions. To build parts of the vessel at different locations and in different portions can add more layers of challenges, as ships are delicate systems where small differences in engineering and production planning could cause problems. Examples would be modules where small changes or adaptations in positioning of the equipment could destabilize the vessel or at least change the conditions for ship stability[8]. Granted, this would also be the case with complete vessels, but as the modules can be substantial in size and conditions from where it is built can be different from where it is to be installed, can make it difficult to fit, install, or even get the engineering right.

In the Modnet report of 2007, three types of vessel construction was proposed. These were unique ships, configurated ships, and optimized ships. These were categorized from least standardized to most standardized, with modules being thought to fit into the middle segment (Longva et al, 2007). This middle segment was based on delivering ships with good quality and the ability to offer flexibility and variation in a set of choices predefined by the shipyard, hence falling into the category of product configuration (Brathaug et al, 2008; Beckman & Rosenfield, 2014; Longva et al, 2007). This was meant to be able to deliver solid vessels at a high quality, but with short delivery times, and a relatively high amount of flexibility. Modularization could also serve as a cost reduction measure as reuse of functioning module types reduces time and money spent on product development, especially since the modules require less research to be added to the portfolio. Other studies such as Baldwin & Clark (1997) confirms this view and adds that modules can provide customers with high quality solutions at a lower price due to increased production efficiency, and the ability to provide quality through modules and a standard hub. Implicitly the report states that modules are less relevant for prototypes, unique constructions, and for completely cost optimized shipbuilding. Though not stated explicitly, it seems like several of the mentioned studies have a large focus on cost efficiency, and less on using modularization as an innovative approach that allows for standardization in combination with innovative modules. The mentioned studies do not specifically target modularization in the shipbuilding industry, but the results are general enough to be considered as valuable. Approaches such as strategies where modularization is used to allow for more innovation rather than an increased level of standardization is difficult to find, as such an approach will be further investigated in this study.

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[8] This is information from the authors background as a naval engineer.

To create a base for proposing module construction strategies, a closer look must be taken at the stages in shipbuilding and how they fit with module construction. An adaptation of the building stages for ship construction from the literature review will be made for module construction, to understand which stages are required for the construction of a module, as well as important key factors. This will be followed by an attempt at identifying important construction characteristics and requirements, as well as relevant challenges for module construction.

7.3 Adapting ship construction stages to module construction

Modules can come in different shapes and sizes. Depending on the request of the customer, and the capabilities and willingness of the shipbuilder, a module can technically consist of any part of the vessel that being an engine room, a bow, or the midship (Semini et al, 2018, Hagen & Erikstad, 2014). It is obvious that different parts of the vessel imply different quantities of input value, as the constellation that makes up the module will be different depending on which section of the ship it is. An engine room will most likely contain more technical equipment and relatively less steel than for example the bow. In the following adaptation of the ship construction process into modules, a general approach to modules will be used, as a specific choice of module type would limit the usability of the study. Though, the modules are considered to be stand-alone constructions that can be built separately from the hull.

7.3.1 Stage 1 – Project planning

Though the scope of this study is mostly about the manufacturing process, the project planning stage is crucial for a well-functioning project. The project planning consists of engineering, planning, manufacturing planning, resource management and allocation, procurement planning, and other disciplines (Hagen & Erikstad, 2014). Though many of these processes proceed along with the rest of the construction simultaneously (Semini et al, 2018; Hagen & Erikstad, 2014) plans must made prior to the physical construction, and in certain strategies also prior to the project planning stage (Clark & Lamb, 1996). It can be assumed that at this stage, the project has been verified to be within the companies' shipbuilding policy, and that the requirements to carry out the construction is in place.

For module construction using the two-stage construction process, this adds another layer to the manufacturing process. In this stage, plans must be made as to how the interface between the hull and the module are to fit together, at what stage they are to be combined, where this is supposed to happen, and then what facilities that are required at that certain location. In this way, plans, equipment, facilities, organization arrangements, and organization of the physical construction needs to be made. This is for the most part similar to the thought process that needs to be used in regular vessel construction when the production is split between a domestic and a foreign production, but with another layer added as there are now two different construction processes to manage (Semini et al, 2018).

7.3.2 Stage 2 and 3 – Prefabrication and part production

Both prefabrication and part production are capital-intensive activities in the sense that a lot of machinery and facilities are needed to facilitate for the production. As mentioned in the literature review, a lot of heavy-duty machinery is required, as well as operators who can handle the machines.

Prefabrication is a stage where most of the value-added stems from steelwork and from converting materials from raw materials to useful products that are to be used later in the building process. For a complete yard (fully integrated yard) that builds a full-sized vessel in-house, this would mean that all the raw materials had to be processed according to planning and drawings, and depending on how the production is executed, it would have to be stored. Another option would be to produce parts while working on the different stages, such as having one crew work on prefabrication while another crew works on part production, which would reduce costs by limiting the required inventory at stage 2. However, if the materials are not directly used, storing space will be required.

In terms of module building, the prefabrication stage does not change to a significant degree in comparison to building a complete vessel, and the same line of thinking can be used. Depending on the module, it still requires prefabrication, parts, and a steel structure to house the equipment that goes into the vessel, no matter the type of module. The major difference would be how many parts, which parts to make, and when to make it. This means that it for the most part is a volume problem, which can lead to a couple of challenges. If the volumes are lower, as they would be if the module were to be produced domestically without any major related construction, it would be difficult to achieve economies of scale. This would make each product and each work hour relatively more expensive. In addition, if the module were to be produced in-house in Norway and the module of choice were depending on the choice of the customer a wide variety would make it even harder to achieve low costs through repetition.

In the prefabrication and part production stages some cost drivers and facility requirements can be identified for the module production. Just as for a standard vessel production, the cost drivers are for the most part tied to work hours (labour costs), capital (investments, uptime, and depreciation), and storage. There is really no difference between building a module and a vessel at this stage except for the scale and the exact task execution as all the parts are not necessarily going to be the same. In terms of facility requirements, it is difficult to say, because at this stage, the capital requirements in terms of what tools are needed would be decided by what type of module that is to be constructed. Though, if the modules are based on the same materials, the same machines would be needed, but the amount, size, and uptime would differ.

7.3.3 Stage 4 and 5 – Block construction, blasting and painting

In module construction, the yard has a different set of choices in terms of block construction than with regular vessels. In Norwegian shipbuilding, the size and weight of the vessels can differ significantly. When building large vessels, it is a common practise to split the vessels up into different blocks or even complete modules before assembling them at a later stage (Hagen & Erikstad, 2014), so that they can be outfitted and finished while they are easier to handle. This is an approach that can be used while building modules as well, but depending on the size, weight, and content of the module it might be unnecessary and considered as extra work. If the module is small, it might make more sense to simply just assemble the parts straight into a complete module before blasting and painting and avoid the added complexity by first building small blocks, and then assembling them into a module. However, if the module is large or there are parts of the module that needs to be outfitted before assembling the rest of the module, a block approach might be needed. An example of this would be if the module were to contain for example a midship portion on a cruise vessel, which could be very large in comparison to other relevant tasks.

No matter if the module is built as blocks or straight from parts into a module, the job that is to be performed is quite similar in nature. The parts that were created at an earlier stage need to be welded according to plans and drawings into a complete structure which is a labour-intensive job. However, the biggest difference would be the work volume and the facility requirements. As the module is smaller than the ship itself would be, it will contain less parts, and should require less labour hours to be finished. Less labour hours would in most cases imply a proportional reduction in costs tied to labour, and it could also allow for a higher worker efficiency and reduced idle time. If fewer workers/operators are required for the job, this could also allow for more full-time hire which again could lead to cost reduction and a relative increase in experience, both leading to a higher efficiency. This is an interesting observation, because the common perception in production paradigms is that efficiency often increases with large scale operations, especially if the task is repetitive (Beckman & Rosenfield, 2014). This topic will be discussed further in the discussion chapter.

When building the blocks or the module foundation, facilities that are appropriate for the job needs to be acquired. Once complete, the structures are going to be heavy and difficult to move, which means that the yard needs equipment to handle them. Cranes appropriate for handling the weight of the blocks, skids, platforms, and reinforced floor are all needed to be in place before the construction takes place. In addition, if the yard is supposed to handle different modules and on ships of varying sizes, the equipment and facilities need to be dimensioned to handle the larger structures and could serve as a bottleneck in the production. This means that even if the yard usually handles medium sized ships with blocks dimensioned thereafter, if they are to serve larger vessels on occasion the facilities need to be able to handle that. This leaves the yard and the builder with a strategic choice as to how much they want to invest in facilities by allowing for a wider product portfolio. There is a significant difference in making blocks that consist of many thousand tons of steel, both in the earlier stages of the production, but also in terms of building the blocks and handling them. Larger cranes, a larger facility, more difficult logistics, and larger indoor facilities will be needed to accommodate bigger blocks. Labour hours will also vary with size, causing a fluctuation in demand for labour.

In terms of blasting and painting, the size of the blocks (or module(s)) has a proportional impact on the labour hours required. The challenge for blasting and painting has more to do with the increased size of the units as heavier items are more difficult to handle. The yard needs to make sure that jigs are bought and set up so that the blocks are accessible for painters, but also for welders. It is important that the appropriate jigs are used and set up correctly, else the yard risks poor labour quality both in terms of work delivered (for example if the positioning makes it difficult or impossible to do proper welding), and in terms of health, environment, safety concerns.

Though modules are smaller than the size of the entire vessel, they can to a certain degree be built in the same way. A challenge is that in the first phases up to block construction the cost drivers are the same as for traditional shipbuilding. It requires almost all the same facilities, and the work is very similar. However, what module construction allows for is a production downscale and specialization. As it is smaller than the entire ship itself, it allows for lower volumes in the production, which can both serve to decrease efficiency, and increase efficiency depending on production arrangement. A reduction could mean less investment costs because the facilities needed are smaller, it could allow for more full-time hire, which could lead to a higher experience gain. For Norwegian yards this could mean that full-time hired employees which are a lot cheaper than part-time hire could be specialized in module construction. Norwegian workers are renown to be costly, but they do also have a relatively higher productivity (Semini et al, 2016).

The yard could also specialize in particular modules and develop an expertise within a certain area, or even in cooperation with a yard that produces hulls.

7.3.4 Stage 6 – Block outfitting

A common practise in shipbuilding is to perform some outfitting work while the ship still consists of open blocks (Hagen & Erikstad; Semini et al, 2018). As stated in the literature review this allows for *early outfitting* of components and equipment that will present a challenge to install later, or that are just very suitable for early installation. The same can be done for a complex module, but the utility gained from the process might be different. An example of this would be if the module were to contain the engine room or the cargo room, which are for the most part open spaces filled with equipment. Instead of outfitting blocks before assembling the module, the module could simply be assembled as an open structure with no roof (or sealing), and the outfitting process would still be simple. For the yard, it is important to consider the possible gains from early outfitting, or more importantly, the losses gained by not doing early outfitting. There might be certain modules that are more prone to the use of early outfitting because of decreased accessibility in the later stages.

Early outfitting is used to install equipment in places that become difficult to access at a later stage in the building, or to reduce lead time (Hagen & Erikstad, 2014). Depending on the module type, this might or might not be a challenge, and it would also depend on the size and how the module is supposed to fit into the rest of the hull. However, even for module construction, if the yard has a limited number of workers, there could be workers performing early outfitting while other crew builds the other blocks which would also reduce total lead time.

The point is that whether block outfitting will be performed (…to a large degree as some outfitting for sure will be done such as installing small pipes) is a matter of many different factors. Size, which module, how many blocks, facilities, outfitting priorities, lead time, flexibility, are all factors that will have an impact on whether or not block outfitting will be used. It is even possible to install technical equipment such as engines before assembling the module, but it carries with it its own form of challenges.

7.3.5 Stage 7 – Module assembly

In traditional shipbuilding, this stage is called *hull assembly* (Hagen & Erikstad, 2014). In a building process for modules, it makes sense to rename it to module assembly. For a builder constructing modules, assembly of the module can either be done directly from parts which would take place at stage 4, or it can be built into blocks in a traditional manner, outfitted, and then assembled into a module. Different rationale for doing this was presented in the last stage. If the module has been constructed using blocks where these blocks have been outfitted in stage 6, these blocks are now to be assembled into a complete module. The module will in this stage serve as a hull for the equipment that goes into the module, as has many similarities to traditional hull construction. As the structure usually will be made up of steel, the way to assemble the module is by using welding. As stated in stage 4, there need to be facilities in place that can handle the weight and size of the module, before, during, and after the assembly. A plan needs to be in place for moving it after construction.

The two next stages in the building process are dock outfitting and quay outfitting. At this stage module construction makes a break with standard shipbuilding, and two new stages are added to complete and install the module into the vessel, that after installation returns to regular stage 8 and 9. Stage 8 for the module has been called *module outfitting* and stage 9 *module installation* which are required stages to finish the module.

7.3.6 Stage 8 – Module outfitting

After the module structure has been assembled, the module can be outfitted with the equipment that is supposed to go into that section of the ship. This will differ significantly depending on what type of module it is. Up to this point, there has been clear similarities between more standard shipbuilding strategies and the use of module construction. This has been because the module consists of the same materials, hence it has required the same work process. The biggest difference has been the scale and specialization of the operation which modifies the requirements and the output. At this stage, the value-added to the module moves from being oriented around labour hours and steelwork to installation of equipment or specialized labour. For example, for a module that is built as the vessel’s engine and cargo room, the value of the machines and equipment that are to be installed will most likely significantly outweigh the value-added from the labour and steelwork. This would be different for a module that consist only of steel such as the bow or an empty superstructure[9].

What type of equipment that is needed for the outfitting really depends on what type of module it is. It would be ideal to have some sort of pulley arrangement so that items can be moved and placed at its location without the use of extensive lifting gear, while cranes will also be needed for installation of heavy equipment such as engines, gearboxes, shafts, pumps, electro-engines, power plants, switchboards, and more. Because some of the equipment is much easier to install with an open structure it could be ideal to postpone making the sealing until everything that requires cranes and pulleys are installed.

If the module is specialized such as the module containing the engine room, this would limit the amount of specialized labour required for the job. The yard would only need to use engine mechanics, plumbers, electricians, and perhaps hydraulic mechanics for the complete installation, while a complete ship outfitting would require carpenters and a wider workforce.

7.3.7 Stage 9 – Module installation

At this stage this is a complete break from standard shipbuilding, as this stage is not required for complete hulls. This is an important stage in module construction, as the installation of the complex module can make or break a production rendering the operation impossible if not executed properly.

For a yard that simply builds modules on request not having specialized in any particular type of module, this represents a problem with many facets. First, there need to be an agreement and a plan that is mutually understood by the yard that builds the rest of the vessel and the module builder so that the two products are compatible. This would involve everything from engineering, to hydrodynamics, architecture, and practical concerns as to how the module is supposed to be interlocked to the vessel. If the yard specializes in particular modules, a plan of execution could be repeated, improved, and perfected which could increase quality and results, as well as reduce costs. However, that would narrow the yards' ability to respond to demand and offer a smaller product portfolio, effectively reducing the ability to reach more customers.

Second, there need to be a plan as to where the module is to be installed. This could be done at a location in Norway or at a foreign yard, both having their advantages and disadvantages.

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[9] A common expression for the upper structure of the ship, normally the bridge.

Obvious demands would that the yard has the equipment to facilitate the installation such as a drydock, though modules could in theory also be installed at a floating dock or at the quayside.

7.3.8 Similarities and differences between modules and regular shipbuilding

The adaptation from the building stages used in traditional shipbuilding to module construction shows that though the production outcome is different, the building process itself shares many similarities. As a part of the ship, the module will share many of the same components and manufacturing characteristics related to construction and labour structure. Perhaps most importantly, the module construction is also contingent on the same input factors as regular ships, but in different proportions. As steel and labour make up a large proportion of both the manufacturing processes, ways to handle costs to make the project profitable must also be prioritized in module construction. A difference might be the increased demands on quality, lead times, and flexibility as the separation of the construction processes from the rest of the hull increases the demand for technological solutions, and it can be expected that a higher level of quality will be required from the module than the rest of the hull. For hulls, a lower quality can be accepted as long as the price is significantly lower, especially as the low-cost yards are now able to offer this type of agreement (Haugland et al, 2021; Semini et al, 2018).

