Servitization in the Shipbuilding Industry

A Research into the Relation of User Profiles and Service Contracts of High Speed Transport Vessels

Jorrit de Jong

Technische Universiteit Delft

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by

Jorrit de Jong

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Thesis committee:	Prof. dr. ir. R. R. Negenborn,	TU Delft, chair
	Dr. ir. W. W. A. Beelaerts van Blokland,	TU Delft, supervisor
	Ing. D. Mense,	Damen Shipyards

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Preface

This thesis is written to fulfill the graduation requirements of the University of Technology Delft course Mechanical Engineering with a specialization into Transport Engineering and Logistics. I was engaged in researching and writing this thesis from May 2019 to February 2020 in collaboration with Damen Shipyards in Gorinchem.
My passion for vessels and marine operations are partially inspired by both my grandfather's who unfortunately passed away during the establishment of this thesis.
The research was difficult, but conducting extensive investigation has allowed me to answer the question that we identified. Fortunately, both Danny Mense and my tutors from the University, dr. Beelaerts van Blokland and prof. dr. Negenborn, were always available and willing to answer my queries. Thanks to Arnout Jorritsma and his commitment to continue this field of research within Damen.
To my other colleagues at Damen Shipyards I am grateful for the help and support during the process. Special thanks to my colleague *senior intern* Kevin for the fun and engaging discussions regarding vessel maintenance and off-topic brainwaves that helped me with the establishment of this thesis.
Warm thanks to my family and friends who supported me towards the end of this thesis and last I would like to thank my partner Mandy, who was of great support during the complete Master's study.

Jorrit de Jong
Delft, February 2020

Abstract

Research in the field of servitization as a business strategy is emerging since its first appearance by Vandermerwe and Rada (1988) and later but parallel developments by Goedkoop et al. (1999). Servitization is the act of selling complete packages of goods and after sales services. Various industry examples present successes with the implementation of the complete offering of goods and services. However, theoretical substantiation lacks with evidence of implementation strategies leading to successful businesses. This research aimed to investigate the potential of servitization strategies to the shipbuilding industry in terms of service contracts. Dutch shipbuilder Damen shipyards develops, builds, and sells various types of vessels to the broadest sense. Various vessel types introduce even more various vessel usage profiles. This research aimed to find suitable service contracts given a certain user profile. The main research question used as a guidance is "What are the best performing service contracts in relation to the user profile of vessel operators?"

To achieve this goal and answer the question, knowledge regarding servitization contracts is gained using literature. Subsequently, knowledge and data regarding usage and maintenance aspects are gained within the marine industry. Then, a model is developed to implement user profiles and assess the performance of servitization contracts.

The literature review let to answers regarding the first research question "What is servitization and how does it perform?" This question can be answered in twofold; What are servitization contracts? And how do servitization contracts perform? First, as introduced above, servitization is the act of selling complete packages of goods and after sales services. A contract is a legal bounded agreement between a supplier and a customer stating the product offering, conditions, and a financial compensation for delivering these products. Within the application of product, and supplementing service offerings, there exist three main distinctive contracts; Time & Material contract (T&MC), Fixed Price Contract (FPC), and Outcome Based Contract (OBC)s. The contracts differ in the sense of price determination, risk allocation, and demanded certainty. A fourth User Profile Based Contract (UPBC) is introduced to fill a gap between T&MC and OBCs by means of a more tailored usage price determination. Servitization contract performance can be indicated using multiple Key Performance Indicators (KPIs). Contract price (transaction amount), price certainty, and price fairness are of interest from a users point of view. Contract revenue, revenue certainty, and the probability of financial losses are indicators of interest from a suppliers point of view.

An exploration of practice gained insight and knowledge of vessel usage and asset management in the marine industry. The question that led to these understanding is "Which set of usage characteristics affect the serviceability of marine vessels?". To narrow the broad sense of usage of marine equipment this research focused on vessel usage in the offshore wind farm industry. Analyzing monitored data gathered over two vessels showed a unambiguous and recurrent cycle of operations. This cycle is sub-divisible in four vessel states, namely 1) moored in port; 2) in transfer on open sea; 3) drop-off and pick-up personnel between the wind turbines located in the farm; and 4) drifting at sea, waiting for pick-ups and to perform simple maintenance tasks. The gathered data also revealed distinctive usage characteristics in terms of engine load distributions. Marine equipment, among which diesel engines, require a high level of service and maintenance. Both literature and practice have numerous strategies regarding maintenance policies. The maintenance strategy of the main engines as delivered by Original Equipment Manufacturer (OEM) service manual is adapted to predict the Life Cycle Costing (LCC) of the engine. Service calls gained insight in common product failures and are considerably important to include in the LCC calculation. This all let to a set of aspects that completes the cost to maintain the asset.

The theoretical and practical exploration were aimed to gain knowledge to develop a model to simulate and assess vessel operations to eventually answer the third research question; "How does the user profile influence the contract performance in the shipbuilding industry?". The main cost drivers with respect to the user profile are the amount of hours an engine is running in time. Most maintenance is scheduled in relation with the amount of running hours of the engine. In addition, failures are more likely to occurs when engine produce higher loads due to higher stresses, higher oil pressures, higher wear, and more heat generation. Although there are few failure occurrences to analyze from historical data, a linear failure rate correction model is proposed to simulate a varying failure probability depending on the engine load produced at that time.

This ultimately leads to an answer of the main research question; "What are the best performing service contracts in relation to the user profile of vessel operators?". There is a consensus in both theory and experts in practice suspecting there is no single solution to a best contract form for all operators and user profiles. To answer this question more thorough, three case studies are performed to assess the performance of each individual case and user profile.

The results of the cases are used to answer the main research question "What are the best performing service contracts in relation to the user profile of vessel operators?" in a more general way. Strong similarities are found between T&MCs and UPBCs as well between FPCs and OBCs. The main difference between the T&MCs and UPBCs is the risk allocation of the uncertain costs of the life cycle of the vessel. In a T&MC the risk of contingency events is allocated to the user, the uncertainty of the supplier's result depends on the user profile's variance. In case of the UPBC this situation regarding the uncertainty is completely opposite. The user of the vessel owns the risk of an uncertain user profile while the supplier is responsible for the contingency failure events of the vessel. The risk allocation of UPBCs make better sense since the uncertainty regarding the product is allocated to the supplier and the risk of uncertainty of the user profile is allocated to the user. By tuning the parameters of the UPBC's cost per state per hour, the suppliers result can be equalized with the performance of the T&MC contracts without relocating all the risk towards the supplier. OBCs only perform well under specific circumstances such as a high up-time and a high certainty to achieve the high up-time. FPCs perform slightly better than OBCs but might be overpriced if there is a high variance of up-time hours in the user profile.

The aimed practical contribution of this research was to develop a method to determine the best performing service contract given the user profile of a vessel. The general objective of this study was to contribute to the development of theory regarding user profiles in relation with service contracts in the shipbuilding domain. The methodology to include simplified user profiles as a states cycle is developed within this thesis. The operational profile of high speed transport vessels suit this approach since the profile is a recurrent cycle of operations. The approach was aimed to be adaptive to other vessel types and operations. The LCC methodology is then used to retrieve figures regarding costs. Cost and availability figures as a result of failures are the result of available data from the shipbuilder. The four nominee contract types are designed and used to find relations regarding the performance versus the given user profile. The developed methodology and the contract performance versus user profiles is the contribution to practice and theory.

The findings of this research might change the consensus of different contracts and the associated performance into tangible knowledge supported with theories and approaches found in both literature and practice or developed within this research. However, marine vessels are capital intensive assets with long lasting responsibilities from the user and the supplier. Thereby, a failing implementation on just one vessel delivery could result in huge financial damage for the supplier.

Other studies regarding service contracts have shown methods to determine the parameters that eventually result in the contract's price of transaction amount. Other studies have shown the positive influence of performance contracting onto the product's reliability due to the supplier's incentive to mitigate the risk of contingency failures as much as possible to avert the under-performance fee. This research was aimed to investigate the relation of the contract performance and the user profile of high speed transfer vessels. Consecutive could include the aspects of the prior studies for the development of the more advanced service contracts for application in the shipbuilding industry.

The turnover of shipbuilder Damen consists for only 2% of after sales services. This figure is very low considering the life cycle costs of marine transport equipment is estimated to be equal to the purchase value of the vessel. The findings and approach as presented in this thesis could help managers at Damen to further investigate the proposed and more advanced contract forms.

This research is scoped to high speed transfer vessel operations and the main engine service demands. The inclusion of other components might change the outcome of the presented contract performance. This studies aim however is intended to be applicable for other vessel operations, or user profiles, and other or more vessel components.

For further research it is recommended to extend the inclusion of more components into the model to obtain the contract performance figures of complete vessels in the future. The model is based on a small amount of failure data, research into failures in relation to usage will result in better cost predictions and matching contract types. The future developments at the remote monitoring application of Damen will extend the possibilities to define better data and knowledge regarding user profiles and other usage related aspects. A similar elaboration of this research applied to other vessel types might gain insight into new challenges regarding the establishment of user profiles and contract forms.

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Acronyms

AIS Automatic Identification System. 18

CTV crew transfer vessels. 15

ECDIS Electronic Chart Display and Information System. 18

FCS Fast Crew Supplier. 15, 16, 20

FPC Fixed Price Contract. 1, 2, 7–9, 11–13, 29, 30, 36–39, 41, 43, 44

KPI Key Performance Indicator. 22

LCA Life Cycle Analysis. 9, 10, 24, 25, 27, 35, 36, 44

LCC Life Cycle Costing. 5, 6, 9–11, 15–17, 20, 23–26, 28, 29, 36, 44

MTBF Mean Time Between Failures. 18

OBC Outcome Based Contract. 1, 2, 4, 8, 9, 11–13, 29, 30, 37–39, 41, 43, 44

OEM Original Equipment Manufacturer. 4, 17, 22, 24–26, 29, 34, 38, 44

PSS Product-Service Systems. viii, ix, 1, 5, 7, 12, 53, 54

S-BOM Service Bill of Material. 16

T&MC Time & Material contract. 1, 2, 4, 7–9, 11–13, 29, 31, 37–39, 41, 43, 44

UPBC User Profile Based Contract. 9, 12, 13, 30, 36–39, 41, 43, 44

1 Introduction

This research is about servitization offerings in relation to the versatile users and usage of marine transport equipment. It is more specifically aimed to build theories regarding the relation of service contract performance and user profiles from a ship builder perspective. The first aspect, servitization, refers to the development of a suppliers' capability to provide services and solutions that supplement their traditional product offerings. In addition, contracting is a term used to describe the suppliers' duty to deliver the solution for a client to perform their operations. Secondly, user profiles of marine transport equipment includes the set of characteristics to define and distinguish various types of equipment utilization. Theory and practice does not confirm the existence of supplier - client agreements within the marine industry as such. Due to the lack of existence but contrarily the known and successful servitization constructions from other industries, gained the interest to explore opportunities of servitization contracting for the shipbuilding industry. The introductory chapter serves as a base for the research into the theory of contracting in relation to the usage of marine transport equipment. The introduction concludes with a presentation of the general outline of this report.

1.1. Background

Traditionally, manufacturers produce goods and make profit selling the goods, aftermarket spares, and services. Today, the importance of providing solutions rather than selling products has been seen by some as heralding the emergence of new service-based and customer-centric business models. Although the phenomena of providing solutions rather than goods is not new (i.e. Schmenner (2008)), actual large scale implementations are considered novel. Developing the capabilities of suppliers to provide services and solutions that supplement their traditional product offerings is referred to as *servitization* (Vandermerwe and Rada, 1988). Later, parallel developments were researched by Goedkoop et al. (1999) who initiated the term *PSS*. Contracts, as introduced above, are legal and ideally well defined agreements between both parties. In practice, various types of contracts and therein numerous variants exist. Contracts considered within this research are, but are not limited to; T&MC, FPC, and OBC. T&MC are arrangements under which a supplier is paid based on direct labor cost, material usage, and compensation of overhead costs. Contrary, a FPC is predetermined and does not depend on resource usage. Third, OBC are based on predefined specifications or performance outputs. Another aspect in supplier - user contract agreements are risks and the incentive to mitigate the risks. Risks to consider are for instance higher costs due to contingency events, improper use, and a changing operational profile that exceeds or trails the agreed contract dimensions. The domain of this research is to be found in the shipbuilding industry. The research is performed using data and practical knowledge of Damen Shipyards, a Dutch shipbuilding company. Damen offers standardized series of vessels for industrial purposes. The majority of the delivered vessels are tug-vessels, high speed crafts, and, dredgers. Therefor the possibilities in to expanding the service contracts with more solution-orient servitization products gained interests at the shipbuilder. A recent development at Damen is Damen Digital, a remote monitoring system, and is considered as a key enabler of servitization (Grubic and Jennions, 2018).

1.2. Frame of Reference

Servitization, solution oriented product offerings are not a novel business model. Although large-scale implementation of servitization offerings from an shipbuilding company lags in contrast to other industries. The commercial term for servitization, the capabilities of suppliers to provide services and solutions that supplement their traditional product offerings, is often referred to as operational lease or performance contracting (Grubic and Jennions, 2018). Similarly, Power by the Hour and TotalCare are products known from the aero engine manufacturer Rolls Royce and are a form of OBC. Contrarily, car leasing is more similar to FPC since the lessor pays the lessee a fixed amount to use the asset within the contract dimensions. An industry example of T&MC could be a local plumber making a bill of his time spend and resource usage for the repair. The first similar product to discuss is the aero engine maintenance repair and overhaul industry. Rolls Royce's revenue of civil engine deliveries accounted for 57.7% of after-services, serving 13,000 units (Rolls-royce, 2018). Swapfiets, a Dutch start-up ensuring customers a functional bicycle by *swap* a bicycle when it needs maintenance. Swapfiets serving 100,000 customers in spring 2019. LeasePlan, a car lease company owns a fleet of 1.8 million vehicles (LeasePlan, 2018) These large scale commercial examples of servitization overwhelm the shipbuilding industry in general. Damen shipyards delivered 178 vessels in 2018, 6,500 in total (Damen, 2018). The after sales and services accounts for 2% of the companies annual turnover in 2018 (Annual report Damen, 2018). Presumably, economical benefit is here to gain. The shipbuilding industry, vessel deployment, and operational circumstances identifies itself by a wide variety of equipment, relatively slow moving, and subject to all types of circumstances. The vessels are capital intensive and larger offshore platforms additionally draw high day rates.

1.3. Research Topic

This research is about servitization contracts in the shipbuilding industry with respect to user profiles. Practice shows the *possibility* of successful implementation of more advanced forms of service contracts such as OBCs (Liinamaa et al., 2016). Theory and practice does not confirm the existence of large scale implementation in the shipbuilding industry. The different types of contracts mentioned above differ by risk allocation on the one hand and mitigation incentive on the other. In case of vessel service contracting, the usage and vessel condition are correlated by means of intensive maintenance demand. A yet not such well defined concept in this research is the user profile. Earlier, the user profile is defined as 'the set characteristics to define and distinguish various types or equipment utilization'. However, a clear set of characteristics is not defined. Assumeably, the set of characteristics includes quantitative measurable components as well as qualitative customer requirements. This research emerges from rationalization that there is not a single overall best performing service contract for any given user profile.

1.4. Research Question and Objective

The general objective of this study is to contribute to the development of theory regarding user profiles in relation with service contracts in the shipbuilding domain. In practice, customers postulates the usage of a vessel based on (future) projects, a certain functional requirement, and other prospected operations. The aimed practical contribution of this research is to develop a method to determine the best performing service contract given the user profile of a vessel. The general objective and aim leads to the main research question: "What are the best performing service contracts in relation to the user profile of vessel operators?" To support the main research question three sub questions are developed, one to be answered using literature and one to be answered by conducting research:

Q1: What is servitization and how does it perform?

Q2: Which set of usage characteristics affect the serviceability of marine vessels?

Q3: How does the user profile influence the contract performance in the shipbuilding industry?

This research will try to close the gap between scientific and industry research on servitization of marine transport equipment by testing theoretical propositions and practical challenges" The research is aimed at identifying and specifying the user profile as well as specifying the relation between user profiles and service contracts. To attain the objective, the following sub objectives are set;

1. To define the theoretical and practitioners framework to identify the current state in both scientific literature and industry developments regarding servitization and the associated KPIs.
2. To explore the versatile user profiles of operational vessels and the associated KPIs.
3. To develop a method to assess the interrelation of service contracts and user profiles.
4. To design and analyze the performance of service contracts subject to various user profiles within the industry framework.
5. To answer the main research question.

The research questions and supplemented objectives enclose the topic's framework. A suitable methodology to explore the relation between service contract performance and user profiles is to make use of a case studies. The first sub research question helps to define a theoretical framework regarding servitization. A supplementary practitioners oriented exploration provides the answer to the second research question; Which set of usage characteristics affect the serviceability of marine vessels? Using models to simulate vessel operations are aimed to provide an answer to the last sub research question; How does the user profile influence the contract performance in the shipbuilding industry?.

1.5. Relevance of Research

This research tries to develop new knowledge about the performance of service contracts in relation to various user profiles. From a scientific point of view, the gap between theoretical knowledge from the literature and industry implementation is aimed to consolidate. Within the scientific community little publications report qualitative approaches of a servitization implementation, omitted those applying the shipbuilding industry. From a practitioners perspective opportunities to gain additional revenue are evident when the aftermarket supply chain is as well accomplished by the shipbuilder. Rough estimations within Damen shipyards state a equivalent of the initial purchase is spend during the life time of a vessel. This research should increase the understanding of existing service contracts, such as T&MC, and more advanced contracts such as OBC in relation to the user profile of a vessel. Ultimately, this research increases the ability to make better decisions for future expanding of service contract offerings.

1.6. Scoping

To confine the volume of work and to increase the quality of research, a scoping is defined. A vessel is build using components from external suppliers. In essence, a shipbuilder like Damen can be considered as a configurator of vessels. Or, to adopt the universities terminology a vessel can be considered as a multi-machine. This enables a modular approach by selecting vessel components that are of interest to investigate. The aim is to develop an approach to assess the interrelation of servitization contracts and user profiles. A generic model facilitates later extensions of sub-systems. As stated before, the shipbuilding industry identifies itself through a wide variety of vessels and a even wider field of applications and operating circumstances. Therefore, this thesis focus' itself of vessels used to quickly supply crew and lightweight cargo between shore and off-shore locations. Further, the research is narrowed down to main engine maintenance. The main engines are the most maintenance intensive systems on board of a vessel. Moreover, the maintenance execution *strategy* complied is adopted from the OEM. Lastly, the operational circumstances are narrowed down to those serving the construction and maintenance of offshore wind farms.

1.7. Thesis Outline

The remainder of this thesis is structured as follows; The theoretical exploration is presented in chapter 2, the practical exploration in chapter 3. The theoretical and practical exploration leads to the Research design in chapter 4. The case analysis' are presented in chapter 5. To answer the main research question for generally, chapter 6 discusses the founded relations and propositions. The research conclusion is written in chapter 7 and the discussion in chapter 8.

2

Theoretical Exploration

Academic research regarding servitization as a business model is extensively performed prior to the establishment of this thesis. The theoretical exploration is outlined in two parts. First an in-depth survey into the literature regarding servitization is presented in 2.1. The second part, 2.2, considers a survey into a methodology that integrates both usage and costing aspects of assets. The first goal of the theoretical exploration is to contribute toward the first research question: "What is servitization and how does it perform?". In addition, prior developed methods are explored to support the third researches objective; To develop a method to assess the interrelation of service contracts and user profiles.

To answer the first research question regarding servitization aspects of implementation strategies, product-service interrelation, contract theory, and the contracting process are elaborated. The influence of user profiles as a set of characteristics to determine a contracting method is however underexposed in the literature. Contract establishment is by definition a process with, at least, user and supplier involvement. Contracts are legal documents stating the rights and duties of the involved parties. In essence, service contracts as supposed in this research exchange maintenance execution for a financial compensation. To gain insight into the expected cost of vessel usage over the whole life time, a LCC analysis is an obvious method. Therefor, theory regarding LCC is conducted to gain understanding of the method to determine the operational costs.

The theoretical exploration is aimed to result in a theoretical framework to structure further research and method developments. Both found theories and gaps are aimed to form a base to the design phase of this research. This chapter concludes with found propositions regarding servitization, clear contract concepts, KPIs, and refined remaining research directions.

