Master's thesis

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

Celine Mysen

Understanding Offshore Support Vessel Activity by the Use of AIS Data

Master's thesis in Marine Technology
Supervisor: Prof. Bjørn Egil Asbjørnslett
June 2019

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RYSTAD ENERGY

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PROJECT THESIS IN MARINE TECHNOLOGY

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FOR

STUD. TECHN. CELINE MYSEN

Understanding Offshore Support Vessel Activity by the Use of AIS Data

Background
This thesis investigates whether combining AIS data from offshore support vessels (OSV) with spatial and temporal information from offshore infrastructures can provide insight into the offshore support vessel operations. All offshore oil and gas activities are supported by complex logistical patterns and a large number of supply bases making out an industry playing a huge role for the coastal communities. Still, little quantitative data is available on the spatial and temporal distribution of the support vessels activities, and therefore the impacts and characteristics of these activities cannot be analysed. The motivation of this master thesis is to contribute in the filling this information gap and potentially provide valuable insight into an important industry for the Norwegian economy.

Objective
The main objective of this thesis is to investigate whether AIS data combined with detailed information regarding to the offshore oil and gas industry can be used to understand offshore support vessel activities in order to gain more insight in the sector in different market situations.

Tasks
The candidate shall/is recommended to cover the following tasks in the master thesis:

a) Describe the offshore oil and gas industry and the role of the OSVs.
b) Describe the properties of AIS data
c) Develop a methodological framework for identifying OSV activities
d) Conduct a case study to exemplify the model and evaluate the results
e) Discuss and evaluate the case study results and the effect of assumptions and model parameters

General
In the thesis the candidate shall present her personal contribution to the resolution of a problem within the scope of the thesis work.

Theories and conclusions should be based on a relevant methodological foundation that through mathematical derivations and/or logical reasoning identify the various steps in the deduction.

The candidate should utilise the existing possibilities for obtaining relevant literature.

The thesis should be organized in a rational manner to give a clear statement of assumptions, data, results, assessments and conclusions. The text should be brief and to the point, with a clear language. Telegraphic language should be avoided.

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The thesis shall contain the following elements: A text defining the scope, preface, list of contents, summary, main body of thesis, conclusions with recommendations for further work, list of acronyms, reference and (optional) appendices. All figures, tables and equations shall be numerated.

The supervisor may require that the candidate, in an early stage of the work, present a written plan for the completion of the work. The original contribution of the candidate and material taken from other sources shall be clearly defined. Work from other sources shall be properly referenced using an acknowledged referencing system.

The work shall follow the guidelines given by NTNU for the MSc Thesis work. The work load shall be in accordance with 30 ECTS, corresponding to 100% of one semester.

The thesis shall be submitted electronically on Inspera:
- Signed by the candidate.
- The text defining the scope included.
- Computer code, input files, videos and other electronic appendages can be uploaded in a zip-file in Inspera. Any electronic appendages shall be listed in the thesis.

Supervision:
Main supervisor: Prof. Bjørn Egil Asbjørnslett

Deadline: 11.06.2019

Date: 04.06.2019

Prof. Bjørn Egil Asbjørnslett

"We are drowning in information but starved for knowledge."

John Naisbitt, 1982

Preface

This master thesis represents the final 30 ECTS of a Master of Science in Marine Technology at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway. My field of specialisation is within marine engineering and marine system design. The thesis was carried out during the spring semester of 2019 and is a continuance of my project thesis which took place during autumn 2018. Even though the master thesis builds on theory and data addressed in the project thesis, this thesis can and should be read as an independent piece of work.

The thesis is written in collaboration with Rystad Energy, where my contact persons have been Fredrik Ellekjær, Mike McCormick and Lars Eirik Nicolaisen. During an internship in Rystad Energy during summer 2018, I got to learn that Rystad Energy had bought access to the PortVision AIS database. As this was a data source I was eager to learn more about a collaboration on a master thesis was agreed upon, where studying offshore support vessel activity became the selected topic.

The work you now have in hand is a result of many frustrating but also enjoyable hours. During this thesis, I have had the chance to learn the Python programming language, understand the possibilities provided through AIS data and to get a deep understanding of the offshore support vessel operations. I hope you will enjoy learning about these topics as much as I did.

June 6, 2019

Celine Mysen

Acknowledgement

I would like to express my gratitude to my supervisor Prof. Bjørn Egil Asbjørnslett, for his contributions throughout the work with the master thesis. I am grateful for your highly competent guidance during the past year.

I also want to thank my supervisors at Rystad Energy. Thank you, Fredrik Ellekjær, for all the time you have devoted for meaningful discussions and great guidance this semester. Thank you, Mike McCormick, for always answering and helping me with all the Python programming related issues. Thank you, last but not least, Lars Eirik Nicolaisen, for allowing me to write my master thesis in collaboration with you, and to provide me with necessary data. Completing this thesis would not have been the same without all your help and motivation. I would also like to show my gratitude to all my other co-workers at Rystad Energy, both you who have answered thesis-related questions and those of you who have kept me motivated every day.

I would like to thank my fellow students, and especially my office- and roommates for the great support. Also the graduates Patrick Næss, Bernhard Feet and Bjørnar Brende Smestad, who also based their master thesis on AIS data, for meeting my questions with open arms.

C.M.

Summary

This thesis investigates whether coupling Automatic Identification System (AIS) data from offshore support vessels (OSV) with market data from the offshore oil and gas industry can provide insight into OSV operations. All offshore oil and gas activities are supported by complex logistical patterns and a large number of supply bases making out an industry playing a huge role for the coastal communities. Still, little quantitative data is available on the spatial and temporal distribution of the support vessel activities, and therefore the impacts of these activities cannot be analysed. The motivation for this master thesis is to contribute in the filling of this *information gap* and potentially provide valuable insight into an important industry for the Norwegian economy.

A thorough literature review investigating the state-of-the-art within the topic and identifying potential challenges is conducted. The data used in this research consist of data provided by Rystad Energy and data gathered from the Norwegian Petroleum Directorate's public sources. A deep-dive into both the operations of OSVs and the properties of AIS data is conducted with the aim to understand how vessel activity can be described by the use of positioning data. The result is a methodological framework applicable for identifying the spatial and temporal distribution of OSV operations. The steps building up the model is described in detail through this thesis.

The model identifies vessel operations by evaluating the vessels' distance from shore and nearby infrastructures, mainly production platforms and drilling rigs. The model is evaluated through a case study where the activities on the Norwegian continental shelf (NCS) from mid-2013 to end-2018 are analysed. The activity levels are analysed in terms of time spent on voyages and the number of voyages servicing the offshore infrastructures. Overall, the case study showed promising results as the model was able to capture some of the well-known trends and expectations regarding OSV operations. Some of the results were the model's capability to capture the seasonal variations, the dependency between rig and anchor handling tug supply (AHTS) vessel activity and assigning vessel days to each of the fields on the NCS. However, the results also shed light on the complexity of the logistical patterns. Especially, it was found hard to distinguish active work from offshore waiting. It was also found that the fleet's activities cannot fully be described solely based on the offshore infrastructures included in this study.