Depending on the module type, most modules will need to be built as an independent construction with its own miniature hull. This hull that is meant to contain the equipment, and that is to be matched with the vessel hull interface, must be manufactured as a small version of a regular ship, thus carrying with it many of the same requirements in terms of facilities, tools, and equipment. This is the case for the prefabrication, part production, block or module construction, and module assembly stages, though with some notable differences. As the modules are smaller, they are likely to have a completely different proportion of steel-to-technology ratio. They would also require smaller facilities, less workspace, and a smaller workforce, but this would depend on the shipyards’ organization of the work and on the size of the complete construction. Though, relative to building the complete vessel, the module would be smaller, but this also means that vessels that would never be built at a Norwegian yard could still have modules built there. However, this also presents a challenge in terms of module construction, as the same building stages would require the same set of tools and equipment, while the lower scale would make it more difficult to achieve any kind of economies of scale. The investments done in terms of facilities, tools, equipment, and workforce would also put an upper limit on the production capacity and capability of the shipyard meaning that the yard would have to make strategic decisions prior to the investments regarding which module types would fall into their manufacturing strategy. Such decisions could be regarding facilities, infrastructure, having more than one production line, logistics, the extent of operations within the shipyard, to mention some.

There are several challenges for a shipyard that is going to produce only modules, which could be referred to as a *module yard.* As described, shipyard size, production capacity, production capability, tools, equipment, and facilities are all relevant as to the yards ability to handle a variation of constructions. If the shipyard solely builds modules, additional work must also be done to make sure that the interface between the hull and the module is a match, and that all other factors make a system integration possible. As the production process for a ship and a module can have many similarities, many of the same challenges also follow such as high costs for high-cost countries in production of the steel constructions and labour-intensive work, and cooperation with foreign actors to arrange for system integration.

8 Module strategy propositions

In the following chapter, each of the three propositions will be presented. Prior to the presentation of the proposed strategies, some important manufacturing areas will be presented. After the description of the manufacturing areas, general description of each module strategy proposition and the strategies will briefly be discussed and scored according to the competitive priorities by Beckman & Rosenfield (2014). Scores are based on a qualitative assessment of how well the strategies meet the competitive priorities. The range is 1-5 where 5 indicates the highest performance, while 1 indicates the lowest performance, relative to the others. The scores are there to give an indication of the module strategies' general strengths and weaknesses, and to give a basic ground for comparison and discussion.

In Semini et al (2018), different manufacturing areas were highlighted as being important tools to differentiate between offshoring solutions for complete vessel construction. Based on the characteristics in this study and the paper by Semini et al (2018), important manufacturing areas that separates the three strategic approaches can also be used for complex module construction.

The three different strategies will differ on relevant manufacturing areas, in particular the following:

- ✓ Degree of steelwork performed at a foreign yard,
- ✓ Degree of outfitting work performed abroad
- ✓ Degree of details in drawings, engineering, and plans
- ✓ Requirements in terms of production facilities, tools, equipment, and infrastructure
- ✓ Value creation, and value creation ratios
- ✓ Installation of the module

A short description of the manufacturing areas will be given before each of these areas are revisited in the strategic propositions. After the strategic propositions have been presented, the different strategies relation to the competitive priorities will be discussed.

Degree of steelwork performed at a foreign yard

As stated earlier, one of the main reasons shipyards look for alternative strategic solutions, that being in terms of sourcing, standardization, different manufacturing methods, or a change in strategic approach is tied to cost reduction. This is particularly true for Norwegian shipyards, as the high cost level makes domestic production in large scale challenging and will drive the total price of the product up to a level that makes it difficult to win orders (Haugland et al, 2021; Semini et al, 2018). When producing singular modules at a Norwegian yard for use in foreign constructed hulls, there is also a need for the module builder to consider how much of the work that should be performed abroad. The work could be performed sequentially where the steel structure is construed abroad before being outfitted in Norway, in parallel if the work process can be separated, or completely offshored. Domestic steelwork would require a higher degree of investments in facilities, tools, equipment, and infrastructure in addition to the costs that accompany these factors over time.

Degree of outfitting work performed abroad

Outfitting on a ship has varying degrees of complexity from very simple outfitting tasks to complex and technically challenging ones (Hagen & Erikstad, 2014; Semini et al, 2018). Usually, the more of the construction that is performed abroad, the more of the outfitting work is also carried out at the foreign site. This makes sense as the more complete the steel structure is upon delivery, the more difficult and costly it would be to reopen the structure to do installations. In addition, though it might be more cost effective to offshore simple outfitting, doing more complex outfitting at the foreign shipyard opens for intellectual transfer between the Norwegian shipyard and the foreign actor.

An important point for a module yard that solely manufactures modules is the different ratios between steelwork, outfitting, and technology. These might differ significantly from full ship construction.

The last point is that quality, flexibility, or other demands might make offshoring difficult, because factors such as certification, loans, requirements, and class regulations might demand that a particular set of the jobs is to be performed in Norway.

Degree of details in drawings, engineering, and plans

A challenge that increases with increased offshoring (or outsourcing) is both the intellectual and geographical distance between the parties that are involved in the construction. Offshoring requires more detailed plans, drawings, and instructions as they are less involved in the planning stages and might not have the same work structure and understanding as the builder that designed the project. This means that an increased focus on details and coordination with the external party is required to make sure the product correlates with the order. Different cultural backgrounds, work practices, team orientations, skills, and knowledge can complicate the work process and perhaps even lead to unsatisfactory results. For module construction this can be particularly problematic, because if the interface between the module and the hull is unsatisfactory, the module could be useless, while complete hulls are often built as integrated units.

It is also common that drawings, plans, and engineering are continuously made while the ship is under construction, for example during the outfitting stages. This is a lot more challenging if outfitting stages are offshored.

Requirements in terms of production facilities, tools, equipment, and infrastructure

If the module yard has a fixed strategy for its module production, it would require a certain set of facilities. Different degrees of offshoring would demand different production facilities, tools, equipment, and infrastructure to maintain in-house production. A strategy that is based on a complete in-house production would surely require facilities that could perform steelwork, engineering, planning, module assembly, outfitting, and perhaps even facilitate for installation of the module. The more of the work that is offshored, the less equipment would be needed by the module yard. Ownership and investment into less equipment reduces costs, both tied to investments, but also in terms of variable costs (using machines, materials, labour), and fixed costs (rent, etc), maintenance, and depreciation.

Value creation and value creation ratios

Varying degrees of offshoring creates variations in terms of the value that is being created at the module yard. Offshoring can be considered a procurement cost as long as it is performed by a third party, thus most of the value is not created by the module yard itself. The different stages of the building process have varying value creation ratios, meaning that what creates the value at the specific stage changes throughout the construction process. In the early stages of the module construction, most of the value added is tied to steelwork and labour hours, while at the outfitting stages, a lot of the value-added stems from the installation of the equipment. A challenge for the module yard is to assess the prospected value ratios of each module construction to consider if and where this could be built to leave the module yard with eventual profits.

Installation of the module

An important facet of the construction that is likely to vary with different offshoring solutions is the installation of the module. For domestic production there is a big possibility that the Norwegian module yard would like to facilitate for the installation of the module(s) themselves. This is particularly true if the module is highly complex and contains vulnerable technology or makes up a large portion of the ships total value. This could make it risky to transport the module, thus an installation at the Norwegian yard would be a safer solution. A solution with a higher degree of offshoring or lower module complexity could make it more eligible for installation abroad, which would also reduce the facilities required at the module yard. Another option would be *vertical integration* where the module yard could buy a foreign shipyard or workshop to strategically acquire over time services in a low-cost country. This could result in better integration, coordination, less risk for loss of intellectual property, cost, and delivery control.

Module installation will be addressed in each of the three strategy propositions but will also be presented in its own subchapter as it is crucial for the viability of a module-based strategy.

8.1 Strategic alternative I – Domestic module construction

The first strategic proposition is proposed as building the module from scratch at a Norwegian yard. To do this, the module would have to follow the steps proposed in the “building the module” section and would bear a close resemblance to building a complete vessel in terms of production. A complete in-house production of the module would imply that none of the stages are offshored, but there could still be space for other supply chain solutions than simply building everything at a chosen Norwegian yard. Such a shipyard could be called a *module yard.*

A complete in-house production of the module would imply that the module yard needs to perform all the steelwork, outfitting, and assembly at the yard. Because of the cost level in Norway, this would increase the costs of the production, because the cost of labour is comparatively higher than in low-cost countries such as Romania, Turkey, and Spain. In addition, facilities and infrastructure would need to be bought and maintained, both incurring additional fixed and variable costs for the module yard. Thought elaborated in *stages in shipbuilding,* the yard would need cranes, trucks, heavy-duty machinery, welding equipment and jigs to mention some. Steelwork and labour make up a large part of the value-added in the initial stages of the building process. The framework and steel structure of the module would still consist of parts made from raw materials and would need to be manufactured in-house.

An in-house production would give the module yard complete control of the manufacturing process including engineering, planning, manufacturing schedule, knowledge retainment, quality control, and an increased production flexibility. As engineering is often done simultaneously with production, an in-house production would give the engineering detail more time to handle engineering and planning, so that the process does not have to be rushed (Semini et al, 2018). In-house production in Norway could also make sure that sufficient quality is maintained at every step of the building process, and a near proximity between engineering and production departments increases the chance of delays, problems, and confusion being handled quickly. This could also be the case for cooperation between the different teams working on the module, as domestic production reduces the involvement of third-party actors with varying cultural work ethics and procedures

Building the entire structure in-house allows for a high degree of flexibility in the building process, for example in relation to outfitting. Depending on the module, there are situations where early outfitting would be very beneficial such as for example in a propulsion module where oil and fuel tanks are often placed at the deck under the engines. The module yard could also choose to carry out several operations in parallel which could save time, something that could be more difficult to manage if done in cooperation with a third-party.

In the context of this study, modules are not built as regular ship hulls in the sense that they require to be built in a drydock or put at the quayside. This means that a module yard does not necessarily have to be placed by the sea. Depending on the module structure, a module yard could be viewed as a large workshop rather than a shipyard with near-sea facilities. If the module is to be installed at the module yard, it would however need these facilities as the hull needs to be placed in a position where installation can take place. Depending on the type of module, the module yard might need different facilities to perform the installation, for example a drydock if the module needs to be skidded in, or large cranes if the module is to be installed on the upper deck. If the complete construction is done at the module yard it could be expected that the customer would like the vessel to be finished there, because transportation of the module could risk damaging it. It could therefore also be expected that being a module yard, a customer would demand that the yard facilitates for the installation as *module experts.*

Several Norwegian shipyards use hired labour as a part of their labour structure (Haugland et al, 2021). Hired labour allows shipyards to hire services of specific types of labour at request, meaning that it does not need to pay for those services if there is little or no work to offer. This allows for a division of labour at the yard for example so that it can hire steelworkers for the initial stages of the production, and then machinists, plumbers, electricians, and other required specialists at the outfitting stages. Both part-time and full-time hire incur potentially high costs for the module yard, but decisions regarding which organizational structure to use can make a difference on incurred costs, especially over time. Though this topic is also prominent in the other offshoring solutions, it is most relevant for the in-house strategy, as it performs most of the labour in-house. *The topic of part-time and fulltime hire will be revisited in the discussion chapter of the study.*

8.1.1 Costs

A module yard with little or no offshoring is likely to have the highest cost level of the three solutions. Big cost drivers in shipbuilding are steelwork and labour hours (Semini et al, 2018; Hagen & Erikstad, 2014; Haugland et al, 2021), and the highest level of domestically performed labour is using a complete in-house strategy. This would be regardless of module type, as it is the high cost-level in Norway that increases the total costs of the production. Type of module would cause variations in the amount of steelwork as construction of a cargo module, or a bow would contain relatively much more steel-to-technology than for example a propulsion module.

Beside steelwork and labour, investments, and upkeep of facilities necessary to provide a complete in-house production would be cost drivers as well. Investments in necessary tools, equipment, facilities, infrastructure, as well as maintenance and other variable costs would rise the ongoing costs. If the module yard needs to facilitate for installation of the module as well, this also needs to be taken into consideration, as additional costs would be incurred.

Because of improved coordination, more used of fixed teams, and higher operational flexibility, less costs can be expected to be spent on delays, corrections of mistakes, and rebuilds.

Depending on the demand and size of the modules, it is possible that the module yard could gain from economies of scale or from the learning effect in shipbuilding (Erichsen, 1994). This could reduce operational costs over time, but it is unlikely that costs could end up being lower than using offshoring solutions. The size of the modules and the amount of raw materials procured will most likely also have an impact of the average prices on raw materials, as agreements or discounts could be reached for larger volumes of materials.

Finally, the organizational structure of the organization will also have an impact on the cost structure, as part-time hire is on average more expensive than full-time hire as described earlier in the study, but where there is a higher likelihood of paying for idle time in the with full-time hire.

Because of the relatively high costs that are expected when building modules in Norway, especially structures that requires a lot of steelwork and labour, the strategy is given a low score.

Score: 1

8.1.2 Quality

A complete in-house production carries with it some major advantages in terms of quality management and control. First, in-house production allows the yard to plan and keep a close eye on each stage of the building process. Continuous monitoring of the work that happens on the floor, but also in the other departments offers tighter quality control in each work process. Better control of the labour and work operations themselves can also help assure that everything is made in a certain way or at a given standard, which increases safety and quality insurance (Semini et al, 2018). In-house production also allows for outfitting to be performed when the yard finds it suitable. Early outfitting is not necessarily as crucial for modules as it is for complete vessels but depending on the size and type of module it is a valuable option to have.

A complete in-house solution probably offers the best results in terms of quality through increased monitoring, closer proximity between engineering, planning, and the shop floor, and the ability to choose and maintain a certain standard through regular inspections. An in-house production at a Norwegian yard would also probably utilize a Norwegian standard in terms of quality and work methods which relative to many other European actors implies a high standard.

Score: 5

8.1.3 Delivery dependability

An in-house production at the module yard makes the manufacturing process easier to plan, coordinate, but it also makes it easier to make qualified predictions and alterations when needed. For delivery dependability, this makes the module yard able to respond to changes that increases the lead time with changes that mitigates this effect. An example would be the ability to hire extra labour, manage overtime, or to procure materials from other suppliers if it should be necessary. In-house production also makes it simpler to manage and monitor the manufacturing process.

Because the entire module is built at the Norwegian module yard, several work processes such as engineering can be carried out simultaneously to other operations such as outfitting. This serves to save time, and it also allows time for changes and alterations, increasing the likelihood of on-time delivery. Short distances between production and engineering also increases this factor as situations can be handled efficiently with little delay.

Score: 5

8.1.4 Delivery time

For this strategic alternative, the interesting considerations is how the delivery time can be affected by choosing to do this at a domestic yard, and factors that impact throughput time and makes it different from the other strategic propositions are the ones targeted here.

As with quality and delivery dependability, better control of the work process, better communication, more stable teams, more knowledge, and more experience are all factors that can reduce product lead time. In-house production has the advantage that the staff and the production process can be streamlined and reused, limiting the chance of confusion and mistakes. In addition, if there is any chance of gaining advantages from early outfitting this could be used while the module is in blocks, however it is assumed that for this to make any sense the modules would need to be big or very complex.

What is clear is that in-house production allows for a much better control of the delivery time by adjusting the production process and input factors. It can also be assumed that if the modules are very complex or requires a high degree of flexibility in their production, this is better suited for integrated yards as less actors are involved in the coordination. In-house production also allows for the use of predefined work squads and teams who are more efficient when working together, and where the yard knows up front what it can expect from the specific team.

In conclusion, the further the operation is skewed towards in-house production, the more control and better predictability over lead time can be expected.

Score: 5

8.1.5 Flexibility

Because the module yard has a very large degree of control within the module manufacturing process, unexpected situations can be handled as the yard sees it fit. The module yard can change specifications, reschedule, use a different personnel policy, and even use different production methods and solutions if they see it fit. Changes made to the construction can also be implemented, as the expected distance between engineering, planning, and the shop floor is shorter both geographically and intellectually. The ability to use or experiment with innovative solutions is also simpler when there is no or limited use of offshoring solutions, as these solutions does not require coordination across organizations. With fixed teams and domestic production, it is easier to make probable expectations as to how the organization will respond to changes in the production process, which also makes increased levels of flexibility less of a threat. Communication can be expected to function well, and due to the decreased power-distance[10] that can be expected in Norwegian manufacturing a larger degree of involvement from the entire staff can be expected, increasing degree of innovation and efficiency. Norwegian labour is recognized as being both skilled and productive, which can also serve as a threat mitigation factor in terms of flexibility.

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[10] A reference to the degree of hierarchal structure within an organization. Organizations with a high power-distance are hierarchical, which often leads to less intellectual involvement from staff than in egalitarian systems (Meyer, 2014).