2.1. Servitization

Servitization is a term initiated by Vandermerwe and Rada (1988) to describe the observed trend to offer full market packages of customer focused combinations of goods, services, support, self-service, and knowledge. Schmenner (2008) argues that antecedents of servitization stretch back 150 years. Later, Ambroise et al.; Neely et al. both criticized the lack of evidence of the observed trends of both Vandermerwe and Rada, and Schmenner since the literature regarding servitization substantiate largely on case studies. Baines et al. (2009) recognizes similarities between servitization strategies and parallel developments in PSS. Often, a side step is made towards literature regarding PSS theory initiated by Goedkoop et al. (1999). Contrarily, publications found during the exploration of scientific literature discussing servitization often commence stating that it is a emerging business model (Davies et al., 2007; Lee et al., 2016; Slywotzki and Linthicum, 1984; Smith, 2013; Zhang and Banerji, 2017). Most recent literature show engrossment in Outcome-Based Contracting (Batista et al., 2017; Bohm et al., 2016; Essig et al., 2016; Grubic and Jennions, 2018; Ng et al., 2009; Visnjic et al., 2017), Performance-Based Contracting (Hypko and Gleich, 2010; Kleemann and Essig, 2013; Liinamaa et al., 2016) as a more advanced form of servitization.

2.1.1. Implementation strategy

Although servitization is not a novel business model, there is a lack of practice and scientific proof confirming comprehensive application within the shipbuilding industry. Service delivery and solution selling both strive to achieve increased value through co-creation (Raddats et al., 2019). However, the concept of value co-creation is a macro concept that still lacks precise empirical grounding and accurate operationalisation (Kowalkowski et al., 2017; Luotola et al., 2017; Rabetino et al., 2017a).

There is an ongoing debate in the literature on servitization about the financial consequences of the decision to servitize (Neely et al., 2011). Some authors present compelling evidence of the benefits of servitization, often basing their analyses on in-depth investigations in particular firms (Visnjic et al., 2018). Others argue that until firms achieve specific levels of service revenue they will fail to recoup superior financial returns (Palmatier et al., 2008). Yet others highlight the challenges of servitization, arguing that the cultural and organizational shifts required mean that often firms fail to capitalize fully on the opportunities services afford (Gebauer et al., 2005). The outcome of the research to get grip on the servitization paradox is inconclusive, Neely et al. therefore state that a successful servitization implementation depends on the execution and organizational capabilities.

Despite the lack of an unambiguous servitization methodology for financial success literature regarding these organizational aspects is ample (Davies et al., 2007; Green et al., 2017; Visnjic et al., 2018). A multiple-case study research performed by Rabetino et al. (2017b, figure 2) resulted in a strategy map expanding aspects of servitization from a both business and growth perspective. Reflecting on the shipbuilder's current situation the subsequent developments are to be found in the 'internal process perspective - productivity strategy' frame. Rabetino et al. (2017b) proposes the following aspects to elaborate;

- Supply chain development & integration
- Configuring modular product service systems
- Standard service agreements
- Pricing model based on performance or value
- Service centers close to customers

The main gaps within the context of the practitioners situation and literature in the pricing model based on performance or value, the standard service agreements, and modular product-service systems. The placement of service centers near customers has a more practical nature and is therefor out-scoped. The supply chain development and integration relies, according to Rabetino et al. (2017b), on enterprise resource planning (ERP) systems. The strategy map is included in Appendix A.

As stated in the scoping in chapter 1, a vessel is configurable by design and therefor the service system is to construct modular as well. Standard service agreements, or contracts, are discussed in subsection 2.1.2 and further developed along the econometric framework in chapter 4. A pricing model based on performance or value is firstly approached using LCC methods as reviewed in section 2.2. Theory regarding value drivers and KPIs are discussed in the consecutive subsection.

2.1.2. Product - Service interrelation and performance

Lee et al. (2016) examined what products are applicable to offer as a servitization. Research into choosing a servitization strategy over conventional manufacturer-service provider systems perform better if products demand a higher level of service. Vessels are subject to a high intensity maintenance schedule. Therefor servitization as a strategy in the shipbuilding industry is, from a product perspective, confirmed.

The first aspect to discuss is the interrelation between (physical) products and services. Products and service systems in a manufacturing industry exist in a spectrum of purely product delivering to purely the offering intangible services. The literature often refers to this spectrum as the Product-Service continuum (Gebauer, 2008; Rathmell, 1966). Rathmell state that all industries can be located on a product-service continuum. This model can be used to characterize the companies nature as further developed in Baines et al. (2009). Looking at the characterization of Baines et al. (2009, table II) a threefold distinction can be made: Product-focused operations, Product-centric servitized operations, and Service-focused operations. Comparable industries from other domains regarding complex, capital intensive transport equipment (aerospace and automotive) are to be found in the Product-centric category. Baines et al. (2009) tabulates the characteristics of the three distinctive product-service types as defined by Tukker (2004, Figure 1) PSS model[1]. The performances measures of Product-focused operations are *to specification* and *to cost*. Half way the continuum usage metrics as availability and customer satisfaction are the KPIs of product-centric servitized operations. Service-focused operations are making use of customer satisfaction metrics to measure the contract's performance.

Recent publications regarding servitization as business models emphatically focus on the establishment of supplier-customer relationships, value co-creation, and contracting (Carolina et al., 2019; Chathoth et al., 2013; Kristensen and Remmen, 2019; Luotola et al., 2017; Rabetino et al., 2017b; Visnjic et al., 2018; Zhang and Banerji, 2017). A study into the relation of customer's satisfaction and loyalty as a result are studied by Bei and Chiao (2001). The authors concluded with the proposition that customer loyalty is mainly determined by the level of satisfaction. Key aspects to achieve customer contentment are a trade-off between product- and service quality, and price fairness. A commonly used value driver, on the other hand, is the willingness of both parties to take or avoid risk (Cohen et al., 2007; Hypko and Gleich, 2010). The model proposed by Cohen et al. (2007) uses the measure of risk to indicate whether a supplier or a customer pays for the unforeseen costs. Example given, at a FPC the supplier could decrease his expected net result due a miscalculation or contingency events. On the other hand, fixing the price with a large margin for errors customers might turn-off the contract. T&MC, contrarily, let the supplier bill the resource usage and time spend on a job depending on the job execution. In this case, the supplier takes (theoretically) no risk on contingency events resulting in higher costs.

The sub research question stated above "What is servitization and how does it perform?" can partially be answered after the first subsection. Servitization contracts combine the delivery of physical products with a service agreement to enhance the asset value for both the customer in terms of support and the supplier in terms of after sales. Before continuing to elaborate specific contract types a general conclusion about contract performance can be drawn. The main KPI to consider a service contract from a customer point of view is the right trade-off between the delivered quality and cost is made. Although this is obvious the definition of *quality* might differ from case to case. The quality regarding to the used literature have aspects of (1) willingness to take or avoid financial risk, (2) the outcome of the delivered product, and (3) the price fairness.

[1] See Appendix B for the PSS classification model

2.1.3. Contract theory

To provide more details about contracts a mathematical approach is used to illustrate the differences. The model is adapted from Cohen et al. (2007). The autors state that transaction amount, from a customer to supplier perspective, T can be established using the cost origin and/or a factor (≥ 0) to indicate the weighted appearance in the transaction amount.

$$T(C,B) = \omega + \alpha C - \nu B \tag{2.1}$$

Where ω, α, and ν are the contract parameters. ω is the fixed payment, α the customer's share of the suppliers's cost C, and ν the penalty rate for the supplier's under-performance B. The supplier's net result R is therefor;

$$R = T(C,B) - C \tag{2.2}$$

With $\omega > 0$ $\alpha = 0$ and $\nu = 0$, a FPC is obtained. With $\omega = 0$, $\nu = 0$ and $\alpha < 0$, a T&MC is obtained. Similarly, setting ω to a certain fixed fee with an additional $\alpha > 0$, an cost-plus contract is obtained[2]. Finally, using ω and $\nu > 0$ an OBC is obtained. Consistent with other literature analyzing and comparing these contracts (i.e. Scherer (1964)), this model indicates that T&MC and FPC are polar opposites when it comes to providing cost reduction incentives. With a FPC contract a supplier becomes the residual claimant, and hence it is in his interest to reduce costs as much as possible. In terms of cost risk, the FPC contract gives perfect insurance to the customer because the supplier bears all risks from cost under- or overruns. In contrast, the T&MC contract shifts all risks to the customer, because she has to reimburse whatever the supplier's realized cost may be. At the same time, the T&MC contract provides no incentive for the supplier to reduce costs. In theory FPC and T&MC both do not create an incentive for the supplier to increase the performance in therms of availability towards the customers operations. An OBC (ω and $\nu > 0$) as described by Cohen et al. (2007), conceives the incentive to the supplier to avert the under-performance penalty νB.

OBCs exist in various practices. Discussed OBCs by Grubic and Jennions (2018) let the users pay for equipment availability or economic result. OBCs as discussed by Cohen et al. (2007) emphasize the appearance of the νB term as a definition for a performance contract, Smith (2013) recognizes OBCs as power-by-the-hour contracts. However, there is a consensus in literature that the *outcome* is based on a customer's value metric. Within the focus of the shipbuilding industry, the functionality and corresponding value metric differ between the variety of vessels, i.e. a Search & Rescue vessel must be available when the she is needed while a ferry can be unavailable outside the scheduled hours. In essence, the agreed outcome in return for cost ω are deducted by νB is the agreed outcome is not accomplished.

What is missing in literature and can be expressed in the model of Cohen et al. (2007) is a transaction function that includes an incentive for the customer to reduce the supplier's cost and besides the supplier has a performance incentive towards the customer;

$$T(C,B) = \alpha C - \nu B \tag{2.3}$$

With $\alpha, \nu > 0$. However, this equation shifts the risk back to the customer. To retain the elegance of a predictable transaction amount T and yet without a fixed and bounded amount ω, the transaction amount is to be determined using refined usage cost metrics as a function of the user profile to obtain C^*. The suppliers expected utility, C^* must be therefore substituted for C yielding;

$$T(C,B) = \alpha C^* - \nu B \tag{2.4}$$

[2] Due to similarities with T&MC, C+ contracts are excluded within this research

Using the expected mean-variance utility formula[3] of Sargent (2010) with a sign change to compensate the financial risk;

$$C^* = \mathrm{E}\left[U(C)\right] = \mathrm{E}\left[C\right] + \frac{r\mathrm{Var}\left[C\right]}{2} \tag{2.5}$$

Using this form, the expected deviation of cost C^* introduces an uncertainty that passes or misses the actual supplier's cost C. The expected deviation or $\mathrm{Var}[C^*]$ can therefore be captured choosing a risk aversion factor $r > 0$. This proposed contract form is further referred to as an UPBC. The act to determine the expected cost of the assets during the operational life time is generally referred to as a LCC assessment, further elaborated in section 2.2.

2.1.4. Contracting process

This thesis aims to compare contract types in relation to the user profile. Literature regarding contract establishment, negotiation, and value mapping is ample and conducted to embody the previous sections on contract theory. However, a clear and less abstract comparable flow diagram has to be developed to frame the opposing contract types. This flow diagram excludes the ample discussed contract establishment phase prior to the exploitation phase. In contrast, this model aims to clearly indicate the instant when the transaction amount T is determined.

The model as presented in figure 2.1 is a general representation of equipment subject to periodic and contingency service moments. The operational state is a recurrent state until service action is required, after the execution of service the operational state is reestablished. This loop is exited after the contract period ends. The distinct contracts are discussed below and visualized in figure 2.2. Starting with T&MC, the transaction

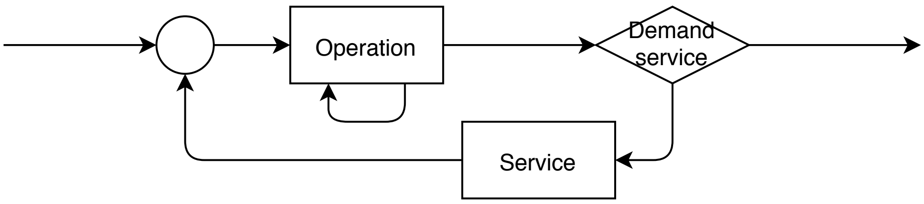


Figure 2.1: General model of equipment subject to service (Own elaboration)

amount T is based on the time spend and material used to execute the demanded service. The transaction moment occurs after the service execution. The transaction amount depends on the time spend and materials used by the supplier to reestablish the operational state. Second, when a FPC is considered as an *all in* price. These contracts are often bounded by a certain usage in terms of running-hours or calendar time (one and two dimensional contracts (Chen and Popova, 2002; Liinamaa et al., 2016)). These contracts state a predetermined price regardless the actual cost made by the supplier. The transaction moment is therefor located at the beginning of the loop. Then OBCs are considered. OBCs are based on outcome metrics such as availability, the transaction amount is therefor determined using the (available) operational state duration. Last, the proposed UPBCs are based on actual use of the vessel enabling the user to reduce the transaction amount if the vessel is used in a more sustainable manner. The instant of transaction is therefor at the end of each period after analyzing the monitored usage data.

2.2. Life Cycle Costing

In most literature the science of the determination of the integral costs of a product from creation to decommissioning is referred as LCC. Contrarily, a study into the environmental impact is generally referred as a Life

[3]See Appendix C for derivation

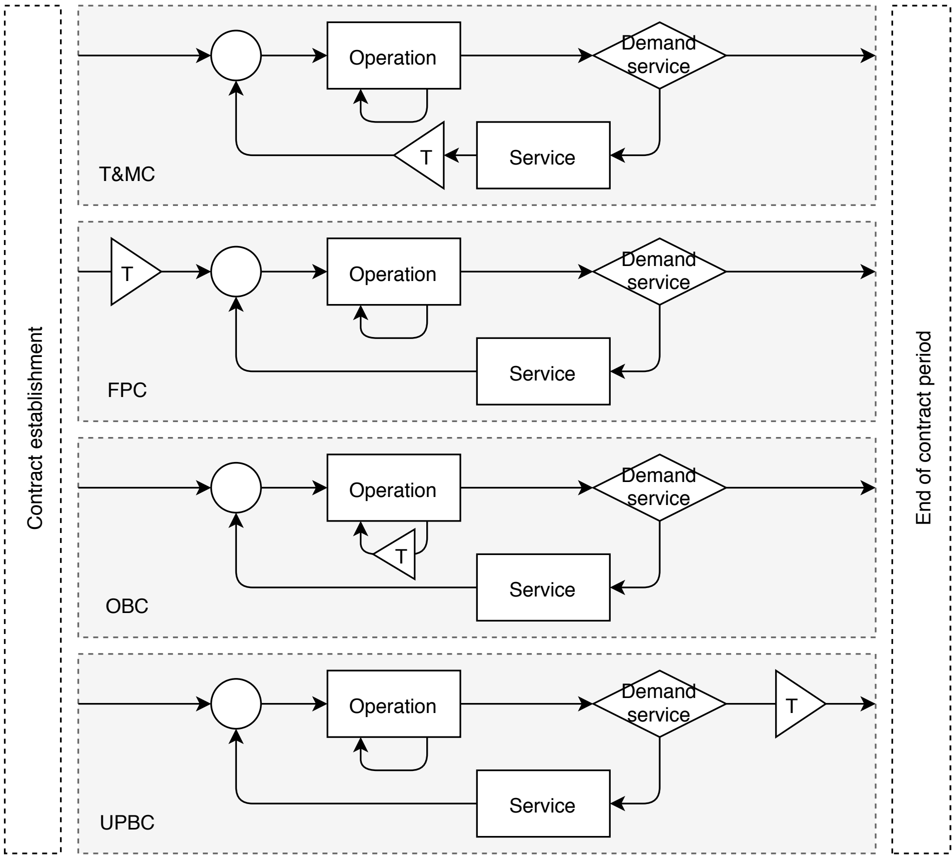


Figure 2.2: Contract workflow and transaction moments (Own elaboration)

Cycle Analysis (LCA).

Other than LCA, the term LCC has various appearances including LCCA, TCA, TCO, ELCC, and WLC (Miah et al., 2017). Thereby various, though overlapping, definitions are stated. SAE defines LCC as *"the total cost of ownership of machinery and equipment, including its cost of acquisition, operation, maintenance, conversion, and/or decommission"* (Society of Automotive Engineers, 1999). The international standardization organization ISO defined LCC as *"a technique which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial costs and future operational costs"*. Likewise, in (ISO, 2011) LCC according to ISO15686 *"assessing the total cost of ownership, including the operational and running costs"*. In contradiction, ISO defined WLC as *"all significant and relevant initial and future costs and benefits of an asset, throughout its life cycle, while fulfilling the performance requirements"*.

In contrast, LCA is a more coherend and well defined term. The definition of a LCA is *"a technique to assess environmental impacts associated with all the stages of a product's life from cradle-to-grave"* (Cays, 2017). LCA emerged in the late 60's and arouse interest rapidly ever since (Mcmanus and Taylor, 2015). During the 60's and 70's LCAs were company driven, concerned single issues and rarely publicly published (Hunt and Franklin, 1996). The awareness of environmental impact due to production and use, shifted the LCA's focus to pollution prevention (Mcmanus and Taylor, 2015). The actual first signs of the term LCA is mentioned in 1990 (Klöpffer, 2006). The methodology described by Fava et al. (1991) is still generally used today. Subsequently the first ISO standards regarding LCA were developed in the late 90's adopted and amended from the SETAC standard. Since the 00s, LCA became increasingly policy driven (Mcmanus and Taylor, 2015).

Conventional LCC is, to a large extent, the historic and current practice in many governments and firms, and is based on a purely economic evaluation, considering various stages in the life cycle. It is a quasi-dynamic method and generally includes (conventional) costs associated with a product that are borne directly by a given actor and is usually presented from the perspective of the producer or consumer alone. Internalized (or to-be-internalized) external costs that are not immediately tangible, or not borne directly by one of the life cycle actors in question, are often neglected. Additionally, conventional LCC analysis' does not always consider the complete life cycle; for example, EoL operations are excluded in many conducted publications.

A LCC analysis consists of four stages; scoping, data gathering, analysis, and a result assessment. Although literature is quite unambiguous about the four stage road-map, further implementation and execution instructions are underexposed due to their practical case-to-case differences. To conclude the survey concerning LCC, it is conceivable to adopt the framework as proposed in literature. The framework is further elaborated in chapter 4.

2.3. Theoretical Framework

The theoretical framework aims to outline and conclude the base to continue with the practical exploration phase in chapter 3. The theoretical exploration has addressed two topics; servitization and LCC. Theory regarding servitization are mainly focused from a marketing perspective, presenting potential economic results (Reynoso et al., 2011) and discusses findings from case studies. Below, a enumeration of general statements is presented to exemplify challenges of this thesis' topic.

- A successful servitization strategy depends on execution and organizational capabilities (Davies et al., 2007; Green et al., 2017; Neely et al., 2011; Visnjic et al., 2017)
- There is a general lack of scientific consistency in successful implementation strategies (Rabetino et al., 2017b; Zhang and Banerji, 2017).

Besides, the following facets are accordant in the conducted literature.

- All business offerings can be located on the product-service continuum as proposed by Goedkoop et al. (1999)
- Products demanding a higher level of service performs better in a servitized product offering (Lee et al., 2016)
- Remote monitoring is key in servitization (Grubic, 2018; Romero et al., 2019; Rymaszewska et al., 2017)
- Data gathering is valuable for servitization development (Opresnik and Taisch, 2015)
- Availability and costs aspects are the most common KPIs for servitization offerings (Baines et al., 2009)

Theory concerning contracts showed a generalized formula that synthesizes all basic contract types; $T = \omega + \alpha C - \nu B$. This transaction formula is configurable by varying the value of ω and the parameters α and ν. Traditional service contracts are established such that the user pays the supplier based on the hours spend and materials used on a repair. This form of service agreement is called a T&MC. A more emerging form of agreements are OBCs. OBCs are contracts in which a certain user outcome results in a financial transaction to the supplier. The outcome could be measured in availability or economic results (Grubic and Jennions, 2018). The third form of agreements is deviated from the car industry; using a vehicle for a fixed amount per time called FPC. See table 2.1. Last, literature proposes various but general KPIs to assess contracts. Indisputably economic aspects are key in contract performance. Cost, revenue, and price fairness are the main figures. Risk allocation is a key measure to decide whether the transaction amount is predetermined or completed after the actual cost are made. OBCs are by definition outcome depended. Availability as an outcome is considered as well a KPI.