In conclusion, the case study provides evidence in favour of using AIS data to understand OSV activities. The key part of the model, combining AIS data with infrastructure data, was found to be a success for analysing OSV activity on a region, operator and field level. As no operational data has been available the model has been evaluated based on industry insight obtained during the process of developing the model, annual reports and news articles. This thesis suggests further work in refining the model parameters, improve the quality of the input data and extend the model to cover all types of offshore infrastructures, as well as further model testing and evaluation.

Summary in Norwegian

Denne oppgaven undersøker om Automatisk indentifikasjonssystem (AIS) data kombinert med markedsdata fra offshore olje- og gassindustrien kan gi innsikt i operasjoner utført av forsyningsfartøy. All offshore olje- og gassaktivitet blir støttet opp av et komplekst logistikkmønster og et stort antall forsyningsbaser som utgjør en viktig rolle for kystsamfunnene. Det finnes lite kvantitative data på fartøyenes operasjoner, noe som gjør det vanskelig å analysere sektorens betydning. Motivasjonen for denne masteroppgaven er å bidra til å fylle dette informasjonsgapet, og forhåpentligvis bidra med verdifull innsikt i en industri som er viktig for den norske økonomien.

En grundig litteraturgjennomgang presenteres for å undersøke state-of-the-art innen emnene og for å identifisere eventuelle utfordringer. Datagrunnlaget for denne oppgaven er delvis gitt fra Rystad Energy og delvis hentet fra Oljedirektoratet sine offentlige kilder. Et dypdykk inn i industrien knyttet til forsyningsfartøyene og egenskapene til AIS-data er gjennomført med mål om å tilegne seg kunnskap om hvordan posisjonsdataene kan brukes til å beskrive operasjonene til forsyningsfartøyene. Resultatet er et metodologisk rammeverk egnet for å identifisere fartøyenes operasjonsmønster. Stegene for å bygge opp en slik modell er forklart i detalj gjennom denne masteroppgaven.

Modellen identifiserer fartøysoperasjoner ved å vurdere fartøyenes avstand til nærmeste kyst og annen nærliggende infrastruktur, i all hovedsak produksjonsplattformer og borerigger. Modellen er evaluert gjennom en casestudie hvor aktiviteten til forsyningsfartøy på den norske kontinentalsokkelen fra midten av 2013 og til og med desember 2018 blir analysert. Aktivitetsnivåene blir analysert basert på tiden som er brukt og antall turer som har gått med på å forsyne offshore installasjonene. Jevnt over viser modellen lovende resultater. Casestudiet viser at modellen klarer å fange opp flere av de velkjente trendene og forventningene hva gjelder forsyningsfartøyaktivitet. Dette gjelder blant annet sesongvariasjoner, forbindelsen mellom rig-aktivitet og turer seilt av ankerhåndteringsfartøy, og evnen til å knytte fartøysaktivitet til hvert enkelt felt på sokkelen. Dog illustrerte resultatene også vanskelighetsgraden knyttet til å beskrive det komplekse operasjonsmønsteret. Det ble funnet spesielt vanskelig å skille hendelser hvor skipet faktisk utførte et arbeid med hendelser hvor skipet ventet på å få utføre et arbeid. I tillegg ble det observert at forsyningsfartøyenes operasjoner ikke fullt kan bli beskrevet kun med infrastrukturdataen som er inkludert i denne oppgaven.

Det er konkludert med at AIS-data kan bidra til å gi verdifull innsikt i operasjoner knyttet til forsyningsfartøy. Den delen av metodikken som kombinerer AIS-data sammen med annen markedsdata er funnet til å være en suksess. Siden ingen data på faktiske fartøysoperasjoner har vært tilgjengelige har modellen blitt evaluert basert på generell forståelse av industrien og markedet, årsrapporter og diverse nyhetsartikler. Denne oppgaven anbefaler videre arbeid innenfor feltet og foreslår arbeid knyttet til å forbedre modellparameterne, anskaffe bedre AIS-data eller ta i bruk mer komplekse metoder for å fylle data hull og utvidelse av modellen til å inkludere all type offshore infrastruktur.

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Abbreviations

AHTS	=	Anchor Handling Tug Supply
AIS	=	Automatic Identification System
DP	=	Dynamic Positioning
ETA	=	Estimated Time to Arrival
EOR	=	Enhanced oil recovery
GOM	=	Gulf of Mexico
IMO	=	International Maritime Organization
IOR	=	Improved oil recovery
ITU	=	International Telecommunication Union
MMSI	=	Maritime Mobile Service Identity
MODU	=	Mobile offshore drilling units
NCS	=	Norwegian Continental Shelf
NPD	=	Norwegian Petroleum Directorate
OCV	=	Offshore Construction Vessel
OSV	=	Offshore Support Vessel
PSV	=	Platform Supply Vessel
TDMA	=	Time Division Multiple Access
VHF	=	Very High Frequency

Chapter 1

Introduction

The topic of this master thesis is investigation of offshore support vessel (OSV) activity by the use of automatic identification system (AIS) data. These next sections will aim to explain the motivation for studying this topic followed by a presentation of relevant academic research. Thereafter follows the thesis objectives, scope and limitations. Chapter 1 will be concluded by presenting the structure of this report.

1.1 Motivation

From mid-2014 to early-2016 the world witnessed one of the largest oil price shocks in modern history, with a price drop of more than 70%. The Brent crude oil price went from 115 USD/barrel in June 2014 to 28 USD/barrel in January 2016[1]. The downturn had naturally a particularly large impact on the petroleum industry. With lower oil prices and more or less fixed production costs, many companies struggled to maintain positive margins. CNBC reported in 2016 that over 100 US oil and gas companies had filed for bankruptcy since 2014 and that even more companies were expected to do the same[2]. According to DBS Group Research (2017) oil companies' capital expenditure budgets have been cut substantially since the onset of the oil price collapse. According to Rystad Energy's upstream database, UCube, global capital expenditure in 2016 was reduced with more than 40% compared to 2014. To remain profitable the oil companies have had to take actions to reduce costs by cutting offshore exploration and development activities (Morgan Stanley, 2015) and reducing activity in producing fields.

When oil companies reduced the amount of new projects and cut back on exploration, supporting industries were hit hard by the lack of new orders. One of the oil companies' largest cost in the offshore upstream supply chain is the need of logistics support from land (Aas et al., 2009) and this part of the supply chain was no exception. Even though

[1] https://www.macrotrends.net/2480/brent-crude-oil-prices-10-year-daily-chart, (02.04.2019)

[2] https://www.cnbc.com/2016/09/28/oil-bankruptcies-100-down-maybe-100-more-to-go.html, (02.04.2019)

the land-based support, provided by helicopters and specialised offshore support vessels (OSVs), is crucial for maintaining continuous offshore operations the reduction in oil and gas activities had an impact on the sector. According to Clarkson Research (2016) the oil price collapse in 2014 set OSV day rates plummeting across all regions with the North Sea hit hardest.