Though some of the flexibility in the production is tied to the strategy and the yard, the manufacturing strategy and the business plan also determines the variation in the production process. Flexibility in terms of this strategy is related to how the execution of the strategy is carried out. In-house production can be expected to allow for a large degree of flexibility to handle unforeseen events, and the make changes to the overall production process, but within the scope of the manufacturing strategy. The grade is slightly reduced, as a Norwegian module yard cannot be expected to be large enough to use a high degree of vertical integration. Vertical integration could stabilize actors in the supply chain both upstream and downstream, increasing the flexibility of the module yard more. Without vertical integration the module yard depends on agreements with external suppliers such as raw material suppliers. Though the module yard has the freedom to negotiate and change suppliers, they are not in control of the raw materials they would need within the production.

Score: 4

8.1.6 Order qualifiers and order winners in module strategy I

Module strategy I can be expected to have a high cost level. For Norwegian shipyards this has become one of the reasons as to why it is difficult to win orders, as relatively comparable products can be bought at a lower cost in a low-cost country (Semini et al, 2018; Hagen & Erikstad, 2014; Haugland et al, 2021). For complex modules the costs can be skewed so that the price the customer pays to a higher degree is because of the value-added through outfitting of technological and complex equipment, an area where it is likely that some customers would be willing to pay more. Strategy I could allow a customer to invest in cheap hull construction, while buying modules where there is a higher need for quality and flexibility such as the propulsion or bridge unit.

It can be expected that the high score in every competitive dimension except for costs will attract customers that have a high demand for quality and flexibility in their production, perhaps especially if they are requesting innovative solutions. A module yard would be in a good position to explore innovative solutions as there is a complete degree of manufacturing control.

8.1.7 Summary of module strategy I

- Is based on complete in-house production in Norway, where the module yard manufactures complete modules for ship projects. The shipyard specializes in module construction of complex modules that is individually constructed and added to a hull through an interface and is built to serve as a subsystem of the ship.

- Has the highest degree of domestic steelwork and labour and is most likely to have the highest cost level.
- Performs all engineering, planning, and drawings in-house, possibly reducing lead times as this can be done in parallel to other parts of the production.
- Requires facilities, tools, equipment, and infrastructure to match the production mix stated in the business plan and manufacturing strategy. This can be expected to be much more than in the strategies that use more offshoring, which serves as cost drivers.
- Has the highest degree of production flexibility, increasing the likelihood of innovation, better delivery dependability, a better chance of skewing lead times.
- Is most likely expected to offer solutions for module installation, that being at their own facilities or facilitation of installation at locations abroad.
- Value-creation stems from all parts of the building process but depending on the module a higher degree of value-added from technology and outfitting is to be expected.

8.2 Strategic alternative II – Domestic module outfitting

In module strategy II, all the construction stages up until the modules steel structure have been produced and assembled are offshored. After the steel structure of the module has been assembled, the module is transported to the Norwegian module yard, inspected, outfitted, tested if possible[11], and installed or transported to the location where it is to be installed into the hull.

Use of this strategy would imply that almost no steelwork is done in Norway. As modules are generically smaller than vessel hulls and does not need to be assembled at a shipyard, several locations could be considered for the use of such as strategy. Modules could be built at large workshops and in cooperation with steel companies, especially as it is only the steel structure of the module that is to be built in low-cost countries. This increases the bargaining power of the module builder, as it allows the use of many different actors. The construction of steel structures is expected to be relatively simple (Semini et al, 2018), and could also pose small

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[11] This would depend on the type of module. As an example, a propulsion module would have subsystems that could be checked and tested after installation, prior to module installation.

production risks as most of the complexity in the building process comes with outfitting. If produced only as a steel structure with a low degree of outfitting, transportation of the unit should pose little threat of damaging the equipment prior to arrival at the Norwegian module yard.

Offshoring production of the steel structure requires early outfitting to be done abroad. Depending on the type of module, this could result in the module yard having to reopen the structure after arrival in Norway if the outfitting is not done, or for the foreign workshop to take care of the outfitting prior to module assembly. If the structure must be reopened for outfitting, this is costly and time consuming, and it would require the module yard to have tools and equipment for the job. Foreign outfitting, especially performed by a company that is not specialized in ship or module construction would require close coordination and good drawings.

If the steel structure is to be built at a foreign location, good plans, drawings, and coordination need to be in place prior to the construction, to make sure that the product that is requested is what can be delivered. Engineering needs to be carried out ahead of production, and there is a limited possibility of doing this in parallel to the production. Increased focus on error handling must be expected as must tighter coordination, as there can be differences in work culture between the locations.

For module strategy II, less facilities, tools, and equipment will be needed to facilitate for the construction of the module, as the module yard is only expected to carry out inspection, testing, outfitting, and perhaps installation. The trust and relationship between the module yard and the workshop that is being used for the steel structure will have an impact on the equipment needed by the module yard, as if the steel structure must be reopened or corrections must be made, more tools is needed at the module yard for the job. Ideally the module yard would not need equipment that is required to handle anything prior to the outfitting stages, as it increases costs and causes delays. Facilities and equipment for handling the module would still be needed such as cranes, infrastructure, indoor halls, jigs, pulleys, tools, welding equipment, and a quay if installation is expected to take place on site.

In terms of value creation, module strategy II removes some of the value-added at the Norwegian module yard and makes it a procured service from and offshored provider. The value creation in this strategy for the module yard stems from the value-added in the outfitting stages of the production. Depending on the type of module, there can be expected to be a major difference between the steel-to-technology ratio, and if the operation is to be profitable for the module yard, it would be important that the ratio favours the value-added in the outfitting stages. It can be expected that for highly technological module types such as a propulsion module that contains engines, gears, shafts, pumps, generators, and other auxiliary systems, the steelwork would only make up a small portion of the total value of the module. This might be different for other types of modules, and the module yard would need to consider the profitability of different jobs. In this strategy there is a clear split between value-added to the module that is expected to be non-profitable for the Norwegian hull yard, and the outfitting that is expected to be the opposite.

In terms of module installation, as the module is outfitted and finished in Norway, it could be expected that customers would like to have the module installed in Norway as well. Similarly, to module strategy I, it could be expected that even if the module could be transported and installed at a foreign location, the module yard is expected to have the expertise to facilitate for the installation. Though, if the module is to be installed into a hull, it might be easier to just transport the hull, which would require facilities such as a drydock, a floating dock, or a quay depending on the size and placement of the module.

8.2.1 Costs

Though difficult to clearly estimate, it can be expected that significant cost savings can be incurred by the use of offshoring, so that the entire steel structure is built at a foreign workshop or yard. Depending on the complexity of the ship, traditional shipbuilding in Norway has shown that steelwork in some cases make up a large portion of the costs and value of the ship (Hagen & Erikstad, 2014), and the following correlation is expected to follow for module yards, but where the ratios vary significantly depending on the module type. Increased costs in engineering, production planning, and coordination can be expected as the work needs to be done in a shorter time, and in more detail. This is not expected to add significant costs to the project.

Due to the little requirements for steelwork at the Norwegian module yard, cost savings can be made on facilities, equipment, tools, and infrastructure, as heavy-duty machinery for part production and module assembly is no longer required. Though, equipment to handle and move the module and equipment would still be required for the outfitting stages, though the facilities could be optimized for outfitting operations.

Because the steel structure is delivered as a complete unit to the module yard, it might in some cases be necessary to reopen the unit to perform outfitting, either because the Norwegian yard does not want to offshore the job, or because the foreign workshop have insufficient knowledge to perform it. This could increase costs, as work needs to be redone, and if the module yard does have the tools and equipment for the job, this needs to be rented for the specific job.

Score: 4

8.2.2 Quality

Norwegian production is recognized as delivering high quality solutions in shipbuilding production (Haugland et al, 2021). If the steelwork is offshored, a lower grade of quality is to be expected from the structural elements of the module, while a high quality will be assured in the outfitting stages of the operation as this is performed domestically by the module yard. Though, to make sure that the quality is at a certain level, specifications, drawings, and engineering needs to be in tight coordination with the workshop that is being used for the steel structure.

Though it can be expected that the quality would be lower with more extensive use of offshoring, the valuation of quality would make an impact into the total view on quality based on the customer's request. Under given circumstances the customer might consider quality in the steel structure of the module as less relevant than quality in the outfitting work and equipment installation, thus evaluating the module as of no less quality than if performed in-house. Though, as a general conception it can be expected that the quality in the steel construction is lower than for in-house production. In some cases it could be possible that offshoring allows for a higher quality in the steel structure, as the workshops specialize in steel construction, and benefits from increased production of steel.

Score: 4

8.2.3 Delivery dependability

An expectation when using external sourcing solutions is that the builder gives up some of its direct control of the production, thus meaning that supplier disruptions are difficult to change. If there were to be disruptions such as supply chain ripples[12], delays, manufacturing failure, or

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[12] Supply chain ripples are low probability, high effect events that can occur and disrupts supply chains, often propagating through a supply chain affecting everyone in it. An example is the corona-pandemic of 2020 (Dolgui et al, 2018; Ivanov, 2020).

other supplier related problems, these would have a direct impact on the builders' ability to finish its product on time. It is only when the steel structure is delivered at the Norwegian yards own facilities that the builder can invest in measures to shorten the delivery time and get back on schedule, often through intensified use of labour hours and resources at Norwegian prices. Increased difficulties in coordination, eventual corrections that need to be made during the project, and time to rework and repair mistakes would also make it more difficult to make good assessments of lead times and therefore also delivery dependability.

Score: 3

8.2.4 Delivery time

The use of offshoring adds time to the production because of more difficulties tied to engineering, coordination, and planning, but also because of logistical concerns such as module transportation and handling. Rather than building the entire module in one place where very little transportation is required, the module needs to be built, prepared for transportation, moved onboard the ship, disembarked, and moved into the location where it is to be outfitted prior to installation. This is an operation that is both costly, but also takes time away from the module manufacturing itself, and that is heavily contingent on wind and weather that is completely uncontrollable (Semini et al, 2018). In addition, since the module yard can have little direct power over the steel manufacturer, there can be an uncertainty as to the speed and efficiency of the teams that are producing the modules steel structure.

In a case where almost all the steelwork is offshored, a lot of the responsibility to deliver on time and to compress production time lays in the hands of the external suppliers. This also means that if the builder wants to shorten the production times, this needs to be done in cooperation with the steel manufacturer as most of the construction is carried out there. Once the module is back at the Norwegian yard, lead time can be reduced by time-efficient solutions during the outfitting and installation stages, but these are technically demanding stages expected add a lot of value to the module and should thus be prioritized in terms of quality. The score reflects that a big portion of the total project is carried out externally, leaving the builder with little ability to control and compress the lead time.

Score: 3

8.2.5 Flexibility

The use of external suppliers will probably have a depriving effect on production flexibility. The ability to react to changes in orders, modifications in plans or drawings, or innovative solutions are quite difficult to handle across organizational boundaries and even within organizations that are geographically dispersed (Semini et al, 2018; Platts & Song, 2010). The difficulty of implementing changes across organizations makes changes in the part production, block construction, and module assembly difficult to implement, and if implemented involves a significant risk of causing mistakes and delays. This can make builders reluctant to try innovative solutions or to add beneficial changes into the production unless there is a tight organizational connection between the builder and the steel manufacturer. Vertical integration could increase the flexibility, as could long term cooperation or agreements. However, in comparison to a complete in-house production it can be assumed that changes and alterations will happen a lot more slowly and at a greater risk. This is particularly true if the builder is reluctant to share information about the project unless it is necessary for the specific construction, something that could leave the steel manufacturer with different outlooks and ideas for the complete construction. A segregation of the different parts of the project would in that case reduce mutual learning effects and could cause problems, especially if the plans and drawings are unclear as the steel manufacturer builds purely on plans, and not on a complete understanding of the project.

What can be observed is that when physical control of the production is offshored, the flexibility can be assumed to decrease, because the direct control of the production is no longer at the module yard. This does not mean that the shipbuilder [the module yard] has no impact on the manufacturing process, but it means that it is significantly more difficult to implement major changes and to transfer a vision of the exact product the builder had in mind across organizational and cultural boundaries. It is therefore likely that only small and very specific changes would be made, especially if the builder is reluctant to share information about the project. The reliance on a third-party also makes the builder dependent, and at risk of being affected by disruptions or ripples at the third-party such as supply chain or logistical problems. This shows how a separation of the manufacturing process extends the risk of being impacted by supply chain disruptions as there are now two actors that can be affected by its own disruptions, but where both will have an impact for the builder.

Score: 3

8.2.6 Order qualifiers and order winners in module strategy II

In this strategy, the intention is to use an external supplier for all the steelwork, and gain benefits from low-cost steelwork and labour, or at discounted prices. Typically, this would be an ideal strategy for builders who does not have the ability to invest in equipment and facilities for a complete production, or in situations where the cost estimates show that this is not viable. For large module types that consist of a lot of steel and where the demands in terms of quality and flexibility is not at the highest level this would be a suitable option as it would significantly drive the costs down. Even in modules that have a low steel-to-technology ratio it could be a viable solution, as it will still drive the costs down without necessarily sacrificing quality in the most relevant areas. Module strategy III is a more cost-efficient option for module construction and can be well suited if the builder expects to build a lot of modules that are very steel and labour intensive. This must be considered up against requirements in terms of quality, delivery dependability, delivery time, and flexibility as these can also serve as both order qualifiers and order winners.

8.2.7 Summary of module strategy II

- Steelwork is offshored to reduce costs without necessarily diminishing the total quality of the product, as the quality input is expected to stem from the outfitting
- Outfitting is for the most part carried out at the module yard, though some simple outfitting can be done at the foreign workshop
- Offshored steelwork for modules does not necessarily need to be done at a shipyard, but can be done at a large workshop, giving a lot of flexibility and potentially bargaining power to the module yard
- Offshored steelwork reduces quality and flexibility in the production at the initial stages, though steelwork is expected to be simple work that does not require close coordination. Complex tasks such as technical outfitting is done at home where the production flexibility and quality is expected to be higher
- Value-added stems from the outfitting, and can for some module types be expected to make up a large portion of the total value of the module
- Order winning priorities can vary depending on the module type, but for highly technical units it can be expected that relatively low prices combined with high quality and flexibility can win orders.

8.3 Strategic alternative III – Complete module offshoring

The third strategic option is to offshore the entire construction to a foreign workshop or shipyard. For a Norwegian shipbuilder this would imply that planning and engineering is carried out domestically, while almost all the steelwork and outfitting is done abroad.

For this strategy, no steelwork is expected to be done at a Norwegian module yard. This also means that facilities for steelwork such as part production machines, welding tools, or other forms for heavy-duty machinery would not have to be invested in. There are several ways to organize a module yard if this strategy is to be used. The shipbuilder could function solely as the project owner and only have responsibility for planning, coordination, and engineering, basically functioning as a project manager on behalf of the customer. Other variations might be that the shipbuilder has facilities to carry out the final stages of the production where it might do some very limited outfitting, perform inspections and testing, and perhaps facilitate for the installation of the module. The latter solution would require an increased investment in facilities and a staff that could handle the tasks, while the former solution does not require any permanent facilities.

A very limited amount of outfitting would take place at the module yard, meaning that the foreign producer has the responsibility of both the simple and the more complex tasks in the manufacturing process. Excellent drawings, coordination, and planning would be required to make sure that the product is satisfactory, but a great deal of trust would have to be given to the company that built the module. Factors that could improve coordination would be useful, as the Norwegian shipbuilder has very limited capacity to rework or change anything from the production. For regular ship construction it is often common that even if most of the outfitting work is offshored, the Norwegian shipyard retains some of the outfitting responsibility, especially for parts of the ship with a high degree of complexity. In a module strategy this could be more complex, as the facilities necessary for the installation are non-existent, pushing an even higher responsibility for the production over on the foreign workshop.

For module strategy III, almost all the value-added from the production will from the Norwegian shipbuilders' point of view stem from procurements. The value-added will for the most part come from engineering, coordination, planning, supply chain agreements, and added premiums, but could also in part come from testing, and module installation.

For strategies with extensive offshoring, transfer of knowledge and intellectual property can be challenging to handle. Praxis, know-how, engineering, planning, and drawings all need to be shared with the foreign constructor to increase the likelihood of a satisfactory result. This can be adopted by the foreign yard and used in domestic construction, which eventually could lead to competition. As the entire production is offshored, significant insight into the entire intellectual process must be given to the foreign yard. This threat is reduced if much of the work is carried out at a workshop with little or no capacity to replicate the complete building, engineering, or planning process as many of the workshops or shipyards that are used for offshoring operations often do little engineering themselves (Semini et al, 2018).