The answer to the first research question "What is servitization and how does it perform?" yields: Servitization is defined by Vandermerwe and Rada (1988) as the offering of full market packages of customer focused combinations of goods, services, support, self-service, and knowledge. Servitization offerings are inherent to agreements established by suppliers and users specified and covered in a contract. This thesis' focus is to investigate the performance of service contracts in relation to the user profile framed to the main engines. The main contracts; T&MC, FPC, OBC, and the proposed UPBC differ from complexity but all fit on the PSS continuum of Goedkoop et al. (1999) and are therefor considered as servitization offerings. The performance of contracts are mainly determined by economic aspects of both supplier and customer. When considering OBC the outcome metric is an additional KPI besides the outcome primarily depends on the equipment's performance. Baines et al. (2019) presented performance metrics used per product classes of Tukker (2004) and Bohm et al. (2016) risk assessments:

- User's transaction amount T
- Supplier's contract result R
- User's price fairness $\frac{T}{C}$
- Supplier's probability of positive result $P(R > 0)$

Due to the lack of consistency in both implementation and execution strategies, and the stated objective "To develop a method to assess the interrelation of service contracts and user profiles", there is a demand for an implementation framework. This, together with Rabetino et al. (2017b) proposed design of a "modular PSS" a refined third research objective yield: "To develop a implementation framework and a methodology to assess the contract performance in relation to the user profile".

Contract	T&MC	FPC	OBC	UPBC
Based on	Time spend and materials used to keep the equipment functional	A fixed price to cover the cost for keeping the equipment functional	The outcome of the equipment	Usage metrics and outcome in terms of availability
Supplier's economic result (benefit)	If equipment needs maintenance	If equipment is functional	If equipment achieves the desired outcome	If equipment is operational
User's economic result (benefit)	If equipment is functional	If equipment needs maintenance	If equipment is used according to the desired outcome	If equipment is operational
Risk reduction incentive	User	Supplier	Supplier	Supplier & user
Cost reduction incentive	User	Supplier	Supplier	Supplier & user
Customer supplier transaction T	αC	ω	$\omega - \nu B$	$\alpha C^* - \nu B$

Table 2.1: Contract characteristics

3
Practical Exploration

The practical aspects of this research are to be explored using the knowledge and information from the shipbuilding industry. The main goal in this chapter is to answer the second research question: "Which set of usage characteristics affect the serviceability of marine vessels?".

This chapter appoints the design of vessels and their operational purposes in section 3.1. Referring back to the introduction; this thesis' focus is limited to fast crew supplying vessels deployed for offshore wind farm construction and maintenance. The pith of the matter that affects the LCC, asset management, is elaborated in section 3.2. The second to last section examines the concept of *user profiles*. The theoretical framework concludes the practical exploration by addressing the features to include in the research phase in chapter 4 and 5.

The shipbuilding industry is highly international oriented and partnership based. Therefor, the organization must comply with various cultures, climates, and waters around the globe in their vessel design and after sales services. This thesis is established in cooperation with Damen Shipyards, a Dutch based multinational shipbuilding and shipyard group. Damen builds vessels for various purposes; work boats including tugs, platform vessels, fishing and aquaculture, and dredging equipment; high speed crafts including crew transfer vessels, pilots, search & rescue, patrol, and civil guardian vessels. Transport vessels including inland and seagoing transport, public transport vessels, and ferries. Damen also develops naval vessels for various defense departments around the world. The last group worth mentioning is the super yachting department, Amels, as part of the Damen Group. Damen delivers these as standardized vessels *configure to order* or custom designed *engineering to order*.

The focus of this thesis is to assess service contracts in relation to the user profile. As is concluded in the theoretical exploration, implementation strategies lacks in consistency. The aim is to cope with the proposed modularity, standardization, and pricing model by Rabetino et al. (2017b)[1] but with an explicit case study intend on fast crew transfer vesselss (CTVs) within the offshore wind farm industry.

3.1. Vessel Design and Operations

Damen delivers CTVs named Fast Crew Supplier (FCS) vessels specifically designed to serve the offshore wind farm construction and maintenance phases. The vessels considered in this research is the FCS 2710 (figure

[1] See strategy map of Rabetino et al. (2017b) in appendix A

(a) Fast Crew Supplier 2710 landing platform

(b) Fast Crew Supplier 2710 side view

Figure 3.1: Damen build fast crew suppliers (Images from Damen)

3.1). The FCS has a dedicated landing platform to easily moor on a wind turbine's mono-pile. The twin hull design and axe bow enable the vessel to be operable at rough sea states outperforming other transfer vessels or helicopters. The vessel is laid out with a front deck able to transport light weight cargo, a "business class" accommodation to seat 24 persons, and house seven crew members. The vessel is equipped with two drive trains able to generate up to 2162 bkW with a top speed of 25 knots. As mentioned, the vessel has a dedicated bow fender to moor on offshore structures providing personnel an easy pass.

3.2. Asset Management

Asset management refers to the systematic approach to the governance and realization of value from equipment that a organization is responsible for. Within this section, an overview of maintenance strategy and execution, personnel, facilities, and remote monitoring is provided. This thesis' focus is limited to the main engine maintenance. The main engine LCC aspects are from a maintenance perspective the most influenced by the user profile i.e. 82 % of the engine maintenance tasks are determined by running hour intervals in case of the Caterpillar C32 engine. The maintenance cost of the main engines account for 57% of the total cost of vessel maintenance after one year of operation with eight running hours a day. This section continues to focus on after sales services within the in consideration of the composed theoretical framework.

3.2.1. Supply Chain Management

Supply chain management is the flow of goods and services throughout a system. This section reflects on the "Supply chain development and integration" of the strategy map in Rabetino et al. (Appendix A). The list of components installed in a Damen vessel is documented by the Configuration Management Department of Damen Services. This document, the Service Bill of Material (S-BOM), acts as the root document to offer future services and spare parts. After the establishment of the S-BOM the maintenance plan and initial provisioning package is composed. After the vessel's delivery, Damen offers a world-wide spare part deliveries via service hubs and supplier networks. Further service aspects regarding maintenance and usage monitoring are discussed hereafter.

3.2.2. Maintenance strategy

In both literature and practice, the developments regarding maintenance are ample and is never standing still due to ongoing developments in both maintenance applications and improvements of the equipment itself. The establishment of a maintenance execution plan has a strong practical nature. Literature regarding maintenance have a versatile subdivision of maintenance strategies. A subdivision is presented in figure 3.2 in accordance with Ben-Daya et al. (2013); Mishra and Pathak (2012); Mobley (2002). Vessels demand a high level of maintenance due to the high number of mechanical components, a high level of demanded

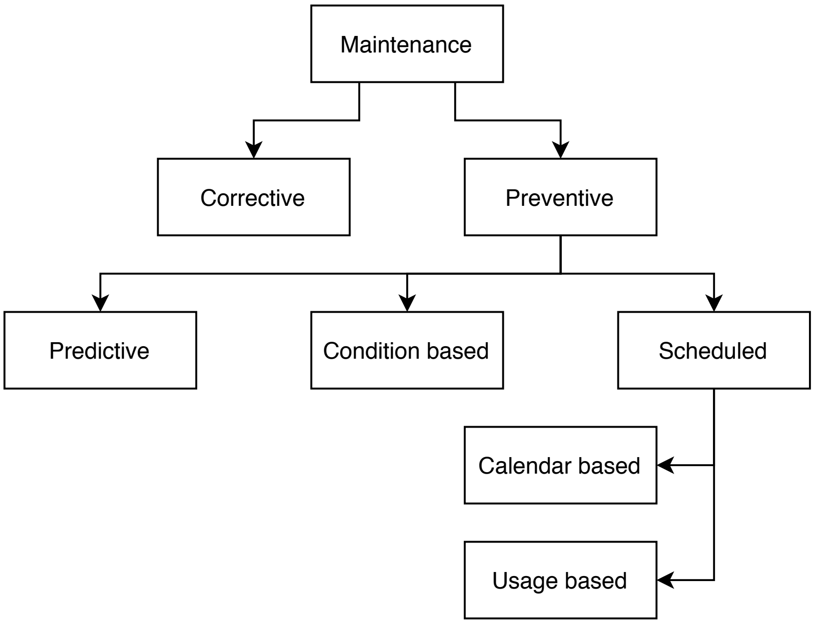


Figure 3.2: Maintenance methods (Own elaboration)

availability, and maintenance to meet the regulation- and certification requirements. A vessel is configured using component from various suppliers. Main engines are provided by Caterpillar, MTU, and Volvo primarily. These, and the majority of equipment suppliers develop their own maintenance plan which is included with the vessels delivery. Maintenance engineers at Damen adopt the OEM maintenance plans and includes it to the vessel maintenance instructions database available for the vessel's operators.

3.2.3. Maintenance execution

Vessel maintenance includes a wide variety of tasks. Some maintenance tasks are performed daily in order to monitor the condition of critical components. Other maintenance tasks comprise a complete preventive engine top-end overhaul every 10,000 running hours. Practice categorizes three levels of maintenance;

- Organizational Level Maintenance (OLM)
- Intermediate Level Maintenance (ILM)
- Depot Level Maintenance (DLM)

OLM includes maintenance tasks crew of any vessel can execute. No special parts or specialists knowledge is required. ILM tasks are those to be processed with assistance from shore, knowledge and possibly require special tools. Lastly, DLM tasks can only be processed by an expert or OEM personnel. Special knowledge and possibly special tools are required (Maintenance Guidelines, Damen). Parallel to the level of maintenance, the maintenance planning indicates the personnel required for the maintenance task. Three levels of personnel are defined able to execute maintenance. First, on-board crew carry out all maintenance tasks able to be executed while sailing. Then, shore support members are those who execute maintenance that cannot be executed while sailing. Last, external personnel are considered specialists hired directly from the supplier to carry out complicated maintenance tasks. The maintenance plan furthermore prescribes the necessary facilities to execute the corresponding maintenance task. Again three facilities are distinguishable; on-board-, shore-, and docking facilities. A vessel carries some essential spare parts and tools by default on board. Other specialist tools and equipment are stored on shore and collected prior to the maintenance execution. A docking facility can completely hoist a vessel on dry land. Concerning the LCC, hiring (external) personnel and the renting of facilities are additional costs of maintenance.

3.2.4. Remote monitoring

Grubic (2018) and Opresnik and Taisch (2015) discussed the importance of remote monitoring and the value of big data in servitization strategies. Remote monitoring systems are key enablers for servitization, Grubic (2018) has identified three broad groups of benefits of remote monitoring: (1) Mitigation of risks, (2) Efficiency and effectiveness benefits, and (3) Improving knowledge about the performance of product in service. This subsection first presents the main existing monitoring systems. Hereafter developments regarding an IoT application within Damen are discussed. The section concludes with the value and practicality of the available data.

Monitoring systems for vessel operators exist in various applications. Automatic Identification System (AIS) is an automatic tracking system that uses transponders on ships and is used by vessel traffic services. AIS information supplements marine radar, which continues to be the primary method of collision avoidance for marine vessels. Information provided by AIS equipment, such as unique identification, position, course, and speed, can be displayed on a screen or an Electronic Chart Display and Information System (ECDIS). AIS is intended to assist a vessel operators and allow maritime authorities to track and monitor vessel movements. Live AIS data is free available online, historical data can be bought from various providers[2].

On board equipment often includes (local) monitoring systems to inform the vessel operator with condition information and system malfunctioning. These systems provide key information to operate the vessel and are primarily displayed at the wheelhouse's instrument panel.

Damen recently launched an IoT platform *Connected Vessel* that gathers and shares the information as described above via internet networks. The data is online available for vessel owners and service engineers at Damen Shipyards. Connected Vessel is in the course of the establishment of this thesis under development. Despite, vessel tracking and main engine characteristics are able to extract and will be further discussed in section 3.3.

3.2.5. Product reliability

Early research by Nowlan and Heap (1978) showed six failure patterns characterized in two groups; increasing failure probability due to aging processes, and failure patters with random (constant) failure probability in time. Research performed by Nowlan and Heap (1978) is still valid to, at least, understand the basic theory of maintenance of mechanical and electrical components. In most literature regarding reliability studies use one or more of the six characteristic failure patterns as shown in figure 3.3. The graphs in figure 3.3 indicate the failure probability f as a function of time t. Failure probability f and failure rate λ are related by $\lambda = \frac{f}{R}$ with $R = 1 - \int f$. λ is defined as the reciprocal value of the Mean Time Between Failures (MTBF), see equation (3.1). Birolini (2014) states that a constant failure rate is applicable for most practical circumstances.

$$\mathrm{MTBF} \equiv \frac{1}{\lambda} \tag{3.1}$$

Six failure patterns are subdivided in two groups; First a set of patterns showing a clear increase in failure rate due to aging i.e. wear or fatigue. The second group contains the failure patterns with distinct early-life differences. The failures of group II cannot benefit from a preventive maintenance action and is even disadvantaging in case of pattern F. The patters are visualized in figure 3.3. The presented percentages indicate the occurrences of failure patterns in early maintenance research performed by Nowlan and Heap (1978).

To model failures and predict product reliability and availability, theory and practice often refer to sta-

[2] Denmark and the US provide free historical AIS data

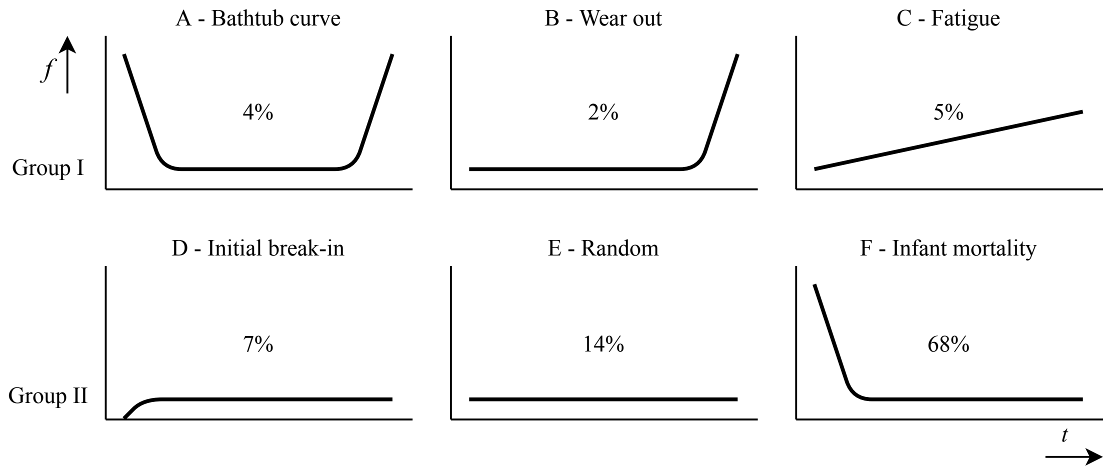


Figure 3.3: Failure patterns

tistical analysis of gathered failure data. Historical failure data is, in practice, usually deficient to retrieve accountable figures. Prior causes are on the one hand lacking or undisciplined use of administration systems or total absence of Damen mechanics in the reparation process. However, to get grip on some figures statistical analysis is performed on warranty data. Table 3.1 shows the relative frequency of warranty calls per system group of all high speed crafts delivered by Damen. Group 200, main machinery, accounts for a quarter of severe issues. The complete overview of system codes is provided in appendix E. Random failures

no.	System code	f_{HSC} [%]
000	General	0.8
100	Hull and Superstr.	12.8
200	**Main machinery**	**24.5**
300	Primary systems	21.1
400	Electrical system	17.7
500	Deck equipment	3.4
600	Secondary systems	2.3
700	Joinery and accomm.	4.4
800	Nautical, com. and auto.	13.0
900	Special equipment	0.0

Table 3.1: Overall relative severe issue frequency of high speed crafts

primarily occur by human or operation related causes. Certain use influences the failure rate λ per failure type k. Failures considered in this research are intended to add the (stochastic) contingency events during the operations of vessels. A set of five failure types k are distinguishable from the data.

- Leakages
- High temperatures
- Electric failures
- Filter failures
- Mechanical failures

The five frequently occurring failures are retrieved using Damen's warranty data and service calls. Both maintenance execution and contingency failure events affect the vessel's availability. An illustration of availability affection by maintenance activities and contingency failures is given in figure 3.4. Consistent with the theoretical framework, availability is an important KPI considering the vessel's user profile. The user profile, in

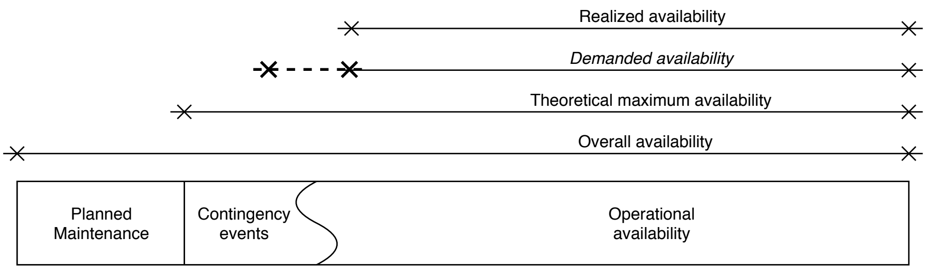


Figure 3.4: Availability illustration (Own elaboration)

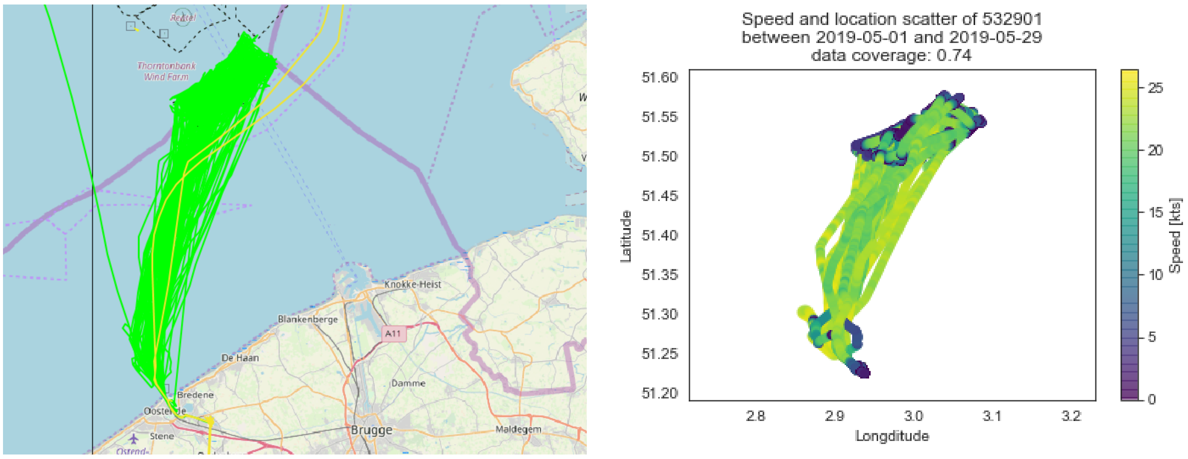
terms of demanded sailing hours to complete a certain operation, is bounded due to the scheduled maintenance activities and down-time due to failure events.

3.3. User Profiles

The user profile is a set of characteristics to describe the way an user operates the vessel. This section aims to empirically retrieve usage profiles of vessels used in the construction of offshore wind farms. First a typical track profile is discussed, then a analysis of operation time is performed. Hereafter, an investigation regarding engine characteristics is performed. This section then appoint environmental aspects that are of interest considering LCC.