The vessels are usually chartered by the oil companies either on long term contracts or from the spot market. The long term charter cost and spot day rate are dependent on the vessel characteristics and the OSV supply and demand balance. With offshore oil and gas installations being the main source of employment for OSVs the OSV supply and demand balance is mainly dependent on the activity in the offshore market and implicitly the oil price (Strømberg, 2015). There are mainly two types of installations OSVs are servicing; production facilities and mobile offshore drilling units (MODUs). Exploration and development activities are heavily dependent on drilling units which again depend on OSV support. With drilling activities being postponed the demand for OSVs rapidly decreased. DBS Group Research (2017) reported in 2017 that contracted utilisation rates had seemed to hit a bottom as OSV owners were operating near cash break-even. Renegotiation's of existing contracts were also a reality. Vessels on long term contracts at higher day rates risked facing pressure from oil companies to renegotiate the rates downward. As a consequence, there have been several reports of OSVs being stacked, early termination of contracts and vessels at yards not being paid for by the owners. DBS Group Research (2017) reported that the AHTS fleet was shrinking for the first time in years in 2017, due to a large proportion of deliveries being deferred or cancelled. According to Clarkson Research (2016) the majority of available, modern DP2 vessels at the beginning of 2016 were down-manned and required a period of 1-2 weeks for reactivation.

In addition to being a crucial part of the oil and gas industry, the OSV sector is a major source of employment along the coastal communities (Kaiser and Snyder, 2013). According to Norwegian Shipowners' Association (2019) the total maritime industry[3] in Norway employed 85 000 people and contributed to value creation of NOK 142 billion in 2018. The ship owners make up the largest segment of the industry, measured in both value creation and employment. OSV activity has also a direct economic benefit associated with several other businesses such as trucking and barge operators, shipbuilding and maintenance, platform fabrication and a large amount of oilfield service and supply companies (Kaiser, 2010). The sector is also impacting port activity, coastal environment and infrastructural requirements (Kaiser and Narra, 2014). Despite the size and importance of the fleet, the sector is less analysed than e.g. the rig sector. This is partly because of the lack of (readily available) data and partly due to the size of the fleet making analysis challenging. Where other sectors publish their contracts on a fairly visible basis, this has not been true for the OSV sector. As such, the industry lacks a complete, consistent and bottom-up view on OSV vessel usage. All the above mentioned industries could gain from more visibility on OSV utilisation. A data-driven approach could potentially decrease port congestion by forecasting the number of vessels connected to each port, reduce emission by allowing operators to optimise their fleet usage and provide information on competitive vessel designs.

[3]including shipowners, yards, maritime services, seafarers, equipment providers and R&D, environments

In the past, sea transport surveillance has suffered from lack of data, but current tracking technologies has rather transformed the problem into a problem of overabundance of information. International Maritime Organization (IMO) imposed in 2002 a requirement of installing Automatic Identification System (AIS) on almost all commercial vessels (IMO, 2002). AIS is an automatic system tracking and reporting vessel positions multiple times each minute, leading to a vast amount of data. AIS was originally meant for increasing safety at sea by identifying other vessels nearby, but with the increased capability of storing and handling large amounts of data, the system has gained additional value. Tsou (2010), an early study on AIS data, found that the data potentially was of great value, but not fully exploited. By storing all positions of from vessels, the possibility to gain insight into various maritime industries is huge. A more detailed explanation of AIS data can be found in Chapter 2.2.

The motivation for this study is to use the available and treatable AIS data sent from offshore support vessels to analyse the sector and hence provide more insight to an important but less analysed part of the oil and gas industry.

1.2 Literature Review

The papers reviewed represent the foundation of the work and give a broad understanding of the thesis' topics. Literature on OSVs has been studied with the aim to gain a deeper understanding of the vessels' operations and identify parameters affecting vessel activity. In addition, both literature concerning oil price fluctuations and the exploitation of AIS data have been reviewed. This section will provide a summary on some of the works within these topics and identify unexplored fields, creating opportunities for this thesis.

Academic studies on the OSV sector have mainly been focusing on optimisation of fleet size, mix and scheduling. The primary concern of these kinds of problems is to construct a fleet and/or a delivery schedule satisfying a set of offshore installations' needs at a minimised cost. Halvorsen-Weare and Fagerholt (2017)'s study consisted of determining an optimal fleet size and mix of OSVs to charter and their weekly routes. Two new mathematical models (an arc-flow model and a voyage-based model) for solving the OSV planning problem were presented. Fleet composition was also studied by Shyshou et al. (2010). In this study a simulation model was developed to define the cost-optimal fleet of AHTS vessels on long term hire for different future spot rate scenarios. Volatile spot rates and high long term rent cost for AHTS vessels were part of the motivation for the study.

Fagerholt and Lindstad (2000), Halvorsen-Weare et al. (2012), Shyshou et al. (2012) and Borthen et al. (2018) are some of the studies focusing on optimising fleet schedules, often referred to as the Periodic Supply Vessel Planning Problem (PSVPP) (Kisialiou et al., 2018). The primary concern of these kinds of problems is to construct a delivery schedule for a given fleet. When Fagerholt and Lindstad (2000) studied this the routing policy was recognised by operational requirements and ad-hoc needs with frequent deviations from the original schedule. It was suspected that the supply services could be performed more efficiently. The paper found that their solution would have potential cost savings corresponding to 43% of the servicing costs at the time. The PSVPP is an optimisation exercise that has been extended to more complex models and solved with multiple heuristics. Halvorsen-Weare et al. (2012) developed a two-phase algorithm, where the first phase consisted of generating all the shortest feasible voyages and the second phase of solving the voyage based problem.

These PSVPP studies diverse from each other by the algorithms used and the real-life situations included, such as inhomogenous fleets and time windows. Common is that the robustness of the vessel scheduling plan is often not included as a main part of the study. Robustness is defined as *the capability for a voyage or schedule to allow for unforeseen events during execution* in a study conducted by Halvorsen-Weare and Fagerholt (2011). On the Norwegian continental shelf (NCS) there can be harsh weather conditions that may force the operators to deviate from the original plan, potentially introducing high costs. Christiansen and Nygreen (2005), Halvorsen-Weare and Fagerholt (2011) and Halvorsen-Weare et al. (2013) focused on including a robustness aspect to the optimisation problem. Some of these studies recommend adding slack to each voyage, i.e. requiring that each vessel has some *free* hours before or after each trip. Another approach is to combine optimisation and simulation. Halvorsen-Weare and Fagerholt (2011) used a three-step approach; first all candidate voyages were generated, secondly, a simulation was run for each of the candidate voyages where uncertainties such as weather data were included. For all voyages, the robustness was measured by the amount of *not delivered volumes*. This was included as an additional cost for each voyage in the third step. The third step consisted of running an optimisation model deciding the cost optimal combination of possible voyages satisfying given restrictions.