8.3.1 Costs

With module strategy III, the lowest cost level of the three solutions can be expected. No steelwork, and very limited outfitting is to be done in Norway, which decreases the overall cost level. Very limited investments into equipment, facilities, tools, infrastructure, and such is required for the production, as this is all done at a foreign workshop or yard. Increased costs in terms of engineering, planning, and coordination are expected as the manufacturing process is to a large degree outside of the Norwegian shipbuilders control, increasing the requirement measures to make sure the construction goes along according to plans and specifications.

Score: 5

8.3.2 Quality

If the entire production is offshored, it will be significantly more difficult for the Norwegian shipbuilder to control the building process and make sure that the level of quality is as expected. A lower quality in general must be expected, something that can be considered as satisfactory for parts of the production such as the steelwork, but not in other parts of the production. This presents a challenge as different customers and different types of modules might have varying demands for the production. If the module yard is not equipped to handle outfitting in areas where the foreign yard cannot deliver satisfactory quality, it could lead to orders lost of complaints on the product quality. A tighter cooperation with a foreign workshop for example through vertical integration could aid in reducing these problems and increase quality control and coordination.

Though the quality of the product is expected to decrease with an increasing level of offshoring, it is possible to achieve high-quality results if done in cooperation with a workshop (for example through vertical integration), or because the workshop has experience and skill in specific parts of the job.

As a total assessment, the quality is expected to sink with increased offshoring, because it is more difficult to carry out regular inspections, solve occurring problems quickly, and make sure that the knowledge and skills of the workers are at a sufficiently high level. A lower level of quality can be expected then using the module strategy I and II.

Score: 2

8.3.3 Delivery dependability

With increased levels of offshoring, it makes it more difficult for the Norwegian shipbuilder to control the manufacturing process and to handle occurring problems. The foreign workshop might not have the same culture and regulations in terms of delayed production, something that in the shipbuilding market can have severe consequences (Haugland et al, 2021). A high degree of offshoring also means that drawings, engineering, and plans need to be finished prior to construction, so that the workshop can form their own manufacturing plan to execute the construction. Misunderstandings, confusion, and errors might be harder to identify and correct at an early stage, causing delays in the production process. The less control that is the hands of the Norwegian shipbuilders, the harder it is to predict and handle the outcome.

Score: 2

8.3.4 Delivery time

As with delivery dependability, offshoring the entire production makes it more difficult to handle unforeseen events or problems in the production process, but it also makes it more difficult to compress lead time. The Norwegian shipbuilder has a limited amount of power to manage the foreign workshops work procedures or make changes so that lead time can be reduced, especially if it is altered throughout the construction time and not prior to the building process. Transportation of the module can also cause increased lead time as wind and weather can be unpredictable and add several weeks to the complete project if the module is to be transported to Norway or another location for installation. If the module is to be installed at a foreign location, it could serve as a time reduction, effectively reducing delivery time if it can be done without complications and error.

Score: 2

8.3.5 Flexibility

As with many of the other competitive dimensions, offshoring the production decreases the ability to handle unforeseen events as the workshop or shipyard that builds the module is effectively in control of the production. This implies that most of the flexibility from the viewpoint of the Norwegian shipbuilder must be carried out prior to the construction process, as alterations at the later stages increases the complexity of implementing changes. In complex manufacturing processes it is common that changes in one location or to one system often has a propagating effect on the complete construction, which can cause delays and errors, especially if done cross cultures and geographics.

With offshoring, innovation would also become more difficult, as to convey innovative solutions and plans without being able to effectively monitor the construction process can make it a lot more challenging.

Similar to module strategy II, vertical integration between the Norwegian shipbuilder and the foreign workshop or shipyard could simplify both innovation and manufacturing control. Vertical integration causes a lower degree of flexibility in other facets as the company becomes more prone to local disruptions such as political, cultural, or geographic factors that could influence the production (Semini et al, 2018).

Score: 1

8.3.6 Order qualifiers and order winners in module strategy III

In module strategy III an effort is made to reduce the manufacturing costs as much as possible. This is done through offshoring of the steel and labour-intensive parts of the production in addition to outfitting, reducing the requirements for facilities as well. The trade-off is less control of the production process, with reduced quality control, coordination, and flexibility. Though innovation and high quality production is possible it is less likely to happen as it is increasingly difficult to coordinate, manage, influence, and control as the degree of offshoring increases. Because the costs can be reduced by offshoring steel and labour-intensive parts of the production, a low-cost level can be assumed to be an order winner, as long as the cost reductions does not disqualify the module as an option to regular shipbuilding.

8.3.7 Summary of module strategy III

- The entire production is offshored, though some outfitting can be done at the Norwegian module yard.
- The most solution with the expected lowest cost level of the three module strategies
- Has a low expected degree of quality, delivery dependability, delivery time, and flexibility in comparison to the previous two strategies. Different modules and solutions can mitigate these factors, but the low performance is due to less direct control and influence over the physical manufacturing process.
- The value-added stems from engineering, planning, and coordination, but can also in some cases come from some outfitting, testing, and installation of the module.

Table 1: Module strategies score

Module strategy	**Strategy I**	**Strategy II**	**Strategy III**
Category			
Costs	1	4	5
Quality	5	4	2
Delivery dependability	5	3	2
Delivery time	5	3	2
Flexibility	4	3	1

9 Discussion

The discussion part of this study is separated into two chapters. In the first chapter, the module strategies from the result chapter will be analysed and discussed to find comparisons, differences, and the implications of each strategy on the competitive priorities, in relation to each other. In the second part of the discussion chapter (chapter 10), an analysis and identification of important decision areas relevant for complex module construction is added to create a more holistic approach as a part of the manufacturing strategy.

9.1 Implications for shipbuilder performance

In this chapter, the strategies will be compared and discussed to see how choice of strategy has implications for the Norwegian module builder's performance. There is expected to be both similarities and differences between the module strategies.

It is important to consider the externally given factors for the projects in addition to the direct performance from each strategy. It is likely that there is a place for each strategy, where they all have their strengths and weaknesses according to different scenarios. The shipbuilders' manufacturing strategy, business plan, the current market, domestic factors, and the customer makes a difference for each project. Module portfolio offered by the module builder, and size of the organization will also have an impact on the execution of the strategies. Offshoring strategies is only one specific avenue for strategic differentiation as the module yards are also heavily affected by the way the organization is governed. Strategic decisions as described in the literature review will have a major impact on the outcome of its project, such as decisions made on the strategic, tactical, and operational level.

The following analysis of the competitive priorities will be a qualitative analysis and is based on reasoning from the work done in the results chapter.

9.1.1 Costs

From the result, it seems like there is difference between the cost structure in the use of each strategy. Because of a different division of steelwork, labour, outfitting, and investments, the expected cost for the use of each strategy must be expected to differ significantly. However, even if the work is offshored, it must be considered as project procurements, and it still incurs a cost for the Norwegian module builder. This must be taken into consideration when comparing the different cost profiles. Cost implicates several different factors and will be divided into subsections.

Steelwork

The module strategies range from complete domestic module production to complete offshoring with no steelwork being done in-house. Steelwork often makes up a large part of the total costs in shipbuilding, but it can be more difficult to assess the amount of steelwork that goes into a module. It can be expected that every module requires some sort of bearing steel structure, and that on average the costs tied to steelwork could make up a decent part of the module. This is something that would depend on the customers reason for buying the complex module from a module yard instead of having the same unit built as an integrated part of the vessel at a foreign location, and therefore at a lower price. It is likely that the customer would want to procure a hull where it is cheap but invest money into quality where it is required or where it adds the most value to the total product. This does not mean that the module does not contain a lot of steelwork, but that it is likely to be comparatively less than for a complete vessel in general.

No matter the amount of steelwork, it must be considered as a cost-increasing factor to perform it in-house, as labour costs are significantly higher in Norway than in comparable locations abroad (Haugland et al, 2021; Semini et al, 2018; Hagen & Erikstad, 2014). Though Norwegian labour is comparatively more productive than competitors according to a study by Mellbye et al (2015), it is not enough to offset the cost increase in terms of wages.

Another challenge with steelwork is the procurement of steel. Because of its remote location and the scale of the production it can be expected that steel is relatively more costly for a Norwegian module yard than it is for large workshops or shipyards located in closer proximity to the steel mining industry. Such workshops can often have better infrastructure and logistics for receiving and transporting steel, in addition to equipment, know-how, and agreements that reduces the average cost of steel. This also indicates that if the modules consist of relatively low amounts of steel, the investments that goes into domestic steel manufacturing, transport, logistics, and economies of scale would be low, and would probably serve to increase the unit price of each ton of steel that goes into the product. The prices are also affected by externally given factors such as steel availability and exchange rates.

For module strategy II and III, most of the structural steelwork is offshored. This reduces costs and implications added by doing the steelwork domestically, but this will also make the module yard vulnerable to changes on the supply side such as price increases.

Outfitting

For module strategy I and II, the outfitting is carried out domestically, with some exceptions in module strategy II. Some complex outfitting can also be handled at the Norwegian module yard in strategy III, but it is expected to be at a very low degree. Outfitting carries with it costs in terms of labour and procurement of equipment, where outfitting abroad can be expected to be cheaper. However, where outfitting abroad is cheaper, domestic outfitting is expected to be of a higher quality, easier to coordinate, and has a lower risk of mistakes and rework. While module strategy I takes care of its own outfitting and can do it at the exact appropriate time to mitigate costs and increase quality, the biggest difference is between strategy II and III. In module strategy II, simple early outfitting can be done on the modules steel structure, something that can be beneficial as if it is not done the structure must be reopened for outfitting in Norway incurring additional costs. This might also be the case if the outfitting work done abroad is poor and faulty and can mitigate the cost benefits from the offshoring solution. However, most of the complex outfitting is performed in Norway while using module strategy II which increases costs in terms of labour hours, but could reduce costs in terms of mistakes, delays, and rework. Offshoring strategy III is the cheapest solution as all of the outfitting with minor exceptions are carried out at a foreign yard.

Facilities

Because the degree of outfitting and steelwork varies with the module strategies, there are different requirements in terms of facilities, equipment, tools, and infrastructure for each strategy. While module strategy I requires all the facilities needed for a complete construction of the module following all the construction steps, strategy II requires less or no facilities for handling steelwork. This would reduce the costs tied to owning or renting equipment, but also for operators who can handle the heavy-duty machinery required for making parts and assembling the module. Module strategy III being the opposite of module strategy I would require little or no facilities for production at all, perhaps except for testing and module installation. Depending on the size, the product mix, and the volume of the production, costs tied to investments, maintenance, direct, and variable costs could be substantial, an extra cost incurred if a complete module yard is to be used.

Depending on the solution for installation of the module, it is unclear how each strategy affects the facilities required for this part of the process. As transportation of the finished module from a module yard utilizing strategy I could incur risk of damaging the equipment it is likely that a customer would like the module to be installed in Norway, especially if the module is of a substantial size. Smaller modules are more likely to be transferred in a safe manner and could be shipped and delivered anywhere. The same is expected for the use of module strategy II, but for module strategy III there might be good reasons to install the equipment at a foreign location as the module is close to being finished while already at a foreign site. The latter would reduce the requirements for investments into facilities near the sea so that the module could be installed, but in most cases especially for module strategy I and II, facilities near the sea with access to a drydock, a quay, and perhaps a floating dock would be necessary.

Engineering, planning, and coordination

Though needed for all the strategies, it is expected that with increased levels of offshoring, more time and money need to be put into engineering, planning, and coordination. This is because the foreign workshop or shipyard cannot be expected to perform any engineering themselves, and because more detailed plans and drawings are required to achieve the expected result when using external sourcing. This does not mean that time and money does not go into engineering, planning, and coordination while using module strategy I, but the timetable is skewed, and less detailed plans can be used as Norwegian labour can be expected to have a higher competence, and to be more independent. Simpler drawings and instructions are usually sufficient while working at a Norwegian yard. In module strategy II, because only the steelwork is offshored there might be a higher need for more detailed drawings as for steel production several more options are available for use such as workshops and not only shipyards. A workshop that is used to handle steel production, but not necessarily blocks or modules for ships might need better instructions, than a shipyard building the same construction. The steelwork for the ship is however expected to be simple structures, and the more challenging part of the engineering process is tied to outfitting. For strategy III, though a workshop might still be used it is likely that a small shipyard might be the best solution as it would be easier to facilitate for module installation after the construction has been finished. This also increases the chance that the shipyard has some sort of know-how in terms of shipbuilding, but it must be expected that module strategy III must spend most on engineering, planning, and coordination.

Module strategy I is a solution that uses the most stable work force and could reuse the same staff over several projects. This would train the organization to function better as a unit, and simplifies coordination, especially over time. This reduces the need for active coordination, as the organizational work structure remains the same over time, even for variations in the project. For increased levels of offshoring, this becomes more difficult as several actors are involved in the project both at simultaneous and different times. While the manufacturing process at the module yard using strategy I could be arranged as continuous with teams that know each other, the module yard using strategy II has a split operation where the teams at the Norwegian yard need to take over work that has been performed by someone else. Inspections, reopening of the steel structure for outfitting, and getting to know the structure takes time and requires more coordination than a continuous building process. When starting the outfitting process, it is also common that for complex equipment, personnel and supervisors from the suppliers will be involved in the installation process, which requires additional extensive integration and coordination, which will incur extra costs. Depending on the arrangement between the Norwegian shipbuilder and the yard that builds the module, extensive coordination between the yard and the different suppliers will also be required to facilitate for a correct installation, which would also demand more resources in the case of more offshoring.

Because modules are constructed as individual subsystems, there is a difference between the demand for engineering and coordination from complete vessel production. The modules are smaller and often restricted to fewer systems, which could reduce the overall complexity, the scale of the job, and therefore also the costs. However, if compared at the same volume (meaning the construction of several modules), each module is expected to represent a relatively higher complexity, because of relatively more outfitting to steelwork.

9.1.2 Quality

In the strategies, the quality is expected to be reduced the higher the use of offshoring. The general conception is that foreign workshops or shipyards have a lower task-specific competence, different work cultures, and perhaps less experience with ship construction, especially if the steel structure is built at a workshop and not a shipyard. The reduced quality expectation is not always directly tied to a definite result, but an expectation that an equal quality level as for complete Norwegian production is not expected from a low-cost country. Module strategy I has the highest level of quality as the entire manufacturing process remains within control of the module yard making inspections, testing, and work procedures a lot easier to control. Short distances between engineering and the work floor also makes it a lot easier to correct and handle mistakes, receive elaborations or explanations where it is necessary, as well as increased time to perform engineering and make drawings as it can be done in parallel to some of the physical construction.

When offshoring is used, the control over quality by the module yard is reduced, and extensive measures must be made to make sure that the quality remains at a minimum level. This can be done by sending supervisors, but it is not always easy to identify or to make a foreign supplier do work according to corrections made by the customer (in this case the module yard). Module strategy II only offshores the steelwork and is therefore less prone to the downsides of the reduced quality. Though structural mistakes can be costly to fix, the steel structure for a module can be expected to be rather uncomplex and should be possible to offshore without risking a substantial reduction in overall module quality. If extensive outfitting is offshored such as with module strategy III, a reduction in overall quality is to be expected. Difference in material quality, type of cables, pipes, damage on equipment are all factors that can reduce the quality of the total product, and that is more difficult to control if the work is offshored. Since the modules are expected to have a higher relative complexity it would be challenging for the Norwegian shipbuilder to coordinate all of the outfitting that is going into the module, and it might need to handle this coordination through the company that built the module. If the module is highly technical, for example a propulsion module, the increased number of actors and the lack of production control makes the final result less reliable, which could hamper the quality either actual or perceived. For this reason, there are companies who are willing to spend additional money on vessels being built at Norwegian shipyards (Trøen, 2022), and this could be expected to be particularly true if the production can be split between a hull and complex modules where ensured quality is an order winner.

9.1.3 Delivery dependability

Delivery dependability is important for shipbuilders, and as the complex module is a part of the total ship it can be expected to follow a lot of the same rules and regulations. This means that late projects receive harsh sanctions or fines that can eat up the profit, and even render the project non-profitable (Haugland et al, 2021; Hagen & Erikstad, 2014). From the module strategies it seems like the more of the production that is offshored, the less control the Norwegian shipbuilder can control the production times and the external effects affecting the production times. This makes the delivery dependability lower, as there are more unknown factors in the production where the Norwegian yard has no control or ability to monitor the process. The use of an offshoring partner does not mean that delivery times cannot be met, but it reduces the direct control of events that alters the delivery time and where the Norwegian shipbuilder might not have any power to change the situation. A topic that has been repeated through the strategies is the module yards' ability to handle unforeseen events with corresponding measures if the production is kept in-house. Mistakes, delays, or repair work can be handled by hiring more labour or by separating the work process and handle more than one process in parallel. Increased quality control and better coordination is also easier the less cultural boundaries that exist between the workforce and reduces the chance of delays and mistakes. This indicates that module strategy I has a clear advantage over both module strategy II and III, as the control to make changes and handle upcoming situations lays completely with the module yard.