3.3.1. Data Visualization

As issued before, fast crew supplying vessels are deployed to deliver crew and lightweight cargo between on- and offshore locations. The graphs in figure 3.5 show a recurrent track between the port of Oosteinde (Belgium) and wind farm Norther. Figure 3.5a Show the track record of a fast crew supplier, figure 3.5b indicate the speed sailed at the given location in knots. The graphs clearly indicate the moor location, a full speed transfer, and an area at sea where the wind farm is located. Besides the three distinguishable states a fourth state is proposed in an interview with the crew; drifting. The vessel often waits for new pick and drop calls. During this time an operator shuts one engine and drifts outside the field, on-board crew is able to perform maintenance tasks while drifting. The next aspect to consider are the engine characteristics. Engine data is



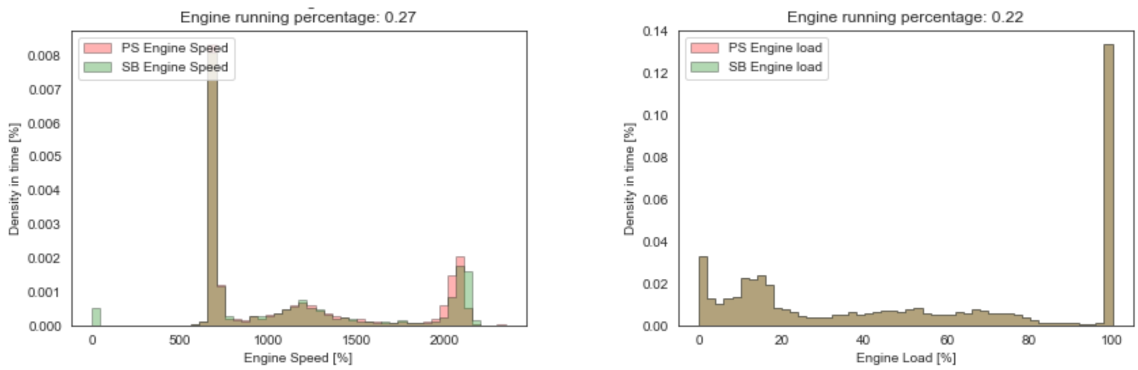
(a) Nautical chart with track history

(b) Graph with location and vessel speed

Figure 3.5: Track profile Oosteinde and wind farm Norther during construction

gathered over the same period as the graphs in figure 3.5. The Damen build FCS2710 is equipped with two main engines, one in each hull of the catamaran.

The graphs in figure 3.6 both show a histogram of the gathered data. Figure 3.6a indicates the RPMs of both main engines. The first spike at 635 RPM is the idling speed of the main engine, the spike at 2100 RPM is at full throttle. The curve in between indicate various maneuvering moments in port and at the wind farm. The graph in figure 3.6b show the engine load in time with a corresponding profile; idling at zero, maneuvering in the mid band and the spike at 100% is a result of full throttle during the transfer state. Engine



(a) Histogram of main engine RPM

(b) Histogram of main engine load

Figure 3.6: Engine characteristics of a fast crew supplier

characteristics are presented due to their influence in maintenance intensity and failure probability. Higher loads are inherent with higher wear, changing loads are inherent to undesired stresses and heat distribution within the drive train.

3.3.2. Data Modeling

This research aims to develop a model to assess the performance of service contracts in relation to their user profile. The vessel usage, therefor, needs to be modeled to test (future) use cases. A set of distinguishable vessel states is recognized; in port, transferring, in field, and drifting. The state sequence and transitions are visualized in figure 4.3, which is represented as a Markov chain. The state s of the vessel is on time i indicated with s_i. The link and annotation $p_{s,s+1}$ indicate the direction and probability of transition to state s_{i+1}. Note state T appears twice to comply with the Markov chain property stating a state transition only depends on the current state to prevent the vessel returning to port without arriving in the field, equation (3.2).

$$P(s_{i+1}|s_1,...,s_i) = P(s_{i+1}|s_i) \tag{3.2}$$

Each state of this Markov chain contains information regarding the usage characteristics in that particular state. Usage characteristics include duration figures, engine usage, transition probability, and related failure probabilities. Markov chains can be represented as stochastic matrix with elements $p_{i,j}$ indicating the probability of state changes. The matrix in equation (3.3) is a representation of the Markov chain in figure 4.3. This matrix must be build as a right stochastic matrix; each row must sum to 1.

$$P(s_{i+1}|s_i) = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & p_{F,D} & p_{F,T} \\ 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{3.3}$$

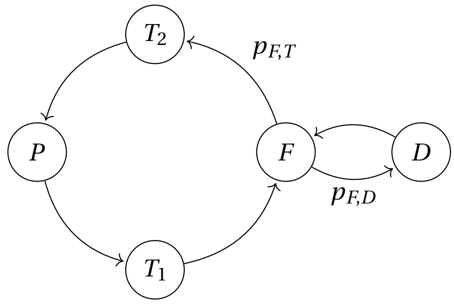


Figure 3.7: States and state transition probabilities (own elaboration)

with state vector $\vec{S}$;

$$\vec{S} = \begin{bmatrix} P & T_1 & F & D & T_2 \end{bmatrix} \tag{3.4}$$

All states in $\vec{S}$ contain the state duration information, usage metrics, and failure probabilities. The state transition matrix as shown above acts as an example suitable for vessels operations within the offshore wind farm industry. Other vessels types and operations demand a redesign of the Markov state transition chain. In addition, other states can be included to suit the vessel usage. The resultant Markov matrix, however, is aimed to be applicable to the model to assess the relation with the various service contracts.

3.4. Practical Framework

The practical exploration named aspects of maintenance, contingency failures and usage characteristics to use in further analysis. An answer to the second research question, "Which set of usage characteristics affect the serviceability of marine vessels?", is threefold. Planned preventive OEM maintenance primarily depends to the accumulative hours of engine usage. The remaining 20% of maintenance tasks are based on calendar time intervals. Then, data showed contingency failures via gathered warranty data. Experts state that aspects of engine usage can influence the failure rate. Regarding this engine usage, the load rate is within the bounds of the IoT application accessible and therefor used to correct the failure rate λ_k. Availability is an important KPI in case of service contracts with outcome metrics is terms of availability.

The final aspect discussed is the sequence of vessel state transitions during a cycle. As shown on the plot in figure 3.5, the vessel cycles between the field and port frequently for resupplying, crew change, and maintenance activities. During the activities in the field, the vessel often drifts to wait for further instructions and pick-ups. The vessel state Markov chain (fig. 4.3) and transition matrix (eq. 3.3) hold for those operations, other operation types or vessels demand a redesign for their specific situation. The aim is to cope with the proposed modularity, standardization, and pricing model by Rabetino et al. (2017b) must therefor be able to anticipate to any state transition matrix.

4

Research Design

This chapter aims to define the research approach enabling an effective way to answer the main research question "What are the best performing service contracts in relation to the user profile of vessel operators?" as unambiguously as possible. The research topic considered within this thesis emerged from a perceived absence of advanced servitization contracts within the shipbuilding industry. Literary publications considering both concepts applied in the marine domain are absent. Consistent with lacking scientific elaborations, evidence of extant in practice is scarce likewise. Theoretical and practical exploration gained insight into contracts and operational circumstances in the shipbuilding industry. Data and understanding of maintenance activities and failure behavior is acquired within Damen Shipyards. In addition, vessels currently in operation create operational data to acumen the operational aspects of their deployment. These real use-cases formed the base to model the user profile. An assessment of the results evaluates the relation of equipment usage and the performance of the obtained contract types. Figure 4.1 illustrates the assemble of the performed research so far. The vertical shaded blocks indicate the aspects retrieved form the theoretical and practical exploration, and their connection to the states of the LCC methodology. The horizontal shaded blocks identify the three consecutive phases to perform a case study. This chapter is outlined similarly to the research outline; First the theoretical and practical frameworks are reviewed to fit the sub objective "*To develop a model able to assess the interrelation of servitization contracts and user profiles*" in section 4.1. Then the LCC methodology is elaborated in section 4.2. The preliminary model, consisting of three phases, is discussed in 4.3. The consecutive Case analysis chapter aims to define use cases as input for the preliminary model.

4.1. Framework Review

The section aims to review both theoretical and practical framework to fit the stated research objective. First, the scoping is amended to canalize the gained knowledge from prior chapters. Second, assumptions are discussed. The assumptions are stated to cover knowledge gaps, present biased and tacit elements, or to simplify out-scoped aspects.

4.1.1. Scoping

The models scoping is stated below.

- Aging processes are excluded from machine maintenance and failures

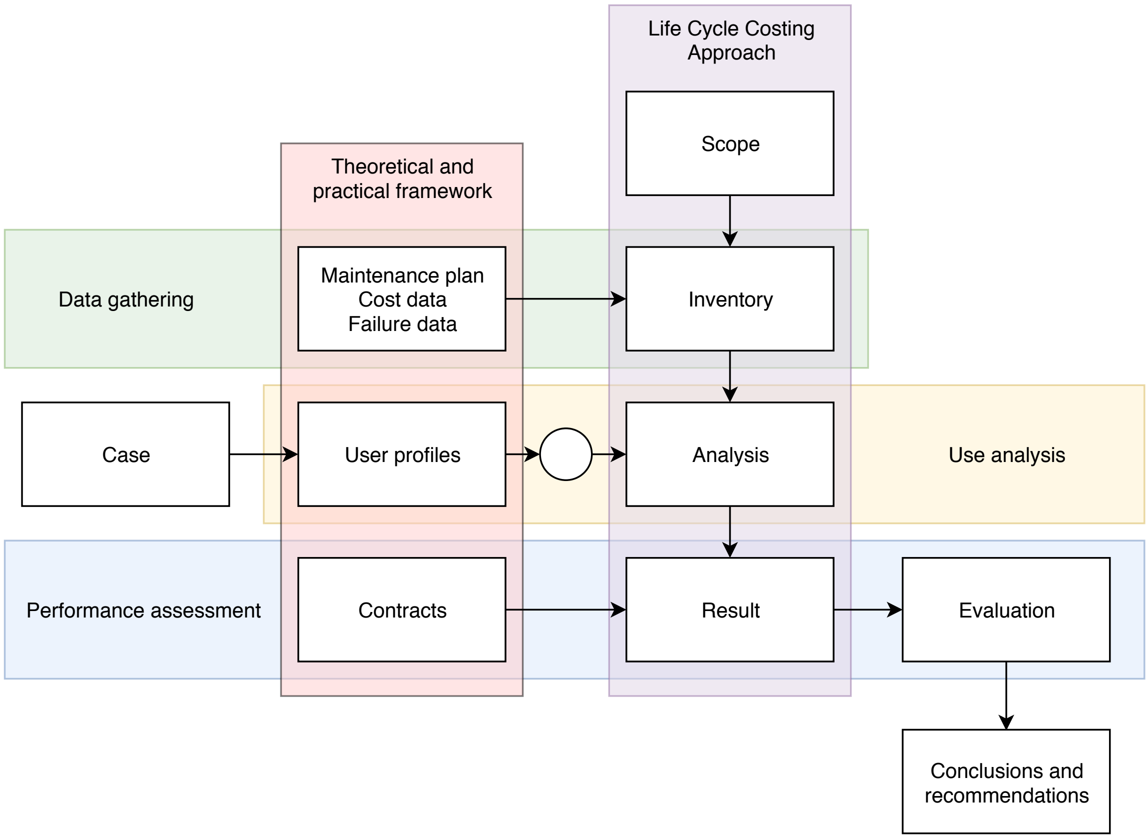


Figure 4.1: Research outline

- Correction for inflation is not taken into consideration
- Contract choice does not influence the user profile
- The supplier's cost are limited to the cost of maintenance and failures ($C_S = C_O + C_G$)
- Warranty aspects are excluded from analysis

4.1.2. Assumptions

The models assumptions are stated below

- The maintenance schedule is perfectly executed
- Repairs recover the system to *as good as new*
- Spare part costs are retail prices as suggested by OEM
- Spare part margin is 25%
- Damen personnel margin is 25%

4.2. Life Cycle Costing

Common methodologies found in the publications are examined and adapted to use as a framework within this research to develop a LCC model. Frameworks as examined during the literature survey are within the theme of LCA predominantly adopted from the ISO standard ISO14040. Authors who combined LCA and LCC models generally benefit from the ISO LCA framework and include therein a costing calculation to a certain integration level. The outline of the proposed framework is adapted from Curran (2013); Emblemsvag (2001); Favi et al. (2018); Karvonen et al. (2019); Kjær et al. (2015); Luttenberger (2017); Miah et al. (2017); Vaughan et al. (2010). The widely used methodology is a four-stage road-map. The first stage defines a *scope* to describe the system, functions, and boundaries. The scope includes a *Functional unit*, a *Reference flow*, and a *System boundary*. The functional unit includes the main purpose of the vessel and the to-be included phases. Remark that in case of studying more than one alternative at least the functional unit must be identical. The Reference flow concertizes the functional unit into a specific outline of included systems. Thirdly, system boundaries define the in- and outputs for each phase of the life cycle. The life cycle of a vessel, as embraced in most literature, consists of three phases. Beginning with the construction phase, then the usable life time and finally the end-of-life phase. For the purpose of this research, the main focus will lie on the use phase of a vessel. Without going into detail the operational phase also includes the maintenance aspects. The second stage comprises the collection of the exact life cycle aspects. From a customer point of view, the functional requirements and user parameters are to be determined within this stage. From a technical point of view, the suitable configurations are to be examined or to be fixed for the qualification and quantification of the reference flow. During the use phase, an inventory of the expected usage and corresponding scheduled maintenance and contingency events affecting the cash flow has to be made. The end-of-life phase could either be selling or disposing the vessel. The third stage is the actual calculation of the input towards an output in terms of costs within the LCC. Examples in the literature show various levels of complexity, difficulty and detail. The fourth and last stage concerns the representation of the results. To manually interpret the outcome of the LCC, graphs, charts, and diagrams are of common use.

The remainder of this chapter is used to present the mathematical model as base of the LCC calculation. The letter c/C is used as a symbol for various *costs* aspects. Small $c_{...,i}$ is used to appoint the costs of $\ldots$ on a certain time step i. Summing $c_{...,i}$ over i yields $C_{...}$. To retrieve a good estimate of the mean and variance of the stochastic model, multiple simulations have to be performed. Therefor $n \in N$ mark the simulation run n of total N simulations, see table 4.1

Symbol	Description		Unit
$c_{...}$	Cost of …	-	[€]
$C_{...}$	Total cost of …	-	[€]
i	Time step i	$0 < i \leq T$	[hour]
T	Time horizon	-	[hour]
n	Simulation run	$0 < n \leq N$	[-]
N	Total number of runs	-	[-]
o	Maintenance job	-	[-]
O	All maintenance jobs	-	[-]
g	Failure	-	[-]
G	All failures	-	[-]

Table 4.1: Life Cycle Costing model symbols

The cost of OEM maintenance initiated on time step i is determined using (4.1). Often, multiple maintenance jobs are joined or coincidence according to schedule. the cost of a single maintenance job $c_{o,i}$ is determined by the cost of spare parts, facility usage, and personnel given the hourly rates and job duration. The total cost of maintenance initiated on time step i is;

$$c_{O,i} = \sum_{o \in O_i} c_{o,i} \tag{4.1}$$

Total cost of spare parts per time step is summed over all time steps to yield the overall cost of spare parts during time T of simulation n.

$$C_{O,n} = \sum_{i=0}^{T} c_{O,i} \quad \forall n \tag{4.2}$$

Similarly, the cost of contingency failures are summed using;

$$c_{G,i} = \sum_{g \in G_i} c_{g,i} \tag{4.3}$$

And accordingly;

$$C_{G,n} = \sum_{i=0}^{T} c_{G,i} \quad \forall n \tag{4.4}$$

Total cost of maintenance C_m in simulation n therefor equals;

$$C_{m,n} = C_{O,n} + C_{G,n} \tag{4.5}$$

To assess the distribution of maintenance costs, N simulations are ran to retrieve (4.6) Expected cost of maintenance and (4.7) variance;

$$\mathrm{E}\left[C_m\right] = \frac{1}{N} \sum_{n \in N} C_{m,n} \tag{4.6}$$

$$\mathrm{Var}\left[C_m\right] = \frac{1}{N} \sum_{n \in N} \left(C_{m,n} - \mathrm{E}[C_m]\right)^2 \tag{4.7}$$

The LCC is scoped to main engine maintenance and failures, the resulting suppliers cost C_S are therefore $C_S = C_m$ These equation are used to accomplish the supplier's cost C_S, as stated in section 4.1 the suppliers cost as intended in (2.3) are limited to the cost of maintenance.

4.3. Preliminary Model

The preliminary model describes the process indicated in the horizontal bars in figure 4.1. The three stages are data gathering, use analysis, and a performance assessment.

4.3.1. Data Gathering

The data gathering phase of the preliminary model aims to collect data as defined in the scope's functional unit and reference flow. The LCC input consists of a maintenance plan, spare part costs, costs of contingency failures, personnel, and facility costs. Maintenance schedules are adopted from OEM service manuals. Table 4.2 presents an example maintenance task of a C32 Caterpillar diesel engine.

Item	Example	Unit
Job code	`102978E01N`	
Job description	`Replace fuel filter`	
Discipline	`Crew`	
Estimated duration	`0.5`	[h]
Job condition code	`In port`	
Maintenance level	`OLM periodic`	
Frequency	`500 running hours`	[h]
Quantity	`2`	[pieces]
Part number	`1186175`	

Table 4.2: Example maintenance task

The gathering of cost data is done via the corporate ERP system, sales engineers, and warranty data. Table 4.3 shows the cost values deviated from these sources in accordance with the scoping and assumptions provided in section 4.1.

The cost of contingency failures are unable to subtract from corporate data. Since there is a scarce in the

Item	Cost	
Crew rate	0	[€·h^{-1}]
Shore support	80	[€·h^{-1}]
External	140	[€·h^{-1}]
Sailing	0	[€·h^{-1}]
In Port	0	[€·h^{-1}]
Docking	300	[€·h^{-1}]
Spare part	Various	[€·h^{-1}]

Table 4.3: Supplier's costs

literature proposing such methods but contrarily of influence according to practice, a linear correction model is proposed in (4.8);

$$\lambda_k = \lambda_{0,k}\mathrm{E}[EL] \tag{4.8}$$

With EL the engine load factor. Service data revealed five common failures (k) that occur most frequent; leakages, overheating, electric failures, filter failures, and mechanical failures.

k	λ_0 [h^{-1}]
leakage	1003^{-1}
overheating	4012^{-1}
electric failures	667^{-1}
filter failures	0^{-1}
mechanical failures	802^{-1}

Table 4.4: Failure rates

Repairing contingency failures entail costs for the customer and supplier. Due to lacking data, the cost of reparations are modeled using a gamma distribution shaped by a mode and mean cost value. a (shape) and θ (scale) are derived using;

$$a = \frac{\text{mean}}{\text{mean} - \text{mode}} \tag{4.9}$$

$$\theta = \text{mean} - \text{mode} \tag{4.10}$$

With mean > mode. The cost distribution is determined using expert opinions and are presented in table 4.5

k	mode [€]	mean [€]
leakage	800	1200
overheating	600	800
electric failures	120	160
filter failures	40	100
mechanical failures	1200	1600

Table 4.5: Failure costs

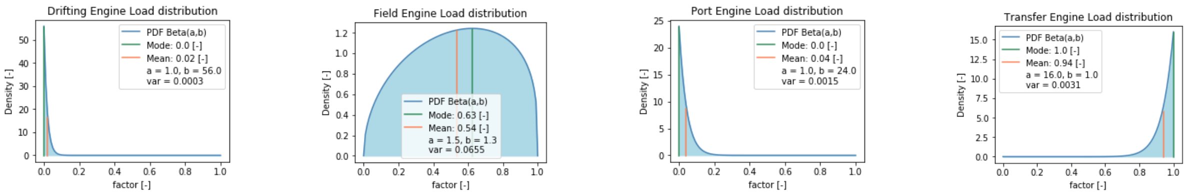
Failures occurrences $g = g(\lambda_k)$ and the resulting costs, $c_{g,i}$, are implemented in the use analysis, section 4.3.2. The cost of maintenance personnel is presented in table 4.6.

k	C_S [€h^{-1}]
Crew	0
Damen mechanics	80
Caterpillar specialists	164

Table 4.6: Cost of personnel

4.3.2. Use Analysis

The use analysis phase of the preliminary model relates the cost data with the user profile to determine the LCC. Prior to the analysis stage, the inventory stage is completed (see figure 4.1). Section 3.3 gave insight in tracks of a vessel used to assist the build of an offshore wind farm. Measurement revealed a fluctuating cycle duration. Besides studies into cycle duration, engine characteristics per state are analyzed as well. The engine load distribution per state are given in figure 4.2. To model these and future user profiles, statistical



(a) Engine load while drifting (b) Engine load on location (c) Engine load in port (d) Engine load during transfer

Figure 4.2: Data of engine characteristics and duration of vessel states

models are used to simulate this stochastic behavior. Then, planned maintenance is related to the vessels running hours and calendar time according to the user profile. Contingency failures are included into the life cycle to simulate the real world situation. This section concludes with the coupling of usage data to the LCC equations in section 4.2. Fast crew suppliers are designed and used to transfer crew and lightweight cargo between on- and offshore locations. In the case of constructing and maintaining large offshore wind farms these vessels sail a recurring cycle. This cycle is visualized using a Markov chain in figure 4.3. With P for

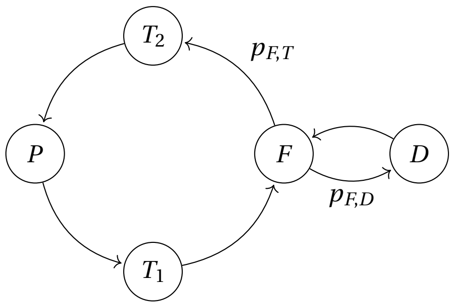


Figure 4.3: States and state transition probabilities (own elaboration)

port, T for transfer, F for field, and D for drifting. The value of $p(s_{i+1}|s_i)$ indicate the probability of the state transition to $s+1$ given the current state s. The above Markov chain can be represented in a probability matrix P as shown in equation 4.3.2. Given the state can only make a transition to an adjacent state, the matrix can be simplified to:

$$P(s_{i+1}|s_i) = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & p_{F,D} & p_{F,T} \\ 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{4.11}$$

with state vector $\vec{S}$;

$$\vec{S} = \begin{bmatrix} P \; T_1 \; F \; D \; T_2 \end{bmatrix} \tag{4.12}$$

The duration of each state is modeled using gamma distributions with input similarly to equation (4.9) and (4.10). The gamma distribution generates the random state duration D_s;

$$D_s \sim \text{Gamma}(a_s, \theta_s) = \frac{1}{\Gamma(a)\theta^a} x^{a-1} \mathrm{e}^{-\frac{x}{\theta}} \tag{4.13}$$

with $\Gamma(a) = (a-1)!$, and shape factors $a, \theta > 0$. The consecutive state duration is again randomly generated using the a_s and θ_s according state s. Within each state, the engine load curve L associated with state s is constructed using a beta distribution;

$$L(x; \alpha, \beta) = \frac{x^{\alpha-1}(1-x)^{\beta-1}}{\mathrm{B}(\alpha, \beta)} \tag{4.14}$$

With $\mathrm{B}(\alpha, \beta) = \frac{\Gamma(\alpha)\Gamma(\beta)}{\Gamma(\alpha+\beta)}$ and $\alpha, \beta > 0$. The mean and variance of L are used to determine the failure rate λ_k (see equation (4.8)). The failures appear stochastic since there is a failure probability of $(1-\lambda_k)^{i-1}\lambda_k$ (Geometric distribution) occurring after i time steps since λ_k is, in accordance with Birolini (2014, p. 65), constant. Sea state and ambient temperature are included as single values. After these steps, a timeline accumulates the running hours. At each time step i, the maintenance data is checked if any of the maintenance jobs has a corresponding interval time. After the user data is included in the model the use analysis phase results in n simulation outcomes presenting the simulated life cycle of the vessel. Hereafter, in section 4.3.3 the results are assessed with the defined service contracts presented in table 2.1.