Some studies have also been focusing on the design of the OSVs. Aas et al. (2009) explored the supply vessel as a mean of transport and carried out a logistic analysis based on OSV usage on the NCS. Most research up till then had been focusing on the routing problem alone and not focusing on how the design of the supply vessel and its ability to execute the transport job affect logistics. The focus of the paper was to analyse the design of OSVs with the aim to identify how they can be improved to better support operations. This was done by elaborating the PSV's main logistical features and study the main logistical issues. Vidal et al. (2015) developed a model comparing different OSV designs for different missions. The designs were compared based on operability and capital cost with the aim to facilitate better decision making. The output of the model was the vessels' main attributes and a design decision making tool.

Mark J. Kaiser has in several papers (Kaiser (2010), Kaiser and Snyder (2010), Kaiser and Snyder (2013), Kaiser and Narra (2014) and Kaiser (2015)) studied the spatial and temporal dynamics of the OSV's working network with a focus on activities in the Gulf of Mexico (GOM). In the first paper (Kaiser, 2010) the author developed a methodological framework for quantifying the number of OSV departures from ports based on the oil and gas activities in the basin. The result was an input-output model where the characteristics of oil and gas activities such as duration, magnitude and life cycle stage were entered as input. The number of port departures for vessels servicing these activities was the output of the model. To translate offshore activities into the number of port departures model parameters were introduced. These were used to estimate the number of vessel days needed to support each offshore activity, if multiple installations were visited on the same trip or not and also which onshore base to serve which offshore activity. The model parameters were crucial for the validity of the output of the model and not easy to define. The aim of the study conducted by Kaiser and Snyder (2010) was to estimate the OSV needs per stage of activity for offshore operations (one of the model parameters needed for the model presented in Kaiser (2010)). This was done based on data collected from company planning documents, fleet utilisation data from oil and gas companies and service providers as well as data from interviews and surveys. Kaiser and Snyder (2013) further used this data to parameterise the model presented in Kaiser (2010). The results were found to be quite sensitive to the input data and model parameters. The paper concluded that the model should be revised once better and more complete data becomes available.

Kaiser and Narra (2014) investigated the possibilities of using AIS data to identify the logistical patterns of OSV that further could be used to parameterise the model from Kaiser (2010) more correctly. Vessel events were identified solely by the use of AIS data. The events were aggregated by port, area block, vessel type and event class (offshore-to-offshore, shore-to-offshore etc.) Based on this model and AIS data from June 2009 it was possible to get an understanding of the relationship between offshore activities and port visits. A shortcoming of the model was the use of proxy variables introduced to define offshore events. An offshore event was recorded if a vessel was observed within a given area for more than 2 hours with an average speed less than 2 mph. The results from the model were shown to be dependent on how these variables were defined. By keeping the time threshold at 2 hours but changing the average speed limit from 1 mph to 3 mph over 3000 more offshore events were identified over the same period (June 2009).

The study by (Kaiser and Narra, 2014) is the first known study using AIS data to understand OSV operations and activities. There are several papers exploiting the use of AIS data for other purposes. They vary greatly in findings but show that AIS can be used beyond its original purpose. This is commented by Ou and Zhu (2008) and confirmed by findings in other research. Ou and Zhu (2008) concluded in their study that the potential benefits from AIS are far beyond its original designated use as aid for navigation. Some of the identified AIS applications were legal evidence in accidents, information about traffic patterns, planning of aids to navigation and fleet management. The main limitation they pointed out was erroneous data. AIS data has also been shown to be valuable for input in simulation models (Goerlandt and Kujala, 2011), speed estimations (Leonhardsen, 2017), route generation for ship emission calculations (Goldsworthy, 2017), identifying global trade patterns (Kaluza et al., 2010), and forecasting freight rates (Næss, 2018). AIS data is also shown to be applicable for identifying different ship types (Smestad et al., 2017) and location of ports (Millefiori et al. (2016a) and Millefiori et al. (2016b)). These applications enable AIS studies to be conducted without the use of commercial ship and port databases. In addition to provide insight on the spectre of AIS usages these papers also present methods for working with and extracting valuable information from the positioning data.

Studies focusing on how fluctuations in oil price affect nearby industries have also been reviewed. Hofmann et al. (2018) examined the influence of oil price shocks on the financial performance of logistics service providers. The result showed that oil consuming sectors react negatively at the beginning of an increase in oil price, but is surprisingly quick to recover and do to some extent even profit due to increased activity in the market. Fuel in the OSV sector is often paid by the operators, meaning that the vessel owners will not profit from low oil prices in the same way as other logistic providers. OSV owners will rather be harmed by the decrease in activity. Ringlund et al. (2008) analysed how oil rig activity in non-OPEC regions is affected by the crude oil price. The relationship between oil rig activity and crude oil price were estimated by the use of dynamic regression models that were augmented with latent components capturing trends and seasonality. The results indicated a positive relationship between oil rig activity and crude oil price. The results did however vary across regions; the price response was found to be weaker in Europe than e.g. in the US. Pickering and Sengupta (2015) wrote an article focusing on how operators can survive in a low oil price environment without having to decrease activity levels. The authors believe that integrated operations, also known as the *digital oil field* could be a critical factor that enables sustainable economic operations. The digital oil field is a generic term for the application of smart information technology improving safety, efficiency and productivity of oil and gas operations. The authors states the adoption of integrated operations have been patchy and that there is a lot of unused potential in the technology available today.

1.2.1 Remaining Opportunities

The literature review indicates that the OSV sector is fairly well studied in terms of optimisation of fleet size and mix and vessel scheduling. Where these papers confirm that there exist ways of operating a fleet more cost efficient than others, fewer studies have focused on the actual fleet operational pattern and activities. There have been comments on how changes in the oil price affect other industries but, to the author's knowledge, no one has studied how low oil price environments may affect the operator's use of the OSV fleet. Lastly, previous research confirms that AIS data is suitable for a variety of applications and also for identification of OSV activities as performed by Kaiser and Narra (2014). However, where Kaiser and Narra (2014) defined vessel activities solely based on AIS data, it seems like no one have tried the same but by combining AIS data with additional information on offshore infrastructures such as locations, operators, life cycle stages etc.

Thus, by combining AIS data with infrastructure data (most notably locations and status of production platforms and drilling rigs) and build a model able to identify OSV operations this thesis may contribute to valuable information. The model can be used for various purposes such as to compare OSV activity in different oil price environments and compare operators' sailing patterns.

1.3 Objectives

The main objective of this thesis is to investigate whether AIS data coupled with market data from the offshore oil and gas industry can be used to understand offshore support vessel activities in order to gain more insight into the sector from a region, operator and field point of view in different market situations.

To address the main objective a set of research objectives have been defined. The objectives are identified as the necessary steps in order to understand the OSV activities.

- Describe the offshore oil and gas industry and the role of the OSVs.
- Describe the properties of AIS data.
- Develop a methodological framework for identifying OSV activities.
- Conduct a case study to exemplify the model and evaluate the result.
- Discuss and evaluate the case study results and the effect of assumptions and model parameters.