For module construction, as it is expected to be limited steelwork, strategy II is not as affected in terms of delivery dependability as module strategy III, and there is a clear difference between them. Strategy II offshores relatively simple work and can if needed be compensated by increased measures during the outfitting part of the production. Solutions could be to add shifts or increase number of workers during the outfitting part of the production to compensate for slow production or late arrival of the steel structure. Depending on the type of module, most of the work is expected to be in the outfitting phase of the production which gives most space to correct problems in terms of time. However, for module strategy III, the entire production is carried out by foreign actors and a higher uncertainty towards delivery dependability must be expected in the production. To the delivery can also have negative effects on the quality of the production as if pressured, the foreign yard might be willing to cut corners to handle the delivery schedule. Module strategy III marks a shift in the Norwegian shipbuilders time to handle delivery dependability by compensating for time lost in other areas of the operation, even if some of the outfitting is carried out in Norway. This could cause even bigger problems for the Norwegian shipbuilder as it would add time for transportation which can also be both time consuming and unpredictable.

If some of the module is built at a foreign yard, especially in module strategy II, the module needs to be transported to the Norwegian module yard for outfitting. Transportation adds time to the production process where no work can be done except for engineering and planning. Transportation can be unpredictable as wind and weather can cause delays for embarking, transportation, and dis-embarkment of the module. A poorly facilitated transportation can also cause damage to the module that needs to be repaired before the work can proceed. After arrival a quality control and inspection must be done to make sure that the module is of sufficient quality and that no corrections need to be made. Modules can be of varying sizes, but the most efficient way to transport them is by sea due to cargo capacity. For module strategy II it is only the steel structure that needs to be transported, and there is little risk of damaging early outfitted equipment or critical equipment as it is only added after the arrival in Norway. If the module is to be transported to Norway after completion in module strategy III, is it more of a challenge as the equipment is suspectable for damage. Insecurity about the state of the module upon delivery would significantly impact the delivery dependability. For that reason, it might be better to install the module from the foreign yard to increase the delivery dependability, instead of adding another layer of probable challenges.

9.1.4 Delivery time

As with delivery dependability, increased offshoring reduces the direct control of the manufacturing operation for the Norwegian shipbuilder. This allows the Norwegian shipbuilder a limited control over time management and scheduling, especially as a reaction to events in the production process. With module strategy I, an increased flexibility in the manufacturing process allows the yard to change and utilize different methods to compress lead time, and it might carry out several operations in parallel to save time in other parts of the operation. Variations in labour force and simultaneous work processes can reduce the lead time for the module, which could both increase production efficiency, and serve as an order qualifier or winner. Short distances between the different departments such as engineering and the work floor allows for a better flow of information, as well as the use of established teams that have experience with working together. In addition, if the entire construction is carried out at the Norwegian module yard, it would be easier to overlap production processes as it can be difficult to take over a half-completed job from other party.

Depending on the type of construction, as modules are often smaller it can be more difficult to compress lead times by allowing several work processes at once or by increasing the amount of work being carried out at the same place. In hull construction or on larger vessels, several operations can be carried out at the same time either by working in different zones, or on different blocks prior to assembly. Modules can be built as blocks as well, but this is often unnecessary as the size of the module makes it more efficient to construct it straight into a complete module steel structure. The available space makes it more difficult to work in several zones at once, and as a complete module it is also difficult to split the production into different stages (simultaneously). If this was the case, then there would be less of a difference in lead time between module strategy I and II directly in terms of parallel work, but benefits could be found in reduced overlap time, already established teams, better communication, and the yards' ability to perform engineering and drawings while the construction and outfitting is being done.

Module strategy III is a special case, as when the entire construction is offshored the Norwegian shipbuilder has little impact on the lead times at the foreign yard or workshop. It does not necessarily mean that the lead times must be longer, but it means that decisions made by the Norwegian shipbuilder has a very little impact on the lead times the foreign yard can deliver. An opportunity to solve this could be vertical integration of the module yard and the foreign yard, which would allow for better control of the work process and decision-making at the foreign yard.

Though increased levels of offshoring reduce the control over lead time, the Norwegian shipbuilder can still put pressure on the foreign yard by threatening to change supplier, or other measures that would be of little benefit for the foreign yard. This could make the foreign yard compress lead times, but the danger is always that it reduces the overall quality of the product. This is a problem in regular shipbuilding, but it can be a catastrophe in module construction, as the reason for choosing to buy complex modules from a Norwegian module yard would likely often be tied to high quality requirements for the specific subsystem contained in the module.

9.1.5 Flexibility

Flexibility is the module yard's ability to handle unforeseen events, handle changes from suppliers, customers, within the yard itself, and to innovate. As stated earlier, it is expected that when customers buy complex modules from a module yard it is because it either is a production requirement that those subsystems need to be of a certain quality, or because innovative module specific solutions are needed. To maximize the flexibility in the production would be suitable for module types that require innovative solutions, or where a lot of changes are expected to occur during the production process. Examples could be modules containing equipment that are not yet made and that is not stock goods, or where there is a limited supply for the goods and materials that goes into the product. It could also be that adaptability is required due to the construction parameters of the hull. If a high degree of flexibility is required for the module it is expected that module strategy I would be the best solution. This is because module strategy I gives the module yard the best opportunity to control and manage the entire construction process from start to finish, giving a maximum degree of freedom to make alterations and changes. Short communication distance also makes it easier to convey changes or occurring events that needs to be handled. As the manufacturing process is under the Norwegian module yards complete control, the production schedule could be changed to compress lead times, to increase time for specific parts of the production, or to match arrival of different components. This could be particularly important if the product that is built is a prototype or if other parts that goes into the module are innovative.

Module strategy II still retains a lot of flexibility, especially in the outfitting stage of the production. It would however be difficult to maintain a high degree of flexibility in the steel construction as when it is offshored it is much more difficult to control. It also requires drawings and plans to be ready at the start of the project so that the foreign yard can execute the drawings from a complete picture. Long communication channels and different cultures makes alterations not only difficult, but risky. This only counts for the steel structure and depending on the total value of the steel structure it might have a small impact on the total value of the product, but then it could had been more beneficial to just perform the entire operation at home. While the flexibility in the steel production is significantly diminished, flexibility in outfitting, testing, and installation is mostly completely retained. As this for many modules could be considered the part where most of the value-added happens, it puts module strategy II at a clear middle ground between strategy I and III. Type of module, time spent on steelwork and outfitting, and value-added from the two different processes will determine the recommended degree of flexibility and therefore also strategic match.

Module strategy III must be considered to have a low degree of flexibility, both in terms of the final product and in the manufacturing process. High degrees of offshoring often require premade drawings in plans, which leaves very little space to keep developing these under the manufacturing process. The difficulty of conveying information across work cultures and geographical distances in addition to different hierarchical structures in foreign countries makes it difficult to implement changes or to use innovative solutions. For module strategy III this is the case for steelwork and outfitting, but in some cases also testing and installation. Reaction to changes in customer orders or due to unforeseen events can be expected to be more challenging, expensive, and time consuming to handle.

What seems to be clear is that there are certain uses for all the different strategies, depending on the module yards priorities and strategic choices as they all provide advantages and disadvantages. All the strategies can be considered as a way to adapt to the specific module yards situation, and they need to be combined with other strategic decisions in order to constellate a successful manufacturing strategy.

10 Discussion part 2

In the previous chapter, the competitive priorities framework (Beckman & Rosenfield, 2014) was used to consider each of the proposed module strategies performance in terms of the competitive dimensions. The use of offshoring is important in terms of strategic choices, but it needs to be combined with other strategic decisions that allows a module yard to capitalize on its competitive advantages and avoids or mitigates its competitive disadvantages. For this reason, a discussion regarding important decision areas for module yards will be done in an attempt to identify strategic decisions that will in part form the module yards manufacturing strategy. These decision areas are made based on the literature review, the results of this study, and on qualitative reasoning. After, the decision areas will be discussed together with the module strategies, before being used in an example that illustrates a practical example of how these can be used to construct a complex module within the scope of this study.

10.1.1 Type of module

A recurring theme in presentation and the discussion regarding the module strategies have been that the type of module is highly relevant for the outcome of the chosen offshoring strategy. Modules with a high ratio of steelwork compared to outfitting or technology has more to gain from using offshoring solutions that facilitate for lower steel and labour prices. The opposite correlation is probably also true.

When looking at Norwegian competitive advantages and disadvantages for shipbuilding the major disadvantage has over time been a cost level that has made many of the described building stages unviable competitively (Haugland et al, 2021). However, this does not mean that the products produced and delivered by Norwegian yards are insufficient, but simply that products with common characteristics and a sufficient quality can be procured from competitors at a lower price. In economy this is referred to as *product substitution*[13] where other European shipyards have become near perfect substitutes for many facets of the vessels, but at a lower price. This simply means that the willingness-to-pay for the Norwegian vessels in most cases have decreased, because of a high degree of available substitutes that are still within the minimum requirements. Though this is a description of the situation for Norwegian shipyards that facilitate construction of complete vessels, the cost drivers are also relevant for module construction. What drives costs for vessels must be expected to also drive costs for modules as they are built using many of the same methods and materials, though it can be expected that scale and ratio of steelwork to outfitting are determining factors in the success of module strategies.

For customers to be interested in using a solution where one module yard is tasked with building a specialized complex module while using another shipyard for the rest of the construction, something must make it worth the time and investment from the customer. This means that it would make little sense to construct a vessel using a split construction (two different yards) with all the additional coordination, installation, and risk for production of a module that simply could be built as an integrated part of the vessel. It must be assumed that the reason for using modules from a module yard either is because of better cost efficiency, better technical solutions, or because the module is so specialized that it needs to be built at a very specific location. Better cost-efficiency would typically be modules that are structured so that offshoring would provide lower costs, but the offshoring and installation process in itself would add costs to a hull or vessel that is likely to already be built at a low-cost location. It is therefore reasonable to assume that customers who is interested in using module yards, for example in Norway does this to benefit from Norwegian competitive advantages, while also benefitting from the competitive advantages of the low-cost location that builds the rest of the vessel. This indicates that it is more likely that the Norwegian module yards would be chosen so that the customer could benefit from the two latter suggestions: better technical solutions and innovative highly specialized modules.

For the Norwegian module yard this reasoning indicates that module solutions are unlikely to be chosen because they can be built cheaper in Norway, but because of the competitive advantages offered such as high-quality construction and design, high degree of flexibility,

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[13] Product substitution is a situation where the demand for a product is not only depending on its own price, but on the price of similar products (alternatives). The more similar (substitutable) the products are, the more sensitive it will be in terms of price changes (Riis & Moen, 2017; Hoff & Helbæk, 2018; Mulhearn & Vane, 2012).

high competence, experience with advanced and innovative solutions, and a technologically advanced industrial cluster in near proximity that can provide high-tech solutions.

Because of the technologically advanced options are that available in near proximity of many Norwegian shipyards, typically modules that contains equipment for deck operations, propulsion, thrusters, electrical, automation, or navigation equipment could be built in Norway at reasonable prices and high quality. Because of the wage structure in Norway, engineering is relatively similar in price to many other comparable countries, but tight integration between suppliers and yards, and a highly developed technological base makes technological installations relatively cheaper and safer. Having technical equipment installed in Norway would also benefit from similar culture, and perhaps mutual effects in learning and development, while also significantly reducing costs tied to logistics. Because of similar work cultures, monitoring and coordination should be relatively simple.

It is important to state that there could be variations in the production that could mitigate the costs of a module with a high degree of steelwork and a low degree of technology such as smart technology, robots, and mass production, and that it could be made profitable. However, in a Norwegian context it seems unlikely that there would be requests for module construction that would be better produced using an integrated solution (that it is simply built as a part of the hull), and it would also be unprofitable to the shipyard as it does not benefit from the competitive advantages. Based on this discussion, one criterion for Norwegian module builders can be extracted when making product mix decisions:

- ✓ **Degree of technological and outfitting content.** Technology and outfitting are a part of the Norwegian competitive advantage and should be used to increase the domestic value-added. This could be done all the way from domestic production to planning and engineering. Though steelwork in Norway is done at a competitive disadvantage, there are offshoring solutions that mitigates this, and does not necessarily disqualify the project. However, degree of technology and outfitting should be leading factors for a module type to qualify.

10.1.2 Size, shape, and restrictions

Modules can in theory be built in any size and consist of any part of the vessel. Orders could be received for a bow, the superstructure, an engine room, or the midship. Though the module yard could choose to have a policy where any type of module is up for consideration it would be more beneficial to create a frame and boundaries, or a product portfolio that makes up the product mix. There are several reasons for this. First, the size of the module would depend on the module yards' facilities, so that to allow for production of larger modules, larger facilities would be needed which includes everything from housing, storing space, infrastructure, cranes, jigs, pulleys, etc. It would also need to facilitate for a larger labour organization and find a way to handle the variations in demand, both in module size, and in order numbers. This would be affected even with some degree of offshoring, especially if some of the outfitting is done in Norway. For this reason, strategic choices must be made as to what the size and volume limit of the module unit should be and adjust the facilities in correlation with these choices. The discussion on module strategies showed that in-house production spends the most money of facilities, and this would increase if the module yard were to allow for a large variation in module size where the largest modules varied heavily from the smallest modules in the portfolio. Each module yard would need to make estimations as to what kind of orders they can expect, and where there is most to gain overall from the total number of projects. It is likely that larger projects can have larger real profit margins even if the relative margin is lower, but if these modules are rare and requires investments and ongoing costs that outweighs the profits, then it is if little use.

If the module makes up the midship or one of the lower sections such as the bow, the bulb[14], or the stern it is likely to consist of a lot of steel, complex curvatures, and positions that makes installation and transportation of the hull difficult. Though steelwork is already one of the Norwegian yards disadvantages, complex curvatures make this even more difficult, because these need to be built and welded manually by use of skilled labour. This would add to the steelwork costs, while often also being areas of the vessels that does not have to contain a lot of technological equipment, though this could vary. The use of technological equipment under coming shipbuilding paradigms could be expected to even out costs for steelwork as labour is replaced by robots for some steelwork and welding, but through personal communication, several current and previous actors in the shipbuilding community have commented that it must be expected that complex curvatures still need to be done manually for quite some time[15].

A consideration for the module yard is also the positioning of the modules. The location of the module is highly relevant for the module yard because it determines the method that can be

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[14] A bulb is a part of the lower structure of the vessel placed at the front, right under sea level. Its purpose is to break the waves and make the vessel more aquadynamic.

[15] Conversations with contact no. 2 and 3, primarily through emails.

used for module installation. This could be illustrated by for example the difference between a deck module and a bow module, as a deck module could be finished, lifted by cranes into position on the upper deck while the hull is at the quayside. The bow on the other hand would need to be installed in a drydock, which would be further complicated as the hull cannot be transferred to the module yard without a structure that seals the bow of the vessel. This means that the location and type of module could have an impact on the facilities needed at the module yard, and if the module yard facilitates for installations domestically or only builds and transports modules for installation at foreign yards.

Choices would also have to be made as to the extent of each module. This would again be a choice of product mix, and the module yard would have to make decisions as to how extensive the module systems should be. The module yard would have to discover if each module would have to be made completely as a one-of-a-kind project where the solution would be developed in cooperation with the hull yard, or if a strict portfolio with restrictions would be more beneficial. An example of module restriction decisions would be the extent of a propulsion module. The propulsion module could contain one or more engine rooms, and could contain fuel, oil, pump systems with more, or simply engines, gears, shafts, and thrust bearings where it would simply be connected to already established auxiliary systems.

Based on this discussion, three criteria for module construction can be identified:

- ✓ **Decide a module size limit for the product mix.** The module size is relevant. Increased module size requires larger and more extensive facilities but can generate larger profit margins. The decisionmaker need to consider the market and the likelihood of receiving large project orders. If a low volume of large orders can be expected, then facilities modified for large module construction might generate higher costs than necessary.
- ✓ **Location of the module.** Module location is relevant as the installation of the module is highly dependent on where it is situated. Different locations require different installation solutions, and therefore facilities. In addition, the location of the module often carries with it demands as to for example complex curvatures.
- ✓ **Extent of the module(s).** The module yard needs to decide if it is to make fully integrated subsystems or systems that are to be connected to another system interface. Second, the module yard needs to decide how it is to integrate with the hull builder. The module yard could choose to make fully complete integrated subsystems where the hull builder need to adjust for the module, or an interface standard could be made.