4.3.3. Performance Assessment

The final phase of the model is the contract performance assessment. The performance assessment as shows in figure 4.1 contains the final phase to evaluate the nominee contract forms. Per case evaluations, this phase aims to contribute to the answer of the third research question; *How are user profiles related to the performance of service contracts?*.

The various contract types as defined in the theoretical exploration are the T&MC, FPC, and OBCs. All contracts can mathematically be descibed by the establishment of transaction amount $T = \omega + \alpha C - \nu B$. The first term is the fixed amount of the transaction. Second is the share α of the suppliers cost C. The last term is the share of the supplier ν of the under-performance fee B. A gap in the literature is found that includes both αC and νB. To reduce the risk of the uncertain amount C, an expectation of C, $\mathrm{E}[C]$ is to be determined using a LCC model. The symbols used in literature may cause conflicts within this research, therefor the set of symbols is redefined. Table 4.7 presents the symbols used.

Symbol	Description	Value	Unit
C_T	Transaction amount	$\in \mathbb{R}$	[€]
C_R	Supplier's revenue	$\in \mathbb{R}$	[€]
C_S	Supplier's cost	$\in \mathbb{R}^+ \cup \{0\}$	[€]
C_S^*	Supplier's expected cost	$\in \mathbb{R}^+ \cup \{0\}$	[€]
C_U	Under-performance cost	$\in \mathbb{R}^+$	[€ hour^{-1}]
ω	Fixed price	$\in \mathbb{R}^+ \cup \{0\}$	[€]
σ	Supplier's cost share parameter	$\in \mathbb{R}^+ \cup \{0\}$	[-]
υ	Under-performance cost share parameter	$\in [0,1]$	[-]
ρ	Risk aversion parameter	$\in \mathbb{R}^+ \cup \{0\}$	[-]

Table 4.7: Contract symbols

Both literature and practice show versatile applications and implementations of the nominee contracts types included within this research. To assess the contract performance and compare the options, well defined contract terms have to be stated. With cognizance of literature and practice and in agreement with the project's scoping the contracts are specified. Theory shows consensus regarding the contract principle, value drivers, and considerations (section 2.1.3 and 2.1.4). Nevertheless, financial formation for contract costs are to be found in the confidential domain of companies. Practice, in addition, learns that vessels newly delivered are under warranty for at least one year time. Financial aspects can influence the C_T, for the purpose of this research warranty aspects are out-scoped. This section aims to clarify the financial formation that suits the shipbuilding industry.

First, T&MC let the user pay for the service and materials used to maintain the vessel. Within the preliminary model, the cost of maintenance is derived from the engines OEM maintenance plan. Additional contingency failures are of full responsibility for the user as well. The cost of personnel and facilities are defined per case in the chapter 5. For the comparability of financial results, all repairs involving shore support or externals are provided by the supplier. The suppliers cost parameter σ is used to add a margin. Second, FPC are, in accordance with literature and practice, one- or two dimensional bounded. A FPC is valid until the bounds are reached. Most often contracts are valid for a predetermined calendar time i.e. month or year. In addition to time bounds, a use based bound supplements the contract conditions. Running hours or mileage are of common use. Within the contracts bounds, the user pays the fixed fee ω regardless the cost made by the supplier. The fixed price is determined with an assumed utmost abidance of the contract dimensions. A margin to mitigate the risk of a negative result is considered as well. Third, OBCs exist in various practices. Discussed OBCs by Grubic and Jennions (2018) let the users pay for equipment availability. OBCs as discussed by Cohen et al. (2007) let the supplier pay a fine for unavailability. Availability demand is however determined by the user's operational profile. Also, OBCs are often applied in situations with a pool of assets owned by the supplier. Within the topic of this research a single vessel operations are considered and therefor the design of an OBC has to be redesigned to fit the shipbuilding and marine industry. The outcome of an OBC is a measure of the demanded availability minus the realized availability, see figure 3.4. For this to accomplish, the demanded availability must be agreed on contractually. The fixed fee ω is determined as a function of the cost per running hour, yet the transaction amount is determined after measuring the realized running hours. Fourth, UPBCs include both a user 's share of the supplier's cost and a supplier's share of the user's unavailability costs. This contract is a refinement to the above contracts since the usage is monitored and rated to complete the transaction amount. Practice conveys a relation of failure probability and usage characteristics. Use data gathered from vessels show recurrent operations. The obtained vessel states in section 4.3.2 have different characteristics and therefor other expected costs (C_S^*). The fee for unavailability is determined similar to OBCs.
The main equation to distinguish different contract types is redefined to (4.15);

$$C_T = \omega + \sigma C_S^{(*)} - \upsilon C_U \tag{4.15}$$

The supplier's result accordingly equals;

$$C_R = C_T - C_S \tag{4.16}$$

The value for σ and ν determine the margin ($\sigma > 1$) or share ($\sigma \leq 1$) of the transaction amount C_T as function of the supplier's cost C_S. The default margin is presented in section 4.1 as 25%, σ therefor equals 1.25[-].
Further elaboration of ω, the term representing the fixed amount of the transaction amount C_T, is a function of the expected running hours and the expected cost C_S^*.

$$C^* = \mathrm{E}\big[U(C)\big] = \mathrm{E}\big[C\big] + \frac{\rho \mathrm{Var}\big[C\big]}{2} \tag{4.17}$$

To obtain the risk parameter ρ in a convenient way it is proposed to use ρ^* to indicate the sigma certainty level by means of the standard deviation under the assumption the central limit theorem holds $C_{S,n} \forall n$ is normally distributed, $C_S \sim \mathcal{N}(\mu, s^2)$.

$$C^* = \mathrm{E}\big[U(C)\big] = \mathrm{E}\big[C\big] + \rho^* \cdot \sqrt{\mathrm{Var}[C_S]} \tag{4.18}$$

C^* is used to determine the cost per running hour for OBCs and UPBCs

The four KPIs are determined using the following four equations. Equation (4.19 and (4.20) both return absolute figures regarding costs and revenue. Equation (4.21) and (4.22) return fractions indicating the risk and price fairness. The transaction amount for is determined using;

$$C_T \ = \ \omega \ + \ \sigma C_S \ - \ \upsilon C_U \tag{4.19}$$

Literature revealed KPIs or value drivers applied in various industry contexts. Both supplier and user aspire a best contract suiting their situation. Both parties strive to obtain the best economical result of the offered service. The supplier's economical result equals the user's transaction amount minus the supplier's cost.

$$C_R \ = \ C_T\big(C_S, C_U\big) \ - \ C_S \tag{4.20}$$

The supplier adhere a certain risk profile i.e. the probability mitigation of unanticipated costs and ending with a negative result.

$$r_S = \mathrm{P}(C_R < 0) \tag{4.21}$$

Contracts partially or completely consisting fixed fee's can also be evaluated by assessing the price fairness. Price fairness refers to an users' assessments of whether a seller's price is reasonable, acceptable or justifiable (Xia et al., 2004). Within the framework of this thesis price fairness can be assessed by the proportion of the transaction amount relative to the costs made.

$$PF = \frac{C_T}{C_S} \tag{4.22}$$

The four KPIs are used to assess all four contract types in each of the following cases in chapter 5.

5

Case analysis

A case study approach is selected to answer the last sub research question "How does the user profile influence the contract performance in the shipbuilding industry?". This chapter starts with the establishment of the base case to validate the model with measurements from a real-life case. Then other cases are selected to assess the contract performance in other and future scenario’s.

5.1. Base Case and Validation

The base case aims to validate the developed preliminary model as presented in chapter 4. The base case concerns the construction of a large offshore wind farm along the coast of the United Kingdom. The wind farm is named ’East Anglia ONE’, enable to generate 714 mega watt with 102 wind turbines (4coffshore.com, 2020). The field is located 30 nautical miles east of Southwold. The data is collected from a Fast Crew Supplier 2710 equipped with two Caterpillar C32 diesel engines. The track history shown in figure 5.1 is gathered over

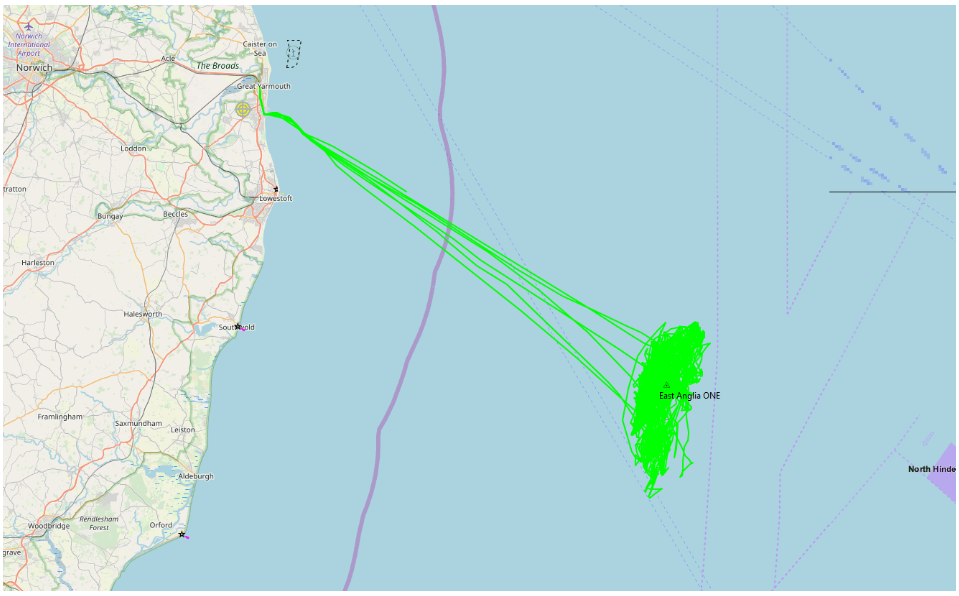


Figure 5.1: Track history

23 days of operation. Within this time frame, the vessel returned to port only three times for maintenance and resupplying. The vessel was able to moor at a large platform vessel located at the field.

5.1.1. Maintenance Data

The maintenance data used in this case consist of the OEM schedule for both C32 engines. The spare part prices are retrieved from the shipyard's ERP system.

5.1.2. User Profile Design

The usage of the vessel is measured using remote monitoring data. The total duration of the measured period is 552 hour, equivalent to 23 days. The engine ran 49% of the time, 270.5 hour. The vessel spend on average 16.06 hours in port and 1.256 hours per six transfers. The vessel spend the remaining 397.04 hours on and near the wind farm construction site. Given the engine running percentage, the vessel is, per 24 hour, drifting for 11.8 hour and operational for 12.2 hours. The Markov chain to comply with the measured user profile is presented in figure 5.2. The user profile is further evaluated in section 5.1.4.

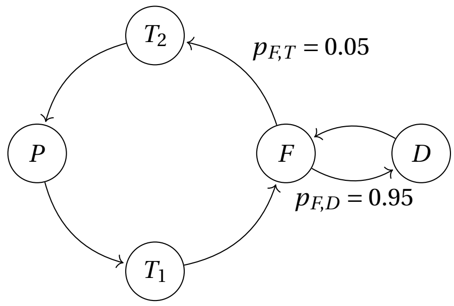


Figure 5.2: States and state transition probabilities (own elaboration)

5.1.3. Failure Design

Well structured and valuable failure data regarding vessels with similar user profiles are scarce. Failure data of 8024 C32 engine running hours is used to generate the failure rates as presented in table 5.1 given a measured mean engine load of 44.5%.

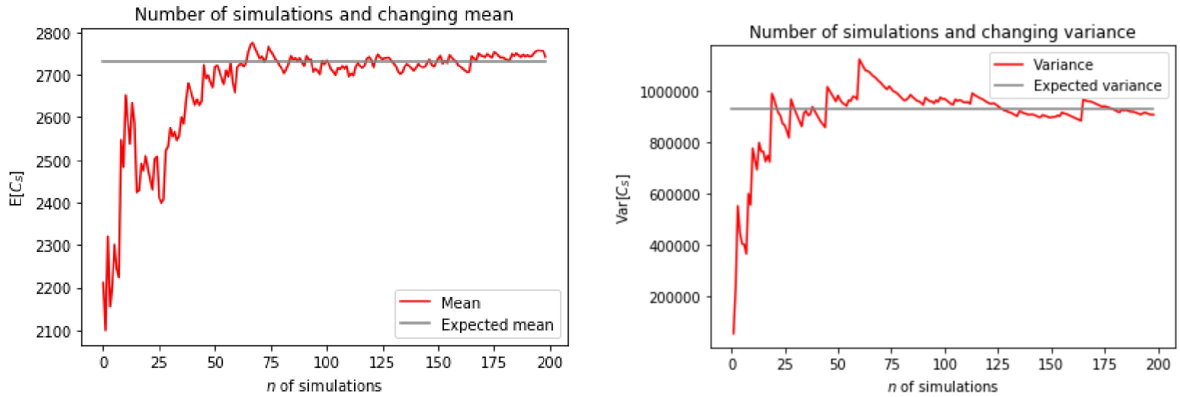
k	λ_0 $[h^{-1}]$	C_g mode	C_g mean
leakage	2254^{-1}	800	1200
overheating	9015^{-1}	600	800
electric failures	1498^{-1}	120	160
filter failures	6245^{-1}	40	100
mechanical failures	1802^{-1}	1200	1600

Table 5.1: Measured failure rates

The actual failure rate λ_k is per state determined using $\lambda_k = \lambda_{0,k} \cdot \text{E}[L]$. The consequences of contigency failures are expressed in costs and time of unavailability. Depending on the type of contract, the costs are charged to the user or supplier. If a failure occurs, the vessel is unavailable for a duration of four hours mostly with a mean of eight hours. The costs to repair the failure are randomly generated using a gamma distribution with a mode and mean as shown in table 5.1

5.1.4. Simulations and Validation

The model is created as a discrete event model. To obtain the LCC including uncertainties a Monte Carlo approach is applied. The number of simulations to obtain the mean and variance of the LCC is to be determined. Below, the mean of an increasing number of simulations is plotted in figure 5.3a. Similarly, the changing variance with an increasing number of simulations in figure 5.3b. Both graphs show a near constant line after 100



(a) Converging mean

(b) Converging variance

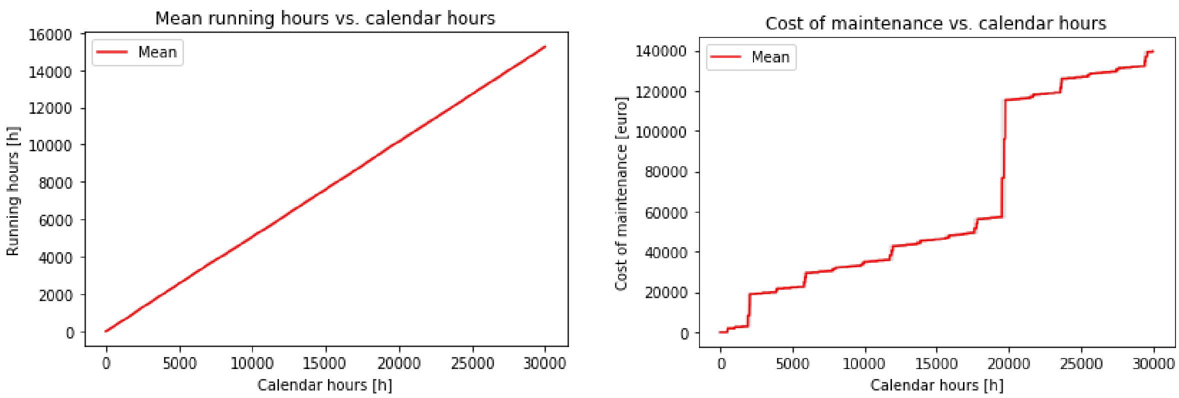
Figure 5.3: Converging mean and variance with increasing number of simulations

simulations. The resulting user profile in terms of state duration are compared with measured data from the remote monitoring system. Table 5.2 present comparable results.