1.4 Scope and Limitations

The scope of this thesis is to develop a methodological framework for investigating the potential that lies within coupling AIS data from OSVs with market data from the offshore oil and gas industry, by translating the vessel movements into general operational statuses. The detail level will be such as *in transit* or *at site* and not a true description of what kind of support the vessels are providing to the installations. The scope is further constricted to focus on offshore activities, meaning that time spent in port is less discussed in this thesis.

The study is limited to only use data from infrastructure located above sealevel, i.e. production platforms, drilling units and supply bases. The study will also be limited to only investigate the general operations of PSVs and AHTS vessels, excluding a part of the OSV fleet. The model will be tested based on the available data sources, meaning that constructing complete data sets with complex gap-filling methods are defined as out of scope for this thesis. Furthermore, no hard data on OSV operations has been available for evaluating the model results. The discussion is thus limited to evaluate the model results based on industry insight obtained in the process of writing this thesis and from public sources such as annual reports and news articles.

1.5 Report Structure

The structure of the remaining of this report is as follows.

Chapter 2 - Background provides necessary background information for further reading. The information is concentrated on the OSV sector and the properties of AIS data.

Chapter 3 - General Approach gives an introduction to the general methodological approach used in the thesis. The chapter also gives an introduction to the case study conducted in Chapter 6.

Chapter 4 - Data Foundation presents all the data sources and explores the AIS data the model will be based upon.

Chapter 5 - Methods presents the methods used to treat the AIS data and a detailed description of the logic building up the model used in the case study.

Chapter 6 - Case Study conducts a case study with the aim to exemplify and evaluate the model.

Chapter 7 - Discussion discuss the work done, the case study results and the choices made building up the model.

Chapter 8 - Conclusion concludes on the work done in this thesis in the light of the objectives. Recommendations for further work is also presented.

Chapter 2

Background

This aim of this chapter is to provide the reader with the necessary background information for further understanding. Some important terms and concepts regarding both the OSV industry and the characteristics of AIS data are presented.

2.1 The Offshore Support Vessel Sector

In order to operate offshore installations regularly support and supply from land is essential. This is provided to the oil companies by helicopters and offshore support vessels (OSVs). Wherever there are offshore oil and gas activities a support industry will evolve and play an important role as a major source of employment along the coasts (Kaiser, 2010). Examples of required support are the transportation of supplies such as food and equipment, construction work such as pipe-laying and decommissioning, and towing and mooring operations. The characteristics, complexity and duration of the needed support will vary from site to site and between seasons. This is mainly due to different types of offshore units requiring different logistical needs Aas et al. (2009), but also field specific factors such as number of persons offshore and the field's life cycle phase. In addition, the weather conditions on the NCS pushes operators to perform most of their OSV dependent work during the calmer summer months, leading to demand variations. The life cycle phases and different installation types are described in Section 2.1.1 and 2.1.3 respectively. In order to satisfy all the installations' needs, the OSV fleet consists of several specialised vessel types that range from simple to highly customised constructions. The most important OSV types are described in 2.1.2.

OSVs are owned by vessel owners and contracted to oil companies to provide services. Either from a specific port to several installations for an extended period of time or to cover a broader set of services, and not tied to a certain route between ports and offshore installations. OSVs can also be working in the spot market where they are chartered by the oil companies on an as-needed basis, usually, to perform a specific task for a shorter period of time, referred to as short-term spot contracts. The oil companies' decision of which vessel to charter and what contract type to be used is a complex issue. The relevant choice is whether to take a tailor-made vessel on a long-term charter, a vessel that better suits the needs or to charter a mainstream vessel that is not as suited, but cheaper (Aas et al., 2009). This decision may vary in different market situations and between operators. On the NCS, where offshore operations are highly dependent on weather conditions, there is a great value in having vessels available for your own operations, instead of depending on the spot market when a weather window is within sight.

When a vessel is on contract (either long term or spot) it is at the disposal of the oil companies round the clock. This means that the vessels are not only working when they are operating offshore, but also during mobilisation and waiting time. The oil companies plan and schedule all vessel activities, and it is common that they pay for fuel, bunker oil and harbour fees. Operation of OSVs makes out one of the largest upstream[1] logistics chain costs for the oil companies (Aas et al., 2009). Annual time charter cost of a single OSV can be 10-15 million USD (Halvorsen-Weare and Fagerholt, 2017). In most cases vessels are chartered and operated by a single operator, however there are also a few supply vessel pools; several oil companies share the use of the same supply vessels. According to Olje- og energidepartementet (2004) a supply pool between Esso and Equinor (former Statoil) in 2003 reduced the supply cost with 10 % and Hydro, at the time, estimated that a similar pool with Equinor would reduce the cost of supply vessels with 10% to 20 %.

When a vessel is not on contract with an operator or working in the spot market the vessel owners will try to minimise the operating costs. This can be done by taking the vessel out of activity for a longer period of time. A vessel taken out of operation is often referred to as *stacked*. A vessel can be warm or cold stacked, where the two differs in how fast the vessel can be reactivated. A warm stacked vessel will be maintained and machinery is kept warm while cold stacked vessels are virtually abandoned (Shinn, 2017). Stacked vessels are often placed in ports or on buoys along the coast, and not in busy supply bases. Karmsund Port is a port with places suited for stacking vessels, as seen in Figure 2.1.

Figure 2.1: Picture of stacked vessels in Karmsund Port. Picture obtained from KarmsundHavn (2016)

[1]The upstream supply chain consist of supplying offshore drilling rigs and production platforms with necessary supplies while the downstream is defined as bringing oil and gas onshore to customers.

Since the offshore installations' need of support cover a wide range of activities and vary during an oil field's lifetime the following sections will elaborate the different stages of oil fields, the different vessel types used and the main offshore installation types.

2.1.1 Oil Field Life Cycles

According to Kaiser (2015) more or less all petroleum projects passes through the same five life cycle stages; exploration, development, production, redevelopment and decommissioning. Both the nature of each stage and the characteristics of the offshore units used causes the need of support to vary greatly.

During the exploration stage oil is searched for through seismic surveys and exploration drilling is performed. Seismic surveys and site clearance are examples of activities that need minimal support (Kaiser, 2010), mainly just helicopters for crew change. Exploration drilling, on the other hand, is highly dependent on support from shore and is performed to prove whether hydrocarbon exists on a potential field or not. With multiple exploration wells being drilled on each site, the overall duration of this stage may last up to several years. The drilling operations are performed by mobile offshore drilling units (MODUs). These units (often) need vessel support to moore and move between well locations as well as a steady stream of supplies including drill pipe, casing and mud.

If the exploration drilling is successful the development stage begins. The aim of this phase is to find a commercial path for producing the discovered resources. The stage varies in time from as little as six months to several years, and consist of engineering, fabrication and installation of the production facility. The installation phase vary from a few weeks to several months depending on complexity. The activities during this phase are mainly transportation of structure modules and installation as well as drilling activities and construction work on the seabed such as pipe-laying. OCVs are commonly used during this stage for installation of platforms, umbilicals, export pipelines, flow-lines and other subsea equipment (Kaiser and Narra, 2014).

