Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Marine Technology

Magnus Rønningen

An Exploratory Study of a Norwegian Ship Design Process

Master's thesis in Marine Technology
Supervisor: Stein Ove Erikstad
July 2022

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Preface

This thesis is submitted to conclude my Master of Science degree in Marine Technology at NTNU, specialising in Marine Systems Design. The thesis work was carried out during spring and summer of 2022 mainly at NTNU Trondheim, but with two visits at a ship design company's office to collect data material for the thesis. It is a pre-study towards continued PhD work where its findings provides the basis for future research.

As I started on an integrated PhD programme at NTNU this semester, I registered for additional course work alongside the thesis work. The thesis deadline was consequently moved to the 31 July to compensate for the added workload. In the beginning of the semester I signed up for three courses, *MR8100-Theory of Marine Design*, *IFEL8000-Introduction to Research Methodology, Theory of Science and Ethics*, and *TDT4257 - Digital Platforms and Service Innovation*, amounting to 19 ECTS credits. During March I decided to not continue with TDT4257 to devote more time to the thesis work. Moreover, to allow time for one of the research stays with the design company, I completed only half of the course IFEL8000. which will consequently be completed during fall of 2022. MR8100 was completed in June this semester.

I owe gratitude to several people for support and guidance during this final semester. First of all, to my supervisor Prof. Doc. Stein Ove Erisktad for valuable discussions regarding the theory of marine design as well as guidance and feedback on the thesis work. Second, to the representatives from the ship design company for supplying data material, their hospitality and guidance during visits at their office, and feedback on the thesis. Finally, to my friends and family for their unconditional support and encouragement.

Magnus Rønningen

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Abstract

Reduced competitiveness among Norwegian ship design companies in recent years promotes the need to critically review their practices so as to identify measures that may foster improvement. As a source of information to investigate these practices, in particular, their design process, data from a ship design company's enterprise resource planning (ERP) system exhibits potential due to its current use in tracking and planning design projects. Therefore, this thesis pursues the following research question (RQ): *Is data from a ship design company's ERP system an appropriate source of information for describing and measuring activities and resource expenditure in their design process?*

To answer this research question the thesis work includes a literature review on relevant subjects related to ship design, as well as an assessment of data from a ship design company's ERP system. The purpose of the literature review is to provide a basis for understanding the ship design practices that might be investigated from the ERP system data. Its findings highlight a set of information elements that are used to assess the information content of the ERP system data. By processing, examining, and analysing a provided data set that includes data on ship design projects from 2015 up until early 2022 the presence and quality of these elements are used to determine the applicability of the ERP system data.

A key motivation for the stated RQ is to determine whether the ERP system may serve as a data repository for exploring the relationship between resource expenditure and competitiveness in future research. The ship design company of which design process the data is supposed to represent operate mostly with tender-based projects. For every tender invitation they accept, a project is registered as an opportunity to later be reregistered if it becomes a contract. There is no information in the data set that indicates whether an opportunity project turned into a contract, thus further investigations of the information content are conducted on opportunity projects and contracted projects separately.

The results from this investigation indicate that the answer to the research question is yes, but there are limitations. Lost tender-based projects are considered the most interesting to study further due to their impact on lost profit. Unfortunately, these projects are also the ones with the least detailed information content. Nevertheless, the information it provides may still provide insight into why some contracts are won while others are not, albeit with a limited detail level. Projects that have turned into a contract, on the other hand, allow for more detailed analysis. In addition to reducing expenses on not-paid-for projects, as would be the case for a lost tender-based project, increasing profits from paid-for projects, whether related to won tenders or FEED projects, is considered an important means to stay profitable. Thus investigating more in detail activities and resource expenditure in these projects may foster improvements in current ship design practices for the ship design company.

Sammendrag

Redusert konkurranseevne blant norske skipsdesignfirma i senere år fordrer en kritisk vurdering av deres nåværende praksis for å identifisere nødvendige tiltak som bedrer situasjonen. Som en informasjonskilde til å undersøke denne praksisen, mer bestemt deres designprosess, utpeker data fra et skipsdesignfirma sitt ERP system seg som en potensiell kandidat grunnet dets nåværende bruk til å planlegge og overvåke prosjekter. Derfor, undersøker denne oppgaven følgende forskningsspørsmål: *Er data fra et skipsdesignfirma en gyldig informasjonskilde til å beskrive og måle aktiviteter og ressursbruk i deres design prosess?*

For å svare på forskningsspørsmålet inkluderer arbeidet med oppgaven et litteraturstudie med fokus på relevante tema tilknyttet skipsdesign, i tillegg til en vurdering av data fra et skipsdesignfirma sitt ERP system. Formålet med litteraturstudiet er å gi en grunnleggende forståelse av praksiser i skipsdesign som potensielt kan undersøkes ved hjelp av ERP data. Funnene fra litteraturstudien fremhever et sett med informasjonskomponenter hvilket blir brukt til å vurdere informasjonsinnholdet i ERP dataene. Ved å prosessere, granske og analysere et tilsendt datasett med data fra skipsdesignprosjekter fra 2015 til tidlig 2022, hvorvidt disse komponentene er tilstede og kvaliteten på de brukes til å avgjøre egnetheten til ERP dataene.

En hovedmotivasjon for det gitte forskningsspørsmålet er å avgjøre hvorvidt ERP systemet kan virke som en kilde til å hente ut data for å utforske forholdet mellom ressursbruk og konkurranseevne i fremtidig forskning for det aktuelle skipsdesignfirmaet. Skipsdesignfirmaet som dataene skal gi informasjon på, opererer hovedsaklig med ”tender-baserte” prosjekter. For hver ”tender-invitasjon” de aksepterer, registreres et prosjekt som en ”opportunity” for senere å registreres på nytt dersom prosjektet blir kontrahert. Det er ingen informasjon i dataene som knytter sammen disse to registreringene og dermed gjøres videre undersøkelser hver for seg.

Resultatene fra disse undersøkelsene antyder at svaret på forskningsspørsmålet er ja, men at det er noen begrensninger. Tapte tendere vurderes som de mest interessante å undersøke i videre forskningsarbeid grunnet dets påvirkning på tapt profitt. Dessverre, er også disse prosjektene de med minst detaljerte data. Til tross for dette, så er det potensial i informasjonen som ligger i dataen på disse prosjektene med hensyn på å undersøke hvorfor noen projsekter blir kontrakt og andre ikke, selv om det må gjøres på et begrenset detaljnivå. Prosjekter som er tilknyttet en kontrakt gir derimot muligheter for mer detaljerte analyser. I tillegg til å redusere utgifter på prosjekter som ikke blir betalt for, som er tilfelle i tapte tendere, så vil det å øke profitt på prosjekter som er betalt for, enten det er vunnede tendere eller ”FEED” prosjekter, være et viktig steg mot å gjøre lønnsomme skipsdesignaktiviteter. Dermed kan mer detaljerte vurderinger på aktiviteter og ressursbruk i disse prosjektene gi grunnlag for forbedringer i dagens skipsdesignpraksis for det aktuelle skipsdesignselskapet.

Contents

List of Tables

List of Figures

Abbreviations

ABD	Accelerated Business Development
AM	Aftermarket
CD	Customised Design
$FTCDA$	Fast-Track Concept Design Analysis
$HOLISHIP$	Holistic Optimisation of Ship Design and Operation for Life Cycle
$HVAC$	Heating, Ventilation, and Air Conditioning
IND	Indirect
LOI	Letter of Intent
NB	Newbuilding
RSC	Responsive Systems Comparison
SBD	Set-Based Design
$SBSD$	System-Based Ship Design
SD	Standardised Design
$SRtP$	Safe Return to Port
$VISTA$	Virtual Sea Trials
VO	Variation Order
VR	Virtual Reality

Chapter 1

Introduction

1.1 Background

For many decades the Norwegian maritime industry has been well recognized for its success in delivering effective, competitive marine systems solutions [Norwegian Government 2019]. Existence of the cluster phenomenon and completeness of the value chain - encompassing ship owners and operators, yards, design companies, equipment manufacturers, and service companies - are considered main drivers for their success [Reve and Sasson 2012]. Shipbuilding, constituting ship- design and production, are critical activities in this cluster connecting the horizontal transport and non-transport service value chain as well as the vertical industrial value chain of the maritime industry [E. G. Jakobsen and Basso 2021]. Norway has long been a key player in shipbuilding, but emerging contenders from low-cost countries have caused a substantial decline [Haugland et al. 2021]. For the past decades some companies have managed to maintain their competitive position by focusing on advanced and highly customised solutions, but their competitive edge in these segments is also decreasing [Helseth and E. W. Jakobsen 2021].

In general terms, a company may be considered competitive if their solutions or services are valued more than that of their competitors or if the costs associated with developing the solution or providing the service are lower than their competitors [Fjeldstad and Lunnan 2018]. With ship design, value is associated with the development of the description of a physical product, the ship, and the need or problem it solves for the customer and the customer' customer, the shipowner and the ship operator. Being a customer-oriented activity, achieving a competitive position in ship design depends on the extent to which the companies can deliver a solution capturing customer needs and expectations, including development- and operating costs. The design process provides the means by which these solutions are conceived and thus governs how well customer needs and expectations are incorporated as well as the associated costs. Through a set of activities, a design is developed aiming to have an expected revenue-making potential outweighing the cost of owning and buying the vessel [Ebrahimi 2021]. Due to the intrinsic complexity of ship design, the uncertainty of future operating context and the multitude of stakeholders involved in a vessel's life cycle, this remains a task with potential for improvement. Furthermore, delivering the better solution is only a necessary, but not sufficient condition to stay competitive. While ensuring the better design solution for their customers and other relevant stakeholders, design companies need to consider their resource expenditure and the cost of developing their solutions. If the revenue from won contracts does not exceed costs associated with developing designs, it will not matter how well the design solution meets customer expectations as the design firm will not be able to keep their operation running. Although several proposals have been made to improve the design process, repetitiveness and iteration as described by Evans [1959] still seem very much prevalent, ultimately causing inefficiency and non-competitive solutions.

The need for improvement led to the initiation of the DREAMS (Design Re-Engineering and Automation of Marine Systems) project in 2021, aiming to investigate how Norwegian ship design companies can improve their competitiveness and market attractiveness by re-engineering and automating their business- and work processes. Automation is typically applied to speed up current processes, either by the automation tools being faster and more consistent than conventional practices or by freeing up resources which may then be devoted to other potentially more value-adding tasks. Re-engineering on the other hand involves changing existing processes and is accomplished by challenging old ways of thinking [Hammer 1990]. Part of the competitive advantage experienced by Norwegian ship design companies through the years has its roots in their longstanding traditions in delivering ship design solutions [Erikstad et al. 2022]. Yet some of these traditions may also hinder innovation if they are not aligned with emerging technologies and markets. The project will address current ship design practices and investigate improvement potential through the perspective of the organisation, the process and the product.

The expected outcome of the project includes knowledge, methods and tools supporting the improved competitiveness of ship design operations in Norway. This thesis aims to contribute to this outcome by acting as a pre-study toward continued PhD work, where its findings will form the basis for further research.

1.2 Research Objective

Mapping current practices, consisting of the activities they conduct as well as associated resource expenditure, is considered a key first step in assessing improvements in competitiveness. Knowledge regarding current practices resides first and foremost with a firm's employees. Yet other sources of information such as guidelines for work procedures and data from enterprise resource planning (ERP) systems may also prove to be important sources of information. This thesis will investigate the last option and whether it is applicable to gain insight into current practices, with main emphasis on the ship design process. As the ERP system is normally used to track the progress of ongoing projects and plan new projects, it is likely to contain valuable information regarding activities and resource expenditure. Consequently, the main research question (RQ) becomes:

Is data from a ship design company's ERP system an appropriate source for describing and measuring activities and resource expenditure in their design process

To answer this research question, the thesis work includes a literature review on relevant subjects with respect to ship design practices, as well as an assessment of data from a ship design company's ERP system. The literature review is intended to provide a basis for understanding the ship design practices subject to investigation in the ERP system data. Further, the applicability of ERP system data will be determined by assessing its information content; both what kind of information it contains and the quality of that information. This is carried out in three parts: First, the data will be pre-processed and cleaned to prepare it for further analysis. As the data already has a defined structure, this will mainly revolve around understanding the existing structure; what information it contains as well as what information may be relevant for further analysis. Second, an initial familiarisation and examination will begin to assess the information content and its quality by means of visualisation and simple descriptive statistics. A large sample will be considered here, before a more detailed examination will be carried out in the case study which constitutes the third and final part of assessing the information content of the ERP system data. The case study aims to investigate the information content quality by quantifying activities and resource expenditure in a (set of) design project(s), and discussing whether the numbers seem to accurately represent the ship design project(s) they intend to. The research objectives may be summarised as follows:

RO1. Review the theoretical foundation and methods in engineering design.

RO2. Describe the ship design process as presented in ship design literature.

RO3. Define the concept of value creation in ship design.

RO4. Analyse the information content in data from a ship design company's ERP system.

RO5. Quantify activities and associated resource expenditure in data from a ship design company's ERP system.

A key motivation for the stated RQ is to determine whether the ERP system may serve as a data repository for exploring the relationship between resource expenditure and competitiveness, by means of, for instance, operations research and statistical analysis. If the research work provides a negative answer to the RQ, further PhD work has to rely on other sources of information. Selected case studies of recent or ongoing ship design projects where information is provided from interviews and observation of ship design company employees are potential candidates.

1.3 Thesis Structure

The thesis is structured into six chapters as follows: Chapter 1 presents the background and objective of the thesis. Chapter 2 covers the literature review, providing a basis for understanding the ship design practices that may be extracted from the ERP system. Chapter 3 describes the methodology governing the thesis work. Chapter 4 begins by introducing the empirical data subject to investigation and ends with a case study on selected ship design projects. Chapter 5 discusses the findings from the thesis work and intends to provide an answer to the research question. Chapter 6 presents the final conclusion along with possibilities and recommendations for further work.

Chapter 2

Literature Review

2.1 Design Fundamentals

The act of design arises from identifying an existing situation which deviates from the preferred one [Simon 1996]. This deviation represents a problem upon which the designer devises courses of action aiming to approach the preferred situation. It is thus a goal-oriented process defined by the current understanding of the two different situations, and more importantly, how they deviate from each other, as this provides the basis for deciding on how the designer may further proceed with the problem-solving activity. This rather broad definition of design as provided by Herbert Simon [1996] does not exclude other problem-solving activities like prescribing medical treatments and creating a plan for achieving fitness goals. Goel & Pirolli [1989], on the other hand, delimits design further, advocating that all design efforts exhibit certain invariant characteristics. Other problem-solving activities may exhibit similar characteristics, but for every deviation from these characteristics, they are described as less of the prototypical example of design. They further exemplify engineering, architecture and instructional design as prototypical design cases. In this thesis, design will be considered synonymous with devising courses of action to achieve a product description.

2.1.1 Design as a goal-oriented mapping process

The fundamental design process is often described as a mapping process between the domains *need*, *function*, and *form* [Coyne et al. 1990; Pahl et al. 2007; Farid and Suh 2016]. The need states the outcome the design aims to achieve derived from the market, directly from the customer, and other stakeholders involved in the design effort. In order to meet these needs the design must perform accordingly. Thus, the needs are interpreted and mapped onto the functional domain spanning a set of functions describing what the design should do to meet the intended performance. Suh [2016] avoided the distinction between functions and performances and instead combined them into the more unifying term *functional requirements*, arguing that ideally there should not be a difference between what the design does and what it should do. Finally, the form domain provides a description of the actual design aimed at carrying out the functions and meet the intended performance.

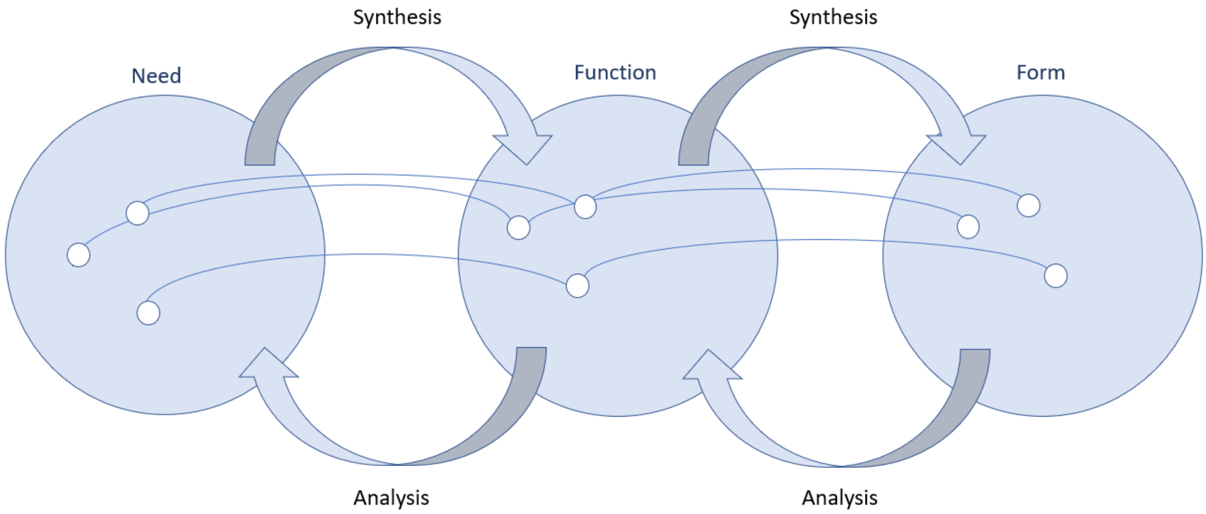


Figure 2.1: Design as a mapping process

The design description constitutes several design parameters, which in a marine systems design setting would be, for instance, length overall, draught, or engine power. The membership, configuration, and scale of design parameters may be varied, where each variation yields a different description and a different performance. It is not obvious which alternative will meet the intended performance. As a matter of fact, the actual performance provided by a design description usually deviates from the intended, necessitating iteration in order to meet the intended performance.

Design iteration may be seen as a repeated loop of analysis, synthesis and evaluation where each loop will facilitate learning and consequently a design achieving an actual performance which is closer to the intended [Gero 1990]. Synthesis may be seen as the first part of an iteration loop, progressing from the need to a physical description by utilizing current knowledge. The last part of an iteration loop is the analysis where the physical description is examined with respect to the function it should perform. By evaluating the result of the analysis, the designer learns about the synthesised solution and generates new knowledge. The designer cannot learn about the design before it is synthesised, thus the more solutions that undergo this looping process, the more the designer may be able to learn, and the actual performance is likely to approach the intended.

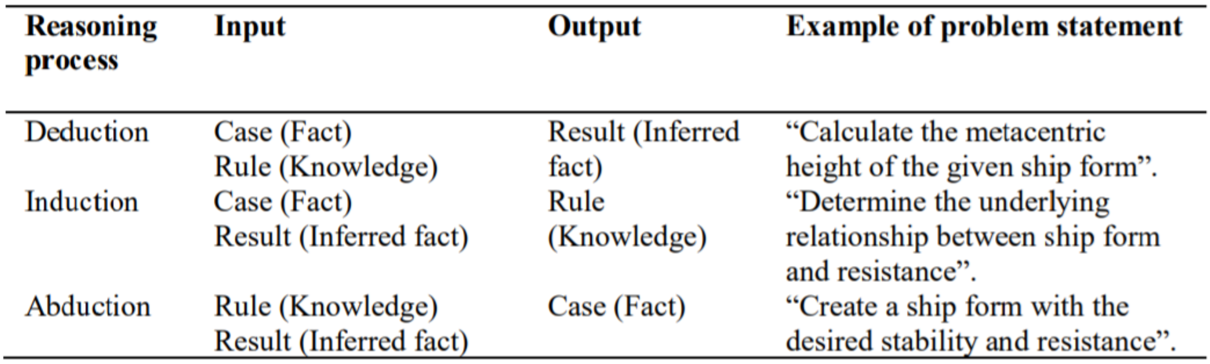
Analysis will in this respect be carried out to enable evaluation of a synthesized solution, but it is usually also incorporated before a solution is generated. This resembles problem analysis which involves collecting information about the needs to be satisfied by the product, as well as the constraints [Pahl et al. 2007]. The aim of this initial stage of the design process is to provide a clear definition of the problem to solve, usually represented by a set of requirements [Pahl et al. 2007]. Furthermore, the requirements upon which the design is synthesised and evaluated are not facts; they are based on a current understanding of what is needed. Whether or not this understanding is correct is uncertain because it is usually constructed from partial information [Waldron 1992]. As the design process progresses, more information is gathered by synthesising, analysing and evaluating design options. Thus, a considerable amount of iteration may occur, just to arrive at a clear problem definition.

Iteration is often increasingly prevalent as the system to be designed becomes more complex. With increased complexity, more information is necessary to describe the system and its sub-systems and components are often highly interdependent [Lindemann et al. 2009]. With marine systems such as ships, the performance is typically multifaceted and driven by a highly dynamic and uncertain context [Ulstein and Brett 2015; Rehn et al. 2018]. Additionally, the ship itself is a highly self-contained system, where each function of the design problem is carried out by sub-systems within the overall ship system [Erikstad 1996]. This further induces a tight coupling between the sub-systems, which in the design process necessitates continuous feedback of information between tasks that treat them. Due to this coupling, the start of one task typically depends on the completion of another, thereby causing a sequential process in which activities are carried out. The start of an activity sequence is characterised by a certain amount of information. By the end of the activity sequence, new and corrected information is likely to be generated that may improve the design performance, and hence the task sequence is repeated.

2.1.2 Applying and generating knowledge in design

It is evident that to be able to conduct an efficient and effective design process, a clear and correct problem definition is necessary, seeing as it does not matter how well you accomplish the form synthesis if the transformation from customer expectations is already false. However, the ill-structured nature of design makes it challenging to even accomplish a clear problem formulation [Simon 1973]. Ideally, one would have the knowledge and information necessary from the start of the design process, reducing the challenge of providing a clear problem formulation and subsequent design tasks. The main concern would then be to combine this knowledge and information to form the connected whole that satisfies the need, in essence the design synthesis. However, the act of designing will involve a considerable amount of analysis and evaluation to learn and give rise to this knowledge as it is generally insufficient at the beginning of the design process. Utilising knowledge and the generation of knowledge may thus be considered a central part of the design activity as means to achieve the intended performance.

A knowledge-centred view on design has been covered in [Coyne et al. 1990] which provides an interesting parallel of synthesis and analysis, described through deduction, induction and abduction. These modes of reasoning may be described by appropriately arranging *case*, *rules* and *results* as input and output. In a marine systems setting this was neatly incorporated by Pettersen [2018].



Reasoning process	Input	Output	Example of problem statement
Deduction	Case (Fact) Rule (Knowledge)	Result (Inferred fact)	"Calculate the metacentric height of the given ship form".
Induction	Case (Fact) Result (Inferred fact)	Rule (Knowledge)	"Determine the underlying relationship between ship form and resistance".
Abduction	Rule (Knowledge) Result (Inferred fact)	Case (Fact)	"Create a ship form with the desired stability and resistance".

Figure 2.2: Design reasoning modes adapted to a marine system setting [Pettersen 2018, p.13]

In their framework, abduction would relate to synthesis, while deduction would relate to analysis and evaluation. Abduction provides a design description using existing knowledge and information about intended performance, whilst the actual performance is deducted from this description. Induction, on the other hand, relates to gathering information from previous design descriptions and using this information to learn about relationships between the design space and the performance space.

2.1.3 Decision-making in design

So far design activity has been described as finding the means to achieve the needs, a process of synthesis and analysis, interpreting information by utilising knowledge and further generating new knowledge. In this process, many design options are generated, raising the question of how to choose among them. Until a decision is made to pursue an option, the design remains an idea. The realisation of these ideas is carried out through decisions, hence promoting the principal role of the designer as a decision-maker [Mistree et al. 1990]. Hazelrigg [1998] promotes the view of design as a decision-making process through the definition of design as a two-step process of i) generate all design options ii) choose the best one. This definition highlights a distinct characteristic in design, namely that there is no unique solution to the problem at hand. There are in fact many possible solutions and a design process may only hope to find the better solution, not necessarily the best possible solution. This was explored by Simon [1996] who coined the term ”satisficer” as someone settling for the better solution, simply because that it is the best a designer can hope to achieve. Decision analysis and optimisation aim to aid the designer in identifying the best solutions in the design space. However, generating every solution is in practice impossible and since the performance of a design cannot be assessed before it is synthesised, the designer will never know if the best one has even been considered.

Intuitively, by generating many solutions, the likelihood of having considered the best one should increase. Therefore, making the better decision, to some extent, relies on the generation of design solutions. In this respect, creativity plays an important part by affecting the synthesising ability of the designer. Creative solutions may involve entirely new ideas, investigating unexplored areas of the design space, or novel combinations of previous ideas, exploiting familiar areas of the design space [Pahl et al. 2007]. The latter is perhaps the most common approach in ship design where the design process typically starts with an existing design and modifies it to new requirements. This may facilitate a short response time, yet better designs may exist in other areas of the design space, inviting the risk of not designing the better solution. Computer support may somewhat aid the creative process by having a much higher capacity than the human designer alone to synthesise and evaluate solutions (see for instance [Van Oers 2012]. The computer is limited, however, to exploit the information input provided by the designer. Given a set of input parameters a computer may generate and evaluate numerous alternatives, but this presupposes that the designer has made an initial judgment regarding performance- and design parameters. Thus, the generation of alternatives relies on a current understanding of what is required to satisfy customer needs, and they may all be worse than options not considered. A set of good candidates generated from a more systematic, goal-based procedure may be just as effective, yet more efficient than generating as many as possible (see for instance [Levander 1991, Brett et al. 2006]).