State	Measured [h]	Simulated [h]	Error [h]
Port visit	16.06	16.15	0.07
Field	270.5	270.9	0.4
Drifting	244.8	245.6	0.8
Transfer time	1.3	1.6	0.3

Table 5.2: Measured and simulated state duration

To validate the maintenance costs, the model's time horizon is extended to 15000 running hours to include all maintenance tasks within the timeline. The cost of maintenance is validated using Caterpillar's data sheet. The data sheet claims the cost per running hour equal to €4.61. The preliminary model returns a cost of €4.57. The cost of maintenance is graphed in figure 5.4. The average number of failures, according to the

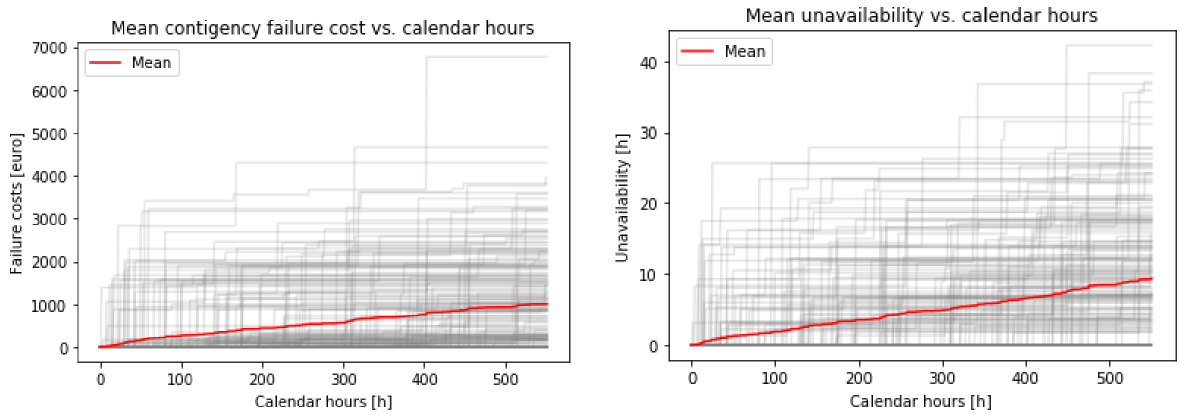


(a) Running hours over time

(b) Converging variance

Figure 5.4: Cost of maintenance relative to engine running hours

measured failure data, is 2.20 failures over a time span of 552 hours. The mean number of failures from the model equals 2.15 over a time span of 552 hours. The mean cost and unavailability are €1001.56 and 9.31 hours, see figure 5.5. The overall LCC amounted to €2742.08. The validated and other LCC aspects are sum-



(a) Simulated failure cost

(b) Simulated unavailability

Figure 5.5: Converging mean and variance with increasing number of simulations

marized in table 5.3. With the above, there is no ground to reject the preliminary model's validity. The model,

LCC aspect	Data avail.	Simulated	Pass
`User profile`	✓	✓	✓
`Cost of maintenance`	✓	✓	✓
`Failure occurrences`	✓	✓	✓
`Failure costs`	✗	✓	★
`Unavailability`	✗	✓	★

Table 5.3: Validated items

within its domain of applicability, is sufficiently accurate for the intended application.

5.1.5. Measurements

The preliminary model showed accurate results in comparison with the real-world case. With these results, figures to quantify the cost of predetermined (fixed) prices can be obtained. As discussed in section 2.1.3, FPC are quantified using the estimated cost and a margin to reduce financial risk. The proposed UPBC as well uses fixed prices for usage, but is in contrast to OBC determined using gathered monitoring data. First, the fixed fee for FPCs is determined using the preliminary model. FPC are often restricted in time or running hours, however not restricted in usage profiles. It is essential for a risk averse supplier to charge a certain margin. In accordance with the used methodology, ω can be obtained using (5.1) for FPC and (5.2) in case of OBCs.

$$\omega = \sigma\big(\rho \cdot \max\{\mathrm{s}[C_S^*]\} + \max\{\mathrm{E}[C_S^*]\}\big) \tag{5.1}$$

$$\omega \cdot h^{-1} = \sigma\big(\rho \cdot \max\{\mathrm{s}[C_S^*] \cdot h^{-1}\} + \max\{\mathrm{E}[C_S^*] \cdot h^{-1}\}\big) \tag{5.2}$$

Cost figures are obtained using the model, the cost rate for each vessel state is tabulated in 5.4. The presented figures include both C32 engines.

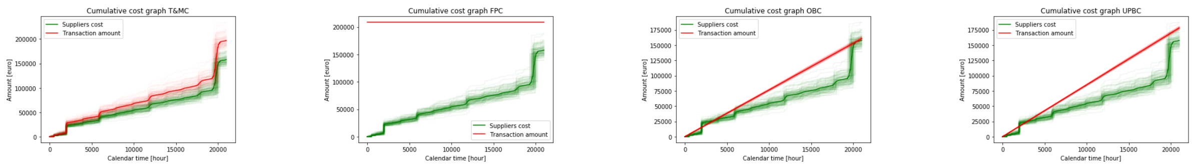
The presented rates in table 5.4 show different rates for the various vessel states. With these rates, the fixed prices for ω and C_S^* can be determined.

State cost [€h^{-1}]	E[C_S^*]	s[C_S^*]	unavailability [h^{-1}]
Port	1.77	0.40	0.001
Transfer	14.77	0.71	0.03
Field	13.81	0.60	0.02
Drifting	1.68	0.51	0.01

Table 5.4: State cost rate

5.1.6. Contract Performance Assessment

Further analysis of contract performance requires a set of assumptions forming a business case scenario. Let σ equals 1.25, i.e. the margin on spare parts and personnel is 25%. The base case user profile is used to analyze the contracts performance for this particular case. Later case analysis' might return different performance figures. The graphs in figure 5.6 and table (5.5) shows the outcome of the KPIs as discussed in section 4.3.3. T&MCs are convenient to assess. FPC demand additional assumptions, the supplier selects a margin to mitigate the risk of a negative balance after the contract period. Equation (5.1), states the proposed method to determine ω. Nevertheless, the contract dimensions cannot be made unbiased with knowledge of the outcome of the operational period. For the purpose of comparison, lets assume a certainty of 1 and a contract dimension of 10.000 running hours (engine running percentage of 50.6%). 10.000 running hours are based on the complete maintenance cycle. Similar arguments hold for OBCs. OBCs include a fixed fee for outcome in terms of availability, also, a fee is transferred from the supplier to the user in case of unavailability. A certainty level of 1 is applied to OBC and UPBCs. Analyzing the figures, it confirms the consensus presented



(a) T&MC cost development (b) FPC cost development (c) OBC cost development (d) UPBC cost development

Figure 5.6: Accumulating costs over the contract duration case East Anglia ONE

Contracts	E[C_T], $s[C_T]$ [€]	E[C_R], $s[C_R]$ [€]	PF [-]	P($C_R > 0$)
T&MC	197097.41, 11312.63	39419.48, 2262.53	1.25	1.0
FPC	208785.8, 0	51107.87, 9050.1	1.32	0.99
OBC	160830.76, 1869.53	3152.84, 9563.8	1.02	0.63
UPBC	172157.44, 1542.93	14479.52, 9543.85	1.09	0.94

Table 5.5: Contract table

in section 2.1.3. T&MC shift the risk of financial fluctuation towards the user. Contracts with fixed prices are more expensive, i.e. the transaction amount C_T is higher, but contrarily shift the risk towards the supplier. The result gained to the supplier increases increases in case of fixed prices, besides the possible fluctuation is large too, resulting in a lower P($C_R > 0$).

5.1.7. Case Conclusion

The base case analysis showed similar output with measured user profile input from a real world scenario. Cost analysis showed corresponding costs compared with OEM data sheets. Failures occurred during operation are as statistically as prospected. Thereby, the model returns figures to assess the contract choice for the given case. The model fits to the purpose of this research and is verified with the analysis of the results. Regarding the assessment results, figures represent the nominee contracts' characteristics. T&MC suit well to situations wherein the supplier is risk averse in combination with a user accepting that risk for the lowest expected contracts cost but with a risk of exceeding the expected amount. The net result of the supplier is rather high and certain. The price fairness is directly related to the margin σ chosen by the supplier. The FPC is more expensive but mitigates all the risk of exceeding the contract costs for the user. The net result of the supplier is high both due to the differences of the maximum running hours and the expected running hours. The price fairness scores lower as the T&MC. However the save margin and overestimation of use returns a high probability of a positive net result. The complete mitigation of risk at the user is in this case worth considering. The OBC scores marginally positive. The high variance of non-running-hours and the up-time of 50% let the OBC perform worse since the transaction amount is determined by the outcome of running hours. The proposed UPBC scores well with a win probability of 0.94. Tuning the certainty level would however increase the marginal price fairness to 1.25. The contract, besides the OBC has the lowest expected result.

5.2. Case I: Construction Wind Farm Norther

With this case study, a difference situation is simulated to generate a outcome that can be compared to the base case and possible differences in contract performances. This case is situated near the Belgium coast during the construction of wind farms Norther. This wind farm consists of 44 wind turbines generating a total of nearly 370 mega watt. The wind farm is located on a travel distance of 29 nautical miles from port Oostende, Belgium. This case differs since the supply vessel cannot moor near the field due to the absence of larger platform vessels. The contract duration is 10.000 hours.

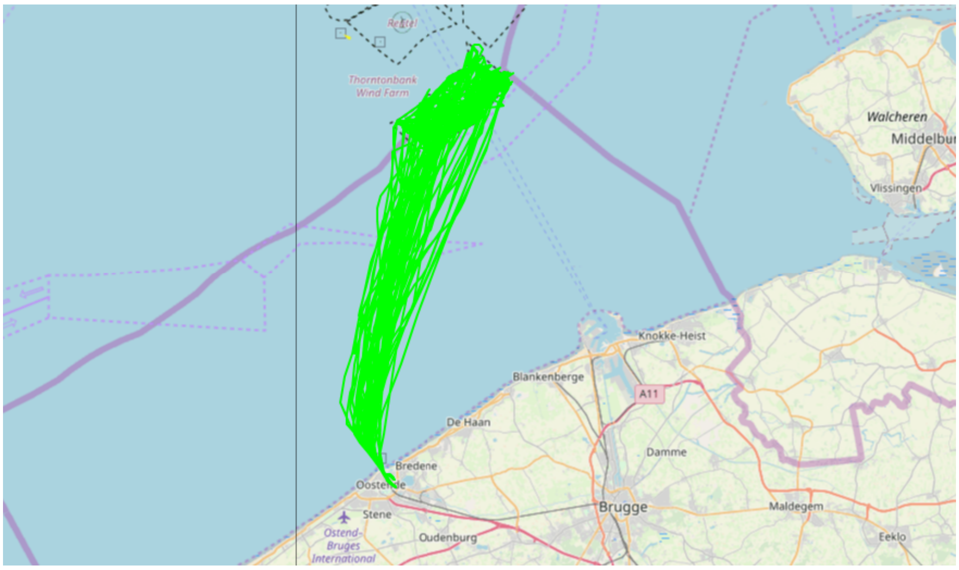


Figure 5.7: Track history Norther

5.2.1. User Profile Design

The user profile within this case is a recurrent cycle made every 24 hours. The state duration values are tabulated in 5.6, engine load figures are provided here as well. The state transitions occur according to the

State	D (mode, mean) [h]	EL (a,b) [-]
in Port	12, 12.4	1, 24
Transfer	0.75, 0.8	16, 1
Field	7.5, 8	1.1, 1.8
Drifting	1.8, 2	1, 56

Table 5.6: user profile case Norther

state transition matrix in (5.3).

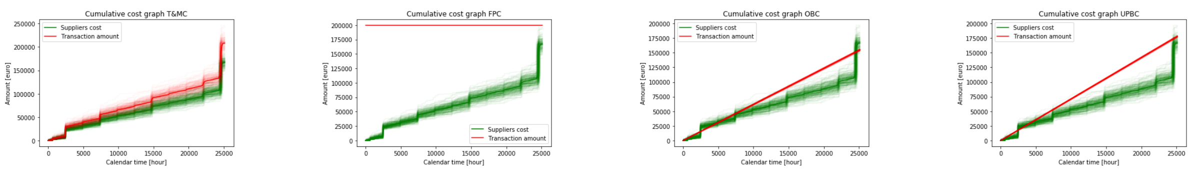
$$P(s_{i+1}|s_i) = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{5.3}$$

with state vector $\vec{S}$;

$$\vec{S} = \begin{bmatrix} P \; T_1 \; F \; D \; T_2 \end{bmatrix} \tag{5.4}$$

5.2.2. Contract Performance Assessment

Further analysis of contract performance requires a set of assumptions forming a business case scenario. Let σ equals 1.25, i.e. the margin on spare parts and personnel is 25%. The Norther case user profile is used to analyze the contracts performance for this particular case to construct the Norther wind farm. The graphs in figure 5.8 and table below (5.7) shows the outcome of the KPIs as discussed in section 4.3.3. T&MCs are convenient to assess. FPC demand additional assumptions, the supplier selects a margin to mitigate the risk of a negative balance after the contract period. Equation (5.1), states the proposed method to determine ω. Nevertheless, the contract dimensions cannot be made unbiased with knowledge of the outcome of the operational period. For the purpose of comparison, lets assume a certainty of 1 and a contract dimension of 10000 running hours (engine running percentage of 40%). 10.000 running hours are based on the complete maintenance cycle. Similar arguments hold for OBCs. OBCs include a fixed fee for outcome in terms of availability, also, a fee is transferred from the supplier to the user in case of unavailability. A certainty level of 1 is applied to OBC and UPBCs as well.



(a) T&MC cost development (b) FPC cost development (c) OBC cost development (d) UPBC cost development

Figure 5.8: Accumulating costs over the contract duration case Norther

Contracts	$E[C_T]$, $s[C_T]$ [€]	$E[C_R]$, $s[C_R]$ [€]	PF [-]	$P(C_R > 0)$
T&MC	208331.65, 10946.91	41666.33, 2189.38	1.25	1.00
FPC	199487.91, 0	32822.59, 8757.53	1.20	0.99
OBC	154761.07, 1061.92	-11904.25, 9240.44	0.93	0.10
UPBC	177939.4, 950.51	11274.08, 9238.87	1.07	0.89

Table 5.7: Contract performance table case Norther

5.2.3. Case Conclusion

The contract performance of the four contracts are tabulated in 5.7. The outcome of the performance assessment is discussed below. The T&MC has compared with the base case a low standard deviation on the transaction amount. The variance of the suppliers result is low as well. This is due to the given user profile with a low overall variance. FPC, therefor, also performs well due to the low variance user profile. The UPBC Scores third in with a probability of a positive result of 0.89. The price fairness is however marginal to one. An user profile with less variance seems to influence the UPBC negatively. The OBC scores worse since the up-time is lower compared to the base case East Anglia ONE. An OBC is strongly determined by the up-time figure since the transaction amount is mainly determined by the outcome measured in running hours.

5.3. Case II: Maintaining Wind Farm Gemini

With this case study, a difference situation is simulated to generate a outcome that can be compared to the base case and possible differences in contract performances. This case is situated near the Dutch coast during the operation and maintenance of wind farms Gemini. This wind farm consists of 150 wind turbines generating a total of nearly 370 mega watt. The wind farm is located on a travel distance of 45 nautical miles from port Eemshaven, Netherlands. This case differs since the vessel is deployed to supply maintenance personnel at the wind farm, the cycle duration has a high variance due to the stochastic behavior of wind turbine failures. The contract duration is 10.000 hours.

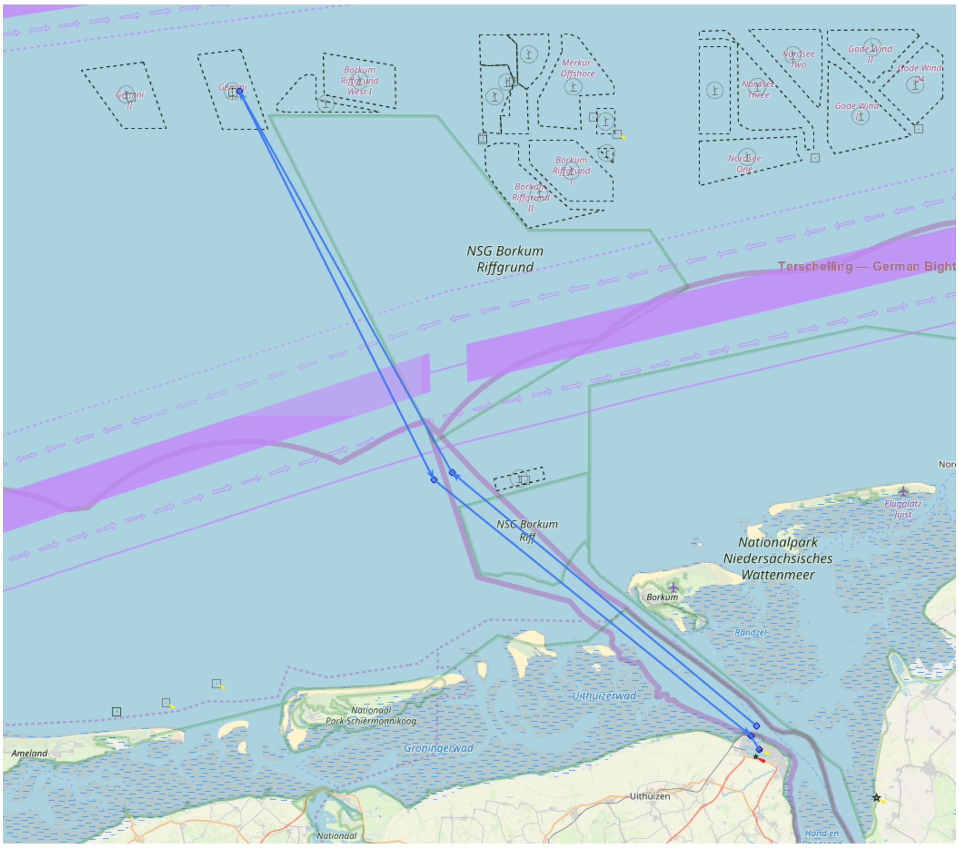


Figure 5.9: Track Gemini

5.3.1. User Profile Design

The user profile within this case is a recurrent cycle made every 88 hours. The state duration values are tabulated in 5.8, engine load figures are provided here as well. The state transitions occur according to the

State	D (mode, mean) [h]	EL (a,b) [-]
in Port	48, 72	1, 24
Transfer	1.8, 2	16, 1
Field	3, 8	1.1, 1.8
Drifting	1, 6	1, 56

Table 5.8: user profile case Gemini

state transition matrix in (5.5).

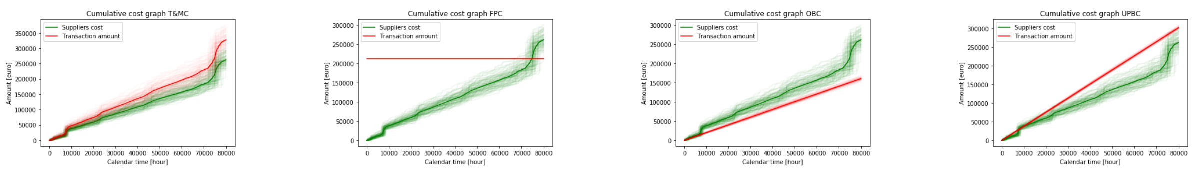
$$P(s_{i+1}|s_i) = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{5.5}$$

with state vector $\vec{S}$;

$$\vec{S} = \begin{bmatrix} P \; T_1 \; F \; D \; T_2 \end{bmatrix} \tag{5.6}$$

5.3.2. Contract Performance Assessment

Further analysis of contract performance requires a set of assumptions forming a business case scenario. Let σ equals 1.25, i.e. the margin on spare parts and personnel is 25%. The Norther case user profile is used to analyse the contracts performance for this particular case to construct the Norther wind farm. The graphs in figure 5.10 and table (5.9) shows the outcome of the KPIs as discussed in section 4.3.3. T&MCs are convenient to assess. FPC demand additional assumptions, the supplier selects a margin to mitigate the risk of a negative balance after the contract period. Equation (5.1), states the proposed method to determine ω. Nevertheless, the contract dimensions cannot be made unbiased with knowledge of the outcome of the operational period. For the purpose of comparison, lets assume a certainty of 1 and a contract dimension of 10.000 running hours (engine running percentage of 13.3%). 10.000 running hours are based on the complete maintenance cycle. Similar arguments hold for OBCs. OBCs include a fixed fee for outcome in terms of availability, also, a fee is transferred from the supplier to the user in case of unavailability. A certainty level of 1 is applied to OBC and UPBCs.



(a) T&MC cost development (b) FPC cost development (c) OBC cost development (d) UPBC cost development

Figure 5.10: Accumulating costs over the contract duration case Gemini

5.3.3. Case Conclusion

The results show differences compared to other cases. This case is chosen due to the high variance and low demand of running hours. The FPC perform bad in cases with a low demand on running hours. A FPC is primarily determined using the expected running hours. However contingency events during non-running

Contracts	E[C_T], $s[C_T]$ [€]	E[C_R], $s[C_R]$ [€]	PF [-]	P($C_R > 0$)
T&MC	327688.15, 20838.45	65537.63, 4167.69	1.25	1.0
FPC	212793.42, 0	-49357.1, 16670.76	0.81	0.01
OBC	160738.25, 3436.46	-101412.27, 17505.71	0.61	0.01
UPBC	301524.7, 2823.0	39374.17, 17444.86	1.15	0.99

Table 5.9: Contract performance table case Gemini

hour states account for an increasing amount is the running hours are low. The UPBC performs well with a good price fairness of 1.15 and positive result probability of 0.99. The UPBC performs well due to the charge of all vessel states of the user profile's cycle. The FPC performs bad due to the low demand on running hours. OBC similarly score bad due to the low running hours. The main reason for these bad performances is the fact that failures still occur in the vessel states that do not account for the running hour total.