The next phase, production and redevelopment, is the longest period of a field's life cycle and where the resources are produced. During this phase manned or unmanned production platforms are located at site over the entire period. These platforms are supported by vessels which transport personnel, supplies, and materials to and from platforms as well as returning waste and chemicals to shore. Redevelopment may find place during the production stage with subsea tiebacks being connected to the facility or new topside modules being installed due to Improved or Enhanced Oil Recovery (IOR/EOR) projects. For large fields with a long production profile, redevelopment is often needed to extend the lifetime of the facilities. The need for support may increase during these projects due to additional employees and drilling units being located at site.

The project enters the decommissioning stage when the production is worth less than the operating and maintenance costs. In this phase, wells are plugged and structures and pipelines are decommissioned. The nature of the decommissioning stage is similar to installation but requires less time. Vessels are needed for activities such as transporting structures to shore and removing anchors. Wells are plugged and abandoned by drilling units and installation removal is often performed by heavy lift vessels. Supporting vessels sets up the anchor for the heavy lift vessels and cargo barges are towed to site to transport the production structure. The decommissioning activities usually range from two to three weeks.

2.1.2 Vessel Types

As mentioned the OSV fleet consists of specialised vessels. Platform Supply Vessels (PSV), Anchor Handling Tug Supply vessels (AHTS) and Offshore Construction Vessels (OCV) are all types of OSVs with different work tasks. According to Vidal et al. (2015) most of the required operations to maintain all proper functions of the offshore industry depends on these three vessel types.

The Platform Supply Vessels (PSV) are referred to as the *trucks of the ocean* as they transport the majority of supplies to all offshore installations. Their main role is to ensure the operation of production platforms and drilling rigs by supplying goods and equipment, such as fresh water, food, oil, tools and cement. Some PSVs may however also be utilised as standby vessels, which are employed by operators for guard duty (Norwegian Maritime Directorate, 1991), and are often located offshore for longer periods. The service time for rig and platform logistics, referring to the time it takes to discharge the supplies to the rig or platform, is dependent on the size and needs of the installation. According to Halvorsen-Weare et al. (2012) the unloading time at offshore installations can vary from 2 - 7 hours. The vessels are also used for returning chemicals and other waste products to shore for recycling or disposal. PSVs are characterised by their dead-weight and deck space (Kaiser, 2015) and their working pattern is usually between onshore supply bases and offshore installations, which either can be permanent installations (platforms) or movable units (rigs).

Anchor Handling Tug Supply vessels (AHTS) carry out operations for towing, positioning and mooring of drilling rigs as well as other marine equipment. They lift, set, recover and relocate anchors and are also used for supply of equipment. The weight of long chains and towing operations require high bollard pull capacity and powerful machinery. These vessels are frequently used during exploration drilling for moving drilling rigs from well to well and between sites and during installation and decommissioning phases. Shyshou et al. (2010) analysed 70 mooring operations from 2002 to 2007 and established a distribution for duration of mooring operations. The mean duration, including waiting time, for the entire mooring operation was found to be right above 202 hours (9 days).

Another important vessel type is the Offshore Construction Vessels (OCV). Some of their main tasks are installation and maintenance of production platforms, drilling rigs as well as subsea equipment such as wellheads, underwater pumping units, pipelines and umbilicals. The vessels also play an important role in the development and construction phase of sites. The vessels are often equipped with remote operated underwater vehicles (ROV) and diving equipment used for subsea operations. Usually, these tasks require larger crane capacities, large bollard pull and a large working deck.

The focus in this thesis will be on PSVs and AHTS vessels as their activities are more directly connected to platforms and rigs than the OCVs, that also do a lot of work on seabed equipment, not necessarily located close to an installation.

2.1.3 Offshore Installations

According to Kaiser (2010) platforms, pipelines and wells make out the primary part of offshore infrastructure. In this thesis, the focus will only be on the infrastructure located above the sea level, which will be referred to as offshore installations. It is common to distinguish between two types of units; those that are mainly producing and those that are mainly drilling (Aas et al., 2009).

Production platforms or ships are units that are mainly producing (but might also be drilling) and stay at the same position for a longer period (Aas et al., 2009). These are designed to be in service for at least one or two decades (Kaiser and Narra, 2014) and are operated by the oil companies. On site there can either be one installation covering all the needs such as production, processing, living quarters and storage, or several platforms connected together by bridges, like Ekofisk in Figure 2.2. Throughout the units' life, they require maintenance and support from service vessels, mostly PSVs. PSVs transport personnel, supplies, and materials to and from platforms. The need of support will depend on installation type, installation size and the crew size. During normal operation for a manned platform support once per week is typical, but very dependent on the platform size. Unmanned platforms are mostly serviced from a manned platform. Typically this is done once to twice a week or on an as-needed basis based on the level of automation and maintenance requirements (Kaiser, 2010).

Figure 2.2: Overview of the installations at the Ekofisk field centre. Picture obtained from Norsk Oljemuseum (2018a)

Wells are mostly drilled from mobile offshore drilling units (MODUs) which can be either drilling rigs or drilling ships. In this thesis rig will be used as a collective term. They are contracted by the field operator and move to different well locations to drill and service wells. Usually it will take up to 4 months to drill and complete one well, and one site will typically have several wells drilled. During the drilling campaign the installation stays offshore and is supported by various types of vessels. The support is dependent on the rig type. Whereas some drilling units can move from site to site on its own machinery (drilling ships) other units depend on AHTS vessels for transportation. Some units require AHTS support for mooring operations while other use dynamic positioning or are resting at the seabed (jack-up). A drilling operation can either take place on an exploration field where there are no production activities, or at fields currently producing. Rigs may then be placed close to or even above already installed installations. While on location the rigs require a steady stream of material from shore due to storage limitation, this is provided either form PSVs or AHTS vessels (Kaiser, 2010). On the NCS these activities are provided almost exclusively from PSVs. A rig will typically only return to shore for maintenance or when not on contract. Rigs, being moving units, shall carry AIS equipment. The equipment is however not required to be on while the units are moored.

2.2 AIS Data

2.2.1 Introdution to AIS Data

AIS, short for **A**utomatic **I**dentification **S**ystem, is a system communicating a vessel's identity and its current position. The system was developed with the aim to decrease the risk of collision by enabling automatic ship-to-ship, and ship-to-shore communication (ITU-R, 2014). With the system, the crew in each vessel can identify all vessels within a certain distance, their positions as well as other technical data such as speeds and headings. Once set up, the system will send all the necessary information automatically. The work of developing the Automatic Identification System was initiated in 1994 as a joint project between, among others, International Maritime Organization (IMO) and the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) (Smestad et al., 2017). Since then, it has become clear that AIS can be used for applications way beyond its original purposes such as monitoring shipping routes, data provision for risk analysis, long term planning and marine accident investigation. In the literature review in Section 1.2, previous papers using AIS for different applications are provided.