2.2 Approaches and Methods in Engineering Design

The designer is faced with two principal challenges when initiating a design endeavour; understanding the problem and solving it [Simon 1973; Cross 2000]. To reach a solution solving an identified need, there may be several approaches which may be adopted. Principally, the designer needs to generate knowledge about the design from information characterising the need, a process of gathering and processing information, and generating and evaluating solutions.

If considering decisions the mechanism that turns the vessel idea into a reality, then the better solution depends on the quality of decisions. Optimal decisions are made when all information is available, which is rarely the case, especially in the early stages of design. The design process will typically keep iterating until sufficient information is available to produce an effective design solution, thus lack of information causes an inefficient design process.

Improving design process efficiency in terms of iteration may either be accomplished by reducing the number of iterations or increasing the iteration speed [Mistree et al. 1990]. Reducing the number of iterations presupposes that each iteration is more effective. Iteration typically occurs as new information becomes available, thus if more information is made available from the start, the number of iterations may be reduced. One may alternatively strive for independence between tasks to minimise feedback. In this way new information will only affect a limited part of the design solution and rework is kept at a minimum. To increase the iteration speed, every iteration may consider each generated design solution to a limited detail level. The effectiveness may be maintained by instead relying on the exploration of a larger, less constrained design space.

2.2.1 Axiomatic design

Axiomatic design intends to improve design activities by providing a scientific basis that makes it possible to distinguish between good and less good design practices [Suh 2001]. It builds on two axioms intending to guide the designer in making rational design decisions whether related to product, process, or organisation.

The independence axiom states that independence should be maintained between the functional requirements (FR). If an FR only affects one design parameter (DP), and visa versa, the independence axiom is met. As a consequence, feedback between design tasks is minimised as an FR-change or a DP-change will only affect the corresponding FR/DP, thereby avoiding extensive rework.

The information axiom calls for minimising the information content of the design and should be sought after when the independence axiom is met. It intends to provide the designer with a means to choose among design alternatives, saying that if several alternatives meet the previous axiom, the one with the least information content should be chosen. This follows the fact that as the information needed to describe a system grows, the harder it is to understand it and thus design it. When less information is needed to describe the system, lack of information is also less likely to occur, and hence one may argue that the need for iteration is less prevalent.

2.2.2 Product platforms and modularity

Complex engineering systems like ships constitute several sub-systems which are assembled to a complete well functioning unity. The structure of these sub-systems, referring to what function they carry out and how they relate to each other to conduct a designated mission, defines the architecture of the system [Simpson 2003; Erikstad 2019]. Based on the interdependency upon which different functions are performed by the sub-systems, the architecture may be classified as either integral or modular. Whereas integral architectures deliver several functions through the same sub-system or collection of sub-systems, modular architectures separate sub-systems based on function, in line with the aforementioned independence axiom. Ships are generally considered integral structures, but modularity may bring benefits in design by reducing feedback between tasks and thereby minimising iteration.

Product platform approaches aim to enable a designer to meet diverse needs without compromising efficiency and effectiveness and incorporates modularity to achieve it. A product platform constitutes a set of modules and shared interfaces in which different variants may be developed by adding, substituting or removing the modules [Simpson 2003]. As the core elements of a product platform are already developed, a designer can exercise reuse to improve efficiency in responding to tenders as well as reduce development cost [Erikstad 2019]. Taking modularity a step further than just variants, it may also support innovation by facilitating a comprehensive exploration of the design space. Instead of using a previous design solution as the starting point - which is to a large extent already fixed in the design space - a set of modules may be selected and adapted to new requirements and necessary functions. As a consequence, the design is less ”locked in” to previous solutions, hence promoting innovation.

2.2.3 Generating knowledge in early stage design

Concurrent engineering aims to proceed with design tasks in parallel in contrast to the traditional sequential engineering procedure. By interconnecting the tasks, information will flow between disciplines, thus allowing designers to consider more *hard* information, based on scientific principles, rather than *soft* information, based on experience [Mistree et al. 1990]. Increasing the ratio of hard to soft information, especially in the early stages of design, is considered to increase the effectiveness of an iteration and hence enable a reduction in the number of iterations. Yet, the approach is criticized for sometimes leading to the contrary as a result of extensive rework [Smith and Eppinger 1998].

Following the principles of concurrent engineering, Set-Based Design (SBD) aims to increase design efficiency and effectiveness by evaluating several design alternatives in parallel. The approach does not pursue a single design option to great depths to gain knowledge, but rather evaluates several alternatives in parallel to gradually eliminate options proven inferior. Detailed specifications are deferred until more knowledge about the design space is gathered and a better understanding of the trade-offs is achieved [Singer et al. 2009]. The strength of SBD lies in its ability to collect large amounts of information without compromising design efficiency.

2.2.4 Decision analysis and optimisation

Given an amount of information regarding the problem to be solved, including a set of requirements derived from the needs, a set of decisions addressing the requirements, and the constraints of those decisions, the design problem may be formulated as a decision-support problem. The purpose of providing such a formulation is to make a clear representation of the problem to solve and as such be able to solve it efficiently. Decisions are represented as decision variables where different configurations of these variables yield possible solutions to the decision-support problem. Several configurations are likely to be feasible by meeting the requirements and satisfying the constraints, but given an accurate problem formulation, the preferable solution may be determined more efficiently.

The challenge, however, is typically to arrive at such a problem formulation. Every formulated decision-support problem is merely a model of the design problem, an abstraction of the real problem based on the information available at a certain point in the design process. As information is often scarce, the answer to the model is not necessarily a good answer to the design problem Ackhoff 1979.

Tradespace models present an alternative approach to decision analysis where the aim is not necessarily to select the best alternative, but rather to gain an understanding of the cost and benefit associated with different design alternatives [Ross et al. 2008]. Along the lines of SBD, it considers many design alternatives in parallel to evaluate trade-offs in the design space. In this way, a better understanding may be achieved and the selection of design alternatives may be deferred until more information is available.

2.3 Ship Design

In ship design, a design project originates from a ship owner who wishes to expand or renew their current fleet, for instance to improve capacity or expand into new market segments, or to replace or renew vessels that no longer provide sufficient value. They do not possess the resources to realise this fleet renewal initiative and hence turn to the ship design company and a shipyard for their competence and expertise. The ship design company develops a ship design description composed of a set of drawings, plans, specifications, analyses reports, and booklets, and the shipyard builds and delivers the vessel according to the description provided by the design company. In this way, the ship design company acts as a supplier to the shipyard. The yard may have its own design office, but often these are separate actors in the fleet renewal initiative.

2.3.1 Business arrangements for ship design projects

The ship owner may initiate the design project either from a closed- or open tender, or as a Front-End Engineering Design (FEED) contract. These three business arrangements differ by means of what design work is paid for, how many ship design firms are involved, and the ownership of the design [Garcia Agis 2020]. In open tenders there are typically several design companies that develop a response to the tender invitation issued by the shipowner. Their response include a conceptual design solution as well as a newbuilding price as estimated by one or multiple yards. The solution which is perceived as the better one by the shipowner is awarded a contract. In closed tenders, only one ship design company is involved, but the shipowner may still choose not to award the contract. In the case of FEED projects, the ship owner pays a ship design company for the development of a concept design, regardless of whether the project is realised.

In either tender-based case, there is no certainty of income from the effort put into the design project. Ship design companies along the coast of Norway mainly operates on such a ”no-cure-no-pay” principle where they risk spending a vast amount of resources on projects which is lost to a competitor. For every tender invitation, they first have to decide whether to accept it, knowing that there is no certainty of winning the contract. If they accept it, the next decision involves allocating a set of resources which minimises the probability of losing the contract. The two main decisions involved in this decision problem may be illustrated as a coupled selection compromise decision support problem as introduced in [Mistree et al. 1991]:

Given : A set of design projects
Identify : Expected revenue
Rate : Projects based on highest expected revenue
Rank : Projects in order of expected revenue.

Given : A set of design projects
Find : The optimal resource allocation
Satisfy : The resource constraints on the design process
Minimise : Probability of loosing contract

Given a set of design projects the goal is to select the set of projects and allocate an amount of resources that maximises the expected revenue while keeping a profitable level of resource expenditure. The expected revenue may be defined as the probability of winning the contract times the contract value, where the probability of winning the contract is likely to be affected by how much resources the design firm allocates to the given project [Erikstad et al. 2022]. Allocating a set of resources comes with a cost, where the optimal resource expenditure maximises the difference between expected revenue and inferred cost. Figure 2.3 illustrates this situation in the case of a single project.

Design projects vary with respect to novelty, contract value, and development risk. This is likely to influence how resource expenditure affects the probability of winning the contract and thus also expected revenue. The reward from allocated resources is believed to be diminishing, following the argument that the most valuable tasks are carried out early in the design process [Erikstad et al. 2022]. Design projects that require a novel, complex design solution are likely to have a high contract value, while more familiar projects that perhaps simply require a standardised solution are likely to have a lower contract value. Furthermore, design projects that allow more standardised solutions are likely to have a relatively steep probability curve that diminishes quickly, while projects with customised solutions are likely to have a more gradual probability curve that requires more resources before the probability starts diminishing. This follows the fact that standardised solutions are often pre-developed to some extent, in contrast to novel, customised design projects, where the designer needs to start from scratch. As more resources may be required to reach the same probability level in customised solutions compared to standardised solutions, a lost contract in the customised case comes at a much higher cost. Hence, although novel design projects have a higher value potential, committing to these projects involves a much higher financial risk. The optimal portfolio is likely to be balanced with both high-risk-high-value projects and low-risk-low-value projects.

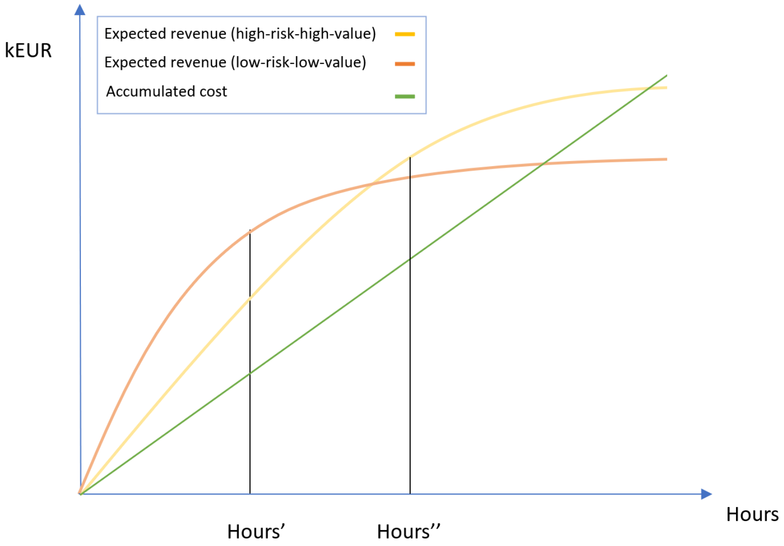


Figure 2.3: Optimal resource allocation depending on project novelty, contract value and development risk, [Erikstad et al. 2022].

Providing competitive design solutions at a profitable level of resource expenditure requires an effective and efficient design process. If assuming that the best solution is the one that wins the contract, then identifying the best solution should yield a higher probability of winning the contract. The design space is nearly limitless, and trying to identify the best possible solution is not likely to provide an efficient approach to delivering a competitive solution. A more efficient approach more in line with the satisficer philosophy presented by Herbert Simon [1996], is to identify what competitors can offer and deliver a better solution. This may be simple in hindsight, but during the tender process, it is impossible to know with certainty what competitors can offer.

If the contract is won there is a shift in focus from achieving the best project selection to the best project execution. Before the contract is signed, each project is treated alongside a vast amount of projects, none of which may necessarily provide any revenue. Projects are selected and prioritised according to what may maximise the expected revenue. After the contract is won the project falls into a pool of much fewer projects where a certain revenue is more or less guaranteed but will depend on the extent to which the contract specification is met. Change orders may occur and will typically infer a deviation from the initial contract specification [International Organization for Standardization 2012]. However, as this have to be agreed upon by the buyer and the supplier it will likely not affect the success of the design project if it is properly managed. Again, following what was presented in [Mistree et al. 1991], this situation may be illustrated as the following compromise decision support problem:

Given : A contract specification
A set of design constraints
A conceptual/basic design solution
Competence relevant to the problem-solving process
Find : A description of a design solution
Satisfy : Constraints of the design problem
The constraint on the design process
Minimise : Deviation from contract specification

2.3.2 The ship design process

Regardless of the business arrangement the design project is initiated with, the ship design company's the design process provides the means by which the ship design solution is conceived and thus governs whether their solution is better or not, as well as the resource expenditure associated with developing the solution. The prototypical ship design process is depicted as a staged process proceeding from a set of initial expectations to concept design, basic design and detail design. The terms for each stage are somewhat varying in the literature, but the main content is somewhat similar and a summary is included below (primarily based on [Erikstad 1996; Rehn 2018]).

The main purpose of *concept design* is to elicit stakeholder requirements and specify the main features of the design which may adhere to these requirements. This is generally comprised of an exploration stage where the design space is explored to identify different solution principles and combine them into concept variants, and an evaluation stage where concepts are compared and the best ones selected. The output of this stage includes an outline specification defining a conceptual solution with its main features.

The *basic design* stage proceeds with the outline specification to greater detail and seeks to determine a solution that is both feasible and preferable to other solutions in all aspects of the desired performance. One of the main objectives is to prepare the class drawings so that production can start. Where the concept design stage mainly focuses on establishing the main features of the design solution, the basic design stage seeks to find the feasible and preferable description of these features. This typically entails making compromises. As mentioned previously sub-systems in ships are tightly coupled which typically causes changes in one subsystem to affect another, and not necessarily in a positive manner. For instance, the dimensions of the machinery system are largely based on the service speed and resistance of the hull. A traditional ship design process typically begins with proposing a hull, then based on the resistance and necessary service speed, the machinery system dimensions are determined. The machinery system may not fit within the initially proposed hull, thereby necessitating hull modifications. However, since the hull resistance is dependent on the shape of the hull, these modifications may also cause the necessary machinery dimensions to increase. Consequently, the designer may have to settle for a lower service speed.

The *detail design* stage intends to prepare for production according to approved class drawings. This includes producing a complete specification of arrangement, form, dimensions and properties of all individual components, materials selection and cost estimations. Since this stage intends to prepare for production, it may be affected by the qualifications and preferences of the shipyard responsible for building the vessel.

In practice, the content or at least the emphasis on each stage may vary. This may be affected by the detail of the customer's technical inquiry, how the design firm chooses to approach the design problem, as well as the yard that is to build the vessel. The customer may approach the designer with a simple business idea which allows for a higher degree of design freedom compared to the opposite case where the customer has a comprehensive design booklet with all particular details and attached General Arrangement [Ebrahimi 2021]. This will naturally affect the content of the early design stages. Furthermore, three main approaches may be considered the starting point for every design process, and typically depend on the novelty of the design project [Pahl et al. 2007]. Original design represents the highest degree of novelty and proceeds through each design stage. Adaptive design starts with defined main features from a similar design and adapts them to new requirements. Variant design starts with components and sub-systems of a previous design and varies the size or arrangement of these components within the constraints of a previously developed product. The latter two approaches may only require carrying out the basic- and/or detail design stage.

As the design process progresses, the freedom to make changes is reduced while the knowledge about the design increases [Mistree et al. 1990]. As illustrated in Figure 2.4 this means that the least is known in the early stages and thus design decisions made at this point may rely on a high degree of judgment and experience rather than scientific measures. This is an undesirable situation as it increases the uncertainty and thus also the confidence in the concept which is pursued. As a result, solutions may be pursued just because they yield a more certain outcome, not because they are the better solution [Ulstein and Brett 2015].

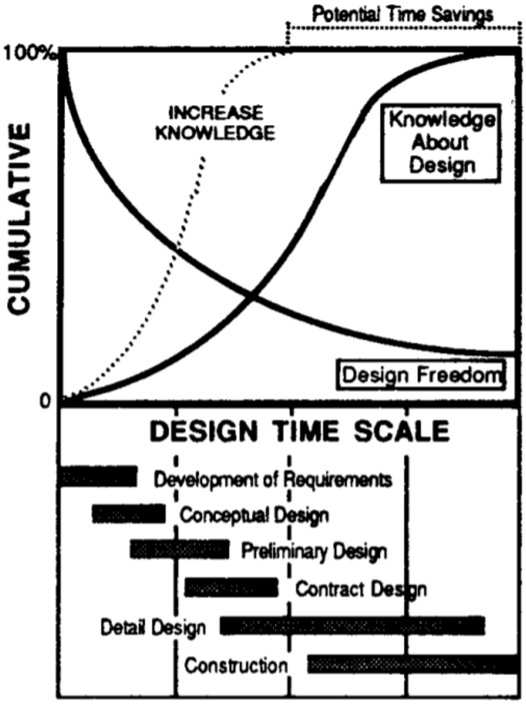


Figure 2.4: The evolution of design freedom and design knowledge in a design process [Mistree et al. 1990, p.568]

The concept design stage has frequently been argued to be the most important design stage [Mistree et al. 1990; Erikstad 2007; Andrews 2018]. The importance of this stage may be supported by its influence on downstream activities and costs, combined with the major decisions being made with regard to satisfying customer expectations. Developing a concept is highly influential on downstream design activities because it entails major decisions concerning main functionalities and parameters that are to be detailed at later stages [Andrews 2018]. Seeing as the main functions are provided by sub-systems within the boundaries of the ship system, these decisions will also pose the largest constraints on the design space. [Erikstad 1996; 2007]. Even though the influence of these decisions is high, the knowledge to execute them is usually low, making it difficult to efficiently meet stakeholder expectations as this knowledge must typically be generated through time-consuming iteration. Moreover, up to 80 % of the total life-cycle cost may be determined this early [Erikstad 2007] and thus one may argue that the competitiveness of the vessel is already largely determined.

Ship design tools

Ship designers apply different tools to facilitate the development and evaluation of design solutions. Different tools vary with respect to resource expenditure and accuracy provided, where applying more accurate tools comes at a cost regardless of the benefit it provides. Although accuracy is generally sought after, it should ideally be evaluated against the value it provides to maintain a balance between achieved value and inferred cost.

There are typically dedicated tools within each discipline; the hydrodynamics discipline commonly apply tools within Computational-Fluid-Dynamics (CFD) and likewise, the structural engineering discipline apply Finite-Element-Method (FEM) tools. Both tools complement each other in the sense that they consider separate parts of the overall vessel performance, which are both needed to evaluate the design.

These tools have been developed to increase the accuracy of calculations that were previously conducted with purely empirical or other experience-related methods. As a consequence one may more accurately assess certain performance characteristics of the vessel.

It is evident that by increasing the accuracy of the tools, the efficiency also decreases. This becomes a challenge in the early stages of design when it is essential to arrive at a sufficiently accurate and robust solution, while ensuring a quick customer response time [Ebrahimi et al. 2018]. Clarifying customer requirements and arriving at corresponding, balanced solution principles is a learning process facilitated by exploring many solution alternatives. Detailed analysis of many alternatives is costly with respect to both time and effort, and thus using these tools in the early stages of design is far from optimal if trying to accomplish quick response times. Furthermore, with discipline-specific tools, the designer spends a considerable amount of time on parts of a single solution which may not be pursued further.

In recent years, more multidisciplinary tools have been introduced to overcome some of these deficiencies. One such example is the Fast-Track-Concept-Design-Analysis tool (FTCDA) which was developed to conduct conceptual design more efficiently [Ebrahimi et al. 2018]. The tool is comprised of a multidisciplinary design platform, integrating design disciplines of marine engineering and naval architecture into one unified analysis. The multidisciplinary design platform is realised through several connected modules, each representing a specific design discipline as shown in the figure below.

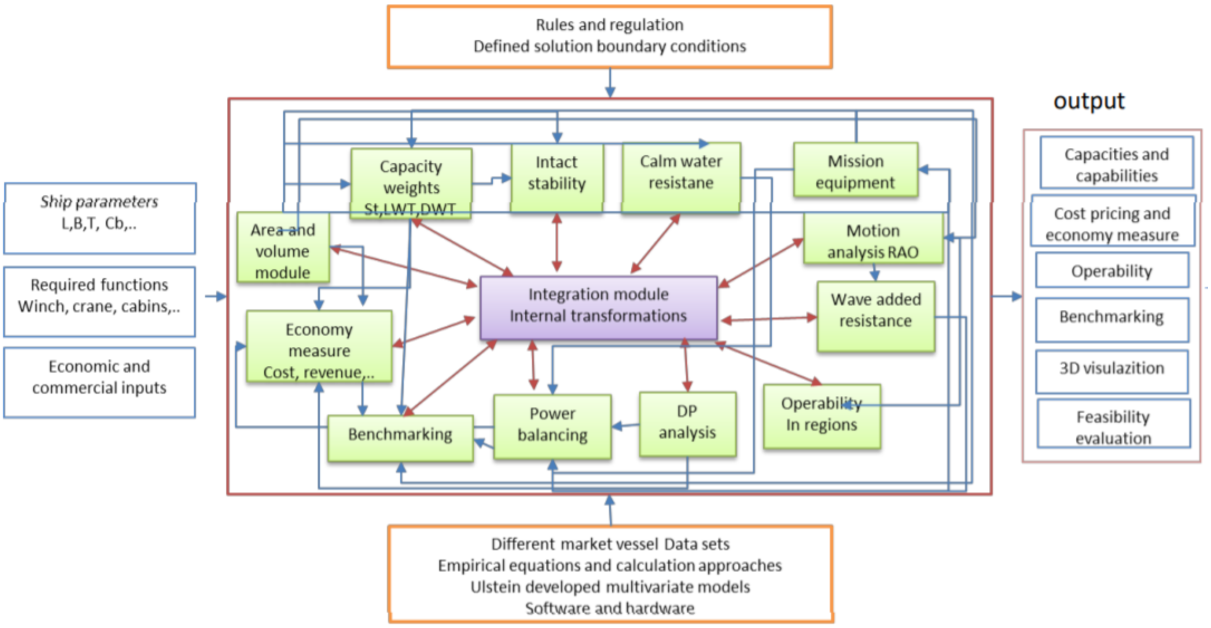


Figure 2.5: Working principle of FTCDA tool, [Ebrahimi et al. 2018]

Main dimensions, equipment requirements and financial and commercial factors like loan, equity and fuel cost are inputs provided by the user. This initiates the calculation procedure where each module receives and provides data from and to other modules. Calculations are performed and solutions ranked by means of statistical approaches like multivariate data analysis and traditional naval architecture procedures. Backed up by test cases, the tool is argued to show a permissible accuracy compared to more detailed discipline-specific analysis [Ebrahimi et al. 2018]. With this in mind, it may be argued that the use of tools like CFD ad FEM in the early stages of design are often excessive and may favourably be deferred to later stages [Ebrahimi 2021].

2.3.3 A review of ship design methodology

Probably the most well-known representation of the ship design process is illustrated through the Design Spiral by Evans [1959], describing the iterative, sequential nature of progressing through the design stages. Even though the Design Spiral may give the impression of ship design as a relatively smooth and continuous process, this is rather an idealisation than an accurate representation. With clearly defined goals and subsequent process structure, ship design might be able to exhibit the characteristics of this idealization. However, the initial expectations are often unclear, making the requirements definition and consequently the form synthesis a process characterized by assumptions and uncertainty. An alteration of the design spiral was introduced by Andrews [1981] to highlight the external influences which act upon the design process. Rather than a closed two-dimensional loop, a more open three-dimensional loop was presented, indicating changing constraints revealed through continuous interaction among the designers and stakeholders throughout the design process.

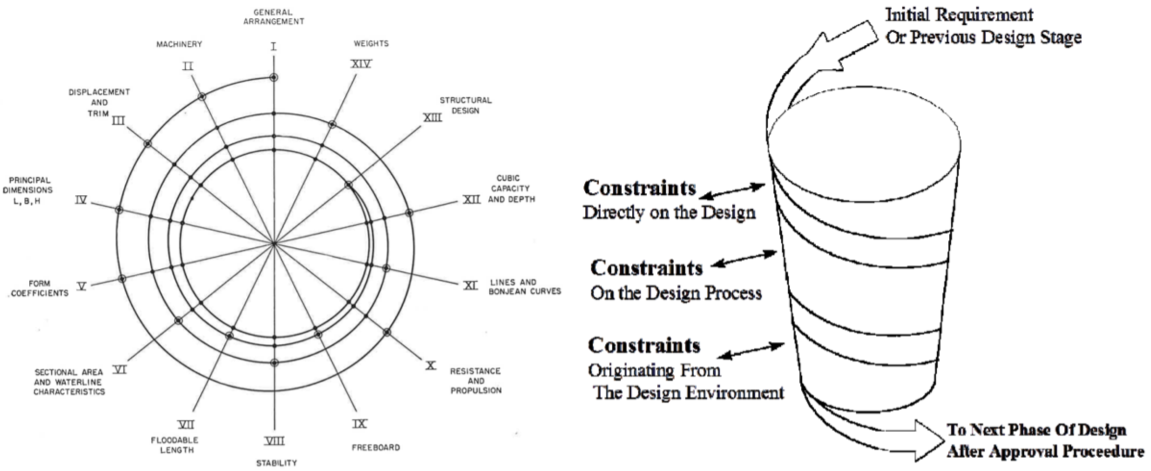


Figure 2.6: Evans' design spiral (left) and Andrews' design spiral (right), [Evans 1959, Andrews 1981].