10.1.3 Standardization or high variation

Previously, standardization was considered as a Norwegian competitive disadvantage in the sense that little standardization has traditionally been used in Norwegian shipbuilding. In a meeting with a previous professor with a background from a large Norwegian shipbuilder it was argued that standardization could be a way to gain many strategic advantages because reuse of tested prototypes and know-how gained from working parts of the same structure could result in benefits not only in terms of reduced costs, but also from increased quality and reduced lead times[16]. Several models within the subject of production management such as Fisher (1997) and Hayes & Wheelwright (1984) present increased production volumes that is often linked with standardization and increased variety as different sides of a dichotomy. Thus, to maintain a high focus on flexibility, variability, quality, and innovation which are considered common traits within the Norwegian production is often depicted as incongruent with standardized design solutions. However, the studies often seem to have very strict definitions and convictions about standardization such as the use of a narrow product portfolio, simple product variations, and a low degree of product flexibility. Through conversations there seemed to be an agreement in that this view should be changed, as standardization within shipbuilding is in fact very common, even in one-of-a-kind production such as for standardized parts, bolts, general layout, and basic engineering[17]. Using that perspective standardization and variability are concepts that could be used in a continuum and not simply binary.

For a module yard, the strategy should include an overall concept that says something about the degree of standardization and variation. This has briefly been discussed in terms of module type, size, location, and extent, but decisions such as if the module yard wants to build using a standardized interface or make product series are also important considerations. If the module yard decides to create a general interface that can be used for module types such as propulsion modules, this could make the propulsion modules on the vessels interchangeable, and make modules that are structurally similar, but that can be outfitted with customized equipment. Product series could also be made so that different customers can pick and choose equipment for a certain module, while the module structure remains the same. In the Modnet study by Longva et al (2007) a strategic proposal to standardization using modules is presented, where ships are built using modules that can be configurated by the

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[16] Conversations with contact no. 2.

[17] Conversations with contact no. 2 and 3.

customer. This is an idea where the customer can order a vessel where it can be delivered with different product configurations after the customers specification, making it a *standardized variation* quite similar to how Dell builds and sells computer for its common customer segment (Beckman & Rosenfield, 2014).

Standardization has several advantages. It allows for reduced costs as the products are more similar for each iteration, decreasing production times and number of mistakes, while also allowing for reuse of technical know-how where the product has already been tested. Learning, experience, and several iterations often reduce overall production costs with increasing volumes, which is more difficult to achieve the higher the degree of variety, often caused by changes in the production program (Erichsen, 1994). However, it can be assumed that several customers would like to utilize the fact that Norwegian module yards produce one-of-a-kind production where the module could be tailored exactly to their design. In addition, unless the hull constructor has specific instructions to design the ship so that modules from the Norwegian module yard can be used it can be difficult to create matches between modules and hulls without more flexibility. If the modules must be built in cooperation with the hull yard, it is likely that each solution needs to be adjusted to the specific projects, making standardization more difficult. However, even if the physical construction of the modules is not standardized the work methodology, engineering, planning, manufacturing process, and product breakdown might be standardized to a certain extent. A point remains that the use of standardization can be beneficial, but it might not necessarily be beneficial to do it in an excluding and restrictive manner. It could also be an option to have two separate production lines, one for complete one-of-a-kind modules, and one for standardized models, depending on the production capacity, demand, and facilities. Modules have the advantage of being inherently smaller than vessels, thus more resources could be made available depending on the scale of the manufacturing operation.

The subchapter adds another criterion for module construction strategy:

- ✓ **Decisions regarding type and degree of standardization.** There is much to gain by using some sort of standardization. The module yard needs to consider its customer base, and if a high degree of standardization is viable in the market that they are targeting. If it can be used there are many advantages to standardization though some customer segments might only be interested in a very high degree of variety.

10.1.4 Production volume

Though both size and standardization have been discussed, production volume is also very relevant in terms of strategic decision-making. Increased production volumes have benefits through the effects such as *the learning curve* where an increase in production volume would usually correlate with a decrease in labour hours per unit, or the experience curve where increased production volumes would correlate with a reduction in unit costs (Beckman & Rosenfield, 2014; Erichsen, 1994). In a study by Baade et al (1998) on modular outfitting, observations on the production of engine room modules quite similar to the module definition used in this study reported findings that described these effects with increases in module volumes. This would indicate that increases in production volumes could have beneficial effects for a module yard, but on the other hand, increased production volumes also require an increase in facilities to handle the production. The previous discussion regarding specialization against standardization combined with the risk of overinvestment in facilities, infrastructure, equipment, and tools in case of lower conjectures means that the module yard needs to weigh potential risks against benefits. Strategic choices on operational scale are important, and is followed by a strategic consideration for decision-makers:

- **Decisions in terms of operational scaling and production lines.** Operational scaling would be a natural restriction of the production the module yard is able to carry out. Being a module yard and not a regular shipyard with the capacity of module construction, operational scaling and production lines need to be based on a realistic assumption for demand. A pure module yard is in many ways a niche in the shipbuilding market.

10.1.5 Full time or part time hire

A topic that was briefly addressed in the proposed module strategies were the case of part-time or fulltime hire. In the Menon report (2021) it is stated that many Norwegian shipyards have extensive use of part-time hire. As described earlier in the study, part-time hire offers both benefits and disadvantages for the shipyard, as does fulltime hire.

Part-time hire has the advantage of an increased degree of flexibility as the module yard could decrease employment simply by not hiring labour during times of low demand, or during parts of the manufacturing operation that requires less labour. Part-time hire is a simple way of increasing labour volume if there is a need for more labour hours, this being as a response to unforeseen events, or as a part of the manufacturing plan. This could also be done for specific work groups where the module yard does not want to use full-time hire, for example because that specific job rarely occurs as a part of the module demand. There are several challenges tied to the use of extensive part-time hire. The first is that the price for part-time hire is often significantly higher if standard tariffs are to be followed. There is a higher chance of a variation in workers when using part-time hire, which means that accumulation of competence and knowledge is more sporadic. This means that it would be less likely that part-time labour as a uniform group would benefit from the effects from experience and learning, and that the results provided for the yard would vary more. Part-time labour is very often of different nationalities because there is a general lack of carpenters in Norway, which often leads to an increased demand for coordination, control, and quality assurance. In other words, the use of part-time labour often leads to an increased demand for better drawings, coordination, monitoring, and planning, somewhat similar to the effects observed with the use of offshoring.

Full-time hire has advantages for the module yard especially connected to the accumulation of knowledge, experience, and know-how which increases the likelihood of flexibility, quality assurance, reduced lead times, and better problem-solving capabilities. Full-time hire would lead to fixed teams at the yard that would require less monitoring and coordination, and that would be adept to the Norwegian work culture. In addition, full-time hire is cheaper per labour hour than part-time hire. Challenges with the use of full-time hire are that during times of low production, low demand, or simply work groups becoming idle, they have to be paid as if they were producing at full capacity. During times of low demand, this can be a challenge for the module yard, as it has high costs tied to labour, with no income. Full-time carpenters in Norway have also been scarce for the last years, and there has been a development towards more part-time hire as it is the only available option.

Different types of offshoring solutions could mitigate the importance of employment structure, as some of the work can be offshored to compensate both for costs and for a limited access to employees.

Decisions regarding employment structure is important for the shipyards as it can help increase the quality, flexibility, and reduce cost and lead times if managed well. However, there are risks tied to each type of employment structure, and the costs and benefits needs to be measured according to the module yards specific manufacturing strategy and module building policy. These decisions need to be combined with decisions regarding offshoring strategy to maximize the resources available for the module yard.

The discussion on employment structure leads to the following decision area:

- **Consideration of employment structure.** The employment structure needs to match the chosen module strategy, and can have a large impact on the cost structure at the module yard.

10.1.6 Installation of the module

An important topic that has been mentioned in the result section of the study and that is important for decisionmakers is the installation of the module. As the modules in this study are complex modules that contains both a steel frame and the content to function as a subsystem, the idea is that after production they should be ready for installation into the hull, connected to the corresponding systems, and function.

The module yard is likely to be expected to be experts on the module, which would also include how to install, fasten, connect, and secure the module so that safe operation could be guaranteed. However, it does not mean that the installation needs to be facilitated by the module yard, or at domestic facilities. As with other services, the module could be transported, and personnel could be sent to lead, facilitate, and monitor the installation process of the module.

Installation of the module would depend on the module type, and if the module yard decides that all modules are to be installed at its own facilities, this could either increase the demands to module yard facilities, or it could reduce the number of module types that are to make up the product portfolio. As was described in the sections about module types and locations, there are significant technical differences between installing a module using cranes at the quayside such as a deck module and installing a bow-module that requires a slipway, a drydock, and that causes major complications in transportation of the hull. Reduced facilities would directly reduce the perceived and actual flexibility of the module yard to handle the installation process, but a question that the Norwegian shipbuilder needs to ask is if this would reduce the customer base. It could be assumed that most customers would like to transport the module to the hull yard for installation, especially in case of newbuilds, however in retrofits or module upgrades it might be more likely that the customer would like to carry out the changes at the module yard. If the upgrades or retrofits also were to take place at a hull yard, this would increase the logistical challenges as a third party would need to be involved, instead of a two-part agreement and execution simply between the ship owner and the module yard.

Another option would be to have a policy where installation is carried out at the hull yard in case of newbuilds with support from the module yard, and where the module yard is responsible for transportation, and another strategy for retrofits, upgrades, or special orders. In those cases, the module yard could rent facilities such as drydocks, floating docks, and skids, and add a price premium to the total cost of the module. This could increase the module yards flexibility.

No matter the location of the installation, it would seem ideal for the module yard to have infrastructure and equipment to handle module transportation to and from the yard to a quayside. This would include lifting equipment and transportation that could handle the weight and the complex structures without causing harm and injury to the equipment.

A topic that would also need to be solved is to how the module is to be locked into the hull of the vessel. In the previously mentioned study by Baade et al (1998), the installation of the modules in the early design had problems related to vibrations caused by pumps, propellers, and other types of rotating machinery, but also by general ship movements. The modules need to be constructed so that vibrations and movement of the modules within the hull does not cause damage to either the hull, the module, or the equipment. Though this is primarily an engineering problem and not within the scope of this study it is important to make strategic considerations that allows for installation of a safe and well-functioning design, and that these two criteria are not in conflict.

The discussion on the installation of the module gives the following decision criterion:

- **Decisions must be taken for a general installation policy.** The policy for installation of the module is decisive in terms of which facilities and transportation that is needed at the module yard. It might also have an impact on customers as customers might have different demands as to where the module is to be installed. A difference between newbuilds, retrofits, and upgrades can also be expected, and there might be need for a different strategic alternative for each of these solutions.

10.1.7 Vertical integration

In Semini et al (2018), a high degree of offshoring was often combined with some sort of vertical integration. This allowed better control of the production, reduced costs, the ability to change and improve the production, and from a strategic point of view secured control of a strategic supplier. Vertical integration could also be considered for module construction strategies to secure for example production of the steel structure. Vertical integration would let the module yard assume better control of the production so that the prices can remain stable, Norwegian work methods could be implemented while still situated in a low-cost country, and loss of intellectual property would be less of a problem because it would still be retained within the company. Vertical integration could potentially give the module yard advantages where Norwegian production have competitive disadvantages by gaining from some of the offshoring effects, while retaining Norwegian competitive advantages.

Vertical integration can be costly, and it could reduce manufacturing flexibility if the company located in the low-cost country experiences disturbances to their production. These disturbances could be anything from supply disruptions to unstable political issues. A challenge with vertical integration could be that it might not be as easy to get rid of the supplier if the production for any reason does not function as intended.

Integration is not an option for every module yard as it would demand significant resources and an organization that is able to handle all of the involved businesses. Depending on the module yards size and operational volume (for example number of expected orders) vertical integration could be considered as an alternative.

- **Decisions regarding degree of vertical integration.** For a module yard, vertical integration with a workshop or a foreign shipyard could give several benefits such as securing a strategic supplier, the ability to manage and control the production, and a reduced threat of loss of intellectual property. However, vertical integration locks the module yard to the foreign workshop or shipyard and can be costly. It is therefore a long-term decision that needs to be considered by the module yard, and where potential benefits needs to be considered against potential losses.

10.1.8 Summary of strategic module yard decisions

In the previous part, eight decision areas have been identified for module yards. These decisions can be expected to have an impact on the overall strategic success, and must be balanced against each other, the market situation, and the module yards own business plan. From these decisions areas, manufacturing strategy should be developed, that would determine the scope of the module yards operation. After these decisions have been made, they should be combined with a corresponding offshoring strategy, and matched with the competitive priorities to maximize the utility of the module yard. A summary of the decision areas are:

- Decisions regarding the degree of technological and outfitting content

- Decisions on module size limit for the product mix
- Location of the module on the ship
- Extent of the module
- Decisions regarding module type and degree of standardization
- Decisions on operational scaling and production lines
- Consideration of employment structure
- General module installation policy
- Decisions regarding degree of vertical integration

10.2 Matching strategic module decisions and module offshoring strategies

The first two research objectives of this study were mainly concerned with describing module construction in the context specific to this study, proposing module strategies, discussion of these strategies, and the identification of characteristics that was relevant for strategic decision-making. However, these findings were for the most part concerned with module yards' strategic approach to offshoring, and how these decisions could affect and be affected by choices in terms of competitive priorities. The third research objective were concerned with adding another layer of strategic choices for the module yards and identified decision areas required to make a holistic manufacturing strategy based on Norwegian competitive advantages and disadvantages.

In this part of the study, the discussion following the module strategies and their performance in terms of the competitive priorities will be combined with the identified decision areas to create a more holistic basis for decision making. One of the most important parts of the manufacturing strategy, and an area that has received a lot of focus in this study because it is at the centre of so many other decisions is the production mix. The following subchapter will discuss decisions tied to the module yards' product mix, and show how it affects and is affected by many of the other decision areas, and is a key strategic decision for the yard.

10.2.1 The module yards' product mix

To form a manufacturing strategy, or in this case a basis for a module building policy, the module yard would need to decide on the kind of products it is to produce (the product mix). A part of the competitive advantage for Norwegian shipyards have been emphasized several times throughout the study and can be summarized in the ability to construct products of high quality, with a high degree of flexibility, an ability to find innovative and technologically advanced solutions, flat organizational hierarchies, and an ability to make vessels tailored to suit the customers needs (Haugland et al, 2021; Semini et al, 2018; Hagen & Erikstad, 2014; Semini et al, 2016). These advantages have made Norwegian shipyards well suited for one-of-a-kind production, as long as the customers willingness-to-pay for the products were at a level that covered both costs and paid a profit.

Module product mix is an important decision for the module yard, as it effectively sets a boundary for the type of modules the yard can offer. The module yard could choose to maximize product variety and flexibility by adapting to any customer demand, it could choose certain locations or module types that it produces, or it could go for standardization where it built certain modules only, with the alternative of allowing for configuration.

Complete customer adaptation

In the far end of the dichotomy, the module yard could choose to allow for any type of module construction where only the physical parameters set the limit for the production. Generally, this would be the opposite of a complete module standardization, and it would resemble one-of-a-kind production. Any type of module could be built, and the module yard could take projects that constituted any location in the vessel, as long as it had the facilities for it.

Usually, if the module yard were to focus on complete customer flexibility it would imply that the module yard would have to focus on strategic solutions that maximized the production flexibility. From the module strategy propositions this would often correlate to an offshoring strategy where the least amount of offshoring would be used. This is because for a high degree of customer adaptation, continuous monitoring and adaptation in for example drawings, plans, and engineering would be expected, and it could also be expected that innovative solutions could be a part of the deal. This would favour an offshoring strategy where the module yard was in complete control of the production, and where it would be easier to maintain sharp quality control such as with module strategy I.

There are several challenges connected to the use of a high degree of adaptation. First, at some point, the module yard needs to make decisions as to what kind of equipment and facilities it is to invest in. As shown previously, investments in equipment, facilities, and infrastructure are expensive, and investments that opens for a broad approach to customer orders might waste a lot of resources on facilities that are rarely needed to build the customer orders. On the other hand, if there is a demand for special module types there could be a lot of profit to gain from construction of these projects, especially if the full capacity of the module yard could be utilized.

Second, a lack of standardization is often connected to an increase in costs, and it makes it difficult to benefit from effects such the experience or learning effect[18], and it would also increase lead and production times in comparison to product mixes where more standardization is used.