Regulatory Requirements

In 2002 IMO adopted a new requirement for ships to carry AIS equipment. In SOLAS chapter V regulation 19 it is stated that all ships of 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages and passenger ships irrespective of size is to be fitted with an automatic identification system (AIS). Warships, naval auxiliaries and ships owned and operated by governments are not required to be fitted with AIS. The AIS should always be in operation when the vessel is sailing or at anchor and at least 15 minutes before unmooring. The AIS can, however, be switched off if the crew believes that the operation of AIS might affect the safety or security of the ship e.g. in pirate operated areas. If this is the case, this should always be reported in the ship's logbook together with the reason for switching the system off. In ports, the AIS operations should be in accordance with the port requirements (IMO, 2002).

In talks with the industry[2] it was confirmed that the practical use of AIS was in coherence with the regulatory requirements. It was also informed that the AIS transponders are not turned off in ports during loading and unloading and that there are no possibilities for the crew forgetting to turn the system on before unmooring.

AIS Data Content

When transmitting AIS signals the vessels' identities and positions, as well as other technical information, is sent. Information sent through AIS signals can be divided into four message subgroups; *static*, *dynamic*, *voyage related* and *safety related* data (Bole et al., 2014). Each of these message groups contains different types of data that will be described in this section. Table 2.1 gives an overview of the information transmitted through the different message groups. For a more detailed description of the data in each message group see Appendix A.

Table 2.1: Data transmitted in each AIS message group (IMO (2002))

Message group	Data transmitted
Dynamic	Position, time stamp (UTC), course, speed, heading, navigational status, rate of turn
Static	MMSI, call sign, name, IMO number, length and beam, ship type, fixed location of antenna
Voyage related	Draught, hazardous cargo type, destination, ETA, route plan
Short safety related	Free format of short text message

A Maritime Mobil Service Identification (MMSI) number is, in addition to what listed in Table 2.1, included in every message. The MMSI number is unique for each vessel and is connecting the sender (vessel) to each message (Bole et al., 2014).

All messages are sent automatically with a predefined frequency. According to the International Telecommunication Union (ITU) static and voyage related messages are reported every 6th minute, when changed or upon request. Safety related messages are reported as needed (manually), while the dynamic message frequency is dependent on the ship's status and speed as seen in table 2.2 (ILAL, 2011). The table shows that a vessel will send a maximum of 1800 signals per hour in addition to the static and voyage related data.

[2]E-mail conversation with a large vessel owner company (22.03.2019)

Table 2.2: Ship status and dynamic message frequency (ILAL (2011))

Vessel Condition	Dynamic reporting interval
Vessel at anchor	3 min
Vessel at 0-14 knots	12 sec
Vessel at 0-14 knots and changing course	4 sec
Vessel at 14-23 knots	6 sec
Vessel at 14-23 knots and changing course	2 sec
Vessel at >23 knots	3 sec
Vessel at >23 and changing course	2 sec

The content of the dynamic and static messages are presented in Table 2.3 and 2.4. As mentioned the messages are connected to its sender by the MMSI number. The MMSI number is supposed to be unique for every vessel, but the number may change whenever a vessel changes owner or flag. The MMSI number may also be reallocated to another ship. In cases such as China, there are reports of vessels sharing MMSI number. This can result in a vessel having two different locations at the same time, known as "spoofing" (MaritimeIntellegence.com). This may pose problems and confusion if not taken into account when working with the data.

Table 2.3: Features in dynamic message types

Information	Description
Unixtime	Number of seconds elapsed since 1 January 1970
Position	Coordinates, longitude and latitude
Speed	Speed over ground (SOG) in knots
Course	Course over ground (COG)
MMSI	Maritime Mobile Service Identity (Vessel ID)
Status	Navigational status

Table 2.4: Features in static and voyage specific message types

Information	Description
Unixtime	Number of seconds elapsed since 1 January 1970
Vessel specifications	Length and beam, in meters
Draught	Current draught in meters
IMO number	International Maritime Organization number
Origin	Origin of current voyage
Destination	Destination of current voyage
ETA	Estimated time of arrival in Unixtime
MMSI	Maritime Mobile Service Identity (Vessel ID)
Ship type	Vessel type category

Another common way to identify vessels is by the use of the IMO number. The IMO

Ship Identification Number Scheme (IMO number) was introduced in 1987 through the resolution A.600(15) with the aim to assign a permanent number to each vessel for identification purposes. Unlike the MMSI number, the IMO number remains unchanged if the vessel changes flag or owner; the number follows the hull of the vessel. The identification number is made out of the three letters "IMO" followed by seven digits. The number is assigned to each vessel when constructed. It is required for all vessels over 100 GT, with some exceptions (e.g. pleasure yachts, vessels solely engaged in fishing etc.) to have an IMO number (IMO, 2014). The IMO number is only included in the static messages and not in the dynamic messages. In order to use the IMO number for vessel identification, the MMSI number needs to be matched with the IMO number corresponding to the same vessel.

As seen in Table 2.4 the static message contains information on ship type. Ideally, this can be very valuable for studies like this where only one ship type is of interest. Ship type is reported as a double digit number between 10 and 99. The first digit indicates the general ship type, see Table 2.5 obtained from MMO (2013), and the second indicates what the vessel may be doing or what cargo the vessel may be carrying (Shelmerdine, 2015). According to MarineTraffic OSV's are mainly categorised as number 5, special craft, but Shelmerdine (2015) states that many offshore related vessels are also observed with ship type 9. Since there is no clear tag for OSVs the ship type data is considered to not be reliable and detailed enough for defining the OSV fleet in this study.

Table 2.5: Corresponding digit and ship type in AIS message

First digit	Ship Type
1	Reserved for further use
2	Wing in Ground (WIG)
3	Other vessels
4	High speed craft (HSC)
5	Special craft
6	Passenger ship
7	Cargo ship
8	Tankers
9	Other types of ship

The navigational status reported in the dynamic message could also be valuable in the process of defining the activity of the vessels. Navigational status shall be changed by the crew manually when necessary. It is changed to a digit corresponding to a certain status as seen in Table 2.6. However, it was confirmed by the industry[3] that a very common mistake is forgetting to change the AIS status of the vessel. This is also confirmed by investigating the data. Næss (2018) found several reports where the navigational status was set to *moored* but the speed was above 5 knots.