Developing a ship design gradually unfolds information about the design which may alter the expectations as assumptions are confirmed or falsified and uncertainty clarified. The design spiral approach fails to efficiently integrate the generated knowledge into the process and thus tends to get locked into these initial assumptions. One such assumption generally made in the early stages is concerned with the main dimensions of the ship, often termed initial sizing. This is typically a starting point and subsequent tasks revolve around checking what capacities and performances can fit within this form, hence locking the designer to the initial size [Levander 1991]. The System-Based Ship Design (SBSD) approach aims to address the issue of design lock-in by altering the structure of the ship design spiral. Rather than starting with initial ship dimensions, SBSD first defines functions intended to carry out the mission requirements and establishes areas and volumes or weights required for these functions. The allocation of these functions may be varied along with the ship- dimensions and form in order to arrive at a technically feasible and economically preferable solution. Consequently, the design spiral is "straightened", with more emphasis on needs to function mapping, hence enabling a more correct form synthesis and fewer iterations [Levander 2012].

Similar to the SBSD approach, the Design Building Block (DBB) approach focuses on an initial disposition of systems and functions prior to the assessment of ship form and dimensions [Andrews 1998]. This architecturally-driven approach is a response to Andrews' critique of the traditional "requirements engineering" point of view being too abstract and argues that fulfilling the requirements is highly dependent on assessing visual representations of potential physical solutions in dialogue with the requirements owner [Andrews 2011]. The inclusion of stakeholders in the design dialogue is at the core of ”requirements elucidation” as it enables progressively refining the initial slightly ambiguous requirements. Additionally, a visual rather than a pure numerical representation is argued to be more responsive to concerns issued by the stakeholders, hence increasing the effectiveness of the dialogue.

Advancements in computer power have enabled the exploration of more concurrent methods in ship design as an aid to reducing the overall development time. Two such approaches are VISTA (Virtual Sea Trials) by Erikstad et al. [2015] and HOLISHIP (Holistic Optimisation of Ship Design and Operation for Life Cycle) by Papanikolau [2019]. Both approaches present a platform aimed at enabling parallel development of the different design tasks. VISTA connects a set of disciplines, namely hydrodynamics, power production and auxiliary systems, into a common simulation platform emulating different vessel operations [Erikstad et al. 2015]. Interaction with environmental forces from wind, waves and current is also tested in several contexts to benchmark alternative design solutions and support more robust design decisions. Furthermore, VISTA also takes into account the life cycle performance of the vessel so that the concurrent perspective is maintained not only across disciplines, but in considering variations of performance over time and in different contexts. Similar to VISTA, HOLISHIP considers multiple disciplines of ship design concurrently. It emphasizes that in order to design the optimal ship, it is necessary to consider a holistic optimisation approach of the ship system over its life cycle [Papanikolaou 2019]. Through a common platform, CAESES, HOLISHIP integrates different tools used among the various disciplines to carry out the design tasks identified in the design spiral in parallel by multi-objective and multidisciplinary optimisation [Papanikolaou 2019].

The development of the ship design solutions in digital environments like CAESES and VISTA serve as examples of virtual prototypes, which are common in ship design for verification purposes before the vessel is built [Keane et al. 2017]. The use of physical prototypes, on the other hand, is prevalent in ship design, yet limited. Tank tests, used to predict seakeeping performance and resistance, occur frequently as physical prototyping [Garcia Agis 2020]. However, these prototypes are used relatively late in the design process when changes in the design are hard to comply with. By contrast, other industries use physical prototypes more frequently. For instance ”Snøhetta”, an architectural design company, uses physical prototypes as a means to solicit stakeholder requirements [Fjeldstad and Lunnan 2018]. Prototypes are made directly with the customer and thus in line with the arguments of Andrews [2011] of the advantages of a visual representation, rather than pure numerical representations in the process of defining requirements. This resembles a *Design Thinking* approach, where physical prototypes are developed on the far-from-finished product as a means to ”empathise” with the end user. These are quite low-fidelity prototypes, but consequently also easy to change. The idea is that one may learn about what the user wants through the user’s interaction with the prototype [Liedtka 2018].

Virtual Reality (VR) may be seen as a compromise between physical and virtual prototyping. According to Garcia et al. [2020], VR has potential advantages in ship design, both as a dedicated design tool and as a communication tool for marketing and sales. Although the technology shows potential, it is as of today not suitable as an integrated design tool [Garcia Agis et al. 2020].

Progressing from the Design Spiral to System-based Design and Requirements Elucidation, a shift towards focusing more on upstream ship design activities is apparent. Additionally, more insight might be gained by the use of computer tools capable of making multidisciplinary considerations, with a more holistic perspective. Ship design practices have gradually extended beyond the traditional ship design activities to encompass more of the upstream business case development [Garcia Agis 2020]. A vessel being designed will always be integrated into a broader business opportunity within for instance maritime transport or offshore field development work. The additional considerations posed by this view have not been properly incorporated into traditional ship design practices [Brett and Svensen 2006].

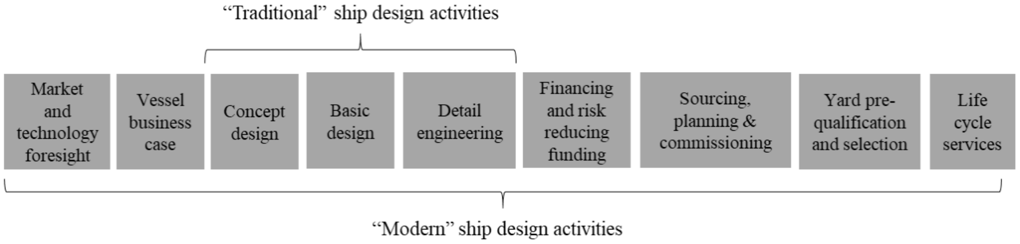


Figure 2.7: Illustrating the extent of modern ship design activities [Garcia Agis 2020, p.86].

The Accelerated Business Development (ABD) framework adapts this business-centred view into the development of a ship design. Starting from a business idea presented by the customer, ABD defines vessel requirements and constraints taking into account the broader commercial, economic and social business aspects which influence the vessel design [Brett et al. 2006; Garcia Agis 2020]. Rather than the architecturally-oriented view advocated by Andrews [2011], ABD relies on generating numerical measures and facts that encompass these aspects. Building on principles from Set-Based Design, the purpose is not to carry out in-depth analyses, but rather to explore in-breath and necessary depth potential factors affecting, in this case not only the vessel design but the business case [Garcia Agis 2020]. This broader view aims to strengthen the designer's ability to properly solicit relevant stakeholder expectations [Brett et al. 2018].

The development of the concept and integrated vessel solution is structured through nine modules as follows [Garcia Agis 2020]. The first four modules of ABD aim to turn the initial business idea into a business concept. This means testing the initial requirements from the customer to ensure the effectiveness of the business solution. The remaining five modules aim to develop the vessel design solution as an integral part of the business concept developed in the first four modules. By means of a range of complementary tools, vessel solutions are benchmarked against competitors to ensure superior performance. An essential tool in this respect, developed to ensure better efficacy in the development of the vessel, is the FTCDA tool introduced in Section 2.3.2. FTCDA acts as a bridge between conceptual and basic design by supporting the corresponding design decisions with statistical approaches like multivariate data analysis and traditional naval architecture procedures [Ebrahimi et al. 2018]. In line with the principles of the ABD framework, the tool evaluates vessel solutions based on the combined technical, commercial and operational performance.

Another approach for structuring the integration of the vessel solution as a part of a business case was presented in [Pettersen et al. 2018]. To better align business strategy with design decisions they stressed the importance of both the problem of defining the problem to solve and solving the problem. This follows the fact that ship design may be viewed as ill-structured problems [Gaspar et al. 2012; Pettersen et al. 2018], and the difficulties in solving these problems may be mitigated by first providing a well-structured problem representation. This may be seen as a way of designing, not only the product but also the process. Somewhat analogous to the DSPT approach presented by Mistree et al. [1991]. Pettersen et al. further demonstrate the Responsive Systems Comparison (RSC) method as an approach to facilitate a well-structured problem representation, in addition to laying out a structured approach for solving the subsequent well-structured design problem. Key to the method is exploring and evaluating trade-offs in the design space (*Tradespace exploration*) to enable identification of design decisions which influences the value of the product for the stakeholders (*value-based decision theory*). Furthermore, RSC also incorporates a way of representing the changing context which may influence the value of design decisions (*Epoch-Era analysis*).

2.4 Value in Ship Design

In ship design value is associated with the development of a description of a product, the ship, and the need or problem it solves for the customer(s), the shipowner (and ship operator). From the perspective of the ship owner/operator, the ship is a resource which supports the activities they engage in. It serves as an input to the intended value creation of their business. The choice of vessel acquisition is a strategic choice based on what they believe will help maximise value creation, it represents a business case on its own and it is the task of the designer to realise it. From the ship designer's perspective, this means bridging the gap between the business space and the technical design space [Brett et al. 2006]. Contrary to the perspective of the ship owner/operator, the ship is in this case an *output* of value creation assembled through a set of activities often including subcontractors like equipment suppliers and/or service providers. These activities constitute the overall design process aimed at realising a vessel solution as an integral part of the business case for the ship owner. As stated by Brett et al.: ”It is not so much the design of the vessel, as it is the design of the integrated business and vessel design solution that counts.” [Brett et al. 2018, p.46].

2.4.1 Value creation logic in ship design

Any business aims to create value for a customer through the activities they perform and the resources they utilise to perform these activities. When the perceived value by the customer surpasses the cost associated with these activities, the business has achieved value creation [Fjeldstad and Lunnan 2018]. Furthermore, a firm whose solutions or services are valued more than that of its competitors is considered competitive. Alternatively, if the costs associated with developing the solution or providing the service are lower than with the competitors, a firm is also considered competitive. Thus, understanding how a business may create value is closely related to achieving competitiveness. How a business creates value may be referred to as their *value creation logic*, where the set of activities they perform and their associated resources describe their *value configuration* [Fjeldstad and Lunnan 2018]. According to Stabell and Fjeldstad [1998] one may distinguish between three types of value configuration models, briefly summarized below:

- **Value Chains** Provide value by transforming input into products. Main activities constitute the operations required to conduct this transformation, activities supporting the logistics of this transformation, marketing and sales, and service. These activities are performed sequentially, in a specific order.
- **Value Shop:** Their value creation logic lies in solving customer-specific problems. The primary activities constitute problem acquisition and clarification, problem solving, decisions, and control

and evaluation. These activities are conducted sequentially and iteratively until a solution that solves the problem of the customer is achieved.

- **Value Network:** Provide value by facilitating a network relationship between people, places and things. Primary activities constitute marketing and contract management, service provisioning, and infrastructure operation. All these activities occur in parallel.

The fundamental notion of design is rooted in problem-solving [Simon 1996], and thus a categorical assessment would define ship design companies as value shops. Value creation typically starts from the customer as the source of a problem definition, initiating the value shop activities of the ship design company as illustrated in Figure 2.8. The first three activities resemble the fundamental design process consisting of need-function-form mapping, iteration, and decision making. *Problem Finding & Acquisition* includes collecting information characterising the need and then defining a set of functional requirements that govern the synthesis of the problem solution. *Problem Solving* is the process of synthesising, analysing, and evaluating solutions according to the functional requirements. Decision-making is represented in the *Choice* activity where the best solution is chosen among those synthesised. The last two activities relate more to how the design description is realised through the build phase succeeding the design phase. Even though the design company does not bear the primary responsibility in this phase, they act as a supplier towards the yard and thus need to ensure that their solution is properly conveyed and successfully implemented. This is mainly addressed as part of the *Execution* activity, including production as well as the preceding design stage which manages the transition from the design phase to production phase by adapting the design description to the shipyard's preferences and qualifications. Finally, the *Control/Evaluation* activity settles whether the ship performs according to contract specification primarily through sea-trial and operation. Figure 2.8 also highlights the iterative nature of problem-solving processes, although iteration in the design mainly occurs as part of the first three activities.

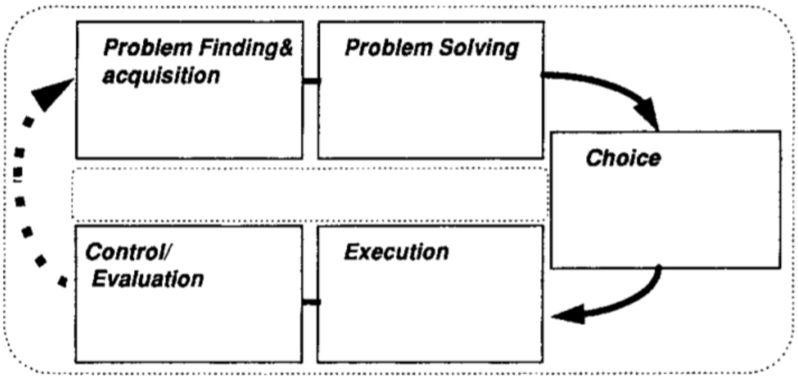


Figure 2.8: Main activities in a value shop, [Stabell and Fjeldstad 1998].

Each design project may require a different set of activities and a unique manner in which these activities are conducted, and the value shop should be configured in such a way that a solution can be achieved that best adhere to the customer preferences. This is not to say that one should unquestioningly take the customer preferences as a given. As stated by Erichsen: ”The user's requirements should be worked out in conjunction with the designers (...)” [Erichsen 1989, p.7]. The key in this respect is to identify what activities to do and how to do them so that the customer's willingness-to-pay exceeds the resources required to conduct these activities. For instance, a typical activity in a ship design project would be to estimate the ship's resistance, where relevant tools would be Computational Fluid Dynamics (CFD) software or empirical formulas like Holtrop Mennen. The resources needed to conduct a CFD analysis way exceeds the resources needed for a calculation with Holtrop Mennen, however, if it is sufficiently valuable for the customer, it may be worthwhile doing. Following this argument, decisions on what activities to perform and how should ideally be made with the knowledge of what resources it requires and how it brings the solution closer to what the customer needs. This is to ensure that the ship design process is well balanced with respect to resource expenditure and the perceived value for the customer.

Figure 2.9 illustrates the main components in a ship design firm's value creation process. In every ship design project, the input is typically represented as a set of needs or expectations which must be interpreted and transformed into a description of the ship. The ship design company possess a set of resources which they allocate to a set of activities governing this transformation. Depending on the design project, the transformation may require a different set of activities and a unique manner in which these are conducted, and the required resource expenditure is likely to vary accordingly. The design description constitutes the output of the value creation process and may be characterised by a set of performance attributes concerning the ship itself as well as the design process. If the ship description provides a ship that can be built and operated efficiently, value is created for the customer, and if the ship description facilitates the customer's willingness-to-pay to exceed the resources required to develop it, value is created for the ship design firm.

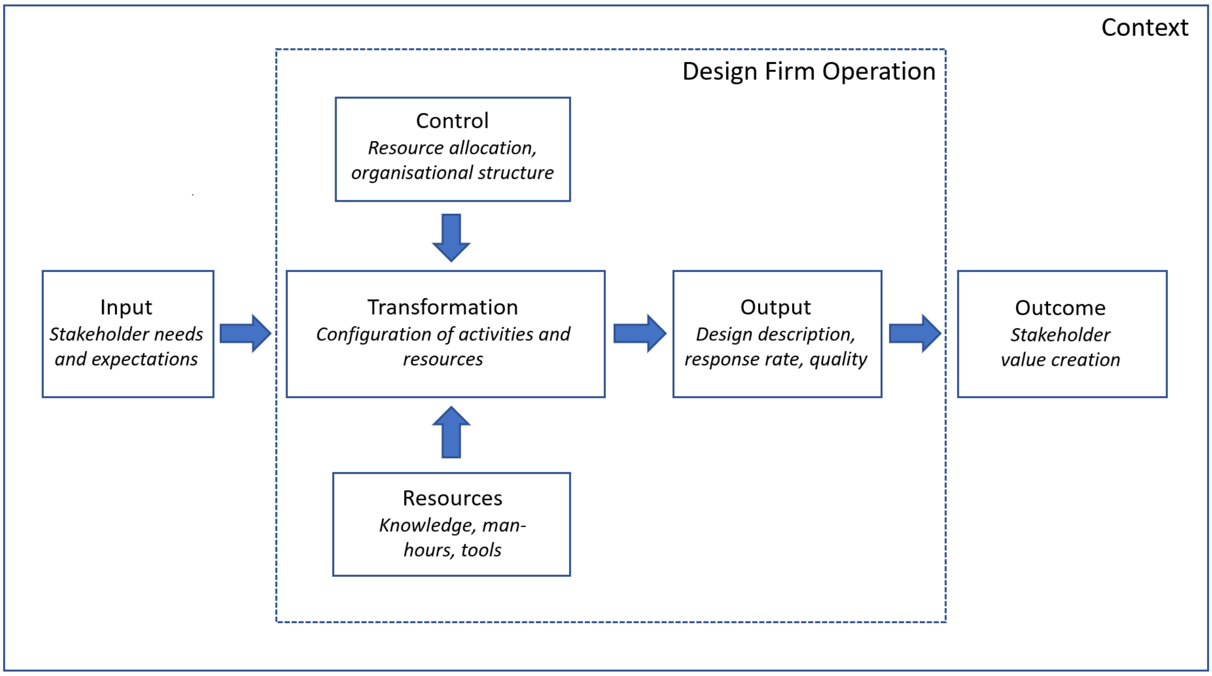


Figure 2.9: Process model ship design

A company's use of resources provides the basis for establishing competitiveness, either by delivering the same product as their competitors at a lower cost or by utilising valuable resources where the ratio of value over resource expenditure is high [Fjeldstad and Lunnan 2018]. Most ship design firms possess the same basic resources such as software and knowledge about the field of ship design. However, the way they are put into action in the ship design process may differ and potentially provide a competitive edge [Teece et al. 1997; Garcia Agis 2020].

A company's ability to create value from the resources they possess governs their value creation capability, where a high ratio of value over resource expenditure yields a high value creation capability. One of the most valuable resources in a ship design company is their knowledge; knowledge about the field of ship design, the ship design process and its tools. This knowledge is held by a company's personnel and thus competent personnel are critical resources in a design project. Yet, a valuable resource does not necessarily infer competitiveness. It becomes competitive when other companies find it difficult to substitute or imitate it, hence providing one company with the ability to deliver something the others cannot [Fjeldstad and Lunnan 2018]. The organisational structure, both physical, social and resource allocation structure governs how these resources are put into action and shape them into competencies [Teece et al. 1998]. As competence cannot be isolated to one factor alone, it becomes much harder to imitate or substitute, thereby providing potential for competitiveness.

2.4.2 Value shop drivers

Categorising ship design activities according to the value configuration models presented in [Stabell and Fjeldstad 1998] facilitates an assessment of the connections between the activities, and the cost and value they contribute to. Considering these *drivers* are critical in exploring how ship design firms may gain the most out of the activities they are conducting. Although one might argue that ship design exhibits characteristics across multiple of the value configuration models, the value shop is considered the most appropriate with respect to the ship design process. Therefore, drivers of the generic value shop will be highlighted further.

Success or lack thereof as manifested by a company's *reputation* is considered one of the most important drivers for value creation in value shop businesses [Fjeldstad and Lunnan 2018]. With more successful projects follows a better reputation which attracts better customers, personnel and collaborators. Better customers are a source of more prestigious projects which may further promote a company's reputation if carried out successfully. Likewise, better personnel and collaborators are central resources which contribute to better knowledge access, as such, improving the company's ability to carry out successful projects.

Since a company's reputation is rooted in the projects they engage in, strategic project selection may be considered an important means to achieve and maintain a good reputation. For each project, the company need to consider whether they have the necessary resources that enable them to carry out a successful project. This must also be weighed against the potential benefit of learning from projects that are somewhat outside their core competence.

Learning is an important feature of the design process as what drives the process towards a solution that meets customer needs. It is a means to generate knowledge about what the customer wants and the product being designed, which improves the designer's ability to produce the intended result. The quicker this knowledge is at hand, the quicker one may make the right decisions and the quicker the process may converge towards a final solution. Value in this respect may be associated with the number of cycles in the value shop diagram in Figure 2.8, partly representing the time it takes to solve a problem. With quicker learning, fewer cycles are necessary, hence increasing the added value.

Like with the development of a company's reputation, learning may also be something that occurs over time across multiple projects [Fjeldstad and Lunnan 2018]. On the one hand, taking on demanding projects may be an important source of learning. A company's competence is shaped by the projects carried out and if a project lies somewhat outside their core competence, they have to acquire new knowledge to succeed with the project thereby expanding the company's competence. Sensing the need for expanded or adjusted competence may leave companies less vulnerable to volatile market situations [Teece et al. 1997], such as in the maritime industry, whether related to ”shipping cycles”, ”economic shocks”, or ”secular trends” like the emergence of new technology [Stopford 2009, p.170]. On the other hand, an unsuccessful project may damage the company's reputation to such an extent that they will struggle to find new projects and attract competent personnel and collaborators [Fjeldstad and Lunnan 2018].

Linkages and *interdependencies* are ever-present among the activities of ship design. This extends from the interdependencies between activities in the firm, between the design firm and the customer and between the activities of the design firm and other external firms involved in the problem-solving effort. The comprehensive ship design problem is carried out by a team, where each team member or group of team members are assigned responsibility for different tasks. The start of one task may rely on the completion of another task hence causing the sequential manner in which activities normally are conducted. Furthermore, the customer is often part of the problem-solving activities as the source of problem definition and continuous feedback. External linkages are also important drivers for value creation, both as means for division of labour and for gaining strategic resources [Fjeldstad and Lunnan 2018]. Ships are complex systems composed of many sub-systems and components. Development of several of these subsystems is outsourced to specialists so that the ship designer may free up resources and focus more on the integration of all sub-systems to the balanced complete system.

Learning and linkages are closely connected. First of all, uncovering what the customer wants and arriving at a set of requirements is a learning process dependent on the linkages between customer and designer. The designer and the customer often work together; the designer communicates design solutions and the customer expresses whether the solution is what they want. Both parties do not possess the same skill level in the field of ship design and thus the designer needs to facilitate for the customer to express their needs as this will both complement the designer and customer. Additionally, due to the succeeding nature of tasks, the effect of learning in one task may propagate through the chain of interrelated tasks. Customer requirements at a certain point in the design process give rise to what activities should be performed, while output from one discipline within the design team may provide input to another discipline in the team. Therefore, when the design team learns something new about the requirements or one design discipline finishes a calculation, other activities and tasks will be affected. If a task affects many other tasks, then it may be seen as contributing to a large amount of the value creation of the overall value shop activities. In this way, the value of one task may be measured through its impact on the definition of succeeding tasks [Stabell and Fjeldstad 1998]. In ship design, soliciting customer requirements and early stage design are examples of such tasks. This is where the drivers are most influential, seeing as, later in the design process the effect of learning is harder to incorporate.

2.4.3 Value propositions in ship design

The perceived value by the customer relates to a set of attributes a company provides through their products and services [Kaplan and Norton 1996; Browning et al. 2002]. Kaplan and Norton [1996] identify these attributes to relate to functionality, quality, price, and time. Different needs within the maritime industry have led to the development of different ship types that span a varying set of functionality. Some have limited functionality, while others are multi-functional. Functionality typically comes at a cost, and vessels that carry many functions are often expensive to design, build, and operate. A broad distinction between ship types separates transport vessels from service vessels, where the main functions of a transport vessel may be reduced to load, transport, and unload, while an offshore vessel ”goes to sea to do something” [Andrews 2018, p.2]. The latter may refer to a broad range of functions supporting various offshore activities, or cruise ships of which service is to entertain its customers. Variations also exist within each segment. Some merchant ships can carry several types of cargo, others carry a single type of cargo, offshore vessels may take on a different set of tasks ranging from development, operation, or decommissioning of offshore assets. Cruise vessels come in different sizes, with different luxury levels, and different facilities onboard, some may operate in polar areas, while others in the Caribbean.

Furthermore, across the different market segments, the importance of functionality, quality, price, and time often varies, which is reflected in production volumes and the degree of customisation of the product offered to the market. The key in this respect is that there should be a match between the characteristics of the product and market segment, and the way the design company assemble their resources and activities [Fjeldstad and Lunnan 2018].

Customised design vs standardised design

Norwegian shipbuilding mainly focuses on *one-of-a-kind* solutions which are highly customised in order to comply with the requests of a specific customer. Other solutions produced in series are typically not developed for a specific customer, meaning that they can be more standardised and still achieve what the customer needs. In practice, standard designs are developed to a large degree before the customer is involved. This includes establishing concepts, developing designs and carrying out engineering activities [Semini et al. 2014]. It is relevant in this respect to introduce the term Customer Order Decoupling Point (CODP), referring to the point in which all downstream activities from this point are linked to a specific customer [Semini et al. 2013]. When the solution exhibits more standardisation, there is less customer involvement and the CODP moves downstream. On the other hand, more customisation is associated with more customer involvement and thus the CODP moves upstream. The dynamics of the CODP is illustrated in Figure 2.10 for standardised and customised design.

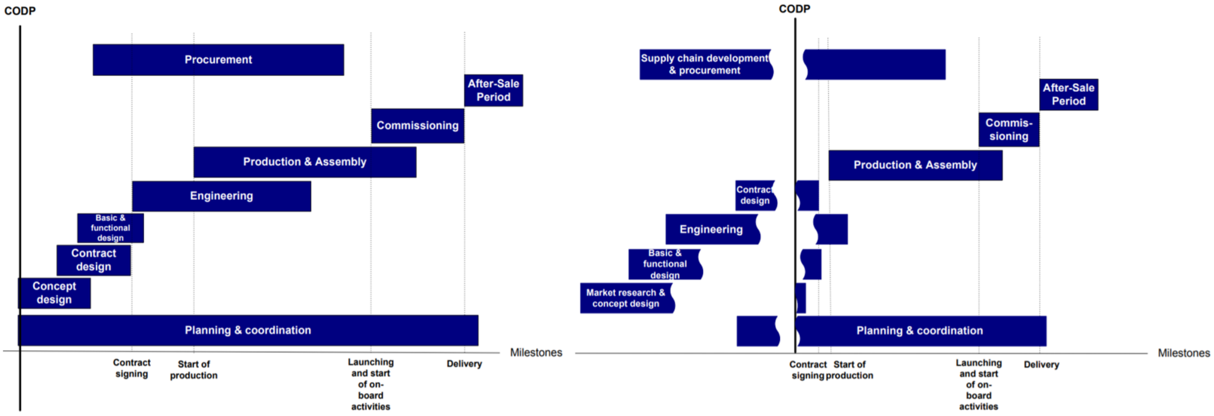


Figure 2.10: CODP Customized design (left) and Standardised design (right), [Semini et al. 2013].