In terms of employment structure, it is difficult to assess if full-time or part-time hire would be the best solution for the module yard. The simple answer would be that if the yard could operate at full capacity and have little idle time for the workers, it would always be beneficial to use full-time hire, as the experience and know-how gained from such operations could be reused. It would also lead to lower costs, and more stable work teams which could have significant effects on quality, flexibility, and lead times. However, as these projects are likely to require more time in development, planning, and engineering, the likelihood of idle time could be increased, and the production efficiency could be expected to be lower, for example by not allowing more then a few ongoing shop floor operations simultaneously. For this reason, part-time hire could be more beneficial, as workers that are idle could be taken out of the job, reducing costs.

Module series with high degree of customization

A solution for the product mix could be to limit modules to certain types such as propulsion modules, deck modules, and bridge modules. These could also be made into series that were standardized to use the same structural design but could vary in size and shapes. This is often done in engine construction where the engines often have the same basic design, but variations in size and utility separates them into different series. The modules could use the same basic layout and therefore also be based on the same modular architecture, but where the customers' needs would determine which size and exact layout specifications it would have. After the layout has been chosen, the customer could make choices as to what kind of equipment it would like to have in the module, or the module yard could standardize even more by offering a pre-set catalogue of options, making it into a module with different configuration choices.

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[18] A reference to the experience and learning curves respectively.

Product series or a standardized layout that can be varied according to given parameters would make the construction simpler and allow for simpler accumulation of learning and skill. It would also allow the module yard to invest in a specific set of equipment, tools, infrastructure, and facilities as the type of modules offered by the yard would function as a natural limitation to the extent of the operation. Though it would limit the module yards flexibility in terms of being able to handle all kinds of module requests, it would make it easier to specialize in modules that are more likely to receive higher demand, especially if these types are based on interaction with hull builders and market analysis. It would also allow the module yard to establish a focus only on modules that they have a clear plan for installing, and supply chain networks could be set up to allow for simple configurations of the modules using the Norwegian maritime cluster is main suppliers. This would let the module yard benefit from Norwegian competitive advantages, while also probably reducing lead times, and increase quality.

To limit the production to certain module series such as only propulsion modules and deck modules would allow the module yard to benefit from multiple factors. First, standardization would likely reduce the costs, and increase the expertise of the module yard over time. The facilities could be adjusted to perfectly match the certain type of chosen modules where the module would not pay for overcapacity, and it could set up production capacity to match exactly what is needed. It would also be much easier to establish an installation plan since the module series are likely to have similarities even if there are differences between them. Drawings, plans, and engineering for the basic parts of the modules can be reused, saving time and money, but also ensuring that the ideas have been tested out before which could ensure a higher quality.

A typical part of the module(s) that could be standardized is the physical framework, the steel frame. This would allow the module yard to have a standard for a part of the operation where the Norwegian module yard has a competitive disadvantage because of the high labour costs. This means that the steel framework could be standardized, while still allowing for a great amount of customer customization through choices in terms of equipment. The equipment could be either completely tailored, or it could be partly standardized through a catalogue of options, for example supplied by automation or engine producers in the Norwegian maritime cluster. For the customer this would allow for a solution that could be cheaper due to standardized steelwork, while also allowing to benefit from Norwegian engineering ingenuity, innovation, high technology, and high-quality work.

A strategy of partly standardized modules with a limited number of module types (or architectures) and a high degree of flexibility in terms of equipment and outfitting could be combined with the proposed module strategy II. Granted, such as strategy could also be built using module strategy I, the standardization of the steelwork would make it ideal for offshoring, especially because the standardization makes it very likely that the process would be repeated in a very similar fashion. This would allow the workshop that builds the steel structure to also benefit from experience and learning to become more efficient in the construction of the metal frame, which would benefit both parts. Through this, the Norwegian module yard could benefit from a foreign workshop or shipyards ability to buy steel at lower prices, and to use cheaper labour for the construction of the steel frames, which can also be expected to be a rather uncomplicated process that should reduce the probability of mistakes and delays. After the construction, the steel frame would be transported to the Norwegian module yard for outfitting, where the module yard could use its contacts in the maritime cluster to buy highly technological equipment at relatively goods prices, install it, and deliver a product that has benefitted both from reduced labour costs and high quality in technological equipment.

A narrow portfolio if different module types or architectures would make it easier to standardize the production and increase the benefits from the offshoring operation. An alternative would also be for the module yard to vertically integrate with the foreign workshop. In that case the module yard could increase the quality of the steelwork, and it could increase its influence on work processes, lead times, delivery dependability, and increase flexibility. However, the most important reason would probably be to secure a strategic supplier. It is however questionable if this should be necessary as there are many steel workshops in Europe, and because of the rather uncomplex nature of the steelwork it is unlikely that it would yield a lot of benefits.

An extreme version of standardization and configuration is to completely standardize the module types to only a certain exact type of module. An example would be a module yard that only produced propulsion modules, only within a narrow scope of parameters, and where the configuration options are very limited. If this module yard could receive any demand for their products, it would be likely to have an operation that could be quite efficient as the facilities could be perfectly matched to only the type of modules they produced. Agreements and deals with suppliers could be made as the equipment portfolio would be slim, and where the same suppliers would be used repetitively. Outfitting operations could be streamlined, and a high degree of expertise and efficiency could be expected in both the steelwork and outfitting operations, as well as a high degree of expertise in terms of product installations. This could be combined with any of the three proposed module strategies, however it is likely to match strategy II or III the most, as the choices are clearly made to increase production efficiency and probably to reduce costs. This does not mean that the products delivered have to be of low quality or leave little profits, as the equipment outfitted into the module could be of top quality and because of the expertise acquired could have a very high likelihood of being near perfection. However, it leaves very little flexibility in terms of innovation and customer customization where this is sacrificed for manufacturing efficiency and reduced cost levels.

If the module yard had an extreme focus on cost reduction, the latter could be combined with module strategy III, and perhaps even vertical integration. This would allow for a complete construction of the module at a foreign yard, where the Norwegian module yard only facilitates for engineering, planning, and coordination. A high degree of standardization would make this function easier as it is difficult to convey flexibility and innovation across cultures and locations. It would also make sense to produce modules that were uncomplex to install, and that could be transported and installed at a foreign location. For the Norwegian module builder this would allow a minimum number of investments into facilities, and it would reduce the complexity of module installation to the minimum. A major challenge with such a strategy is that the production would be so specialized that if there at some point turned out to be little demand for such modules, it would be hard to adapt into a product that customers would buy. On the other hand, if the Norwegian module builder simply facilitated for construction, but had no facilities of their own, there would not necessarily be that many losses, and it would not be directly tied to any big losses, unless there had been use of long-term agreements or vertical integration.

For increased levels of standardization there are likely to be many benefits from the use of full-time hire. As the projects are standardized, experience and learning gained from working on the projects would resemble the effects gained from the experience and learning curves, this meaning that both costs and labour hours spent on the operation could be reduced. Generally, it would be able to increase production efficiency, and in combination with the effects mentioned previously this could be very beneficial. However, if combined with module strategy II, a large part of the work would be offshored to a foreign workshop. This would mean that the initial stages of the production would have no need for full-time carpenters unless several production lines were in production at the same time. For this reason, it would perhaps be more beneficial and cost saving to only use part-time hired carpenters for the outfitting part of the work process. If the full-time workers could be kept productive on different projects during the time the steel structure were under construction, then full-time hire could be a beneficial solution, but it seems costly and unviable as long as a big part of the production is done offshore. However, this would also depend on the size of the module and the total number of employees at the module yard, as a low number of employees could be justified.

Multiple parallel solutions

Another option for the module yard is to use several parallel solutions using multiple production lines. An example of this would be for the module yard to have standard series that it offered with a certain degree of customization, and then to have a separate production line for completely customizable modules that used another strategy. The two production lines could even be based on different module strategy propositions where the standardized modules were built using module strategy II or III, while the customizable module were built using strategy I or II.

The use of multiple production lines would require a significant increase in production facilities at the yard, and it would require two different work shifts that were used to two very different types of operations. It would also require the management of two different supply chains, each with its own methods for coordination. Though two different production lines could be used, these would also require to be within a certain frame in terms of size, location, volume, installation, and extent. The module yard would also need to consider the demand for each type of module to manage the resources in an optimal way.

The importance of choosing product mix

As the previously points have shown, the choice of product mix is strategically crucial and is at the centre of many of the strategic decision areas identified in the study. The product mix also has a large impact on which module strategy proposition that is the most suited for the purpose.

In the next section, a practical example of module yard choices will be presented where a certain product is chosen given the priorities of the yard. The example is intended to show strategic reasoning for a Norwegian module yard that involves the decisions and module strategies identified in this study.

10.3 Exemplification of complex module project

For this example, it can be assumed that the module yard is situated in Norway, and that it wants to retain as much value as possible, while reducing avoidable costs. The module yard would also like to benefit it as much as possible from the competitive advantages in Norwegian shipbuilding, while reducing the impact from the disadvantages. This project can be considered one type of project, while the complete product mix might consist of several others. The example is intended to show the line of thinking and decisions that goes into one type of module that could be a part of the product portfolio. The eight decision areas identified in subchapter 10.1 will be used for strategic choices and will be combined with one of the proposed module strategies from chapter 8.

When choosing a module type for the product portfolio, considerations must be made to all the decision areas that were identified in chapter 10.1. Size, location, degree of technology, degree of outfitting, and module extent are all relevant factors. In addition, the Norwegian competitive advantages must be considered so that the modules that are offered to customers can either benefit from the module yards competitive advantages, or so that the production can be arranged to add these externally.

The Norwegian competitive advantages were tied to services, connections, and the degree of specialization in the local maritime clusters, and the degree of tailoring and innovation. The disadvantages were tied to a high cost-level especially due to high wages (Haugland et al, 2021) combined with a low degree of standardization, amongst other factors. As a starting point, the competitive advantages points towards production where the module yard could benefit from the skills and competence found in the local cluster, and where technology and innovation are an integrated part of the module. Combined with a disadvantage in production that are heavily contingent on use of labour hours such as steelwork and simple outfitting operations, this indicates that highly technological module units that can function as platforms for innovative solutions and that requires high competence would be suitable targets for the product mix. Another indication is that the higher the ratio of technology to steelwork, the more the module yard could benefit from competitive advantages in relation to its disadvantages.

A module type that could fit such a description would be an engine room or propulsion unit. Such as unit would typically consist of a steel structure that functions as a framework for the equipment that goes into the module. The module could contain a wide range of technological equipment such as engines, gearboxes, pumps, generators, switchboards, etc. It could be expected that the equipment would outweigh the steelwork in terms of value-added, as the equipment that goes into such a module would be expensive and concentrated. According to Hagen & Erikstad (2014) as much as 25% of the costs in a complete vessel production is tied to engines and propulsion, which would mean that for a module this value would be significantly higher.

Propulsion modules could be highly complex, as many of the machines in the engine room runs other types of equipment in the rest of the vessel. In addition, much of the equipment in the engine room needs to be connected to systems at other points in the vessel. This means that the module yard would need to make decisions as to the extent of what the module is to contain, and how far it is to reach into the vessel. An example of such considerations would be if the propulsion module were to contain own tanks for fuel and oil, as these tanks are normally placed in the nacelles[19] of the vessel and what kind of equipment that were to be added to the vessel outside of the module. It would be ideal to deliver a propulsion module with natural limits, especially if it simplifies the building and installation process without increasing the complexity of the hull construction. This implies that for example fuel and oil tanks would naturally be left out of the module, as these can easily be placed in other locations while also still being easy to connect to the propulsion module. For the Norwegian module yard, it would be most ideal to maximize the amount of technical equipment that goes into the module so that it can benefit from the value-added by procuring and outfitting the equipment.

Installation for the module should also be considered when choosing module type. For the propulsion module, if the extent of the module would include oil and fuel tanks as well as the entire shaft line with thrust bearings and propellers, the module could become massive and contain the entire bottom rear end of the ship. This complicates the installation and building process, as such an installation would require the hull to be placed at a drydock, and then have the propulsion module skidded into the vessel. For large vessels this could become complicated and demand many resources. A better solution would be to have a solution where the module could be skidded into the hull as would be possible with a propulsion module.

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[19] Spaces in the bottom part of the hull that is often separated by the stiffeners and the support structure of the vessel. These are often used as cargo spaces for water, bilge, oil, fuel, etc.

The construction of a propulsion module would follow the building steps from chapter 7.3 of the study. For a propulsion module it could be expected that the steel structure that carries the equipment could be built rather simply. It would require following the building stages, where parts would have to be prefabricated, constructed, and assembled into a module structure. This construction could either be done domestically using module strategy I, or it could be offshored using module strategy II or III. Module strategy I has advantages in terms of production control, and could guarantee the highest production flexibility, quality, and the best delivery times. However, it also carries with it the highest costs, which will be put onto the customer, and has the highest level of required facilities. Module strategy II would allow the module yard to reduce costs for steelwork, but would retain most of the outfitting, which could be very beneficial for a propulsion module as the equipment is such a big part of the value-added for the project. It would allow the yard to maintain a tight focus on the part of the construction operation that adds the highest value-added, and make sure that it is done with high quality and precision. Module strategy III would have the benefit of minimizing costs both in terms of steelwork and outfitting as the entire operation is offshored, but it is likely that the value-added from the outfitting part of the operation would be significantly less for the Norwegian module yard, and it would be more difficult to maintain a high level of quality. With module strategy III it would also be difficult to benefit from Norwegian competitive advantages, though connections in the cluster could still be used as suppliers.

For a propulsion module it seems to be clear that the most value-added stems from the equipment added to the module, and not the steel construction. For the yard it is important to figure out how important the quality in each part of the construction is for the customer. Some customers demand that each part of the construction is carried out at a certain location and with guarantees of a certain quality, while other customers are only concerned about the outcome of the final product. This would have a major impact on which of the three module strategies that could be chosen, and therefore also on the viability of the operation.

As the propulsion module is highly technological it makes sense that module strategy II would be a viable option, as it would combine the use of offshoring for parts of the operation where Norwegian competitive advantages are low and retains most of the outfitting where Norwegian module yards would have an advantage in production with high quality, flexibility, innovation, and great connections within the local cluster. It does not mean that it would be the most suitable choice for every customer or in every operation, but it is likely that the module yard would need to choose a general line and adapt its production to it. For module strategy II, the module yard would be modified so that the equipment required for the initial building stages would be left out of the investments, and more resources would be invested in infrastructure, tools, and equipment to handle the module outfitting. For the use of module strategy II, it would make sense that the module yard could standardize propulsion modules so that some of the parameters or the architecture remains the same. Examples of this would be choices in terms of size, volume, localization on the vessel, and of course the fact that it would handle most of the technological installations and perhaps even testing. This would allow the module yard to reduce costs from the offshoring even more, to decrease lead times, increase quality, and it would also allow the transportation solution to be somewhat standardized. All of these solutions would make it easier for the Norwegian module yard to make reasonable predictions for costs, work scheduling, lead times, delivery dependability, and what to expect once the module arrives at the Norwegian yard. This could make the outfitting work a lot more efficient, and the standardization would make it simple to plan and coordinate the outfitting operation already while the steel frame is under production.

Building a propulsion module using module strategy II could function well with standardization as described, but it would also be possible to do it using module strategy I and a completely adaptable building strategy. In that case, the customer could request a one-of-a-kind design, that could be completely customized through all stages of the building process. This would require a significant investment into equipment at the module yard to facilitate for prefabrication, part production, module assembly, and it would require large additions to the workforce. Also in this case, even if the steelwork is performed domestically, the value-added from the outfitting could be expected to be a lot higher than that of the steel construction. However, the profit margins would be likely to sink, and the big question for the yard would be how much it would gain from building the steel construction domestically in comparison to when offshored. Because of the high labour costs and the cost of investment and maintenance of equipment required in the early stages of the production it is difficult to see how it would pay off. A low degree of steelwork would result in the investments and maintenance costs of the facilities being expensive while not worthwhile due to the low production, even if it reduces labour costs. A high degree of steelwork would justify the steelwork being done with a higher quality, but would quickly ramp up the labour costs, thus potentially ruling out the module as an order winner. Though there might be module types where this could be justified, in terms of the specific propulsion module, it seems like module strategy I would need to offer significant benefits on the competitive priorities quality, delivery dependability, delivery time, and flexibility that cannot be achieved by use of the other module strategies to be worth the investment and costs.

It would be possible for the module yard to establish two different production lines where one would handle standardized orders, such as propulsion modules with standardized steel frames and configurative options, and one line that could handle propulsion modules that differed widely from those that were set up as standards. This would require a higher degree of flexibility and could require reduced lead times depending on the customer order. However, the cost priority remains the same as in the previous paragraph, and it would be difficult to justify the establishment of steelwork operations domestically to handle these orders, as they could simply be engineered and built at a foreign workshop, and then adjusted by using outfitting once they have been transported back. Two production lines might be beneficial if the module yard can afford it, and if there seems to be enough orders to justify having two distinct production lines.