6
Results

The results obtained in the case study analysis aim to explore the relation between user profiles and contract performance. This chapter aims to find the best performing contract given the user profile without executing the time consuming simulations from chapter 5. The research outline as presented in figure 4.1 is therefor aimed to be simplified to the black box approach as illustrated in figure 6.1. This chapter discusses the gen-

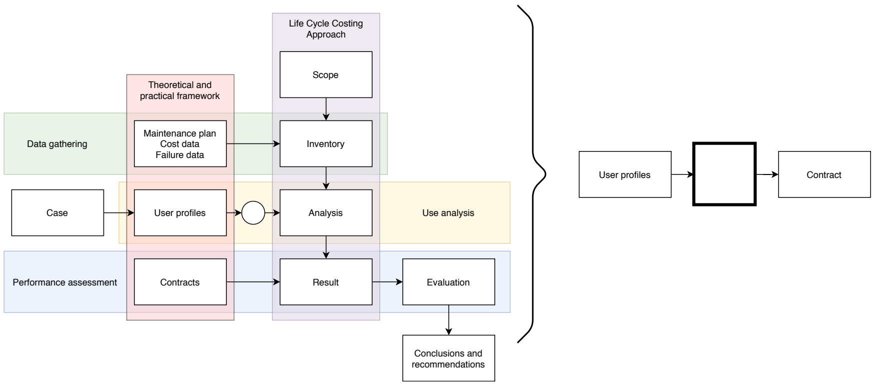


Figure 6.1: Generalizing

eralization methodology to obtain the best performing service contract given the user profile. The chapter concludes with a list of proposition regarding the relation between the user profile and the contract performance. Then a reflection is given focused on the gaps and propositions from literature and practice.

6.1. Generalization

The user profile consists of a set of vessel states and associated failure-, and duration figures, a state transition matrix, and data regarding maintenance and costs. Practice had shown the importance of running hours relative to the maintenance schedule, the total number of running hours after a period is the main cost driver. The running hours are a result of the provided state transition matrix P and state duration distributions (eq 4.13). To obtain the (average) number of running hours, the relative time spend per state is to be obtained first. A method to obtain this *steady state* vector $\vec{s_{ss}}$ is to multiply the initial state vector $\vec{s}_0$ with the state transition matrix P powered to a large number ensuring a converged current state probability vector $\vec{s}_i$ after a large number of time steps i:

$$\vec{s_{ss}} = \lim_{i \to \infty} \vec{s}_0 P^i \tag{6.1}$$

This however never converges with the cyclic matrices as used. Therefor a more elegant method is proposed in literature (Jacobs, 1992; Kemeny and Snell, 1976; Wilmer et al., 1971); there exists an vector $\vec{s}$ such that a multiplication with P results in an unchanged vector $\vec{s}$.

$$\vec{s}P = \vec{s} \tag{6.2}$$

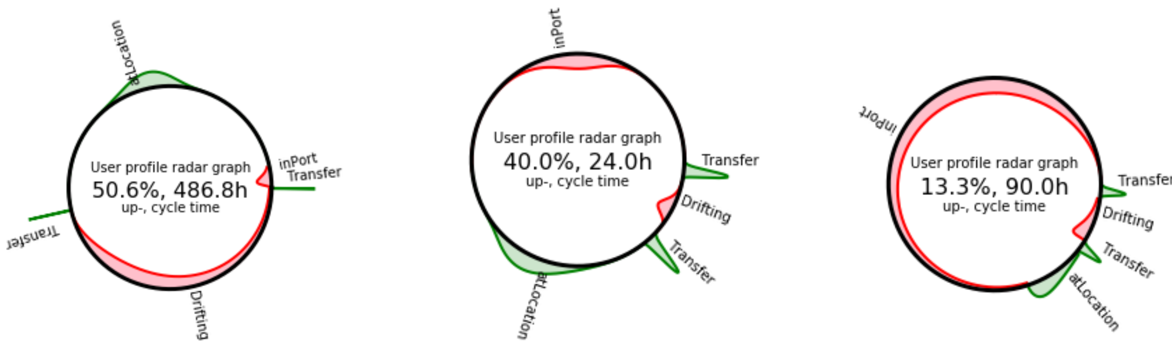
For this to be true, $\vec{s}$ must be an eigenvector of P with eigenvalue λ equal to 1;

$$\vec{s}P = \lambda\vec{s} \tag{6.3}$$

To find $\vec{s_{ss}}$ using this method, the eigenvalues and eigenvectors of P are to be obtained solving (given P is a left stochastic matrix).

$$\vec{s}(P - \lambda I) = 0 \tag{6.4}$$

Resulting in n eigenvalues and eigenvectors given the size n^2 of square matrix P. The eigenvector associated with eigenvalue 1 represents the steady state vector $\vec{s_{ss}}$. A multiplication with the mean state duration results in the mean cycle time of the given user profile. The black circle represents one cycle in figure 6.2. The curves



(a) User profile East Anglia ONE (b) User profile Norther (c) User profile Gemini

Figure 6.2: User profile graphs

wrapped around the circle represent the gamma distributions of the state duration. The height of the gamma distribution curve is normalized to a certain radius for enhance the readability. The high of the curves in then enlarged relative to the mean engine load of the corresponding vessel state. The red and inward pointing curves indicate the vessel states wherein the engine is not running. The green and outward pointing curves are states wherein the engine is used. The graphs are intended to indicate the variance of the state duration with the curve of the gamma distribution. A more pointy curve indicates a low variance distribution. The center of the circle presents the relative up-time and the mean cycle duration. All user profile information, as is used within this research, is included in this user profile radar graph.

The radar graphs are compared with the case study outcomes. The three user profile graphs in 6.2 represent the three performed case studies. Relations between the shape and number in the user profiles and the contract performance assessments in table 5.5, 5.7, and 5.9 are discussed and propositions are made in the consecutive sections.

6.2. Relations

This section aims to graphically indicate strong relations of contract performance in relation to the various aspects of the user profile. The graphs below are drawn using the outcome of the three case studies and the user profile radar graphs in figure 6.2. By analyzing the contract performance and the given user profile, relations are aimed to be found to answer the third research question "How does the user profile influence the contract performance in the shipbuilding industry?" more universally.

The first found relation to discuss is the probability of a positive result versus the variance in time of vessel states wherein the engine is running. T&MCs and UPBCs are not affected by the change in variance. FPCs and OBCs perform better in cases of low variance in up-time states. This effect is caused by the fact that FPC and OBC are based and charged on the running hours only. OBC are strongly affected by an increasing variance because only the realized running hours are charged. See figure 6.3.

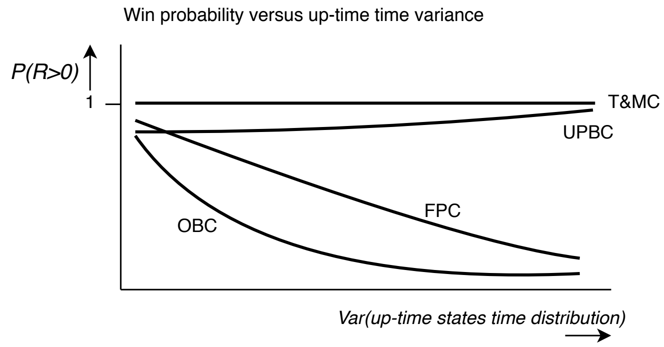


Figure 6.3: Probability of positive result versus variance in up-time

Second, the price fairness per contract type is compared to the up-time of the user profile. T&MCs and UPBCs tend to be constant and parallel to any up-time percentage. FPCs and OBCs evolve parallel upward with an increasing up-time percentage. Additionally, the graphs indicates that FPCs and OBCs are below 1 up too half way. A price fairness of less that 1 indicate a negative result for the supplier. See figure 6.4.

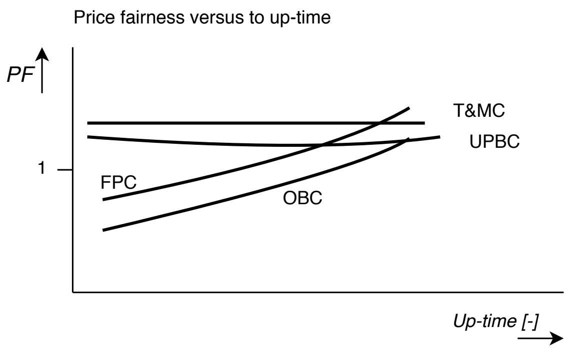


Figure 6.4: Price fairness versus up-time percentage

Then, the relation between the transaction amount T and up-time is given in figure 6.5. It is again visible that T&MCs and UPBC evolve parallel in terms of contract cost for the user versus the up-time in the user profile. The dashed line indicated the break-even line of the transaction amount and the cost of the supplier. The graph in figure 6.5 show similar information with the results in figure 6.4. The transaction amount is higher with less up-time due to the costs of maintenance and failures during the states the engine is not used.

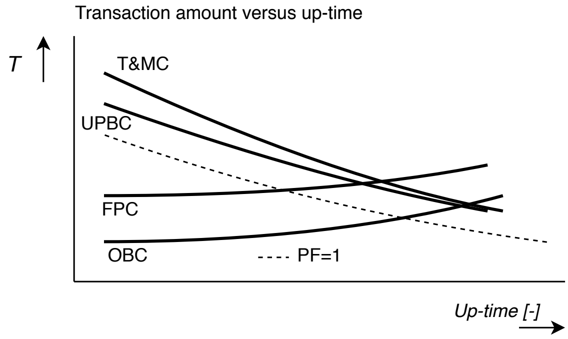


Figure 6.5: Transaction amount T versus up-time percentage

Last, the supplier's result R is related to the up-time of the user profile. Again T&MCs and UPBCs, and FPCs and OBCs evolve parallel in relation to the user profile's up-time. The graphs above have shown strong

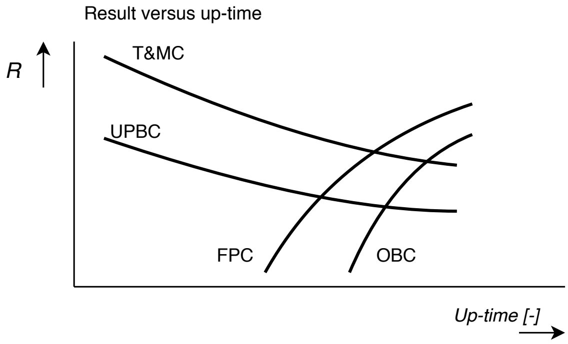


Figure 6.6: Result R versus up-time percentage

similarities between T&MCs and UPBCs as well between FPCs and OBCs. The UPBC was aimed to fill the gap between T&MC and FPC. The main difference between the T&MCs and UPBCs is the risk allocation of the uncertain costs of the life cycle of the vessel. In a T&MC the risk of contingency events is allocated to the user, the uncertainty of the supplier's result depends on the user profile's variance. In case of the UPBC this situation regarding the uncertainty is completely opposite. The user of the vessel owns the risk of an uncertain user profile while the supplier is responsible for the contingency failure events of the vessel.

6.3. Propositions

The contract performances in table 5.5, 5.7, and 5.9 showed varying results regarding the contract performance in various cases. The founded relations are, apart from the relations shown above in the graphs, below represented as propositions.

- The higher the up-time, the better is the performance of an OBC.
- The variance in an user profile is not affecting the UPBC performance.
- The higher the up-time in an user profile, the better a FPC performs.
- A lower variance in the user profile results in a higher certainty of FPCs win probability.
- A T&MC always has a positive result and is less risky for the supplier.
- UPBCs and T&MCs tend to be each other opponents when it comes to risk allocation.
- Contracts with a fixed price aspect have a large variance in expected results, well organized asset management can result is additional revenue within this variance.

- The variance of the transaction amount in a T&MC is related to contingency failures, and
- The variance of OBCs and UPBCs of the transaction amount is related to the user profile

The propositions stated above are as well overlapping as adding new relations as the graphs presented in section 6.2.

7 Conclusion

Research in the field of servitization as a business strategy is emerging since its first appearance by Vandermerwe and Rada (1988) and later but parallel developments by Goedkoop et al. (1999). Servitization is the act of selling complete packages of goods and after sales services. Various industry examples present successes with the implementation of the complete offering of goods and services. However, theoretical substantiation lacks with evidence of implementation strategies leading to successful businesses. This research aimed to investigate the potential of servitization strategies to the shipbuilding industry in terms of service contracts. Dutch shipbuilder Damen shipyards develops, builds, and sells various types of vessels to the broadest sense. Various vessel types introduce even more various vessel usage profiles. This research aimed to find suitable service contracts given a certain user profile. The main research question used as a guidance is "What are the best performing service contracts in relation to the user profile of vessel operators?"

To achieve this goal and answer the question, knowledge regarding servitization contracts is gained using literature. Subsequently, knowledge and data regarding usage and maintenance aspects are gained within the marine industry. Then, a model is developed to implement user profiles and assess the performance of servitization contracts.

The literature review let to answers regarding the first research question "What is servitization and how does it perform?" This question can be answered in twofold; What are servitization contracts? And how do servitization contracts perform? First, as introduced above, servitization is the act of selling complete packages of goods and after sales services. A contract is a legal bounded agreement between a supplier and a customer stating the product offering, conditions, and a financial compensation for delivering these products. Within the application of product, and supplementing service offerings, there exist three main distinctive contracts; T&MC, FPC, and OBCs. The contracts differ in the sense of price determination, risk allocation, and demanded certainty. A fourth UPBC is introduced to fill a gap between T&MC and OBCs by means of a more tailored usage price determination. Servitization contract performance can be indicated using multiple KPIs. Contract price (transaction amount), price certainty, and price fairness are of interest from a users point of view. Contract revenue, revenue certainty, and the probability of financial losses are indicators of interest from a suppliers point of view.

An exploration of practice gained insight and knowledge of vessel usage and asset management in the marine industry. The question that led to these understanding is "Which set of usage characteristics affect the serviceability of marine vessels?". To narrow the broad sense of usage of marine equipment this research focused on vessel usage in the offshore wind farm industry. Analyzing monitored data gathered over two vessels showed a unambiguous and recurrent cycle of operations. This cycle is sub-divisible in four vessel states, namely 1) moored in port; 2) in transfer on open sea; 3) drop-off and pick-up personnel between the wind turbines located in the farm; and 4) drifting at sea, waiting for pick-ups and to perform simple maintenance tasks. The gathered data also revealed distinctive usage characteristics in terms of engine load distributions. Marine equipment, among which diesel engines, require a high level of service and maintenance. Both literature and practice have numerous strategies regarding maintenance policies. The maintenance strategy of the main engines as delivered by OEM service manual is adapted to predict the LCC of the engine. Service calls gained insight in common product failures and are considerably important to include in the LCC calculation. This all let to a set of aspects that completes the cost to maintain the asset.

The theoretical and practical exploration were aimed to gain knowledge to develop a model to simulate and assess vessel operations to eventually answer the third research question; "How does the user profile influence the contract performance in the shipbuilding industry?". The main cost drivers with respect to the user profile are the amount of hours an engine is running in time. Most maintenance is scheduled in relation with the amount of running hours of the engine. In addition, failures are more likely to occurs when engine produce higher loads due to higher stresses, higher oil pressures, higher wear, and more heat generation. Although there are few failure occurrences to analyze from historical data, a linear failure rate correction model is proposed to simulate a varying failure probability depending on the engine load produced at that time.

This ultimately leads to an answer of the main research question; "What are the best performing service contracts in relation to the user profile of vessel operators?". There is a consensus in both theory and experts in practice suspecting there is no single solution to a best contract form for all operators and user profiles. To answer this question more thorough, three case studies are performed to assess the performance of each individual case and user profile.

T&MCs performs good in terms of revenue certainty for the supplier due to the nature of the contract. The user, in contrast, must accept the risk of fluctuations of his costs deviating from the expected costs. The transaction cost fluctuations are a result from contingency failures of the vessels main engine. The net result of the supplier is determined by a fluctuating user profile. Offering T&MCs is however for as well the user profiles as well performance contracts, in terms of all four KPIs. FPCs are by design easy to understand and widely applied in other industries. The fixed price is determined using the suppliers margin and a safe estimation for the expected amount of running hours during the contract period. When the user profile increases in variance, the contract form tend to perform worse due to the mismatch of expected and realized running hours. OBCs show similar performance results in relation to FPCs. OBC tend to perform only well in user profiles with high up-time and low variance in up-time vessel states. By tuning the certainty parameters of an OBC it can perform equally to FPCs. however, this might lower the price fairness while the user profile has a high up-time . Last, the proposed UPBC show similar performance relative to the T&MCs. The UPBC was aimed to fill the gap between T&MC and FPC. The main difference between the T&MCs and UPBCs is the risk allocation of the uncertain costs of the life cycle of the vessel. In a T&MC the risk of contingency events is allocated to the user, the uncertainty of the supplier's result depends on the user profile's variance. In case of the UPBC this situation regarding the uncertainty is completely opposite. The user of the vessel owns the risk of an uncertain user profile while the supplier is responsible for the contingency failure events of the vessel.

To generalize the findings of this research it is confirmed that the consensus of having no one best performing contract for any user profile. The case studies however showed significant differences depending on the user profile. Results of this study can be used to gain understanding of contract choice in relation to a users' user profile. It provides a stronger sales position if the presented contract offerings are justified with these case studies.

The results of the cases are used to answer the main research question "What are the best performing service contracts in relation to the user profile of vessel operators?" in a more general way. Strong similarities are found between T&MCs and UPBCs as well between FPCs and OBCs. The main difference between the T&MCs and UPBCs is the risk allocation of the uncertain costs of the life cycle of the vessel. In a T&MC the risk of contingency events is allocated to the user, the uncertainty of the supplier's result depends on the user profile's variance. In case of the UPBC this situation regarding the uncertainty is completely opposite. The user of the vessel owns the risk of an uncertain user profile while the supplier is responsible for the contingency failure events of the vessel. The risk allocation of UPBCs make better sense since the uncertainty regarding the product is allocated to the supplier and the risk of uncertainty of the user profile is allocated to the user. By tuning the parameters of the UPBC's cost per state per hour, the suppliers result can be equalized with the performance of the T&MC contracts without relocating all the risk towards the supplier. OBCs only perform well under specific circumstances such as a high up-time and a high certainty to achieve the high up-time. FPCs perform slightly better than OBCs but might be overpriced if there is a high variance of up-time hours in the user profile.

The aimed practical contribution of this research was to develop a method to determine the best performing service contract given the user profile of a vessel. The general objective of this study was to contribute to the development of theory regarding user profiles in relation with service contracts in the shipbuilding domain. The methodology to include simplified user profiles as a states cycle is developed within this thesis. The operational profile of high speed transport vessels suit this approach since the profile is a recurrent cycle of operations. The approach was aimed to be adaptive to other vessel types and operations. The LCC methodology is then used to retrieve figures regarding costs. Cost and availability figures as a result of failures are the result of available data from the shipbuilder. The four nominee contract types are designed and used to find relations regarding the performance versus the given user profile. The developed methodology and the contract performance versus user profiles is the contribution to practice and theory.

8 Discussion

This research gained insight in both theoretical and practical aspects regarding servitization with a focus on service contracts for maintenance execution and repairs after contingency failures.
Literature regarding servitization acknowledge the lack of a proven successful implementation strategy. This research tried to elaborate an approach to explore the effect of service contracts, as a part of the complete servitization strategy.
Maintenance manuals and the occurrence of failures are related to the usage of equipment in general. In case of marine diesel engines, 80% of the cost of maintenance tasks are determined by the amount of running hours the engine has accumulated over time. The inclusion of contingency failures into the model introduce stochastic uncertainty regarding the LCC of the vessel. The LCC approach is used to determine the financial developments during the usage of a vessel. T&MCs, FPCs, OBCs, and UPBCs are then compared to the LCC results of a part of the vessels operational life cycle.
The results of this contract performance assessment showed strong similarities between the conservative T&MCs and the newly proposed UPBCs. However, the risk allocation of both contract types is shifted; the T&MC shifts the risk of contingency failures towards the user and the uncertainty of the user profile towards the supplier. The proposed UPBC shifts the risk of contingency failures towards the supplier while the user's transaction amount is determined by the actual usage of the vessel.

The findings of this research might change the consensus of different contracts and the associated performance into tangible knowledge supported with theories and approaches found in both literature and practice or developed within this research. However, marine vessels are capital intensive assets with long lasting responsibilities from the user and the supplier. Thereby, a failing implementation on just one vessel delivery could result in huge financial damage for the supplier.