A merchant vessel is typically produced in series and lends itself well to that of an SD strategy. Vessel designs for the cruise- and offshore industry, on the other hand, are typically developed with a CD strategy. Semini et al. [2014] present different advantages associated with the two strategies which may contribute to competitiveness regardless of the market segments a ship design firm prioritises. The SD strategy may cause shorter lead times and more certain outcomes, as well as limited cost and resource requirements. However, the strategy allows for limited customisation and the design firm must put a larger amount of resources into analysing the market in order to have most of the design and engineering work at hand when the Request for Tender arrives. For the CD strategy, however, the CODP lies further upstream, offering more customisation, albeit at a higher cost and less predictable solutions. Thus from a competitiveness perspective, both strategies make sense. In short, the competitiveness of customised design strategy follows the argument of the customer's increased willingness-to-pay as a result of a solution more adapted to their specific needs. On the other hand, the competitiveness of standardised design strategy follows the argument of lower unit cost [Fjeldstad and Lunnan 2018].

Due to both reduced cost and uncertainty associated with the SD strategy, Norwegian shipbuilders have sought to implement some degree of standardisation to their otherwise customised solutions [Ulstein and Brett 2009; Brett et al. 2018]. This is achieved through modularisation, where the vessel solution is already developed as with standardised design, but some customisation is maintained through the ability to vary certain modules of the vessel. Although it may cause a less sophisticated design in terms of tailor-made capabilities, the vessel solution can still yield an attractive performance by meeting the customer requirements in a less costly manner and shorter development time [Brett et al. 2018].

Servitisation and aftermarket

On the one hand, introducing more standardised solutions introduces the risk of not being able to stand out among the competitors in the sense that it is easier for competitors to achieve the same solution. On the other hand, due to the complexity of developing highly customised solutions, transitioning to more standardisation may free up resources, thus allowing the design firm to devote these resources to other potential value-creating tasks. *Servitisation* may be considered among potential value-adding activities the ship designer may engage in and entails "..shifting focus from selling products to selling solutions, by adding services." [Fiksdal and Kathuria 2011, p.17]. An interesting feature of servitisation in the context of ship design is its strong customer centricity. This was described by Olivia and Kallenberg [2003] through two main elements, summarised by Baines et al. [2009] as follows: The firm's offerings are not centered around the delivery of a properly functioning product but rather the efficiency and effectiveness of the customer's activities related to the product. Moreover, customer interaction does not mainly revolve around selling the product, but instead establishing and maintaining a relationship with the customer. In the case of standardised vessels, this may thus be an alternative way of still offering tailored solutions for the customer. A vessel being built should ideally sustain value throughout its life cycle, which currently span at least 25 years. Designing such a vessel is extremely difficult as the ship designer must try to foresee what value-adding activity the vessel may be used for. One way of handling this challenge is to design a versatile vessel which may take on several potential value-adding activities. However, this comes with a significant up-front investment cost [Rehn 2018]. Instead of attempting to foresee the potential value-adding activities for a vessel and design accordingly, an alternative may be to provide a standardised vessel, continuously optimised through servitisation as value-adding activities become more certain. In essence a dynamic product for a dynamic market. Contrasting versatility, this option represents vessel retrofit. *Versatility* and *Retrofitability* are two ways of handling uncertain future needs of the vessel, where the former satisfies diverse needs without the change of form and the latter by changing form. The value of retrofitability versus versatility was investigated by Rehn et al. [2018] who concluded that retrofitability may be of significant value, especially in the case of multi-year contracts.

Retrofits along with conversions, repairs, and consultancy represent value-adding activities a ship design company may engage in regardless of the design strategy they adopt. In recent years when newbuilding activity has been scarce, ship design companies have been forced to find other sources of income. When few new ships are being built, existing ones may still require modifications and/or repair. Newbuilding activity is highly stochastic and aftermarket activities may provide an alternative means of income when the newbuilding activity is low. Each aftermarket project typically requires fewer resources and is less time-consuming, but also provides less value per project [Garcia Agis 2021].

2.5 Summary of Literature Review

Through the literature review, several topics have been covered to better understand the ship design process that might be investigated through the ERP system. This is considered a prerequisite before analysing the information content of the system, both to understand the information within and to define essential elements of information considered necessary to evaluate the applicability of the system.

Every design effort stems from a set of needs or expectations, which in the case of ship design is associated with a shipowner who wants to expand or renew their existing fleet of vessels. Needs and expectations are perhaps too inexplicit to be identified directly from the ERP system, but if specific *projects* are identified, the owner of the data is likely to be aware of the needs and expectations governing the design initiative.

A fleet renewal project is initiated either as an open- or closed tender, or as a FEED contract. In a closed tender, the solution must meet the expectations of the shipowner to be awarded a contract, while in an open tender, the solution must meet the expectations of the shipowner in a better way than the competitors to be awarded the contract. For every tender-based project the ship design company risk spending a vast amount of resources on a project which is lost to a competitor, in contrast to FEED projects where the preliminary solution is paid for upfront. A ship design company's design process governs whether their solution is better or not as well as the *resource expenditure* associated with developing the response.

Different vessels have different functions which might affect the *activities* that are carried out in the design process. Vessel functionality may be split across *departments*, each of which is responsible for a limited set of activities on which they apply different *tools*. The activities that are carried out and how, meaning with what tools, is likely to affect the resource expenditure in a design process, and perhaps also the perceived value by the customer.

Project, department, activity, tools, and resource expenditure constitute elements of information that may provide insight into the ship design company's ship design process. These will serve as a basis for determining whether the ERP system is an appropriate source for describing and measuring activities and resource expenditure.

Chapter 3

Research Methodology

3.1 Research Design

Research design is concerned with how the research objective is to be achieved, including chosen research method and its rationale [Kothari 2004; Creswell 2014]. According to Kothari [2004], research objectives may generally be grouped into the following categories:

- *Exploratory* research aims to gain familiarity or new insight into a phenomenon, typically to be able to come up with a more precise problem formulation for later studies.
- *Descriptive* research seeks to describe particular characteristics of individuals, groups or situations.
- *Diagnostic* research studies the frequency of an occurrence or how it relates to something else.
- *Hypothesis-testing* research studies cause and effect relationships, in essence how one variable is affected by another variable.

Five research objectives are formulated to be able to asses the main research question. Figure 3.1 shows how the thesis is structured with respect to meeting these research objectives. RO1-RO3 are investigated in the literature review, aiming to provide a basis for understanding the ship design practices that might be investigated from a ship design company's ERP system. Through the topics of engineering design fundamentals and approaches it begins with establishing the principal mechanisms behind the process of ship design. It further delves into the more specific ship design process and methodology through associated literature. Finally, to provide insight into the rationale behind choice of activities and associated resource expenditure, the literature review includes a section on value creation and how it relates to ship design. This part may be considered exploratory; gaining familiarity with ship design practices and thereby establishing an opinion of what type of information to look for in the ERP system. RO4-RO5 constitute the remaining part of the thesis and will be met by investigating data from a ship design company's ERP system. As with the literature review, this part is also largely exploratory, but may lean towards descriptive as it seeks to describe characteristics of the ERP system data by quantitative measures.

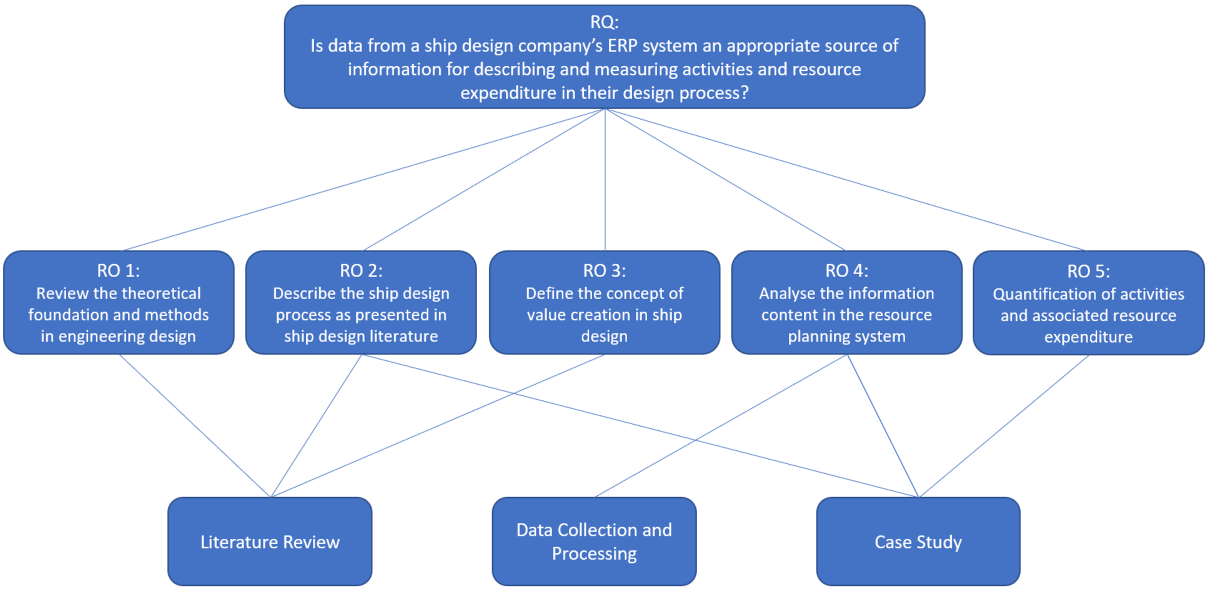


Figure 3.1: Structure of research

3.2 Research Method

The applicability of data from the ERP system will be determined by means of assessing what kind of information it contains and the quality of that information. Ship design projects typically span several months, consist of different activities, performed by different people associated with different departments. Activities may be executed in-house, while others are sub-contracted. They may be performed by simple hand-calculations or may require more time-consuming computer tools. When, what, how, by whom and by which department? These are central questions with regards to what kind of information that may be provided by data from the ERP system and a conceptual model is provided in the figure below:

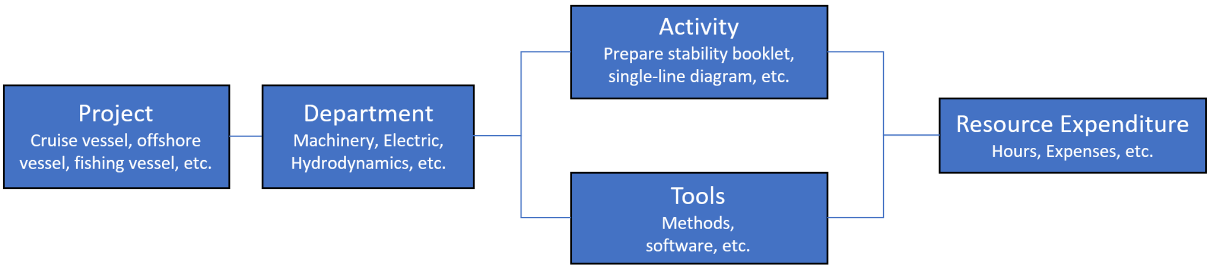


Figure 3.2: Conceptual model of beneficial information elements in data from the ERP system.

Furthermore, the value of this information depends on its quality. If future research is to provide meaningful insight, the data it builds upon needs to be both reliable and valid. Evaluating these two aspects in relation to the collected data will ultimately determine its applicability. Validity involves the degree to which an information element or a set of information elements accurately describes what it intends to [Hair Jr. et al. 2014]. The overall phenomenon the system intends to describe is a ship design company's design process, which is believed to be described by the information elements in Figure 3.2. There are other elements of information that may provide additional insight, but the ones illustrated by the figure are considered essential. Consequently, the validity will increase or decrease depending on the extent to which these elements are present as well as their accuracy. Reliability relates to if the information elements are consistent in what they are believed to measure [Hair Jr. et al. 2014]. If registered activities are inconsistent, it may give an impression that two otherwise similar projects were carried out differently even though they were not. The ERP system may contain all desired information elements, but if none of them are accurate nor consistent, the quality will still be insufficient. With this in mind, the research question along with the conceptual model may be represented as a set of hypotheses. Note that the list of hypotheses is merely for systematic reasons and not to conduct any statistical hypothesis-testing

H0: Data from a ship design company's ERP system is not a valid and reliable source of information to describe and measure activities in their design process

H1: Data from the ERP system contains valid and reliable information regarding activities and resource expenditure on project level.

H2: Data from the ERP system contains valid and reliable information regarding activities and resource expenditure on department level.

H3: Data from the ERP system contains valid and reliable information regarding specific activities and associated resource expenditure.

H4: Data from the ERP system contains valid and reliable information regarding the tools that were used in performing a specific activity.

In these hypotheses an activity is thought of in an hierarchical manner, starting from the basic project level down to a specific activity and the tool used in carrying out the activity. Resource expenditure on a project level does not provide any other information beyond the total resource expenditure in each project and perhaps a temporal perspective. Still, it may prove possible to use this basic information to later test hypotheses like "A higher level of resource expenditure indicates a higher success rate of tender processes.". Increasing the detail level to a department level, resource expenditure may be viewed in light of different departments and their functionality. It is considered reasonable to assume that different vessels and their features will affect the load on each department. For instance, a vessel intended for polar operations will require additional structural considerations in the form of ice class. This may increase the load on the department concerned with structural design as this is considered an essential feature of the vessel value proposition. Furthermore, resource expenditure regarding specific activities is at the core of investigating the ship design process. The design process is composed of a set of activities which require a certain resource expenditure. Ideally, the design process should constitute activities that provide as much value as possible, while keeping a profitable resource expenditure. Thus, in investigating current practices, identifying the specific activities that are carried out and how, meaning with what tools or methods, is of particular interest.

3.2.1 Data collection and analysis method

Data for this study will be collected from a Norwegian ship design company's ERP system. As most Norwegian ship design companies the majority of ship design projects conducted have been within the offshore oil & gas industry, but projects within renewable energy and recreation - revolving around vessels like Service Operation Vessels and Exploration Cruise Vessels - have been dominant in recent years. The data subject to investigation contains information on both completed and ongoing ship design projects from 02.01.2015 to 18.02.2022.

The received data will need to be processed to make it apt for further analysis. As the data already has a defined structure, this will mainly revolve around understanding the existing structure as well as making a decision regarding what information may be relevant for further analysis. These initial consideration will begin to evaluate the validity of data from the ERP system by investigating what information it contains and if it is possible to identify measures for the information elements in Figure 3.2. Further, how the information was registered will give an indication of its reliability.

When the structure is understood, the analysis will further assess the information content and its quality by means of visualisation and simple descriptive statistics. Measures indicating central tendencies and statistical averages, dispersion, and skewness will be adopted and complemented with graphical tools such as histograms and box plots. Histograms are applicable to display frequency of occurrences and shape of distribution, while box plots are commonly applied to display differences across groups [Hair Jr. et al. 2014]. Of the projects registered in the ERP system, the distribution of resource expenditure may give an indication for the resource expenditure in a typical design project. It may potentially vary depending on a number of factors, for instance, ship type, level of complexity/novelty, different customer- and/or shipyard requirements in terms of precision level of drawings, reports, or other documentation, and number of other projects currently under development putting pressure on available resources. Discussing whether these characteristics seem to accurately portray ship design projects will partly assess the information quality from the ERP system. Moreover, in choosing a case or set of cases to study, it is convenient to know something about the larger population it intends to represent [Seawright and Gerring 2008]. In this way, the initial examination of the processed data set will provide a basis for identifying projects subject to investigation in the case study.

The case study aims to investigate the degree to which activities and resource expenditure can be quantified. The investigation will be led by questions such as: What activities does the design process consist of? What are the most resource-demanding activities? Which tasks exhibit the largest variation? Yet, the core of the study is not the numbers themselves, but again whether they seem to accurately portray the ship design projects they are associated with. A limited amount of projects will be considered so as to devote more time to understand the quality of data within the selected projects.

Chapter 4

Data Analysis and Result

4.1 Data Collection and Processing

This chapter describes basic characteristics of the data subject to investigation, collected from a ship design company's ERP system. It gives an introduction of the information elements found therein and describes the processing operations considered appropriate for further analysis.

4.1.1 Data processing

The data was extracted from the company's ERP system and sent to the author as seven separate Excel files which had to be processed in order to facilitate further investigation. Characteristics of the received Excel files are illustrated in the figure below:

Table 4.1: Characteristics of received Excel files

File number	File Size	Rows x Columns	Time Span
1	32 MB	164609 x 27	02.01.2015 - 29.12.2019
2	44 KB	528 x 14	12.05.2017 - 29.12.2017
3	116 KB	1606 x 14	05.01.2018 - 28.12.2018
4	230 KB	3323 x 14	04.01.2019 - 29.12.2019
5	691 KB	11300 x 14	31.12.2019 - 29.12.2020
6	894 KB	14487 x 14	30.12.2020 - 29.12.2021
7	171 KB	2477 x 14	01.01.2022 - 18.02.2022

Apart from the first and last file shown in the table above, each file contains approximately one year of data. File 7 contains data from 2022 up until a few days prior to the day the data was sent, while File 1 contains nearly five years of data. It is further noted that 2017, 2018, and 2019 occur in more than one file. Within each file, a row represents a registered activity. Each activity is characterised by a set of columns, containing different types of information, for instance, the activity name, hours spent on the activity, as well as the name of the project wherein the activity was executed (a complete list of the column names is included in Appendix A.1). With respect to the information included, it is relevant to note that at the end of 2019 the ship design company changed their ERP system, which is reflected in how data is structured in each Excel-file. This includes both the kind of information elements that were registered - meaning that some information only occurs in either of the files - as well as the names of the columns containing different types of information. In Table 4.1, File 1 includes data from the old system, while the rest includes data from the new system. The difference in the number of information elements is evident from the number of columns that are registered in File 1 compared to the rest.

As ship design projects often span more than one year, it is more convenient to handle a single file so that data from a project is not distributed across multiple files. To be able to merge the data, both overlapping dates and different structuring of data need to be addressed. Data from the old system was at first kept as a separate file due to different structuring, while data from the new system was merged into a new file. A closer look at File 1 proved several columns to be irrelevant, and these were therefore removed from the original data set. The irrelevant columns were either duplicates, represented empty rows, or difficult to interpret with respect to the information they contained. After these initial calibrations, the data set was reduced to two Excel-files with the characteristics shown in Table 4.2. The file names are in this case according to which ERP system the data stem from. ”Sys1” refers to data from the old system while ”Sys2” refer to data from the new system. Copies of all original files are stored with the new calibrated files.

Table 4.2: Characteristics of Excel-files after initial calibration

File Name	File Size	Rows x Columns	Time Frame
Sys1	32 MB	164609 x 17	02.01.2015 - 29.12.2019
Sys2	5.5 MB	33716 x 14	12.05.2017 - 18.02.2022

Furthermore, a closer look at the overlapping dates reveals two major differences: i) there is a large peak in the data from ”Sys2” on the final overlapping date, and ii) there is a large difference in the total amount of hours between ”Sys2” and ”Sys1”. These differences may be explained by how data was transferred from the old ERP system to the new one. At the time when the new system was adopted, there were ongoing projects which were necessary to track the progress of. Consequently, data from ongoing projects were transferred to the new system. The earliest starting date for these ongoing projects was 12.05.2017 and hence this is the date where the overlap starts. The overlap ends on 29.12.2019 as this is the last day when the old ERP system was used. The large peak occurs because some of the ongoing projects that were transferred to the new system were re-registered as single-activity entries on a single day. Thus projects which may have spanned several months were registered with their accumulated resource consumption instead of as a set of separate activities with their respective resource consumption. The large difference in the total amount of hours is due to the fact that only ongoing projects were transferred to the new system, while completed projects were not. This further means that ”Sys2” contains incomplete information from 12.05.2017 to 29.12.2019. Therefore, ”Sys1” data is used to cover the time frame up until 29.12.2019 while ”Sys2” covers the remaining dates. To finally merge the two files, information occurring in both ”Sys1” and ”Sys2” were identified and their respective columns were aligned in the new merged file. An overview of the columns is given in Appendix A.1.

4.1.2 Information elements in the ERP system data

Each employee registers daily what activities they have performed, for which projects, how many hours they have spent, and which department they are affiliated with. Exactly how this procedure is carried out in the ERP tool has not been clarified. Yet, by examining the received tabular data, it is possible to obtain a general idea of how the system is structured, which further indicates how the procedure is carried out.

An assumption made with regards to the registration procedure, based on examining the tabular data, is that the first time any of the registered information elements are registered, they have to be typed manually, but once they are registered, later registrations may simply select the appropriate information element from a list in the system. Only ”Project”, ”Department”, ”Activity”, ”Hours”, and ”Date” were used further in this study as the other information elements only occur in either of the original data sets.

Projects are characterised by a project name generated upon project initiation. This name is typically based on the name of the vessel, name of ship segment, name of tender, name of customer, or a project ID. Additionally, some project names are more generic and relate to projects that do not necessarily refer to a specific ship or customer, or even ship design project at all. An example of the latter would be administrative projects. Moreover, as described in Section 2.3 most ship design projects begins by accepting a tender invitation, where design activities before a potential contract are not paid for. These projects represent a contract opportunity and are registered with generic project names that either, indicate directly that they are contract opportunities like ”Prospects” and ”Opportunities”, or names relating to a specific segment or ship type like ”Cruise” and ”Offshore Wind”. It is assumed that if the project turns into a contract, a new project name is registered, and activities will be registered within this project until the vessel is delivered. Thus, a complete tender-based newbuilding project in the data set includes activities from tender invitation to vessel delivery and is registered as two separate projects. In the case of FEED projects, where design is paid for upfront, the project will not be reregistered upon contract signing and simply be registered as one project. There are no information elements in the data-set that indicates whether the opportunity became a contract or not.

Departments are identified by a department name and reflects which department the employee performing the activity is affiliated with. Contrary to the project name, the department name does not change when a new project is initiated. Naturally, a department has the same name regardless of which project the employee is currently working on and as a consequence the appropriate department names are likely to be stored in the ERP system so that employees may simply select them from a list. Employees within a department are considered experts on specific aspects related to ship design, which is somewhat reflected in the department name. It may relate to systems such as machinery, disciplines such as hydrodynamics, or certain parts of the ship like the hull. Some department names refer to a location, which may indicate that the ship design company utilises resources from sub-contractors in other countries. In the original data-set, each activity registration contains information regarding which department the activity was conducted by, but it is not consistent when comparing data from ”Sys1” and ”Sys2”. Variation occurs both in the department names that are included as well as the division and degree of subdivision of departments. For instance, ”Sys1” separates between ”Hull, outfitting and accommodation”, ”Structure” and ”Structure Engineering”, while ”Sys2” classifies Structure, Outfitting, Accommodation, and Ship Weight under the category of ”Hull, outfitting and accommodation”. Furthermore, only ”Sys1” uses department names that refer to a location, which may indicate that all activities from 2020 are performed in-house. However, due to the potential cost-benefits of performing some engineering work in low-cost countries, it is perhaps more likely that this difference is caused by the different structure in the ERP system. It may of course have been decided at one point to not utilise sub-contractors because the integration work was deemed too time-consuming, thereby outweighing the cost-benefit.

Each *activity* is described by an activity name which usually refers to a component or system onboard the ship, for instance, ”Engine Room-Component Layout”, or a specific deliverable, like the stability booklet or general arrangement. It sometimes also refers to an employee role like ”Discipline Lead” and ”Project Planner”. A few entries indicate the tool that was used, for instance, ”Speed & Power (CFD)”. Lastly, quite a few activity names are registered with a customer/tender name or vessel/segment type like ”Ship Owner A” and ”Tug”. For every project, the activity name is assumed to be registered the first time the activity is performed. Thereafter, if more hours are spent on the same activity, the existing activity name is picked from a list of already registered names. Like with the department and department name one would assume that there are activities - and thereby also activity names - that are similar across projects. However, the same activity seems to sometimes be registered with slight name variations across projects. Name variations could of course illustrate an entirely different activity, but some names are unmistakably the same activity. As an example Preliminary Probabilistic Damage Booklet was found with the following names: ”Prelim. Prob. Damage Booklet”, ”Preliminary prob. damage bookl”, ”PRELIM.PROB.DAMAGE BOOKLET”, ”Preliminary prob.damage bookle”, ”PRELIMINARY PROBABILISTIC DAMA”. As shown in Appendix A.1, within each project the activity name seems consistent, but variations sometimes occur when comparing different projects. This supports the assumption that activity names are registered manually every time a new project starts, and once registered, they may be selected from a list. Another thing to note is that, if employees select an activity from a list, it is not unlikely that they accidentally choose the activity above or below the one they intend to pick. Especially when times are busy, they may not notice and thereby register incorrectly. Nonetheless, it seems that corrections occur in the database. Some activities have negative hours, which nullify the incorrect registration. These were confirmed to be corrections by the owner of the data. Finally, it is also possible that someone is not as meticulous with their activity registration and just selects randomly.

Hours and *Dates* are registered with every activity registration. Hours occur in the data set with up to two decimals, for instance, 3.59 hours. Since the number of hours is detailed to the extent of two decimals, it is more likely that the employees register the start time and end time of an activity, rather than the precise hour count. If they for instance type that they started at 12:15 and ended at 13:30, the hour registration may show 1.25 hours. Prior to 2020, resource consumption associated with each registered activity is accumulated to a weekly total and stored as if the entire resource consumption occurred on the seventh day. Resource consumption registered from 2020 is stored with the date the activity was carried out.