Depending on which decisions the module yard makes, the employee structure should be organized to match the product mix, and the chosen module structure, but this would also function the other way where the possibilities in the labour market would have an impact on which strategy to choose. As mentioned, the labour market in Norway can make it difficult to fill up full-time positions at the module yard, thus implying that the only solution would be part-time labour, or a mix of both. Offshoring strategy II and III would partly solve this problem, as they require less physical labour at the module yard, and therefore less full time and part-time labour overall. However, with a propulsion module it is likely that the outfitting work is of crucial importance, and it adds significant amount of value to the module which would make it worthwhile to outfit in Norway. The decision for the Norwegian module yard in that case would be if they want to hire full-time workers for the outfitting process only. This would be very beneficial in terms of quality, efficiency, lead times, knowledge accumulation, and flexibility, but could increase costs over time as they might be idle during the steel production stages (If module strategy II is used). It would also depend on how many projects that can be in progress at the same time, and the size of the staff required at the yard. If there were several projects ongoing at the same time, the production schedule could be set up to match so that the workers would do outfitting jobs in series, reducing the amount of idle time. A smaller staff would also reduce the overall labour costs and increase the knowledge and experience gain, however, it would leave the yard with less flexibility and reduced lead times.

After the module has been built it needs to be installed into the vessel. For a propulsion module it might be risky to transport the module after outfitting, as much of the equipment is sensible to humidity, dust, heat, rain, and other sorts of external exposure. This would favour an installation at the Norwegian module yard, however, to facilitate for such an installation at the yard would require facilities, transportation, infrastructure, and tools. This could be solved by investing in such equipment which would probably incur larges costs for the yard as it would require a quay, probably a drydock, heavy cranes, and a platform to skid the module into the vessel. Another solution would be to rent these facilities. Strategically there might be good reasons to invest in installation facilities such as knowledge of how it works, the ability to plan and schedule, and the ability to make sure it is functioning through responsibility for its own maintenance. For the module yard this could be a strategic resource, and it is likely that these are resources the module yard would like to have control over to avoid delays, increased lead times, and decreased delivery dependability due to these facilities not being available.

The example with the propulsion module shows that all the decision areas identified together with the different module strategies have a combined impact on final outcome on strategy by the module yard. It also shows that different situations and products will have various expected outcomes from the strategic choices, and that there is no clear answer to which considerations that are right or wrong. However, as many of the choices by the module yard has an impact on the yard in the long-term, coherent decisions that allows maximization of the resources and investments must be made so that they are in correlation, and so that they can benefit from the right degree of offshoring. It seems to be unlikely that completely domestic production even in terms of module construction is going to be a viable solution as there is too little to gain from doing the initial parts of the production in Norway. However, it seems very likely that major benefits can be gained from performing outfitting at Norwegian module yards, especially for equipment and specifications where Norway has a competitive advantage, such as technological projects with a high demand for quality and flexibility.

11 Conclusion

11.1 Summary

In this study, characteristics with construction of complex modules in Norwegian shipbuilding has been identified and used to create three module strategy propositions using offshoring strategies and analysed through the competitive priorities framework. This has been followed by a discussion where these module strategies have been compared according to the competitive priorities, and an identification of other relevant decision areas for decisionmakers at module yards. Finally, these decision areas were combined with the proposed module strategies and used in a practical case to show how these combined make up important decision criteria for strategists aspiring to make a manufacturing strategy for a module yard. The study has been qualitative in nature, and the sources for the study has been a thorough literature study where relevant frameworks and concepts have been identified, combined with discussions and unstructured interviews and conversations with several experts and actors from the Norwegian shipbuilding community.

Description and characteristics of modular construction revealed that a more precise definition was required, as the extent of modules and modular construction was wide. This meant that though modularity could be defined, there was different ways to approach modular construction. For this study, modular construction at the module yards in the scope of this study meant module yards that focused only on construction of complex modules, and that therefore did not build complete ships. Complex modules in this sense were modules that could be built as individual systems and installed into the hull of a vessel. However, within that definition, as shown in the study there were a vast array of different configurations, module types, sizes, and other parameters that allowed for extensive strategic choices by the module yard.

Based on the module characteristics, and the characteristics of Norwegian shipbuilding in general, three general module strategies were proposed. These were based on different degrees of offshoring and measured as to how they scored at the competitive priorities given by Beckman & Rosenfield (2014), which also provided a ground for comparison. The three strategies showed distinct differences as to how they scored according to the competitive priorities, as an increase in offshoring of the operation can be expected to have a large impact on the outcome. Module strategy I were based on the lowest degree of offshoring and were based on a complete domestic production of the module. Module strategy II were based on offshoring steelwork, while retaining production of outfitting domestically. Module strategy III would offshore almost the entire operation, while retaining only some outfitting and perhaps installation. The most distinct difference between the operations were the scores tied to costs and flexibility. While all of the scores varied between the module strategies, these had the most distinct differences as module strategy I was expected to have significantly higher costs than module strategy III which was at the other end of the scale. The opposite correlation was true for flexibility as module strategy I provided complete manufacturing flexibility while module strategy III had a low degree of flexibility due to the lack of control over the manufacturing process once it was offshored. In the discussion following the presentation of the module strategies it became clear that unless other criteria are added to the discussion, no one strategy can be said to be any more favourable over the others. There are advantages and disadvantages with each strategy, and it needs to be combined with an extended discussion that includes other decision areas to determine where and when a certain type of strategy would be more favourable.

In the discussion following the module strategies, eight important decision areas for module strategists were identified based on Norwegian shipbuilding competitive advantages and disadvantages. These decision areas highlight strategic areas that are crucial for a module yard when deciding product mix and needs to be considered in combination with the proposed module strategies to benefit from competitive advantages and reduce the impact of the competitive disadvantages. The discussion showed that within the eight decision areas many of the decisions are related to long-term decisions for the yard and must be made in congruence with each other and with the proposed module strategies. If these does not match, the manufacturing strategy is likely to be incongruent, which will lead to strategic decisions that are unsynergetic, and that will lead to a poor strategic fit. Examples of this would be to invest in facilities for complete domestic production and to fully utilize full-time employment combined with module strategy II that uses offshoring for its steel work. This would evidently lead to increased costs and investments where Norwegian shipyards have a competitive disadvantage, while not using these resources anyway due to steelwork being offshored, mitigating the positive cost effects gained from module strategy II.

Combining the discussions on the proposed module strategies and the identified decision areas showed that choices within some of the decision areas are better matched with some of the module strategies and in this way are better strategic fits. This was exemplified with the case example, where in a propulsion module, the choice of a highly technological module where most of the value-added stems from technological outfitting can gain from standardizing the steel structure, and the use of module strategy II. However, it remained unclear if other strategic combinations could yield equal or better results. The conclusion from this part is that though there are strategic decisions and module strategies that are better fits, there are likely to be combinations that can utilize the competitive advantages in a different and smarter manner, so that module construction could yield even higher profits.

11.2 Contribution to the field of study

The purpose of this study was to investigate the possibility of a yard solely focusing on the construction of complex modules instead of complete vessel construction. In the study, it has been found that though regular vessel construction and complex module construction share similarities in terms of competitive advantages, disadvantages, offshoring strategies, competitive priorities, and strategic decisions, though there are enough differences to distinguish between the two and to make considerations purely on module construction. The focus of this study has been on manufacturing strategic decisions tied to offshoring and manufacturing decisions. Based on this study it is difficult to conclude on whether a strict focus only producing complex modules offer more benefits than complete vessel construction, but the study has identified factors and decisions that shows how a module yard could benefit from competitive advantages and reduce the extent of the competitive disadvantages based on strategic decision-making. Complex module construction allows module yards to focus more specifically on the part of the ship construction where they have a competitive advantage, and where the value-added is highest. The results and discussion regarding the proposed module strategies show that offshoring can be managed in a way that matches the module type so that the module yard can benefit from its strengths and offshore parts of its weaknesses. Typically for a Norwegian module yard this would imply offshoring of the module stages where there is a competitive disadvantage, while retaining the parts of the production where the value-added is at its highest. The decision areas would narrow this even further by adding criteria for the production that grants the highest benefits to the specific module yard, for example that it only produces highly technological modules that has a relatively low amount of steel, and a high degree of technology. This would make it able to benefit from offshoring to reduce the cost of the steelwork which is often simple and possible to standardize, while allowing for customization, flexibility, and rapid lead times in the outfitting stages where Norwegian module yards could benefit from the advantages in the cluster, and from local competence. The study also shows that strategic decisions can cause different outcomes for the production and must be put into context based on internal and external factors given at each module yard. This was confirmed in a partial interview, where the interview object clearly stated that one of the biggest challenges for module construction and shipbuilding in general in Norway was that each project had to be considered there and then in correlation with the current circumstances[20]. This indicated that for the current situation, one of the competitive

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[20] A partial interview that was not finished due to time constraint with contact no. 1.

advantages was clearly the ability to adapt to every customer situation, something that also could be done in module construction. The study showed that even though a module strategy combined with decisions that allowed for a high degree of flexibility was possible, there were many downsides to such as strategy because of the increased costs tied to a very high degree of flexibility. To maximize production flexibility, it would be reasonable to maintain domestic production, while also investing in facilities, tools, equipment, and infrastructure to handle modules of all sizes, types, and variations, though the study shows clearly that it would significantly increase costs. It is a good example of the kind of choices the module yard would have to make, as some of these decisions are as described taken for the long-term.

In this study, an attempt at answering the research objectives have been made with an intention of describing complex module strategies and important decisions that could impact a module yard, thus being crucial for the manufacturing strategy. Though an effort to facilitate for thorough and informative results and discussions, it become clear through the study that both shipbuilding and modular construction are topics with wide definitions and is connected to a vast array of theoretical concepts and frameworks. However, important strategic decisions for module construction in shipbuilding were identified, module strategies that discussed and emphasized the importance of offshoring decisions were proposed, and these were combined to create a basis for decision-making in complex module production, in what would be an important part of a module manufacturing strategy. This could be a valuable contribution to discussions regarding complex module construction, a field that has not been properly explored but through this study shows promising characteristics.

It is likely that there is a place for yards that focus solely on complex module construction, as it would allow for an increased specialization where shipbuilders could get the best of both worlds, both in terms of hulls produced in low-cost countries, and modules produced in a country with high quality, high degree of flexibility, innovation, and high technical prowess. What can also be observed from the discussions on the module strategies is that there are also module types that are unfit to benefit from the competitive advantages at a Norwegian module yard. Typically, this would be modules that have a higher steel-to-technology ratio, as the module would be built at a disadvantage. This could be solved through module strategies that favour offshoring, but it seems clear that a high degree of technology and specialization that is in correlation with the competitive advantages are a better fit. What has not been discussed in this study are the prerequisites that is required for module yards to be able to function. It is evident that for module yards to function, cooperation with other shipyards that facilitates for hull construction is needed, this being either by the module yard serving as a supplier, or as a part of the company that receives the order. This could cause complications as an interface is also needed to install the module, which would have to be built by the hull constructor. Several other challenges also exist, such as the cost of investments for a newly started module yard or adaptation of a regular shipyard into a module yard. Perhaps the most important prerequisites for a module yard would be a sound market analysis that could estimate the demand for such a type of construction. A clear cost estimate of the module construction would also be necessary both for the yard that is the produce the module, and for potential buyers who would be likely to treat price as a potential order winner. If there were no demand for such solutions it would not matter how well-thought the manufacturing strategy were as there would be no demand for the solution. This would also be the case for cost estimates, as the price very often is decisive for customers in the shipbuilding market. Finally, the starting point for the module yard would also be relevant, as current facilities and economy would decide which space the yard had to make the decisions identified and discussed in this study.

In sum it can be said that this study has contributed to the field of shipbuilding with identification of strategies and strategic decision areas that are vital to complex module construction and has put these into a combined context. Potential module strategies have been proposed and crucial decision areas have been discussed which could cause a higher awareness for decisionmakers on critical strategic points and evaluations for complex module construction.

11.3 Limitations

This study has several limitations. It is almost solely based on qualitative data, which opens for misinterpretations, or the possibility of a study being used out of its context. To avoid this, literature search structure, and through studies have been done to make sure that the chosen studies would add real value to this study. As a supplement to the study, personal correspondence has been used, which makes the study prone to personal meanings or opinions, that was difficult to verify with other sources. For that reason, none of these conversations, mails, or correspondence has been used as empirical data, but rather a supplement to other studies on the field. Because the field of shipbuilding is a lot more developed than studies that target specifically Norwegian module construction in shipbuilding, topics and studies from shipbuilding has been used and adapted for this study. This highlights two specific limitations to the study. First, to as far extent as possible, sources that target Norwegian shipyards have been chosen, which makes the study more relevant for a

Norwegian context. Second, though there are commonalities, there are also differences between complex module construction in the context of this study and regular ship construction with complete vessels. This has been pointed out several times in the study, but it is suggested that the only way to make sure it is completely relevant for modules is to have studies that target modules specifically, which is difficult because the extension of modular construction in Norway is limited.

In this study there has been a lot of focus on module construction strategies in terms of offshoring and strategic decision areas directly tied to the production of the module. Together, these make up a large part of the module manufacturing strategy as defined in this study. However, the manufacturing strategy definition is broader and captures several other facets that has not been discussed in detail in this study. Thus, there are limitations as to the extent of study on the module manufacturing strategy, and a completely holistic strategy would need further studies within the fields of coordination, engineering, planning, and business plan, and it would also require more detailed plans in each of the topics discussed in this study.

11.4 Suggestions for further research

In this study, the main focus has been on suggesting strategic decision areas and proposing module strategies tied to offshoring. Much focus has been on how these can be combined and how the Norwegian competitive advantages can be used as a part of a manufacturing strategy in accordance with the definition made in this study. However, very little focus has been given to the external and given factors mentioned in the previous subchapter. For future studies on the construction of complex modules in Norway, a cost estimate that could suggest the costs involved in the different strategic propositions combined with strategic choices would be very beneficial in terms of evaluating the viability of the module strategies.

Studies that target specifically planning, coordination, and engineering for complex module strategies would add depth to the strategies and decision areas from this study. In-depth studies of the topics discovered and addressed in this study would also be interesting as specific production planning, factory layouts, resource utilization, and production methods are all topics that could increase insight into cost structure, cost mitigation, and how the competitive advantages of the Norwegian yards could be maximized.

A third suggestion for further research would be a similar study carried out with more empirical data based on interviews, both from Norwegian and international actors. It is likely that there are thoughts in the shipbuilding community about the use of modules, and combined with real experiences and cases, more relevant information regarding strategies and decisions could be made.

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13 Appendix

13.1 Appendix A: Interview Guide

Interview guide

Background information: Initially, the research objectives, the scope, and the theme will briefly be presented for the interview objective. A precision as to which type of modules that is focused on the study will be done, as it is specifically complex modules that contains complete or restricted subsystems that is the target. An example will be given.

Intention: To collect relevant empirical data from someone who has worked with the subject in praxis, and that has specific knowledge about Norwegian and foreign shipbuilding. This could aid in identifying important strategic decision areas, clarify as to which methods that are in use, and aid in explaining potential do's and don'ts in terms of module construction in shipbuilding.

Questions: part 1

1. What is your current role and function?
2. Which strategic approach did the shipyard(s) you studied or were assigned to use for construction of modules in shipbuilding?
3. What were the outcome and experience with the use of that module strategy?
4. What do you consider as critical success factors for construction of complex modules in Norway?
5. Which competitive advantages do we according to your opinion have in Norway that can be used to succeed with a yard concept which only focuses on construction of complex modules?

Before moving on to part two of the interview, a short presentation would be done of the three proposed module strategies made in the study.

Questions: Part 2

1. After the presentation of the three module strategies, which factors do you consider as relevant for each strategy when evaluating these?
2. Are there are certain module types you consider as being more suitable for construction in Norway or that would be more successful?
3. What do you believe to be the most important criteria when deciding extent, size, and type of module to be built at a module yard in Norway?

4. Are there any of the strategies you consider to be more suitable for a Norwegian module yard? Explain.

13.2 Appendix B: Contact Records

Contact no	**Contact information**	**Interview type**	**Length of conversation**	**IOs field of knowledge**
1	Professor in Economics, and board member of a Norwegian shipyard	Teams Emails	2x60min	- Shipbuilding - Economics - Engineering - Business
2	Professor in marine engineering and former employee at a large Norwegian shipyard and the DNV	Teams Emails	2x45min	- Shipbuilding - Physical ship construction - Modules
3	Leading employee at a Norwegian shipyard	Teams Emails	3x45min	- Shipbuilding - Business - Modules

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