Other studies regarding service contracts have shown methods to determine the parameters that eventually result in the contract's price of transaction amount. Other studies have shown the positive influence of performance contracting onto the product's reliability due to the supplier's incentive to mitigate the risk of contingency failures as much as possible to avert the under-performance fee. This research was aimed to investigate the relation of the contract performance and the user profile of high speed transfer vessels. Consecutive could include the aspects of the prior studies for the development of the more advanced service contracts for application in the shipbuilding industry.

The turnover of shipbuilder Damen consists for only 2% of after sales services. This figure is very low considering the life cycle costs of marine transport equipment is estimated to be equal to the purchase value of the vessel. The findings and approach as presented in this thesis could help managers at Damen to further investigate the proposed and more advanced contract forms.

This research is scoped to high speed transfer vessel operations and the main engine service demands. The inclusion of other components might change the outcome of the presented contract performance. This studies aim however is intended to be applicable for other vessel operations, or user profiles, and other or more vessel components.

For further research it is recommended to extend the inclusion of more components into the model to obtain the contract performance figures of complete vessels in the future.
The model is based on a small amount of failure data, research into failures in relation to usage will result in better cost predictions and matching contract types.
The future developments at the remote monitoring application of Damen will extend the possibilities to define better data and knowledge regarding user profiles and other usage related aspects.
A similar elaboration of this research applied to other vessel types might gain insight into new challenges regarding the establishment of user profiles and contract forms.

Last, the author is curious towards new development build upon this thesis in both academic as in practical developments regarding servitization in the shipbuilding industry.

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A

Strategy Map

This strategy map is retrieved form Rabetino et al. (2017b)

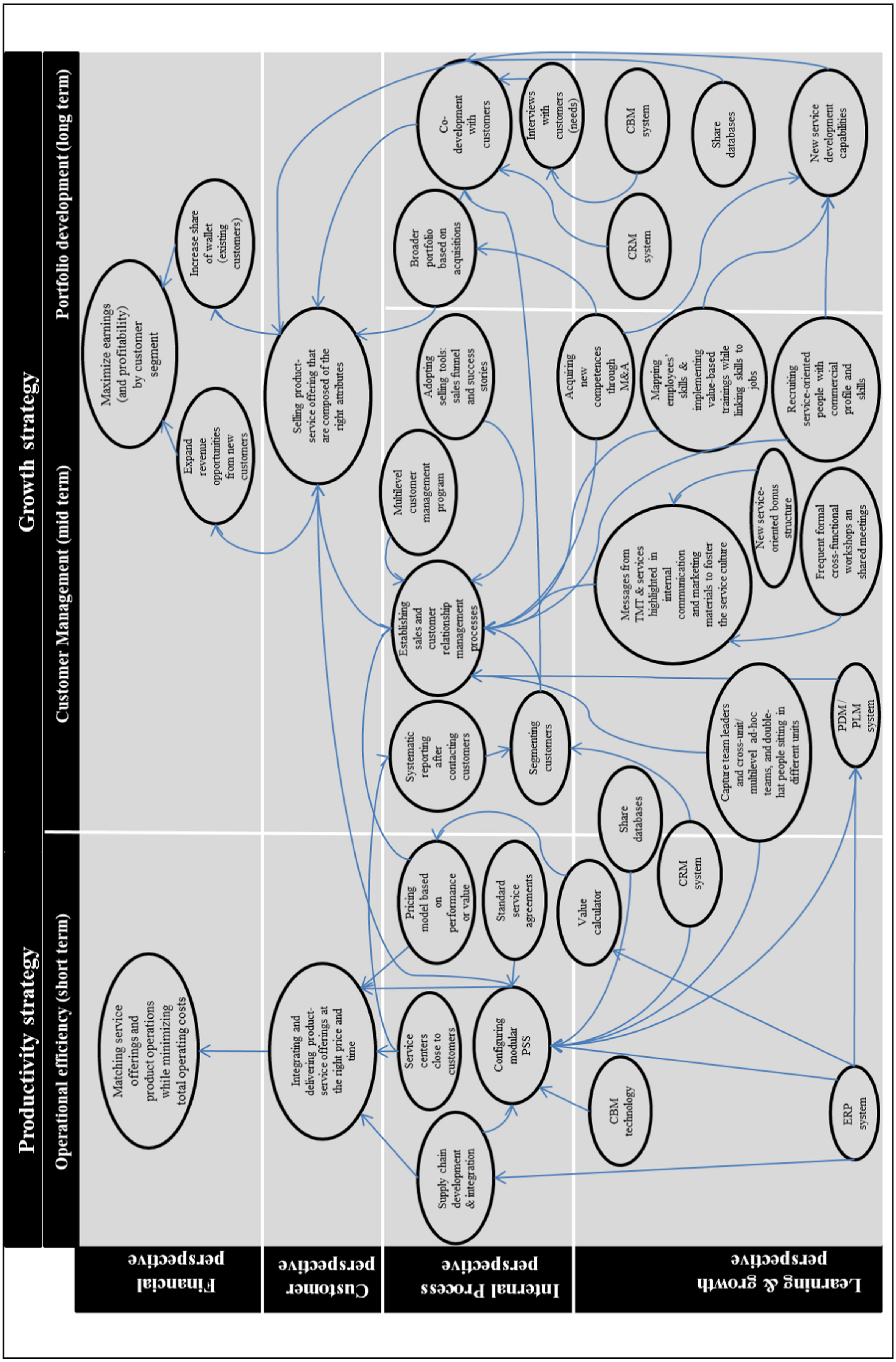


Figure A.1: Servitization Strategy Map (Rabetino et al., 2017b)

B
PSS Classification

This PSS is retrieved form Tukker (2004)

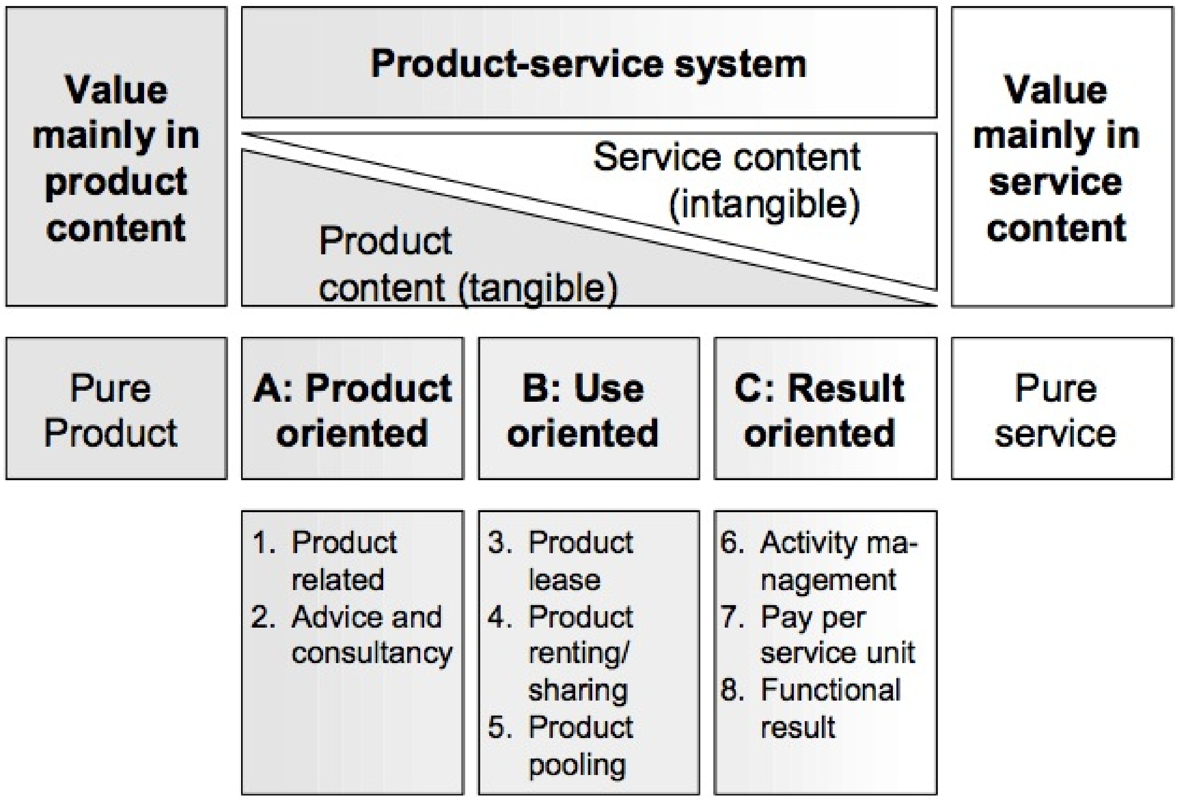


Figure B.1: PSS Classification model (Tukker, 2004)

C

Mean variance derivation

This derivation is retrieved form Sargent (2010)

Mean Variance Utility

In this note I show how exponential utility function and normally distributed consumption give rise to a mean variance utility function where the agent's expected utility is a linear function of his mean income and the variance of his income. The analysis is taken from p. 154-155 in T. Sargent, *Macroeconomic Theory*, 2nd. edition.

Suppose that the utility function from consumption, C, is exponential and given by

$$U(C) = -e^{-\lambda C}, \qquad \lambda > 0. \tag{1}$$

This utility function is increasing and concave since

$$U'(C) = \lambda e^{-\lambda C} > 0, \qquad U''(C) = -\lambda^2 e^{-\lambda C} < 0. \tag{2}$$

Since the utility function is concave, it reflects risk aversion. Moreover note that the Arrow-Pratt index of absolute risk aversion is given by

$$-\frac{U''(C)}{U'(C)} = \lambda. \tag{3}$$

This means that the larger λ is, the more risk averse the agent is.

Next, suppose that C is distributed normally with mean, μ, and standard deviation, σ. Then the density of C is given by:

$$f(C) = \frac{e^{-\frac{(C-\mu)^2}{2\sigma^2}}}{\sigma\sqrt{2\pi}}. \tag{4}$$

Therefore, expected utility is given by:

$$\begin{aligned} EU(C) &= \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\infty} -e^{-\lambda C} e^{-\frac{(C-\mu)^2}{2\sigma^2}} dC \\ &= \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\infty} -e^{-\left(\lambda C + \frac{(C-\mu)^2}{2\sigma^2}\right)} dC. \end{aligned} \tag{5}$$

It is no useful to rewrite the exponent so as to group terms that depend on C and terms that do not depend on C. To this end note that

$$\lambda C + \frac{(C-\mu)^2}{2\sigma^2} = \frac{\left(C-\mu+\lambda\sigma^2\right)^2}{2\sigma^2} + \lambda\left(\mu - \frac{\lambda\sigma^2}{2}\right). \qquad \textbf{(6)}$$

Substituting in EU(C), gives

$$EU(C) = -\frac{e^{-\lambda\left(\mu - \frac{\lambda\sigma^2}{2}\right)}}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\infty} e^{-\frac{\left(C-\mu+\lambda\sigma^2\right)^2}{2\sigma^2}} dC. \qquad \textbf{(7)}$$

Now, for all μ',

$$\frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\infty} e^{-\frac{(C-\mu')^2}{2\sigma^2}} dC = 1, \qquad \textbf{(8)}$$

because the left hand side is just the area under the density function over the entire support when the mean is μ' and the standard deviation is γ. Since this is so for any μ' including $\mu' = \mu\text{-}\lambda\gamma^2$, it follows that

$$EU(C) = -e^{-\lambda\left(\mu - \frac{\lambda\sigma^2}{2}\right)}. \qquad \textbf{(9)}$$

Hence, the objective of the agent is to maximize the expression

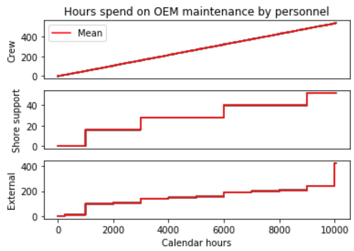
$$\mu - \frac{\lambda\sigma^2}{2}. \qquad \textbf{(10)}$$

That is, the agent is interested in maximizing his mean consumption minus the variance multiplied by a constant. As we saw before, the constant λ measures the degree of risk aversion: the larger λ is, the more risk averse the agent is. Hence the utility of the agent is increasing with the mean of his consumption and decreases with the variance. The rate of decrease with the variance is larger the more risk averse the agent is.

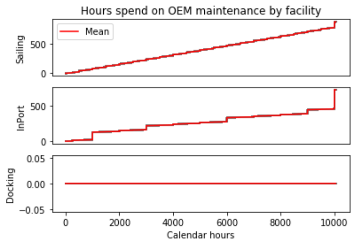
D

Measurements

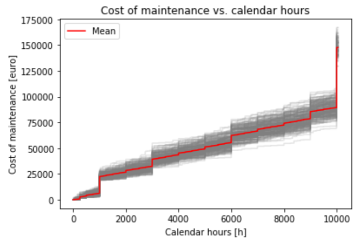
The cost per hour in transfer state are derived using the model to run 10.000 simulated hours. The cost per hour for the other states are calculated similarly Resulting in cost distribution:



(a) User profile East Anglia ONE



(b) User profile Norther



(c) Cost accumulation after 10000 transfer running hours

Figure D.1: Cost accumulation after 10000 transfer running hours

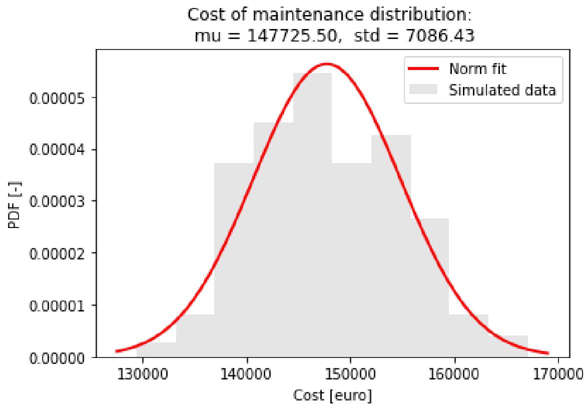


Figure D.2: Cost of maintenance after 10000 transfer running hours

E
System Codes

This system code overview is retrieved form Damen

IFS CODES DAMEN as used in the DMMS system

000	General	300	Primary ship systems	600	Secondary Ship Systems	754	Paint store
031	Classification	310	Bilge, ballast and internal FiFi	610	Hydraulic system	755	Fire extinguisher space
033	Certificates	311	Bilge system	620	Compressed air system	756	Engine room workshop and tools
071	Documentation	312	Ballast system	621	Starting air system	757	Deck workshops
100	Hull and Superstructure	313	Deckwash and internal FiFi system	622	Working and control air system	759	Other stores and workshops
110	Hull	320	Fuel oil system	630	Cargo handling system	795	Miscellaneous
120	Superstructure	321	Fuel oil transfer system	631	Cargo alarm and monitoring system	800	Nautical, communication and automation
130	Hatches, doors and windows	322	Fuel oil supply system	632	Tank cleaning system	810	Navigation lighting and signals
131	Hatches	323	Domestic tank heating system	633	Cargo (tank) heating system	811	Navigation lighting
132	Manholes and manhole covers	324	Heavy oil system	634	Cargo cooling / freezing system	812	Search light system
133	Watertight and weathertight doors	330	Cooling water system	635	Cargo inerting system	813	Signals and flags
134	Bow-, stern doors, ramps and gates	331	Sea water cooling system	636	Cargo tanks (loose)	820	Nautical and bridge system
135	Windows, portholes and blindages	332	AC Cooling water system	639	Other cargo systems	821	Integrated bridge system
136	Cargo hatch covers	333	Fresh water cooling system	640	(Oil) pollution control	822	Radar system
137	Blind covers	340	Fresh, sea and waste water system	650	External FiFi and salvage system	823	Electronic chart system
139	Docking and drain plugs	341	Fresh water supply system	660	Pre-wetting system	824	(D)GPS navigation
140	Stairs, ladders and platforms	342	Sea water supply system	670	Fixed internal FiFi system	825	Compass and gyro
141	Stairs, ladders and climbing steps	343	Sanitary gravity discharge system	680	Cold store and freezing room system	826	Autopilot
142	Railings, handrails and grips	344	Sanitary vacuum discharge system	690	Remaining secondary ship systems	827	Optical night vision
143	Platforms and gratings	345	Waste water treatment system	691	Sea keeping improvement devices	828	Echosounder
144	Boarding platform gangway	346	Internal deck scuppers and drainpipes	692	Waste treatment system	829	Speedlog
150	Additions to ships construction	350	Filling, sounding and de-aeration	695	Miscellaneous	830	Dynamic positioning system
151	Fenders	351	Filling, sounding and de-aeration	700	Joinery and accommodation	831	Dynamic positioning system
152	Push bow	352	Remote tank sounding system	710	Joinery	832	Reference system
153	Bollards and bitts	353	Appendages	711	Floors	835	Joystick system
154	Lifting lugs	360	Lubrication, dirty oil and sludge system	712	Walls	836	DP gyro system
155	Ballast	361	Lubrication system	713	Ceilings	837	Motion reference unit
156	Lashing material	362	Dirty oil system	714	Internal doors	840	Internal communication system
157	Sun awning and rope guards	363	Sludge system	715	Insulation	841	Intercom system
158	Masts	370	Heating, ventilation and AC system	716	Fixed furniture	842	Internal telephone system
159	Hull and superstructure markings	371	Ventilation system	719	Accommodation accessories	847	CCTV system
160	Corrosion protection and deck cover	372	Air conditioning system	720	Wheelhouse and crew accommodation	848	Intruder and burglar alarm system
161	Paint system	373	Heating System	721	Wheelhouse	849	Emergency communication
162	Deck covering (outside)	374	Tracing system	722	Living quarters	850	External communication system
163	Cathodic protection	380	Exhaust system	723	Galley and pantry	851	(GMDSS) communication station
164	Active anti-fouling system	381	Water injection system	724	Mess room	855	GSM telephone system
195	Micellaneous	382	Exhaust gas cleaning system	726	Laundry room	856	Satelite and iridium telephone
200	Main machinery	395	Miscellaneous	727	Hospital and sickbay	857	Satelite data communication
210	Propulsion system	400	Electrical system	728	Crew sanitary spaces	860	Infotainment and office automation
211	Propulsion engine system	410	Power generating system	729	Other accommodation spaces	861	TV, universal disc player and surround system
212	Reduction gear system	411	Generator sets	730	Passenger accommodation	862	E-mail and internet system
213	Thrust system and shafts	412	Shaft generators	731	Passenger accommodation	863	On board SAT television system
214	Propulsion control system	414	Frequency drives	732	Buffets and restaurants	864	Video and audio on demand system
220	Steering system	420	Cables	738	Passenger sanitary spaces	865	Office (W-)LAN system
221	Rudder installation	430	Switchboards and components	739	Other passenger spaces	866	Office PC's
222	Steering gear system	440	Alarm, monitoring and control system	740	Technical spaces	867	Office server and back-up system
223	Transverse thruster	450	Lighting	741	Main engine room	869	Other office and infotainment systems
224	Retractable thruster	495	Miscellaneous	742	Thruster and steering gear room	870	Meteorological equipment
250	Dredge system	500	Deck equipment	743	Bow thruster room	871	Baro-, thermo- and hygrometer(s)
251	Cutter and cutter ladder	510	Anchor equipment	744	Engine control room	872	Anemo meter
252	Draghead and trailing pipe	520	Mooring system	745	Switchboard room	873	Weather system
253	Dredge and discharge pump	530	Fishing gear	746	Technical navigation room	895	Miscellaneous
254	Gantries and swell compensator	540	Hoisting equipment	747	Emergency generator room	900	Special equipment
255	Dredge piping system	550	Anchor handling, towing and pushing	748	Crane, winch and deck rooms	910	Hydro and oceanographic equipment
256	Dumping system, overflow and AMOB	560	Research equipment	749	Other technical spaces	930	Military equipment
257	Spud system	570	Life saving and fire protection	750	Stores and workshops	940	Helicopter equipment
258	Dredge drive systems and control	580	Tender and workboat	751	Cool, freeze and dry stores	995	Miscellaneous
259	Supporting dredge systems and control	590	Diving equipment	752	Rope, boatswain and deck stores		
295	Miscellaneous	595	Miscellaneous	753	Luggage and cargo store		

Figure E.1: Damen system codes