A summary of information elements that occur in both databases for every registered activity is presented in the table below:

Table 4.3: Information elements in registered activties

Information Element	**Registration Procedure**	**Detail Level**
Project name	Manual-Typed/-Selected from list	Project type, segment, vessel type/name/number
Department Name	Manual-Typed/-Selected from list	System, discipline, or location
Activity Name	Manual-Typed/-Selected from list	Vessel type, tender/customer name, employee role, ship system, deliverable
Date	Manual	Weekly (-2020) / Daily (2020-)
Hours	Automatic from date	Accumulated weekly / Daily

4.1.3 Data classification

Data classification involves creating groups based on common characteristics in the collected data set. The principal motivation is that by creating homogeneous groups of the collected data, more meaningful insight may be extracted, either by examining each group independently or by comparison across groups [Kothari 2004]. A group may be based on a set of attributes, which in the case of ship design could relate to, for instance, vessel segment and propulsion type. Groups may also be created based on intervals of numerical values of characteristics like vessel length and number of propulsion units. The classification in this study is conducted according to specific attributes. As described in subsection 2.4.3, projects vary with respect to activities, resource expenditure and expected created value. These differences are believed to be captured by grouping them into distinct project types. Furthermore, different departments typically carry out a limited set of activities and incorporate a specific set of tools. A department categorisation may thus provide a useful grouping to reflect on activities and associated resource expenditure. Also, as a consequence of the inconsistencies with respect to department names, a new departments classification facilitates that more data may be considered equally.

Project type classification

The data set contains numerous projects, which vary widely in scope. From smaller engineering consultancy projects like conducting strength assessments, to complete newbuilding projects, the resource expenditure may range from under ten hours to tens of thousands. As this study is mostly interested in newbuilding projects, these should be identified from the rest of the projects. Three main project groups were defined, namely Newbuilding (NB), Aftermarket (AM), and Indirect (IND), each with its own set of sub-groups.

NB projects typically begin with a tender invitation and end with vessel delivery. It includes activities relating to the main design phases, concept-, basic-, and detail design, as well as supervision and support activities during the production phase. All design stages will not be included in every project as the design company may simply have carried out either concept design and/or basic design. For instance, if in a tender-based project and the contract is not won, the project will end in the preliminary design stages. The NB group includes a further distinction between Opportunity, Contract, and Consulting. Opportunity projects and Contract projects constitute the main newbuilding projects, distinguished by whether a contract has been won or not. Based on initial observations of different activity registrations it seems that when a tender invitation is accepted, a project is registered as an opportunity to later be reregistered with a new project name if the contract is won. For projects that are not tender-based, the project is not registered as an Opportunity. Additionally, the ship design company sometimes provide extra resources to other projects where they are not the main developer. This would resemble activities being outsourced to them. In lack of a better word, this is treated as consulting.

AM projects include engineering consultancy projects, retrofit- and conversion projects, as well as projects related to warranty & claims. Either it constitutes a standalone activity, as may be the case for engineering consultancy projects, or it includes a set of activities as would be the case for retrofit- or conversion projects. Warranty & Claims projects may be initiated after a vessel is delivered and constitutes repair- and replace activities that are free-of-charge for the shipowner. Activities in an aftermarket project may be similar to that of newbuilding projects, but each AM project typically requires substantially less time and provide less value. Retrofit, conversion and standalone consultancy projects are all grouped under Consulting, while Warranty & Claims are grouped separately.

IND projects are projects that are not associated with a specific tender or contract. It may be Research & Development, so as to investigate new market opportunities or products, as well as administrative projects like for instance moving data from the old ERP system to the new one. Many IND projects are not paid for, but some may be granted funding, for instance, in the case of researching sustainable vessel solutions.

The main project categories and their respective sub-categories are illustrated in the figure below:

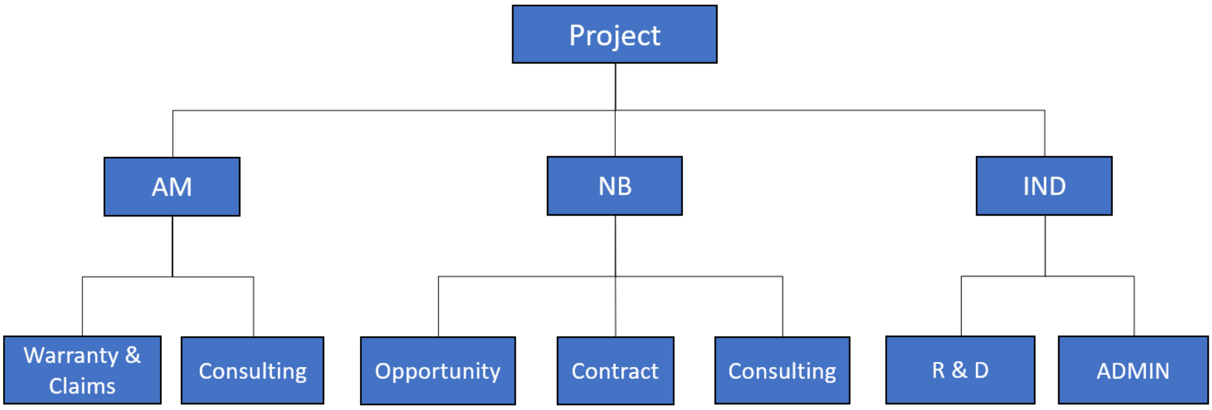


Figure 4.1: Project groups in the data-set

With help from the ship design company, each project in the data set was sorted under one of the categories in Figure 4.1. Many of the projects contained ambiguous names which sometimes made it challenging to identify which category they belonged to. Examples of this may be ’Project’, ’Sourcing’ and ’ENGINEERING’. Still, these projects were few compared to the more transparent ones. Figure 4.2 shows the resulting load on each project category. NB projects occupy the majority of resources every year, followed by IND projects, and finally AM projects. Looking at the yearly development, NB activity had a decreasing trend from 2015 to 2020, but seems to have a positive trend thereafter. The figure seems to reflect the lower newbuilding activity levels during 2020 and 2021 as a consequence of COVID-19 [Norwegian Shipowners’ Association 2022]. Moreover, a gradual increase in AM activities is observed. This is in line with the idea of taking on more AM projects when newbuilding activity is low, as was the case in 2021. Based on these observations, the project categorisation is deemed sufficiently accurate to conduct further analysis.

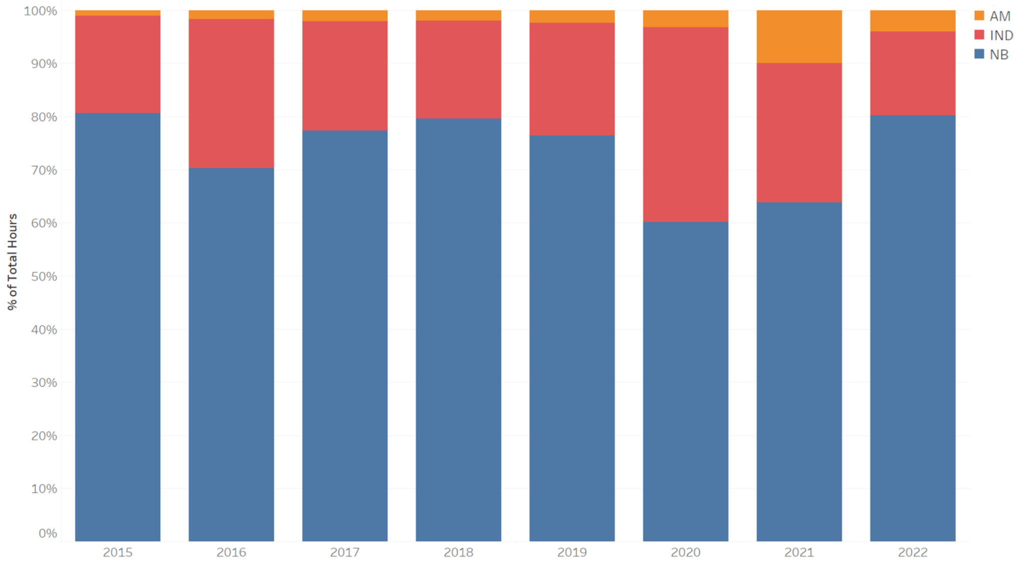


Figure 4.2: Annual resource consumption in main project groups

Department classification

Each department possess a set of specialist knowledge and corresponding tools. Therefore, their tasks and the methods or software they utilise to perform these tasks are usually limited accordingly. Indeed, tasks may involve people from different departments seeing as ships are such integral structures. For instance, preparing the general arrangement (GA) constitutes a highly multidisciplinary activity, where several departments are likely to be represented. Major systems and components, the hydrostatic and hydrodynamic abilities of the hull, its structure-, shape and size all affect the GA. Moreover, it is also likely that departments cooperate prior to the assembly of the GA to avoid too many corrections. Still, if major resource expenditure on a particular project seems to be caused by a department, this may at least give an indication of time-consuming activities and tools. Additionally, variation by department on a set of projects may indicate that different tools were applied within the department across these projects. Another thing to note is that there are naturally fewer departments than there are activities registered in a ship design project. Thus, intuitively, one would assume that there is less variation caused by registration errors in department names compared to activity names. As noted previously, activity names seem to vary when comparing a seemingly similar activity. Therefore, investigating resource expenditure by department may provide a more reliable assessment.

The received data already had a department classification, but as these were different in the two ERP systems it was more convenient to establish new groups that were applicable for both data sets. This was carried out in cooperation with representatives from the ship design company and will be presented below.

Hull, Outfitting and Accommodation is involved in most activities centred around the hull, whether related to shape, size, equipment foundations, interior design, or structural components. It includes activities concerned with the main features of the hull such as defining the hull profile, calculating steel weight, assessing structural integrity, and arrangement of watertight bulkheads. To accommodate large components on board like engines and cranes, foundations are typically necessary to support the hull in certain areas. The associated activities are taken care of by the Hull, Outfitting, and Accommodation department, in addition to other outfitting-related activities like layout anchor and mooring equipment. Finally, activities revolving around the interior design like the layout of doors, arrangement of exits, and structural fire protection are also considered the responsibility of this department.

Machinery & Electrical Systems is involved in the design of all power generating systems whether for propulsion or accommodation purposes, as well as their supporting systems. Activities include preparing plan drawings, piping diagrams and component layout of main engines and generators, switchboard, fuel oil supply, and heating, ventilation, and air conditioning (HVAC).

Hydrodynamics & Stability is involved with all activities that determine the ship's behaviour when interacting with water. Main design features include station-keeping and stability as well as sea-keeping and resistance. Typical activities would be preparing stability booklets, tonnage calculation, inclining test procedure, launching calculation, damage control plan, freeboard calculation, and resistance and power prediction.

Naval Architecture and *System Architecture* have a multidisciplinary role in designing the ship. Naval architecture is typically involved in soliciting customer requirements and activities where different parts of the solution come together to work as a whole. Activities like drawing the general arrangement and component layout of major systems like engine room components are examples of such activities. As ships are composed of many interrelated systems, the System Architecture manage the proper interfacing of these systems.

Design & Engineering constitute activities similar to Hull, Outfitting, and Accommodation and Machinery & Electrical Systems. This group differ slightly from the others as the original department names it consists of related to location and not parts of the ship, systems or components. Most of the activities in this group are carried out by sub-contractors.

Project, *Planning*, and *Logistics* engage in activities centred around planning, follow-up, and coordination. Project typically includes more administrative activities governing the actions of Planning and Logistics, in addition to conveying progress to the customer. Planning creates a project schedule and makes sure the necessary activities are carried out with the right people, in the correct sequence and at the right time to adhere to it. Logistics coordinates suppliers and procurement, making sure necessary equipment and parts are available when needed during the production phase.

Sales & Marketing typically conduct activities in the earliest phases of a newbuilding project, both attracting potential buyers and agreeing on terms for the contract. They engage with the customer and collect information regarding their needs and expectations for the design solution (typically in cooperation with a person from Naval Architecture and System Architecture).

4.2 Data Examination and Case Selection

So far data from the ERP system seems to contain information regarding activities and resource expenditure on project-, department-, and activity level. These observations strengthen H1, H2, and H3. H4 is, on the other hand, not supported due to lack of information regarding the tools utilised in performing a design activity. With project, department, and activity information present, the quality of these information elements needs to be investigated further to be able to answer whether data from the ERP system is adequate to assess the design process of the ship design company. First, a broad consideration will be carried out across a large set of projects to identify the general characteristics of projects in the data set. Based on the observations from the initial investigation, a smaller sample will be selected for the final case study where the goal is to investigate the degree to which activities and resource expenditure can be quantified. The quality of the identified information elements depends on whether the quantified characteristics seem to accurately portray the ship design projects they are associated with.

4.2.1 Case selection approach

The data visualisation software *Tableau* will be used for this task. Access to the software was provided by means of a free student license. The author had some prior experience with the software, but using the software was still a learning process where new convenient features were discovered throughout the process.

Simply being able to identify projects with sufficient quality relates directly to the research question at hand. The more projects that can be identified with sufficient quality, the more appropriate data from the ERP system will be for describing and measuring activities and resource expenditure. The main focus lies on newbuilding projects as this constitutes the main business area of the ship design company investigated and is thus likely to contain more design process relate data. Yet, there is no certainty as to the quality of newbuild projects registered, and thus further examinations of these projects are required.

Different approaches were adopted to identify appropriate newbuild projects. First, the newbuild projects had to be isolated which was carried out by qualitative assessments in cooperation with the owner of the data. Further examination of newbuilding projects was conducted with both qualitative assessments and quantitative measures. Statistical measures were adopted to quantify basic data characteristics and histograms were used to complement the quantitative measures. Each histogram uses bins based on resource expenditure on each project. Tableau customises the bins according to the following formula where n represents the number of projects in the tabular data:

$$No. of Bins = 3 + log_2(n) \cdot log_2(n)$$

A key requirement with respect to the quality of the project relates to the completeness of the project data. Data entry errors or missing data are considered the main causes of incomplete project data in this study. This may occur during activity registration where resource expenditure is registered within the incorrect project, department, or activity. Referring to the resource registration procedure described earlier, these information elements are identified by names and thus either the incorrect name is selected from a list, or new names are registered because the employee is unaware that the name is already registered. The main cause of missing data in this investigation is likely to stem from the limited time span from which the data set covers. The data set includes data from 05.02.2015, thus for a project data set to be complete, it cannot be based on a tender invitation that was accepted prior to this date. Therefore, key milestones like contract signing and delivery should be identified. If contract signing is not available, one needs to consider the time the project was delivered. For instance, if the vessel was delivered in 2015 or early 2016, it is not likely that the project is complete seeing as the data starts from 2015.

4.2.2 Isolating newbuilding projects

Each project contains a project name which was used to organise projects into the project groups shown in Figure 4.1. By classifying projects into *NB*, *AM*, and *IND*, all non-newbuilding projects were disregarded from the sample intended for investigation. As part of the project classification described previously, newbuilding projects were further divided into the sub-groups Opportunity, Contract and Consulting. All these project groups relate to newbuilding projects, but only Opportunity and Contract are part of newbuilding projects carried out by the design company. Consulting includes support-activities to supply other projects outside the organisation with additional resources. Therefore, the sub-groups Opportunity and Contract constitute the main focus of further investigations as indicated in Figure 4.3. From here on, unless otherwise stated, newbuilding projects are treated exclusively as the Opportunity- and Contract sub-group.

Assuming that a tender-based newbuilding project is registered as two separate projects before and after the contract is signed, a complete design project typically includes both an Opportunity project and a Contract project. Therefore, if all design activities in the project are to be investigated as part of a single project, the Opportunity project needs to be connected to the relevant Contract project. However, since there is no information in the data set that indicates whether the Opportunity project became a Contract project, there is no obvious way to connect these projects, and further investigation will therefore be carried out on each project group separately.

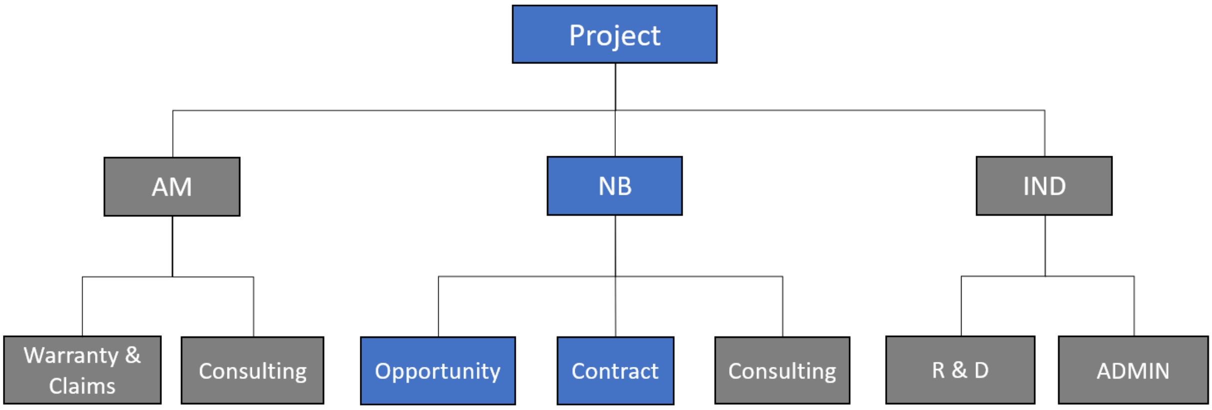


Figure 4.3: Project groups subject to investigation (highlighted in blue).

4.2.3 Examining the newbuilding projects

The newbuilding data set contains 658 831 hours of newbuilding projects (excluding consultancy), whereby 68% constitute Contract projects and the remaining 32%, are Opportunity projects. These hours are distributed across 182 project names, where 59 of them belong to the Opportunity group and the remaining 123 to the Contract group. A summary of their main characteristics are illustrated in Table 4.4. The difference between the mean and median value indicates that the data set does not follow a normal distribution. Consequently, the central tendency is better described by the median, and the quartiles are better estimates of the spread than the standard deviation. The median value is lower than the mean which further indicates that the data is skewed to the right. The upper and lower quartiles indicate a large spread. Furthermore, a surprisingly small difference is observed between the project groups.

Table 4.4: Descriptive statistics of newbuilding project groups

	Statistical measure						
Project group	n	Total Hours	Mean	Median	Std. dev.	Upper Quartile	Lower Quartile
NB	182	658 831	3620	469	7838	3173	54
Opportunity	59	213 065	3611	464	8024	2725	62
Contract	123	445 776	3624	475	7780	3294	51

Figure 4.5 displays the distribution of these projects with respect to the total hours spent on each project. The figure illustrates a clear tendency toward the lower part of the hour scale thereby confirming what was indicated by the characteristics in Table 4.4. The majority of projects do not exceed 2500 hours, regardless of whether they are opportunities or contracts. Along the ”tail” of the figure, both project groups are represented.

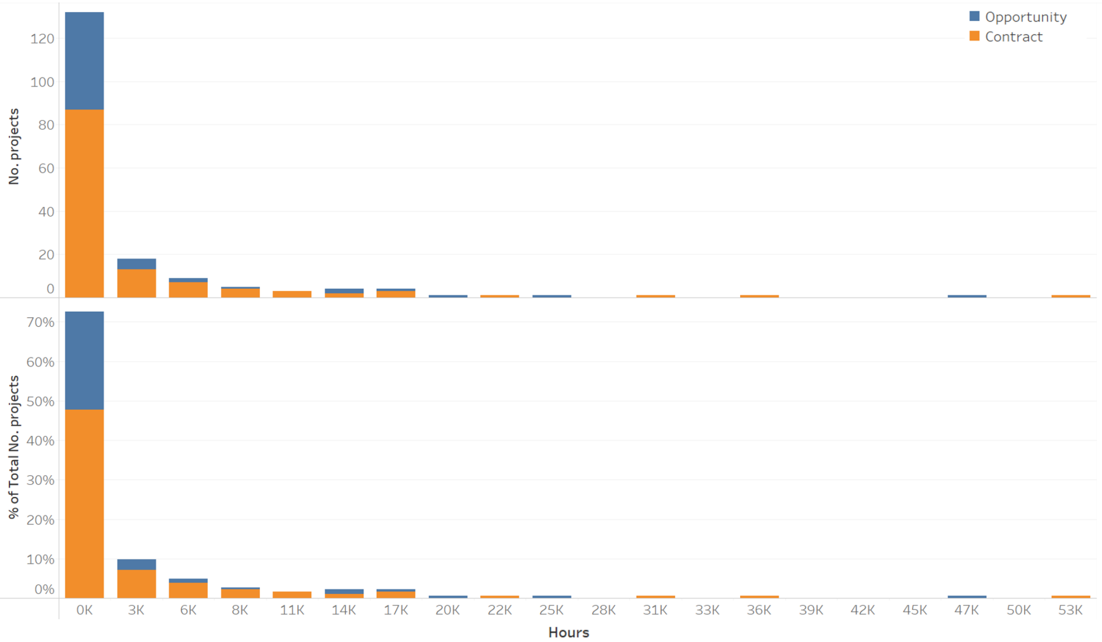


Figure 4.4: Newbuilding projects distribution (bin size = 2788)

For tender-based projects, a measure for competitiveness could relate to the number of won projects over the total number of projects as follows.

$$\text{Opportunity success rate} = \frac{\text{No. Contract Projects}}{\text{No. Opportunity Projects}}$$

Seeing as tender-based projects are assumed to be reregistered with a new project name if they turn into a contract, every Contract project is found among the opportunity projects. If all Opportunity projects ended up with a signed newbuilding contract, there would be an equal amount of Opportunity- and Contract projects and a 100% success rate of opportunity projects. The share of each project group in Table 4.4, however, indicates more than 100% success rate. One explanation could be that there are many FEED projects where no Opportunity was registered. Yet, the main explanation is likely to be the registration procedure where all opportunity projects are registered under a few generic project names. Thus what is identified as a single project from the project name may in fact constitute several projects. This further explains why several Opportunity projects occur among some of the more resource-demanding projects, seeing as the total hours associated with an opportunity project name may be the sum of many projects. Consequently, the project name does not indicate accurately the number of Opportunity projects, nor the number of hours in those projects. Pre-contract project typically never precede the basic design stage where the accumulated hours according to Garcia Agis [2020] typically remains below 3000 hours. Post-contract projects, on the other hand typically require more resources, which is in contrast to what is depicted in Figure 4.4. Many Contract projects occur in the lower left part of the hour-scale. Some of these could simply be paid-for concept studies and or basic design work where fewer hours will be necessary compared to a complete newbuilding project. Yet, as the design company mainly operates on a ”no-cure-no-pay” basis, other explanations may be more representative. Still, if assuming that some of the projects are not tender-based projects, it becomes necessary to distinguish these from the tender-based projects for the success rate measure to make sense. If it is possible to identify a set of Opportunity projects O and a set of Contract projects T from a tender process, the opportunity success rate (OSR) may more accurately be expressed as:

$$\text{OSR} = \frac{|T|}{|O|}, \quad T \subseteq O$$

where $|O|$ and $|T|$ refers to the cardinality of the sets of both respective project groups, and T is a subset of O. In this way all Contract projects from a tender-based process are found among the Opportunity projects.

Examining newbuilding projects - Opportunity

What may be more interesting than simply identifying how many projects end up with a newbuilding contract, is whether resource expenditure seems to affect whether the contract is won or not. According to the success rate measure, a set of Opportunity projects and Contract projects need to be identified first. Within a given time span n of the total time span N, the ship design company have accepted a set of tender invitation and carried out a set of opportunity projects. For each project within the given time span, they allocate a number of hours x_{on}, and the contract is either won or lost. In this way it may be possible to compare resource expenditure in different time spans and whether it affects the success rate.

$$\sum_{o \in O} x_{on} \xrightarrow{\text{Relationship?}} \left(\frac{|T|}{|O|}\right)_n, \quad T \subseteq O, \quad n \in N$$

The project name does not give any possibility of identifying unique opportunity projects, however, further examination of opportunities reveals that individual Opportunity projects can to some extent be identified from the activity name. Activity names in the Opportunity group refer to either customer/tender name or vessel type/segment, or the actual design or engineering task. The activity names that refer to the actual task or vessel segment may include accumulated hours from several opportunities as with the project name. On the other hand, if instead the customer or vessel name is indicated in the activity name, it is more likely that it refers to a unique opportunity project. Of the 520 activity names within the opportunity group, 262 activity names refer to either the customer/tender or vessel type. Two activity names were registered with negative hours and zero hours and were both disregarded. Thus, half of the activity names remain, which may possibly be identified with individual Opportunity projects. If the number of activity names is representative of the number of projects, the number of Opportunity projects is in fact higher than the number of contracted projects. This is more in line with what is expected from ship design companies along the coast of Norway which mainly operate on a no-cure-no-pay basis. The 260 projects amount to 92 293 hours, corresponding to 43% of the total amount of hours in the Opportunity group. Table 4.5 shows the updated characteristics for the selected sample of Opportunity projects. The basic characteristics of these projects demonstrate some similarities with Table 4.4, but the values are downscaled considerably. The mean and median values still indicate a right-skewed distribution, and the quartiles suggest a significant spread.

Table 4.5: Descriptive statistics of opportunity projects

	Statistical measure						
Project group	n	Total Hours	Mean	Median	Std. dev.	Upper Quartile	Lower Quartile
Opportunity	260	92 293	355	118	625	362	27

The distribution of the selected Opportunity projects is depicted in Figure 4.5. The tendency is still towards the lower part of the hour axis, with the majority of projects below 250 hours. Two projects exceed 3000 hours and are identified to the far right in the plot, slightly separated from the rest.

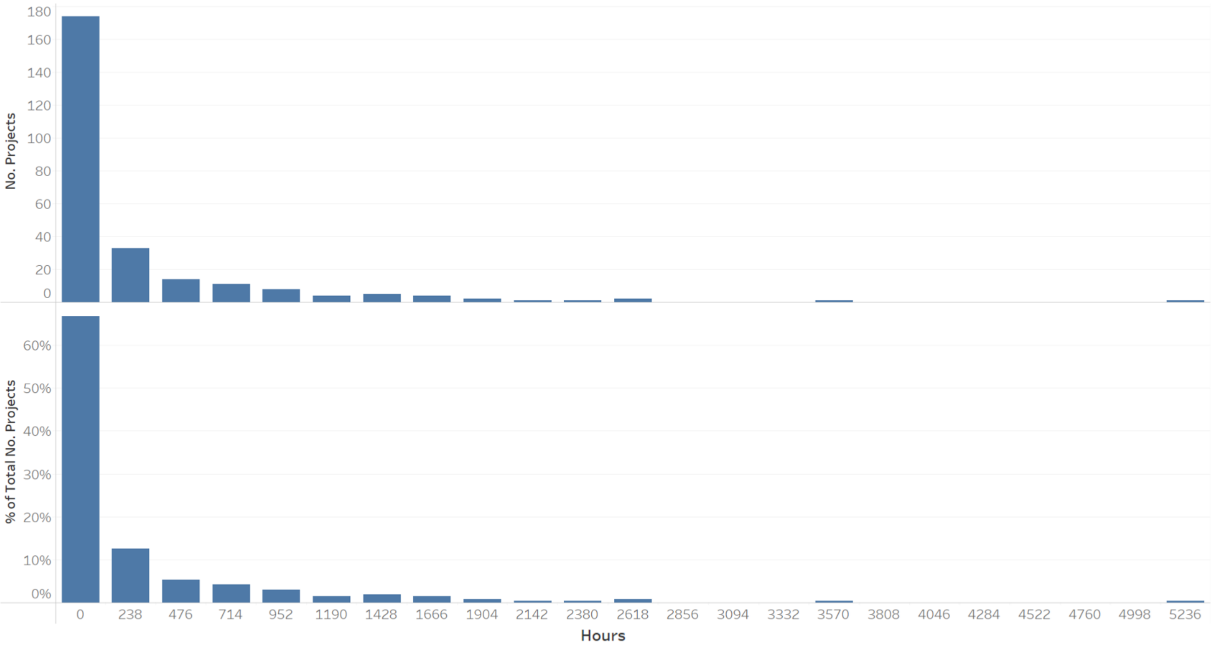


Figure 4.5: Distribution of opportunity projects (bin size = 238)

These characteristics assume that the customer/tender name and vessel type indicate a single Opportunity project. Activity names that include both vessel type and customer name are likely to represent a single project, but if the activity name only includes either, this assumption may be challenged. The design company has a portfolio of standardised designs which according to many of the activity names are used as a basis for responding to tenders. Furthermore, the design company focus on a limited range of segments where the same customer is likely to issue several requests for tenders within a given time range. Therefore, as the same vessel types are likely to be used several times, and the same customer is likely to issue several requests for tenders, either of these alone is not sufficient to identify a single project. Supplementing the name information with the date may help distinguish between projects with the same customer and/or vessel type. However, there may also be tenders simultaneously that use the same vessel type as a starting point, thus adding the date may not be sufficient. Another challenge may occur if the activity registration is inconsistent. It may for instance be registered by one employee with the vessel type, by another with the customer/tender name, and by a third with the actual task. Consequently, projects that are identified as unique according to the activity names may in fact refer to the same project.

From these considerations it is evident that there is a lack of information in the Opportunity group. On the one hand, if using the activity name to identify individual Opportunity projects, the actual design or engineering tasks will not be given. On the other hand, if investigating the actual design tasks, the specific project will not be given. In either case, the departments are fairly often provided. 84% of the total hours include department information, and of the 260 activity names that may possibly be identified with distinct projects, 70% include department information. Regardless, lack of activity information makes it challenging to identify the details of the tender response practices from this data.

Examining newbuilding projects - Contract

The group of contracted projects constitute 445 776 hours in total, which is considerably higher than the Opportunity group. As with the Opportunity group, a right-skewed distribution is evident from Figure 4.6, however, project duration is about tenfold, with most projects below 3200 hours compared to 250 hours. Three projects are located along the ”tail” of the figure, amounting to 28% of the total resource expenditure in the Contract group

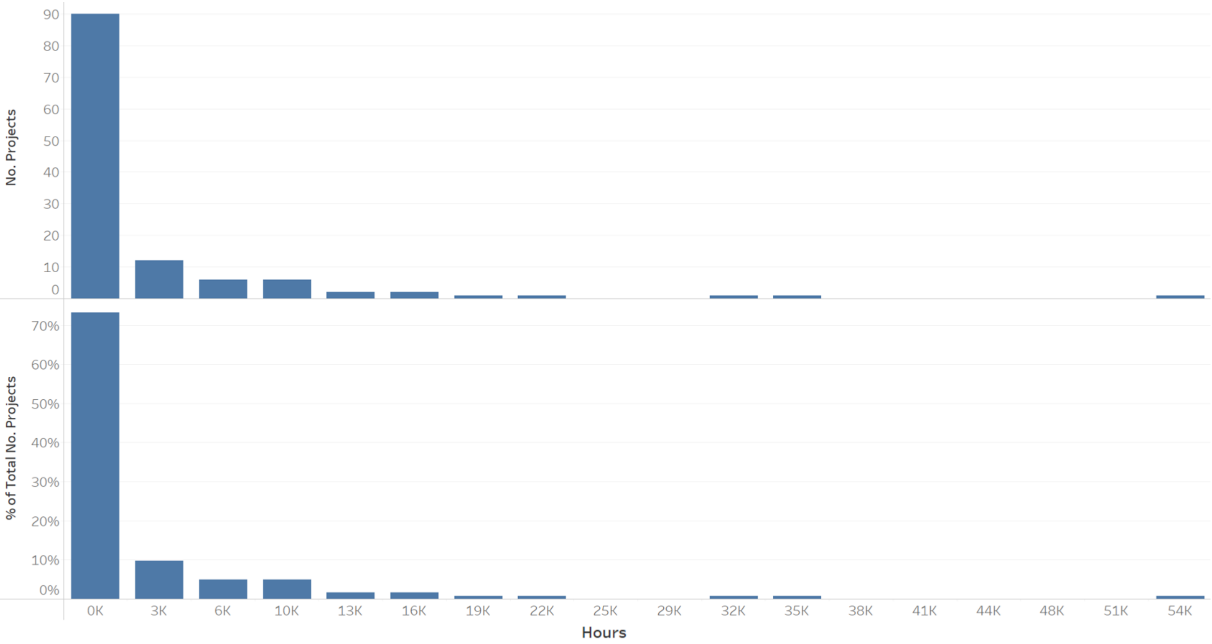


Figure 4.6: Distribution of Contract projects (bin size = 3168)

Even though hours per project seem higher for the Contract group than the Opportunity group, they are still considered lower than expected if assuming that the design company oversees the production of the vessel after the description is handed over to the yard. This assumption may of course not hold true. There may be several projects part of a series where very limited design work is carried out, projects may be incomplete where either, most of the work is carried out outside the time span of the data set, or the design project is not yet completed. Moreover, the Contract group may also include projects where only concept- and or basic design is carried out. If there is a majority of these types of projects, the distribution may be considered more accurate. Still, the lower quartile in Table 4.4 suggests that several projects were carried out with very few hours. It is not likely that a newbuilding project is completed with only 51 hours. If taking a closer look at project names it seems that some projects are registered with more than one name even though they refer to the same project. This may add to the explanation of why the majority of projects do not exceed 3000 hours.

Projects that have turned into a contract include more information than Opportunity projects. Where Opportunity projects simply include information on either project name or activity name as well as hours and date for each registration, contracted projects include information that indicates the activity that was carried out, as well as the department the employee who carries out the activity is affiliated with. Hence, Contract projects may allow for a more detailed investigation if the additional information elements are considered reliable.

The department classification described in Section 4.1.3 splits departments into the categories shown in Table 4.6. The table indicates the number of projects where the respective departments are represented. For instance, about half of the 123 projects include activities carried out by the Machinery & Electrical Systems department, while the HVAC department only participated in one project. All the statistical measures only take into account projects where the department participated. None of the 123 projects are identified with every department represented. One project includes nine departments, where Planning, HVAC, and ADM, HR, Finance are not represented. Most projects seem to only have one or two departments represented.

Table 4.6: Descriptive statistics of departments.

	Statistical measure						
Department group	n	Total Hours	Mean	Median	Std. dev.	Upper Quartile	Lower Quartile
All departments	123	445 776	1046	177	2513	734	25
Design & Engineering	58	186 751	3 220	572	4 960	4 163	110
Hull, Outfitting, and Accommodation	67	67 189	1 003	164	2 070	612	27
Machinery & Electrical Systems	60	63 569	1 059	228	2 491	862	29
Hydrodynamics & Stability	46	28 946	629	292	1012	789	49
Naval Architecture	52	19 081	367	99	602	449	22
System Architecture	18	5 329	296	116	396	462	26
Project	57	35 707	626	235	891	841	12
Planning	8	271	34	29	30	63	7
Logistics	30	10 160	339	150	445	459	27
Sales & Marketing	13	27 535	21184	190	3 339	1 434	82
ADM, HR, and Finance	5	319	64	55	52	73	45
HVAC	1	7	-	-	-	-	-

If all projects within the NB group are in fact newbuilding projects, then most departments should be represented. There may be several reasons for this deviation: there may have been an error during registration where the incorrect department was registered, the department classification may be inaccurate, or the project may simply not be a newbuilding project. Yet, the main reason is likely that projects are in several cases registered with more than one project name, thereby causing only a share of departments to be included in each project. If all relevant project names for a project are identified, a larger share of departments will be included.

Another thing to note is that one would perhaps not expect Sales & Marketing to be registered on projects that are contracted. Sales & Marketing is perhaps more likely to be more involved prior to the contract is won, as part of Opportunity projects or indirect projects. Yet, as Sales & Marketing are likely to be highly involved in making the contract agreement, they may also be involved with contract-related activities during design or production like variation orders.

There is considerable variation in the amount of hours per department in each project. If assuming that each department conducts a limited set of activities, then the cause of this variation may be related to the activities that were conducted in each project. The number of activities, the tools used in conducting the activity, or the productivity of the individual employee may affect the number of hours conducted by a department in a specific project. These aspects may for instance be affected by vessel characteristics and familiarity with vessel segments. Variations are to be expected, especially for design projects in Norway where the main focus is centred around *tailor-made* solutions.

There are in total 2048 activity names in the Contract group. Table 4.7 shows how the number of common activities across projects varies with the number of projects considered simultaneously. It indicates that there are very few projects were activities reoccur. If studying each project separately, every activity is found by adding up all activities in each project. If instead studying common activities across ten or more projects, there are at most 33 different activities that satisfy this condition. The maximum number of projects where a common activity may be identified is 26. Figure 4.7 shows the common activities that occur in at least 15 projects and the variation in number of hours for the projects where they are registered.

Table 4.7: No. common activity occurrences y dependent on no. projects x.

	Common activity occurrences						
x	1	5	10	15	20	25	26
y	2048	106	33	22	9	2	1

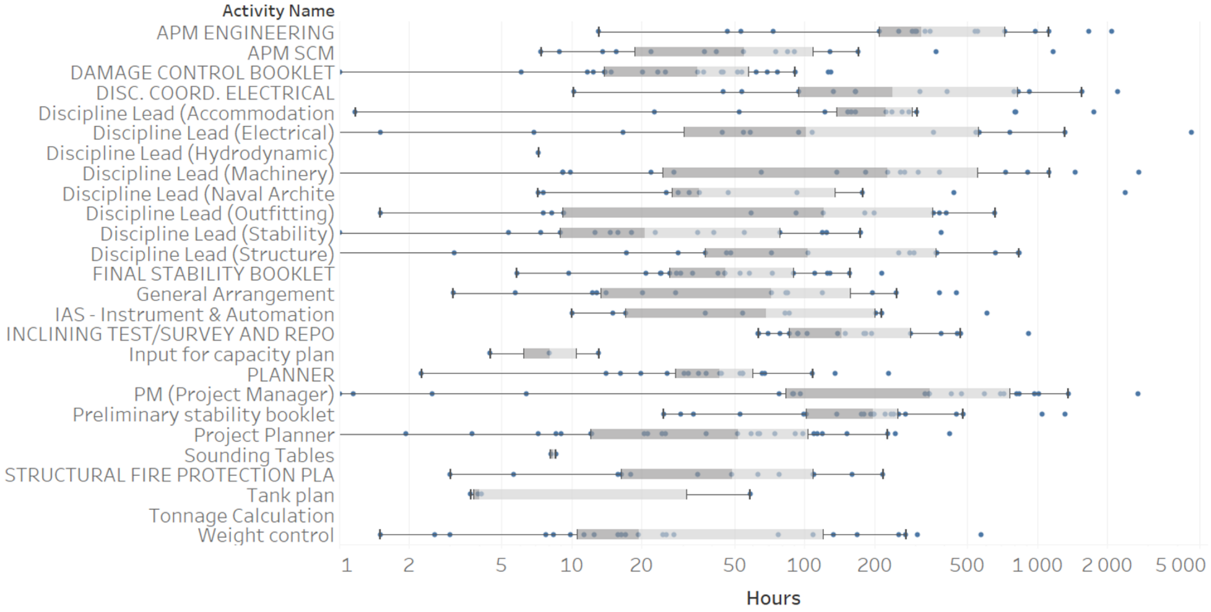


Figure 4.7: Common activities in at least 15 projects.

4.2.4 Summarising characteristics from initial data examination

Through investigating basic characteristics of the NB group there are some preliminary conclusions that may be drawn regarding the information content in data from the ERP system. Table 4.8 summarises the preliminary findings related to the information content, green check marks indicating where the data seems to provide good information, yellow where information is lacking but may be collected, and red x's where there is no information. These findings further strengthen H1, H2, and H3 although the two project subgroups vary with respect to the information they provide. Contract projects provide more information than Opportunity projects and further analysis may have to be limited accordingly.

Opportunity projects provide information on the total resource expenditure for a given time span. Each registration is dated so that resource expenditure within different time spans may be investigated. Studying resource expenditure in any further detail in this project group is possible, but it has its limitations. Resource expenditure on specific projects might be identified through the activity name which indicates vessel type and or customer/tender name in 260 out of 520 activity names. Other activity names refer to the actual design task, but may not be identified with specific projects, thereby ruling out the possibility of investigating differences with respect to activities carried out in each individual project. Department information is given in 70% of the 260 activity names that may be identified with unique projects.

Contract projects include all information elements except *tools*, but the quality of these elements is still uncertain. Name variations - both project name and activity name - has limited the examination so far. Different project names made it difficult to quantify the occurrence of different departments in each project. It is assumed that for a complete newbuilding project, most departments should be represented. However, as projects are registered with more than one project name, a single project name rarely includes more than a few departments. Furthermore, of the 123 Contract projects, only 22 activities where registered on 15 or more projects. Even though Norwegian ship design company's focus on *tailor-made* solutions, one might expect there to be more overlap in the activities that are carried out.

Apart from different project names lowering the resource expenditure associated with each project name, there are probably other projects in the group where the design company did not follow the entire development process from contract to delivery. These projects naturally require fewer hours.

Table 4.8: Summary of information content in NB projects

	Information Element				
Project group	Project	Department	Activity	Tools	Resource expenditure
Opportunity	✓	✓	✓	✗	✓
Contract	✓	✓	✓	✗	✓

Supplying the preliminary examination with a more in-depth investigation in a case study intends to determine the quality of the identified information elements. The quality of department- and activity measures should be investigated further and thus the case to be studied should include both these information elements. With the results from the preliminary examination, this leaves out every Opportunity project, since they lack activity information. Further, since there seems to be considerable variation in both department and activity, two projects will be investigated for comparison purposes. It is important to determine whether these variations are reliable and not simply a result of inconsistencies in the registration procedure. Relatively similar projects will be chosen where one would assume less variation. In this way, potential causes of variation remain limited, so that variation may perhaps be isolated to quality.

4.3 Case Study

The vessels subject to investigation are both relatively new exploration cruise vessels, renamed Vessel L and Vessel S to preserve anonymity. Vessel L is composed of four project names while Vessel S is composed of two project names. Appendix A.4 highlights the location of these projects in the histogram of resource expenditure in the Contract group. The case study begins with presenting an overview of basic project characteristics, before proceeding with the assessment of resource expenditure on project level, department level and activity level. The case study is concluded with an interpretation of the results, discussing whether they seem to accurately represent the design projects they intend to.

4.3.1 Case presentation

Even though both vessels are designed for the same overall segment, there are some differences worth mentioning with respect to vessel characteristics and build strategy. Vessel L is a medium-sized vessel, slightly more sophisticated in terms of the machinery system and structural features compared to the smaller Vessel S. Vessel L was built at a hull yard in Europe, then towed back to Norway for outfitting, while Vessel S was built entirely in China.

A timeline tracking resource expenditure for both newbuilding projects is illustrated in Figure 4.8, with highlighted key milestones. ”Contract Announcement”, as the name suggests, refers to when the newbuilding contract for the vessel was announced. ”Steel Cutting” marks the first step in the production process, while ”Outfitting” marks the initiation of work such as installation of pipes and machinery and cabling and electrical systems, sometimes carried out after the main hull work is completed. Notice that ”Outfitting” is omitted for Vessel S since the vessel was built entirely in China. ”Launch” refers to when the vessel is launched from the dock and ”Delivery” when the vessel is delivered from the yard to the owner.

The total resource expenditure for Vessel L amounts to just over 50 000 hours, spanning a total duration of 43 months, while the total resource consumption for Vessel S amounts to just over 55 000 hours, spanning a time period just short of 33 months. Looking at resource load over time for Vessel L, a gradual increase is evident up until the milestone ”Steel Cutting”, before decreasing thereafter. Vessel S had a steep increase the first five months after the contract was announced, and contrary to Vessel L, the resource load decreased considerably before ”Steel Cutting” began. Reductions in resource expenditure are evident during Christmas and summer break for both vessels. Another thing to note from Figure 4.8 is that vessel L includes resource expenditure prior to the contract was announced, while Vessel S does not.

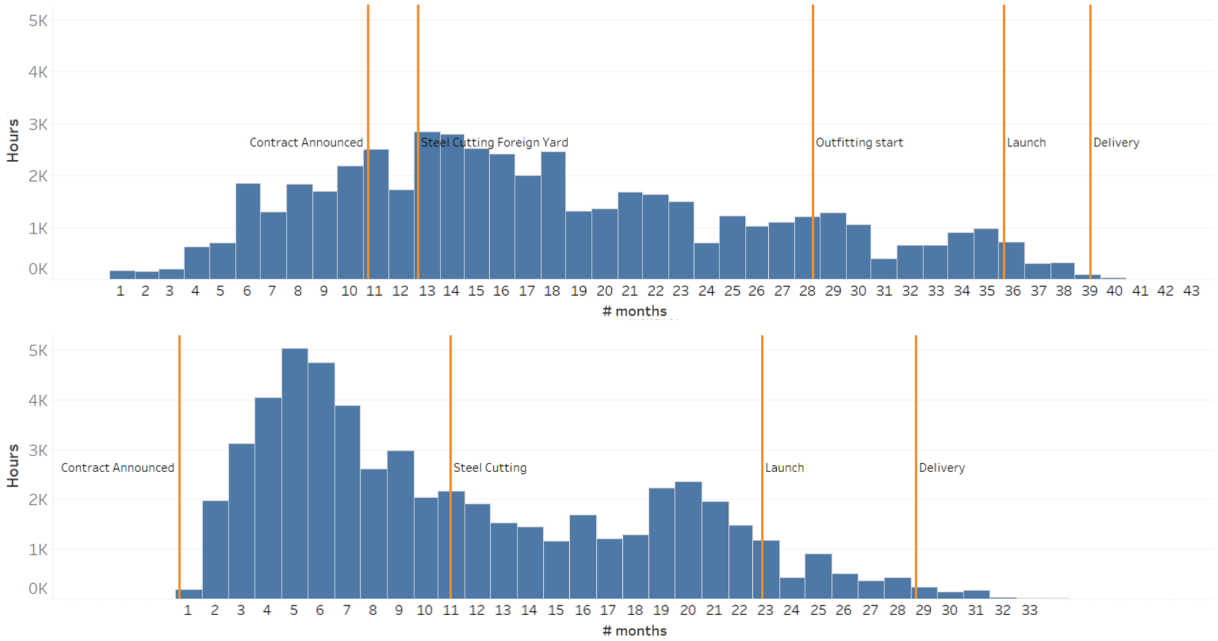


Figure 4.8: Total resource expenditure and duration of newbuilding projects: Vessel L and Vessel S

Taking a closer look at resource expenditure by department, Design & Engineering (DE), Hull, Outfitting and Accommodation (HOA), and Machinery & Electrical Systems (MES) occupy the majority of hours spent in both projects. Logistics, Planning, System Architecture (SA), and Naval Architecture (NA) were the least resource-demanding departments. Planning and Sales & Marketing participated only on Vessel S. The latter constitutes nearly 7000 hours, which is approximately 13% of the total resource expenditure on Vessel S, and more than the difference in total resource expenditure between the two vessels. Among the most resource-demanding departments, DE and MES demonstrate large variations between the two vessels. DE is more resource demanding for Vessel L, exceeding Vessel S with 9000 hours, while MES is more resource demanding for Vessel S, exceeding Vessel L with 8000 hours. HOA demonstrate less variation, with Vessel L demanding an additional 1200 hours compared to Vessel S. Even though NA is one of the least resource demanding departments, the relative difference between the two vessels is substantial. Where Vessel S merely required 102 hours, Vessel L required 2110 hours, which amounts to more than 20 times that of Vessel S. HS is the second most consistent department behind HOA, indicating a 15 % increase from Vessel S to Vessel L. Logistics is barely represented, with under 20 hours for both vessels.

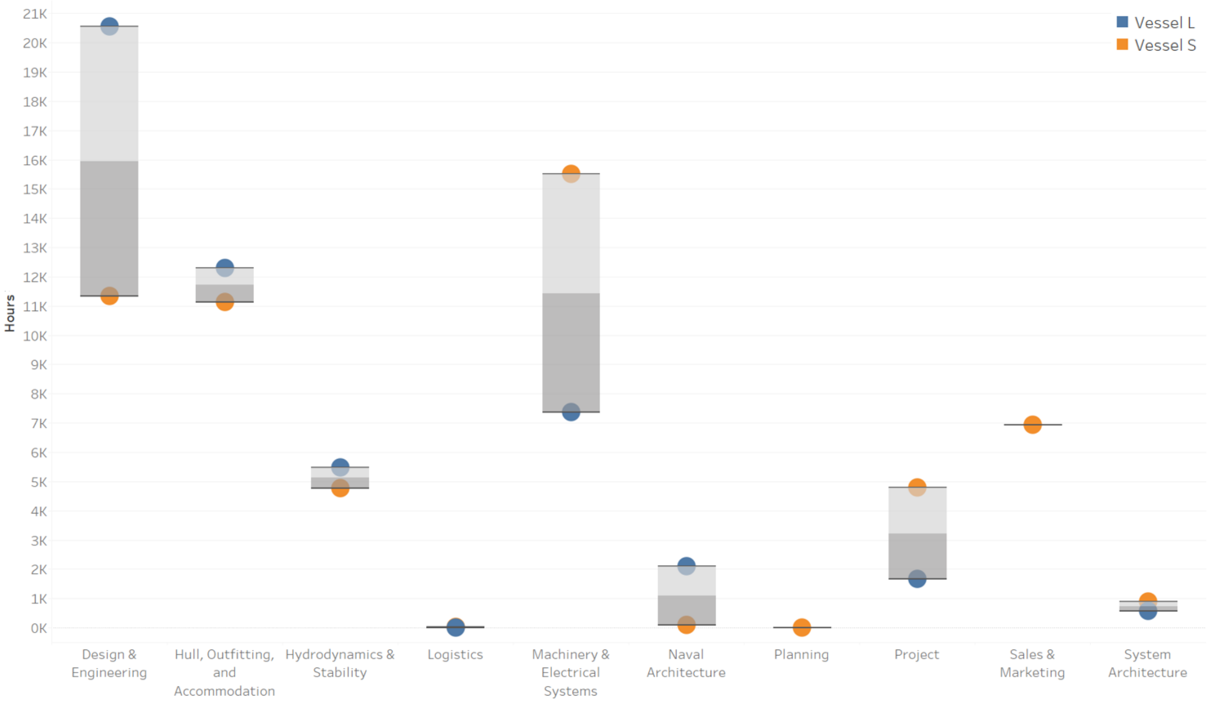


Figure 4.9: Variation in resource expenditure by department.

Figure 4.10 adds a temporal perspective to the department variation. DE, HOA, and MES were among the most resource-demanding departments before launch for both vessels. DE remained this way for Vessel L until launch, but for Vessel S it was superseded by several departments when the production phase started. MES and DE had a similar resource load before the build phase for Vessel S and even though the load on both departments was reduced in the succeeding phases, the load on MES remained much higher. NA is present for both vessels before launch and is highly involved before build for Vessel L. Project contributes during all phases, especially during the first two for Vessel S. Further, Sales & Marketing is present both before production and after launch, but peaked during production. After launch HS had the highest load for both vessels.

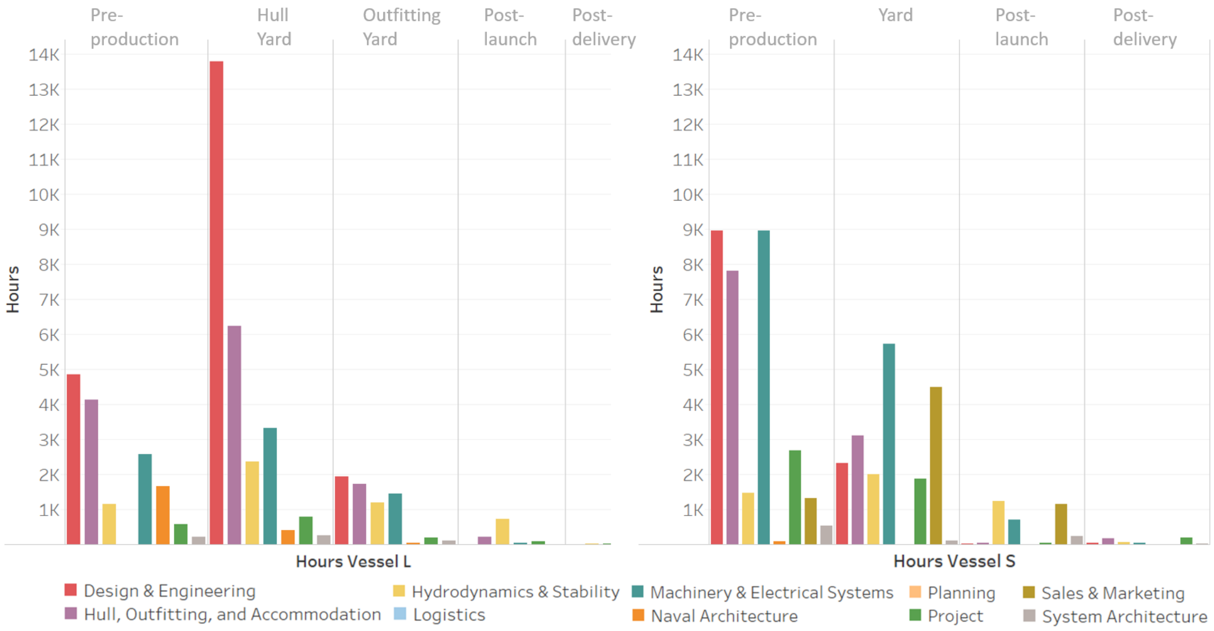


Figure 4.10: Department load variation according to project milestones

To further assess the quality of the information content, a closer look will be made at activities constituting the resource expenditure by HS. Table 4.9 summarises the characteristics of these activities. There are more than twice as many unique activities registered on Vessel L compared to Vessel S, but the time spent on each activity is on average higher for Vessel S. There is also a larger spread in the number of hours among the activities for Vessel S. Since the distribution is right skewed, Vessel S has more activities among the more resource-demanding activities compared to Vessel L.

Table 4.9: Descriptive statistics of activities by the Hydrodynamics & Stability department

	Statistical measure						
Vessel	n	Total Hours	Mean	Median	Std. dev.	Upper Quartile	Lower Quartile
Vessel L	53	5485	103	39	222	90	7
Vessel S	22	4769	217	46	406	154	21

It was previously noted that activity name variation sometimes occurred across projects. Since the number of activities is counted based on unique activity names, slight name variations may cause the number of activities in the above table to be inaccurate and describe activity *name* variation and not necessarily activity variation. Figure 4.11 displays all activity names that were registered for either or both vessels and their associated resource expenditure. As Table 4.9 indicates, several activities were only carried out for Vessel L, but the figure also indicates the same for Vessel S. A closer look at the activity names further suggest that some of these activities were in fact carried out for both vessels, but due to slight name variations they are perceived as unique activities by the analysis software. Preliminary- and final probabilistic damage stability booklet, input to capacity plan, load line and freeboard report, and sea trial attendance were registered for both vessels, but with slight name variations. There are other names with larger name variations that may refer to the same activity. This includes ”Model Test Report” and ”Tank test report”, ”Internal Watertight Integrity” and ”INTERNAL WATERTIGHT INTEGR.PLA”,

”Initial Stability Booklet and Preliminary stability booklet”, ”Intial Probabilistic Damage S” and ”Preliminary prob. damage bookl”/ ”PRELIMINARY PROB.DAMAGE BOOKLE”, ”Safe Return to Port Philosophy” and ”SRtP Voyage Capability Analysi”, and ”Follow-up due to weight change” and ”VO3 - Weight follow up constr.” Although most variations in activity names are found across the two projects, two activity names are also registered with slight name variations within a specific project.

Another thing to note regarding activity names is the varying detail level present in both projects. The description that constitutes the output of a ship design process is composed of a set of deliverables in the form of drawings, diagrams, booklets, plans, and analysis reports. The activities in the design process revolve around preparing these deliverables. Preparing the deliverable itself may be an activity, but the main activities are those that provide input to these deliverables. Some activity names in the data set refer to a deliverable, for instance, preliminary stability booklet, while other activity names refer to an activity that may be part of completing the deliverable. It might be that the preliminary stability booklet activity only refers to preparing the actual booklet and not the other preceding activities that provide input to the booklet. However, looking at the accumulated hours in Figure 4.11, this does not seem likely.

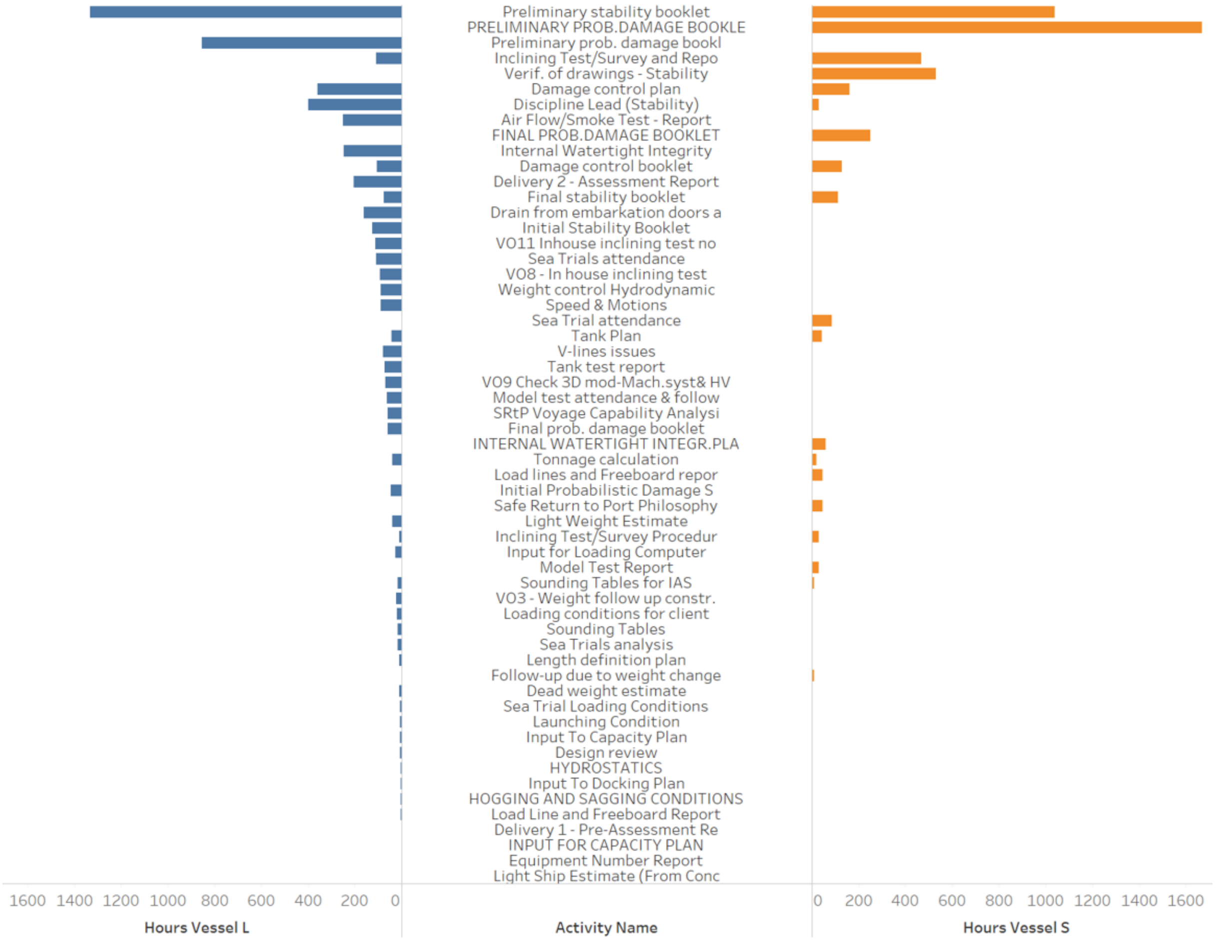


Figure 4.11: Activity names and associated resource expenditure for Hydrodynamics & Stability

Assuming the names with variations are in fact the same activity, then 20 of the 57 activities in Figure 4.11 occur for both vessels. 25 activities were carried out for vessel L and not vessel S amounting to 1394 hours. Only one activity was carried out for vessel S that was not carried out for Vessel L, amounting to 532 hours. Considering only these activities, HS for Vessel L surpasses the resource expenditure of

HS for Vessel S with around 850 hours. This is approximately 150 hours above what was indicated in Table 4.9 which means that Vessel S exceeds Vessel L with approximately 150 hours on the common activities.

Figure 4.12 displays these activities and their associated resource expenditure for both vessels. The most resource-demanding activities were the preliminary stability booklet and the preliminary probabilistic damage booklet. The largest relative difference may be observed for the activities ”Discipline Lead (Stability)”, ”Input for Loading Computer”, and ”Load Line and Freeboard Report” and the largest absolute difference may be observed for both preliminary booklets, ”Discipline Lead (Stability)”, and inclining test/survey report. Vessel L exceeds Vessel S on 13 out of 20 activities, where four of these demonstrate large variation. Of the seven remaining activities that were more resource demanding for Vessel S, three demonstrate large variation.

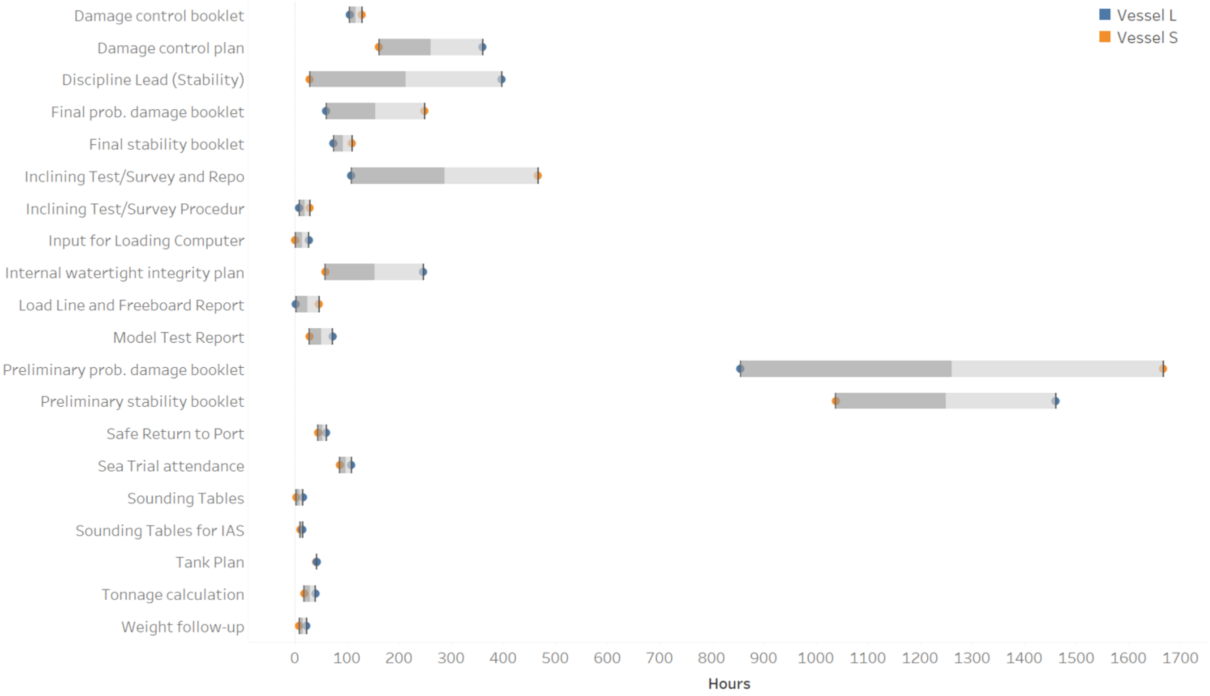


Figure 4.12: Hydrodynamics & Stability

4.3.2 Interpreting case results

Both projects were assumed to only contain data after the contract was signed, in accordance with the project classification. However, the timeline in Figure 4.8 indicates otherwise with just short of 11 000 hours spent on Vessel L prior to the contract announcement. As described in the introduction of the case study, data for Vessel L constitutes activities and resource expenditure associated with four project names chosen from the Contract group. Thus, either, the contract was signed several months before it was announced or one or several of the project names should have been arranged in the Opportunity group. One of the project names has ”LOI” (Letter of Intent) as part of the project name and amounts to 1400 hours. The remaining hours registered before contract announcement are part of a project name that includes hours after the contract announcement as well. This opens up the possibility that projects are not necessarily reregistered with a more detailed project name at the date the contract is signed. Most opportunity projects are not identifiable by means of the project name, but this does not hold true for

Vessel L. This may also be a unique feature in projects where an LOI is involved. Even though an LOI does not ensure a newbuilding contract it signifies a high probability of winning the contract. This may in turn cause the project to be registered as if it was contracted. This higher probability may also explain the additional amount of hours before contract for vessel L compared to other opportunity projects as depicted in Figure 4.5. A higher probability of winning the contract reduces the risk of allocating an additional amount of hours before the contract is signed.

One would perhaps expect Vessel L to require more resources by both Machinery & Electrical Systems and Hull, Outfitting, and Accommodation seeing as the vessel features more sophisticated machinery system and structural features. Figure 4.9 supports this assumption for HOA, but indicates the opposite for MES. As described previously, HOA and MES activities are also carried out by DE. Thus, it might be that most of the machinery and electrical systems related activities were carried out by DE for Vessel L. Figure 4.13 shows the most resource demanding activities carried out by these departments for Vessel S and the corresponding resource expenditure on these activities for Vessel L. It is evident that the activities that were more resource demanding for Vessel S, were not for Vessel L when looking at each department separately. Yet, some activity names that were resource demanding in HOA and MES for Vessel S seem to occur in DE for Vessel L. Particularly the activities ”Electro” and ”Machinery” by DE may include some of the activities that were not carried out by MES for Vessel L. If comparing total hours for each vessel on the three departments collectively instead of each department separately, Vessel L does in fact exceed Vessel S with a little above 2000 hours. Thus, load on departments seems to follow vessel functionality although there may be different practices with respect to activities that are sub-contracted.

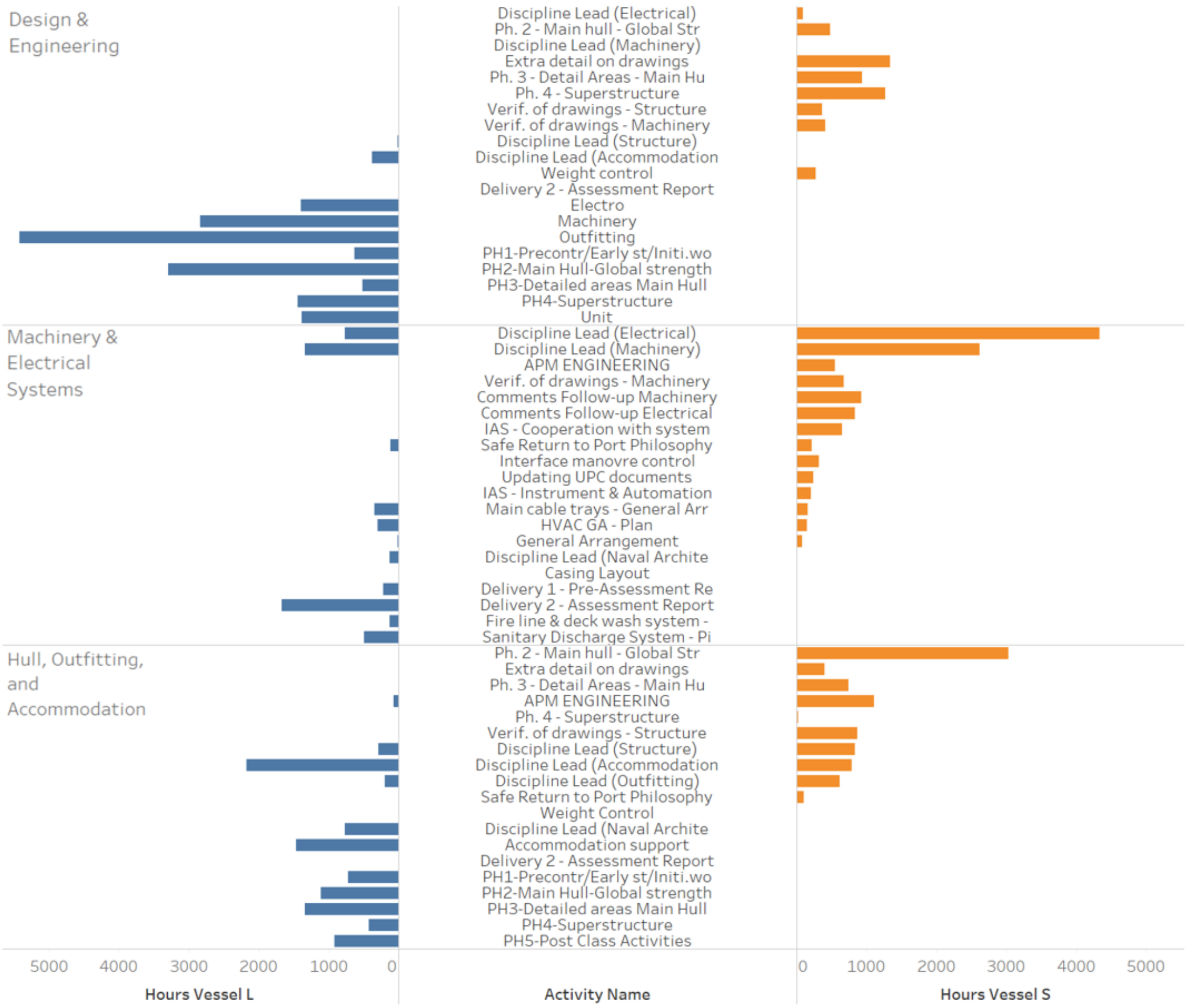


Figure 4.13: Activities by Design & Engineering, Hull, Outfitting, and Accommodation, and Machinery & Electrical Systems

Sales & Marketing is only registered on Vessel S. One would typically assume this department to be involved before the newbuilding contract was awarded, which could make it present in opportunity projects rather than contracted projects. Contract-related work may occur after the project has turned into a contract, for instance in relation to variation orders, but Sales & Marketing was not involved in any of these activities. The vessel was built entirely in China where the design company do not have a design office, but rather a sales office. Therefore all hours by Sales & Marketing may instead relate to activities done by the office in China and not necessarily traditional sales and marketing activities. What may be the case is that during follow-up of the production phase, Sales & Marketing consult with the design/engineering departments in Norway and convey this information to the sales office in China who forwards it to the yard. Alternatively, departments in Norway send a representative to China and when they register hours in China it is registered as Sales & Marketing hours.

Resource expenditure before ”Steel Cutting” was higher for Vessel S which may be related to how the ship was built. Since all production activities happened at the same yard for Vessel S, it may have been relevant to utilise the potential time-related advantages of *preoutfitting* [Semini et al. 2018]. However, this may require that more design work is completed prior to production, especially by HOA department and perhaps the MES department. Figure 4.10 seems to support this where a considerable amount of hull, outfitting and accommodation and machinery and electrical systems work was carried out prior to build for Vessel S, while most of these hours are deferred to a later stage for Vessel L.

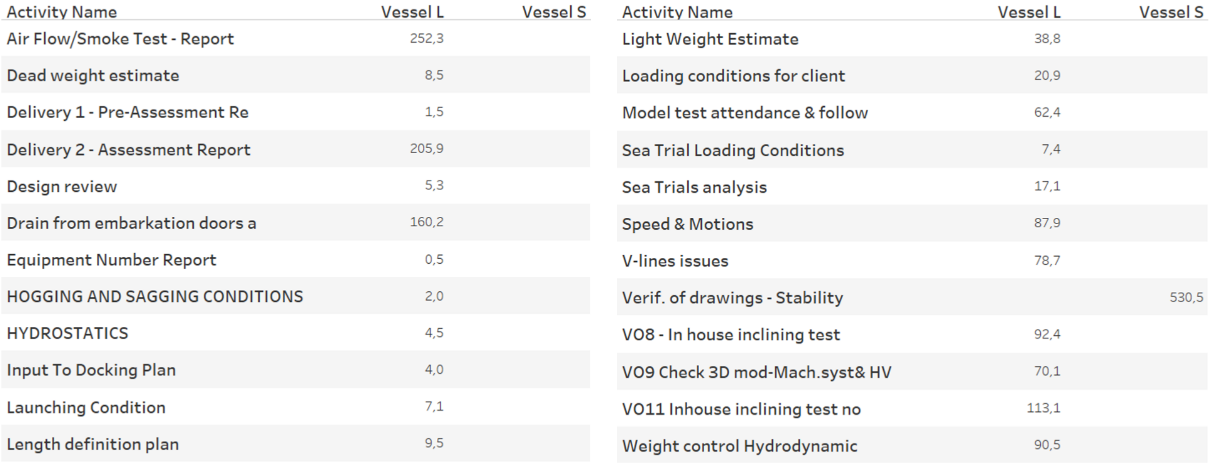
Both preliminary booklets were the most time-consuming activities for both vessels. These booklets remain preliminary until they are approved which typically occurs at the end of the production phase. Many activities go into completing the stability booklet and taking into account the total resource expenditure on these activities it seems that ”input-activities” are registered on the booklets. Another reason for the large number of hours on these activities may be that since the booklet remains preliminary until the vessel is built, they are continuously updated along the project timeline and thus accumulate a large number of hours. In either case, it seems reasonable the booklets are the most time-consuming activities.

What may be less reasonable is the variation between the vessels on the booklets as indicated in Figure 4.12. It is considered likely that these differences may partly be caused by inconsistent registration. Either that more of the ”input-activity” hours were registered on the deliverable for one of the vessels, or simply that hours that should have been registered on preliminary stability booklet, were registered on the preliminary probabilistic damage booklet or the other way around.

The characteristics of activity names exemplified by the HS department did not simply belong to that department. The other departments were also checked and the same characteristics were apparent for these departments. Activity names are registered with slight variations and a varying detail level. Besides, it is worth mentioning that when checking the other departments it became apparent that CFD activities were carried out by the HOA department and not HS as might have been expected.

Even though the activity names suggest that several activities were not carried out for both vessels, this may simply be caused by inconsistent activity registration. Seeing as there are more activities on Vessel L, but on average a higher resource expenditure on each activity on Vessel S, it is plausible that the activities that were not registered on Vessel S were carried out, but as part of another activity name. The activities in question are listed in Figure 4.14 with their accumulated hours, indicating which activities were carried out for each vessel. Many of the activity names in the list refer to fundamental activities that one would expect to be conducted for both vessels, for instance, deadweight and lightweight estimate, speed and motions, and verification of drawings. ”V-line issues”, revolving around the structural integrity of internal bulkheads, may only have been conducted for one of the vessels since it includes ”issues”. VO (”Variation Order”) activities are not unlikely to occur during a design project. A change in requirements or other unforeseen events may cause the supplier to request a variation order to be accepted by the customer. Even so, since these are typically vessel-specific, this particular VO is probably unique for one of the vessels. The activity ”Air Flow/Smoke Test-Report” may relate to ventilation in case of fires on board the ship. Intuitively, this does not seem like a typical HS activity, but perhaps rather a MES activity or HOA related as they typically carry out activities related to the HVAC system and fire and safety. The two ”Delivery” related activities are hard to interpret based on the activity name, Length definition plan as well. Equipment Number report is likely to be the responsibility of NA. The activity referring to docking is also likely to have been carried out for both vessels unless it refers to docking after the vessel was towed from the hull yard to the Norwegian yard, which only took place for Vessel L. Checking the date of the activity indicates that a share of the total hours on this activity was carried out just before the vessel was docked in Norway. The remaining hours are registered just before delivery. ”Model test attendance & follow-up” and ”Speed & Motions” were instead carried out by HOA for

Vessel S. ”Loading condition for client” may have been a unique activity for Vessel L since it also has registered hours on loading conditions for sea trial, the same as Vessel S.



Activity Name	Vessel L	Vessel S
Air Flow/Smoke Test - Report	252,3	
Dead weight estimate	8,5	
Delivery 1 - Pre-Assessment Re	1,5	
Delivery 2 - Assessment Report	205,9	
Design review	5,3	
Drain from embarkation doors a	160,2	
Equipment Number Report	0,5	
HOGGING AND SAGGING CONDITIONS	2,0	
HYDROSTATICS	4,5	
Input To Docking Plan	4,0	
Launching Condition	7,1	
Length definition plan	9,5	

Activity Name	Vessel L	Vessel S
Light Weight Estimate	38,8	
Loading conditions for client	20,9	
Model test attendance & follow	62,4	
Sea Trial Loading Conditions	7,4	
Sea Trials analysis	17,1	
Speed & Motions	87,9	
V-lines issues	78,7	
Verif. of drawings - Stability		530,5
VO8 - In house inclining test	92,4	
VO9 Check 3D mod-Mach.syst& HV	70,1	
VO11 Inhouse inclining test no	113,1	
Weight control Hydrodynamic	90,5	

Figure 4.14: Activities by Hydrodynamics & Stability only registered on either vessel

The case study seems to strengthen H2. Hours on departments seem to follow vessel functionality as well as build strategy. It is difficult to determine whether H3 is strengthened or weakened. On the one hand, there seems to be a significant amount of information to gather from the activities. On the other hand, there seems to be some inconsistency with respect to activity names which challenges the reliability of these activities.

Chapter 5

Discussion

Reduced competitiveness among Norwegian ship design companies in recent years promotes the need to critically review their practices so as to identify the necessary measures that may foster improvement. As a source of information to investigate these practices, data from a ship design company's ERP system exhibits potential and was consequently studied in this thesis.

Providing information on the ship design process is of particular interest if considering it to be the main value-generating process in ship design. By means of a set of resources and activities, the aim is to generate value for a customer and the ship design company's shareholders. If the output of such a process is a ship description that provides a ship that can be built and operated efficiently, value is created for the customer, and if the ship description facilitates the customer's willingness-to-pay to exceed the resources required to develop it, value is created for the ship design company.

The preliminary design stages are argued to be the most influential for the success of the design solution [Mistree et al. 1990; Erikstad 2007; Andrews 2018], but this may also hold true for the success of the design process. For ship design companies mainly operating on a no-cure-no-pay principle, achieving a profitable business is dependent on reducing resource expenditure on not-paid-for projects [Garcia Agis 2020]. This typically includes lost tender-based projects and as these rarely go past the preliminary design stages, a successful design process depends to a large extent on the activities and allocated resources here. Assuming a project is won if the ship design company provide a better solution than their competitors, they need to find ways to achieve this while keeping a profitable level of resource expenditure.

For every design project, the design company need to decide on a configuration of activities and resources that they believe enables this situation. Ideally, these decisions should be made with the knowledge of what and how activities add value. This is where the ERP system may prove to be beneficial. What activities should they do more of? What should they do less of? Are there any activities they should start doing? What activities or even projects should they not do at all? If data from the ERP system can facilitate an assessment of such questions, it may be considered a valuable source of information in the effort toward improved competitiveness in current ship design practices.

Consequently, the main research question pursued in this thesis asks whether data from a ship design company's ERP system is an appropriate source of information to describe and measure activities and resource expenditure in their ship design process. This has been investigated through processing and examining a provided data set that includes information on ship design projects from 2015 up until early 2022. The results from this investigation indicate that the answer to the research question is *yes*, but there are limitations.

5.1 Applicability of Data from the ERP system

The applicability of the ERP system data was assessed by means of gaining an understanding of its information content, both what kind of information it contains and the quality of that information. Following the research method outlined in Chapter 3, the concepts of validity and reliability were used to assess the information content. The validity of the data was addressed through the presence and accuracy of measures representing the information elements *Project*, *Department*, *Activity*, *Tools*, and *Resource Expenditure*, while the reliability of the data was addressed by evaluating the consistency of the measures representing the respective information elements.

Tools is the only elements that is missing although it is occasionally indicated in the Activity. How often the tool is indicated in the activity is not quantified, but preliminary consideration based on initial examination and the case study suggests that it is not consistent enough to use further. The methods and software used to carry out an activity affect the resources required, but it may also affect value for the customer. These nuances may be difficult to investigate unless other information is supplied alongside data from the ERP system.

Every registration in the system includes resource expenditure in number of hours and the date these hours were spent. Any further detail as given by the presence and accuracy of the other information elements varies depending on the project type under consideration. Projects are represented by means of project names, which may refer to vessel name, vessel number, vessel segment/type, or tender/customer name. Following the project classification introduced in Chapter 4, project names in the Opportunity group are typically more generic than those in the Contract group. They refer to vessel segment/type, tender/customer name, or simply Opportunity, and due to the generic nature of these names, typically include registered hours for more than one project. Since the project name does not identify unique projects, it is not valid with respect to assessing resource expenditure for each Opportunity project. In the Contract group, project names refer to vessel name and/or number which increases its validity with respect to identifying unique projects and the associated resource expenditure.

Even so, a challenge remains when investigating Contract projects to ensure the completeness of data within these projects. The distribution of Contract projects with respect to resource expenditure indicates that the majority of projects do not exceed 3000 hours, which is considered quite low if considering project duration to last from the contract is signed to the vessel is delivered. There may of course be projects where only either concept design or basic design is carried out and limited or no follow-up during production is conducted. There may be projects which are not yet completed, or completed projects where only a portion of the project is carried out within the time span of the data set. Further, as exemplified through the case study, projects seem to be registered with more than one project name. As the total resource expenditure is distributed among several project names, the tendency of total resource expenditure as was indicated by statistical measures and histograms in the initial examination is likely lower than the actual resource expenditure. Still, since project names for Contract projects refer to vessel names and/or numbers it is possible to collect all relevant project names and the associated resource expenditure.

Furthermore, the Opportunity group gives no indication of the activities that were carried out in specific projects. An ”Activity name” is given in the project group, that refers to either vessel type and or customer/tender name, or the actual design task. Yet, since only either the activity or the project may be identified, it is not possible to investigate differences with respect to activities carried out in each individual project.

Contract projects, on the other hand, include more detailed information by means of both the activities that were carried out in specific projects and the departments that were involved in these activities. In the case study, resource expenditure by department seems to follow vessel functionality as well as build strategy. More time was spent on Hull, Outfitting, and Accommodation and Machinery & Electrical Systems for the slightly more sophisticated vessel. In addition, as building a vessel entirely in one yard opens up the possibility of preoutfitting, more design work was carried out before the production-phase started for that vessel. Activity is the least consistent information element as both name variations and detail level variations are apparent. Name variations in contrast to detail level variations are possible to edit so that activities with different activity names are treated as the same activity and variation across projects may be investigated. It would be beneficial to have information on tools to supplement activities with additional information, especially when investigating variation across projects.

The lack of detail level in opportunity projects challenges the applicability of the ERP system data in assessing ship design activities on tender-based projects. For each tender invitation, the ship design company has accepted it would be of interest to study what activities and what amount of resources were allocated and whether they were awarded the contract or not. Accepting a tender invitation always induces the risk of spending a vast amount of resources on a project which is lost to a competitor, thereby making it critical to choose projects and allocate resources in a way that maximises expected value. Figure 5.1 presents different scenarios for opportunity projects. The preferred situation is located in the upper left corner of the matrix, while the least desirable is located in the lower right. If projects could be identified in either of these, what were their differences? Maybe something could be learned by comparing their differences so that more projects could occur in the upper left or at least avoid the lower right.

There may still be valuable insight to be gained from the Opportunity group. A measure representing opportunity success rate was introduced in Chapter 4 and is repeated below.

$$\text{OSR} = \frac{|T|}{|O|}, \quad T \subseteq O$$

where $|O|$ and $|T|$ refers to the cardinality of the sets of opportunity projects and contract projects respectively. T is a subset of O so that all contract projects may be connected to an opportunity project. First of all, to study the opportunity success rate, tender projects should be isolated from potential FEED projects in the contract group, and opportunity projects connected to their respective contract projects. This ensures that T is in fact a subset of O. It was previously indicated that a set of complete opportunity projects may perhaps be identified from the activity name. For those projects that became contracts, if the names are detailed enough, meaning that they include both vessel type and customer name, they may be possible to link to their contract project. Since only a sample of the opportunity projects satisfies this condition, it is also important to limit the time span under consideration so that a complete set of projects may be considered. If some projects are left out during a given time span, the success rate measure will not be correct.

With a set of contract projects and opportunity projects within a given time span it may be even more interesting to investigate whether resource expenditure affects the success rate. If it is not possible to compare the activities in two projects where one became contracted and the other not, then perhaps simply their resource expenditure may provide insight. It may not be necessary to identify each opportunity project in the data set. If by some other means one is able to identify the number of opportunity projects within several time spans, then accumulated hours within these time spans may be enough to compare resource expenditure and success rate. Perhaps the ship design company has a database of all tender invitations they accepted, for instance as part of a Customer Relationship Management (CRM) system?

Moreover, even though there currently seems to be very little activity detail in the Opportunity group, it might be possible to add department information for those projects where it is missing. Among the information elements in the data set that were not investigated further, an employee number was given in one of the columns. It is likely that an employee does not only work on opportunity projects, thus departments may be added to the Opportunity group by cross-checking the departments the employee is affiliated with in the Contract group. If possible, this may allow for slightly more detailed investigations of tender-based projects.

Different scenarios for Contract projects are also included in Figure 5.1. The main success criteria is in this case related to whether the contract specification is complied to. There may of course be change orders which change the original specification, but as these have to be agreed upon by both the supplier and the buyer, they should not be treated as deviations in the contract specification. Due to the additional information in this project group, it is possible to investigate further why some projects ended up in one of the less preferred quadrants. The case study suggests that department and activity may add additional insight, although detail variation and name variation in activities must be kept in mind.

A final thing to note regarding Figure 5.1 is that the upper right scenario is perhaps preferred over the lower left scenario, by the argument that at least winning the contract is better than not winning it, albeit with too much resource expenditure. It is evident that it does not matter if you maintain a low resource expenditure if you do not win any contracts. Besides, there may be other non-monetary values in projects, like gaining familiarity with new vessel segments, improved reputation, as well as building customer relationships. Familiarity with new vessel segments may enable the design firm with more options with respect to potential design projects, improved reputation attracts more customers, and better relationships with customers may increase their propensity to buy.

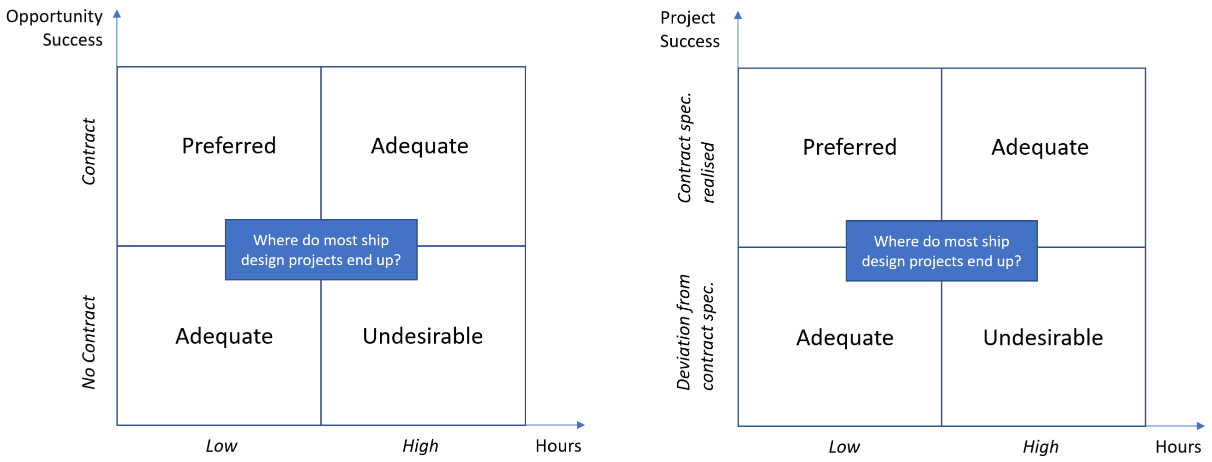


Figure 5.1: Project success before (left) and after (right) contract

5.2 Research Method

The concepts of validity and reliability were used to assess data from the ERP system. This was mainly a qualitative assessment, but it might have been beneficial to extend it with some quantitative measures like Cronbach's alpha and Pearson's correlation coefficient. Since the assessment was mainly qualitative, only two projects were considered in detail. Applying the two quantitative measures could be carried out efficiently on all projects, hence enabling a more complete assessment.

Further, all data originates from the employees who register the activities they have conducted. Therefore, investigating the registration procedure would likely provide more insight into both the validity and reliability of the data. For instance, it was assumed that the first time a project name or activity name is registered it has to be typed manually, but once it has been registered, later registration may simply select the name from a list. If this is how the registration procedure is in fact carried out one might expect more consistent activity names and project names. Yet, the inconsistencies may simply be due to the fact that some employees are less meticulous in their registration procedures.

Moreover, projects are believed to be reregistered with a more detailed project name as they turn into a contract. The project names for Vessel L investigated during the case study, however, suggest that is not necessarily the case. This deviation is believed to be explained by the fact that an LOI was signed before the actual contract was signed. Projects where an LOI is signed have a high probability of securing a newbuilding contract and hence the project may be reregistered as if it was already signed before the contract is signed. None of the other project names included ”LOI” or ”Letter of Intent” in the project name. It is uncertain whether this is because no other projects included an LOI or if simply the project name was registered without it. Again, investigating the registration procedure to a greater extent may uncover these uncertainties.

If won tender-based projects are not reregistered when a contract is awarded, the opportunity success rate measure would have to be adjusted. The original measure assumes that projects that have turned into a contract are also included in the Opportunity group. In this way the number of Contract projects (CP) will always be less than or equal to the number of Opportunity projects (OP) If the reregistration assumption is not correct, the number of Contract projects would have to be added to the denominator as follows:

$$\text{OSR} = \frac{|CP|}{|CP| + |OP|}, \quad CP, OP \subseteq T$$

T is in this case treated as the set of tender-based projects where CP and OP are subsets of T. If every tender process ends with a won contract, OP is zero and OSR equals 1.

Projects were arranged into groups based on assumed common attributes. There may be other groups or extensions to the existing groups that are more accurate. Through the study, it has become evident that at least distinguishing projects that only include early design phases from those that include activities from the tender invitation to vessel delivery would be beneficial. Further, in evaluating opportunity success rate, it is considered a requirement to distinguish between FEED projects and tender-based projects. Still, the classification was effective with respect to identifying newbuilding projects which was an important first step in limiting the number of projects to be studied.

The share of different project groups as illustrated in Chapter 4 was a result from arranging projects on the basis of project names. Although the resulting share of different project groups seemed reasonable, the data set contained some ambiguous project names that may have been arranged under the wrong group. Particularly the ”Opportunity” group, where project names were generic, may include some projects that should instead have been arranged in another project group.

The study was limited to only consider newbuilding projects as this constitutes the main business area of the design company. Still, the aftermarket services are not insignificant and may become even more important for future design practices. Apart from the production related activities like retrofits and conversions, digital services may also serve as a means to add value, for instance by providing decision support during operation, prolonging interaction with the customer, as well as detailed analysis of ship operations which may be used to make better designs in the future. Investigating the data in the aftermarket group may perhaps provide some insight into these activities.

Regarding the case study results it is important to note that even though the data from the two projects investigated seems to represent their respective design projects, these results are not validated by someone familiar with the real design projects. Thus, the conclusions drawn from the case study results regarding the quality of the ERP system data should be evaluated accordingly.

Chapter 6

Conclusion and Further Work

6.1 Conclusion

The findings presented in this thesis suggest that data from a ship design company's ERP system is an appropriate source of information to describe and measure activities and resource expenditure in their design process. There are limitations to how it may be applied, and while some of these limitations seem possible to overcome, they require further examination to be concluded upon.

The applicability was assessed by studying the information content of a provided data set from a ship design company's ERP system. The ship design company of which design process the data is supposed to represent, operate mostly with tender-based projects. For every tender invitation they accept, a project is registered as an opportunity to later be reregistered if it becomes a contract. There is no information in the data set that indicates whether an opportunity project became contracted, thus further investigations of the information content were conducted on opportunity projects and contracted projects separately.

Of the two project groups, the former might be the most interesting group to study further, but unfortunately, it is also the project group with the least detailed information content. Nevertheless, the information it provides may still provide insight into why some contracts are won while others are not, albeit with a limited detail level.

Projects that have turned into a contract, on the other hand, allow for more detailed further analysis. In addition to reducing expenses on not-paid-for projects, as would be the case for a lost opportunity, increasing profits from paid-for projects, whether related to won tenders or FEED projects, is considered an important means to stay profitable. Thus investigating more in detail activities and resource expenditure in these projects may foster improvements in current ship design practices for the ship design company.

6.2 Further Work

To further assess the information content in the ERP system data, it is considered beneficial to assess the registration procedure, for instance by conducting interviews with some of the ship design company's employees. Variations in activity names and project names in particular is believed to be better understood by extending the study with this information.

To further investigate opportunity projects it is necessary to identify either, unique opportunity projects from the ERP system data, or at least how many tender invitations were accepted within different time spans. This may be accomplished by investigating whether the activity names in the opportunity group may in fact be identified with unique projects, or by supplying the resource planning system with other information regarding tender invitations. Furthermore, of the activity names which may be identified with unique projects, about 30% lack department information. If unique opportunity projects are in fact possible to identify, they should be investigated with as much detail as possible. The specific activity is not possible to obtain, but department information may be supplied if the identified projects seem to lack this information. Additionally, the ones that turned into a contract should be connected to their respective contract projects to enable a more complete view of the project.

This thesis acts as a pre-study towards addressing improvements in competitiveness of ship design activities in Norway. As main input factors for value creation, a company's use of resources provides the basis for establishing competitiveness [Teece et al. 1997; Fjeldstad and Lunnan 2018], thus motivating the study of data from a ship design company's ERP system.

Following the thesis findings, Figure 6.1 shows an updated version of the conceptual model of information content in the ERP system. It illustrates the basis for future research with resource expenditure as the *independent variable* assumed to cause or be associated with competitiveness, the *dependent variable*. As the thesis work provides a positive answer to its research question, further PhD work may rely on data from the ERP system to explore this relationship.

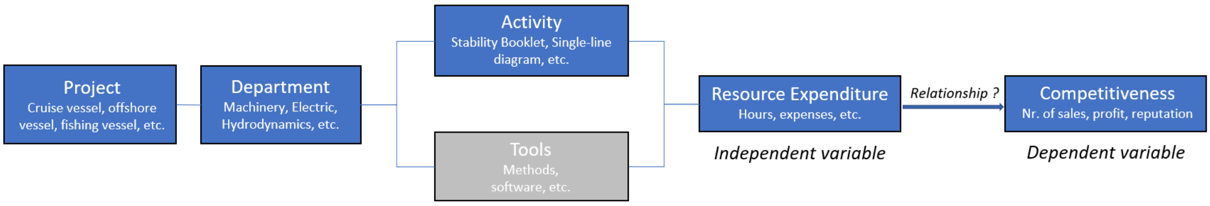


Figure 6.1: Independent and dependent variable to be investigated in further PhD work.

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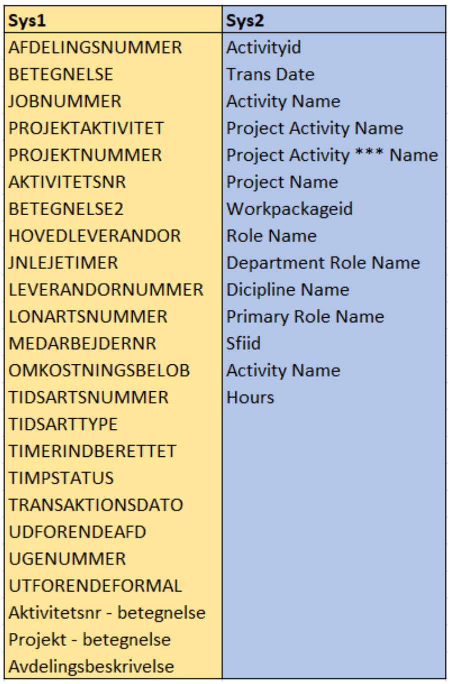
Appendix A

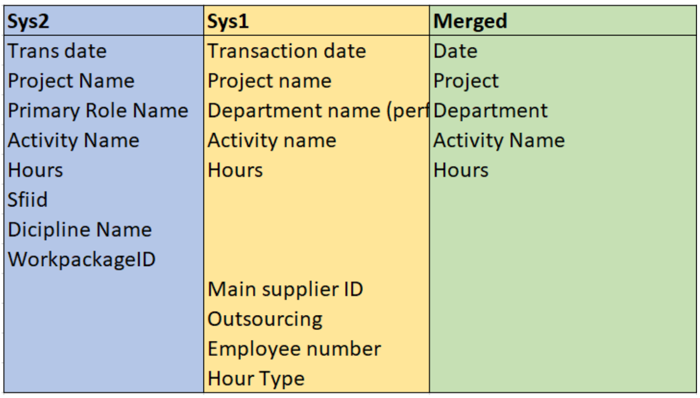
Data Collection

A.1 Data Processing



Sys1	Sys2
AFDELINGSNUMMER	Activityid
BETEGNELSE	Trans Date
JOBNUMMER	Activity Name
PROJEKTAKTIVITET	Project Activity Name
PROJEKTNUMMER	Project Activity *** Name
AKTIVITETSNR	Project Name
BETEGNELSE2	Workpackageid
HOVEDLEVERANDOR	Role Name
JNLEJETIMER	Department Role Name
LEVERANDORNUMMER	Dicipline Name
LONARTSNUMMER	Primary Role Name
MEDARBEJDERNR	Sfiid
OMKOSTNINGSBELOB	Activity Name
TIDSARTSNUMMER	Hours
TIDSARTTYPE	
TIMERINDBERETTET	
TIMPSTATUS	
TRANSAKTIONSDATO	
UDFORENDEAFD	
UGENUMMER	
UTFORENDEFORMAL	
Aktivitetsnr - betegnelse	
Projekt - betegnelse	
Avdelingsbeskrivelse	

Figure A.1: Column names in received Excel-files



Sys2	Sys1	Merged
Trans date	Transaction date	Date
Project Name	Project name	Project
Primary Role Name	Department name (perf	Department
Activity Name	Activity name	Activity Name
Hours	Hours	Hours
Sfiid		
Dicipline Name		
WorkpackageID		
	Main supplier ID	
	Outsourcing	
	Employee number	
	Hour Type	

Figure A.2: Column names in calibrated files and new merged file

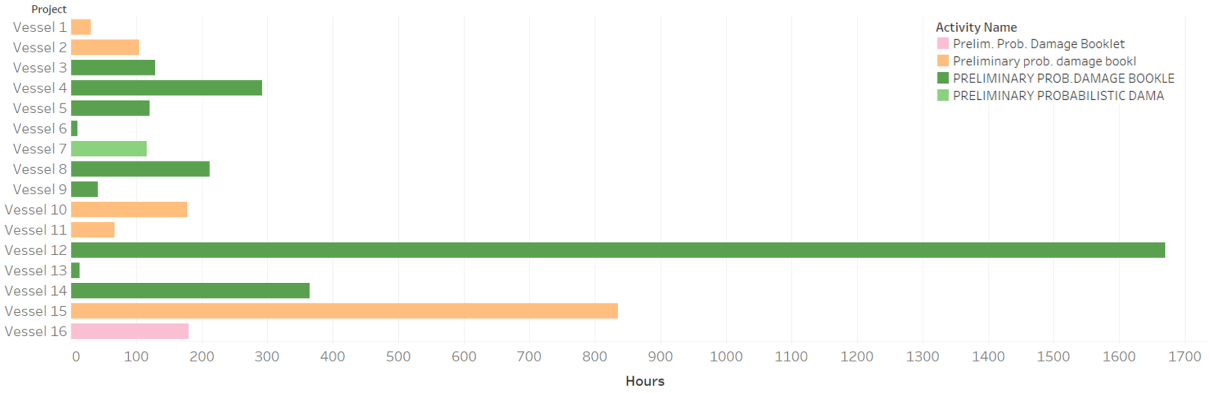


Figure A.3: Activity names vary across projects, but remain constant within projects

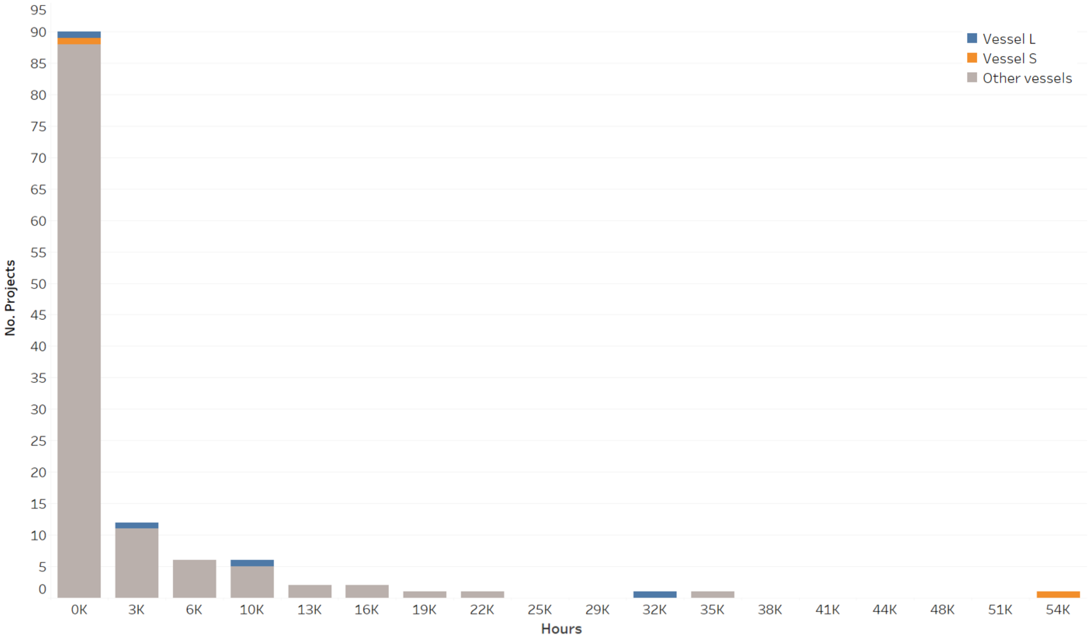


Figure A.4: Highlighting selected projects in the distribution of Contract projects

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