[3] E-mail conversation with large vessel owner company (22.03.2019)

Table 2.6: Corresponding digit and navigational status in AIS message

First digit	Navigational Status
0	Underway using engine
1	At anchor
2	Not under command
3	Restricted manoeuvrability
4	Constrained by draught
5	Moored
6	Aground
7	Engaged in fishing
8	Underway sailing
9+	Reserved/Not defined

2.2.2 Collection Method

Automatic Identification System communicates ship movements and technical data through the maritime Very High Frequency (VHF) bands. Communication is performed through several devices, as illustrated in Figure 2.3. AIS equipment installed on vessels is often referred to as transponders. According to Næss (2018) transponders are installed on more or less all merchant vessels (as required by IMO, see Section 2.2.1). These transponders transmit signals to vessels nearby. In addition, signals sent from the vessels are collected by terrestrial receivers (AIS base stations) and/or satellites. Terrestrial-based AIS receivers are only able to detect messages within a range of 40-50 nautical miles (about 75-90 km) (Skauen et al., 2013) due to the earth's curvature and the fact that AIS signals travel in straight line (Ball, 2013). Satellite sensors, on the other hand, can detect signals from 1000 km altitude (Eriksen et al., 2010). AIS data collected by satellites is called S-AIS data. The satellites can operate in two different modes; direct communication to earth (direct downlink) or recording mode. When a designated satellite antenna is located within the view of a satellite the data is sent directly to the ground centre (satellite antenna on Figure 2.3), referred to as direct downlink. For periods where there are no antenna within the satellite's range to receive the AIS data the satellite records the data and communicates it to a ground station whenever an antenna is within sight (Eriksen et al., 2010).

There are several issues regarding collection of AIS data through satellites. Part of this is due to the nature of how the AIS system is set up. As mentioned, the system was meant for ship-to-ship communication and not global coverage of vessel positions. Since the amount of data needed for the system's original purpose was limited, only two dedicated VHF frequencies are assigned to AIS information. With limited frequencies available each transponder is only allowed to transmit information to receivers for a very short and precisely controlled time period, called time slots. Time is divided into frames, corresponding to one minute each. Each minute is then divided into 2250 time slots. This means that in each frequency band there are 2250 time slots every minute. With 2 frequency bands dedicated to AIS there is a total of 4500 time slots for AIS messages every minute per receiver. This system is known as Time Division Multiple Access (TDMA) (Ball, 2013). Figure 2.4

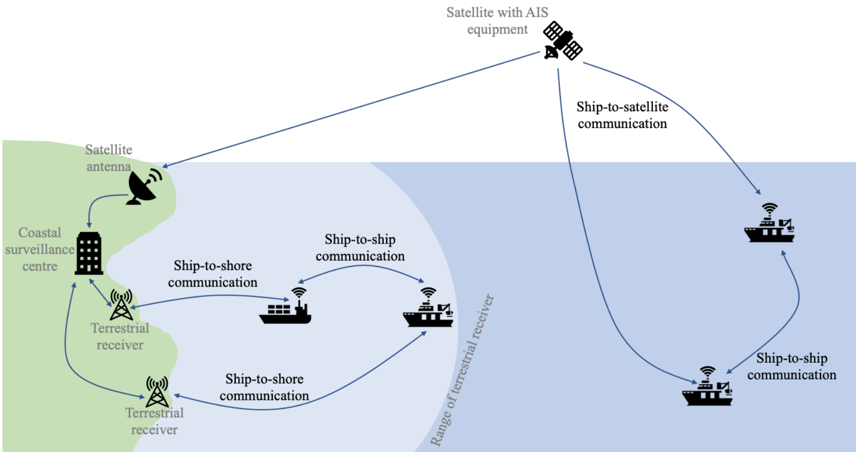


Figure 2.3: Illustration of AIS transmitting and collection system

illustrates how this works.

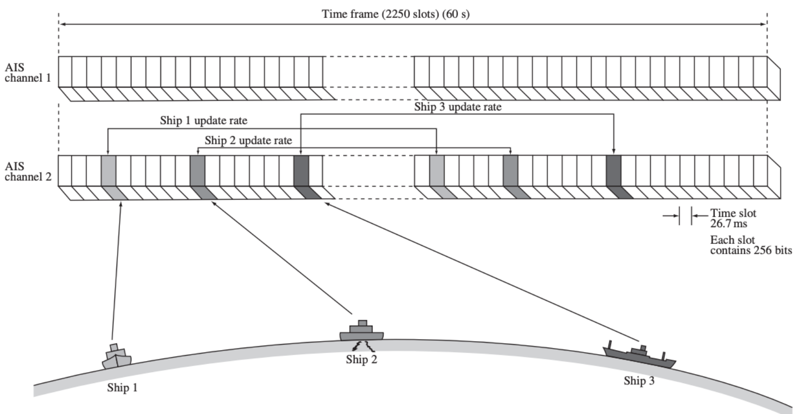
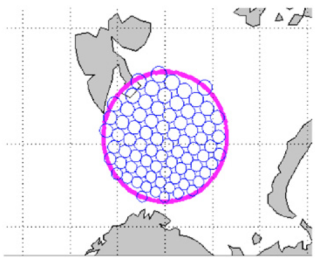


Figure 2.4: Principle of TDMA. Channel 1 and 2 are referring to the two dedicated frequencies for transmitting AIS data. Each vessel are transmitting through its own time slot, with different intervals. Figure obtained from Bole et al. (2014)

From space, a satellite sensor is covering a much larger area than the 40-50 nautical miles a terrestrial receiver is able to detect. According to Høye et al. (2008) AIS satellites located at 1000 km altitude can cover up to 6200 ships at one time. When there are more vessels sending signals within the range of a satellite than there are available time slots, some signals will not be detected. This is called interference and is illustrated in Figure 2.5. The large purple circle in the figure corresponds to the view of one satellite, while the blue circles represent the range the AIS receivers were originally built for. The table to the right shows how many vessels a receiver is able to detect within one blue circle for different reporting intervals. The interference problem may occur if there are many vessels within the field of view of the satellite. Høye et al. (2008) states that a satellite at 1000 km altitude is able to detect up to 900 vessels within its view with a probability of 99%, only 15% of the 6200 ships the satellite may have in its range. High vessel density is often observed close to large ports, and in these areas, there will be terrestrial receivers as well as satellite receivers. In an early study on S-AIS it was concluded that remote ocean areas, where there are few vessels, was the optimal use of satellites carrying AIS antenna (Wahl et al., 2005). A complete data set should therefor consist of both terrestrial and satellite data.



Ship reporting interval	Max number of ships
2 s	150
6 s	450
10 s	750

Figure 2.5: The purple line in the left figure shows an elevated AIS sensor's field of view including several blue circles called "organised areas". The table to the right shows how many vessels the AIS system can handle at once in *one* organised area (blue circle) for different reporting intervals. Figure obtained from Høye et al. (2008)

Another issue regarding satellites is that the AIS signals received are weaker than on the surface of the Earth due to the increased path length. This challenge applies to detection of ships in all waters the satellite covers, whereas the interference issue only applies in areas with high vessel density. To overcome the issue of weak signals more sensitive receivers are used in space than in the shipborne or terrestrial equipment (Eriksen et al., 2010).

The satellite's path and the number of satellites may also impact the quality of the S-AIS data collected. Multiple satellites passing the same area at the same time increases the vessel detection probability since the satellite AIS system seldom is capable of detecting AIS messages from all transponders within its range (Skauen et al., 2013). Figure 2.6 shows how a satellite with a certain orbit will cover some part of the world more frequently than others, leading to some parts of the globe having less coverage than others, which should not be interpreted as less activity.

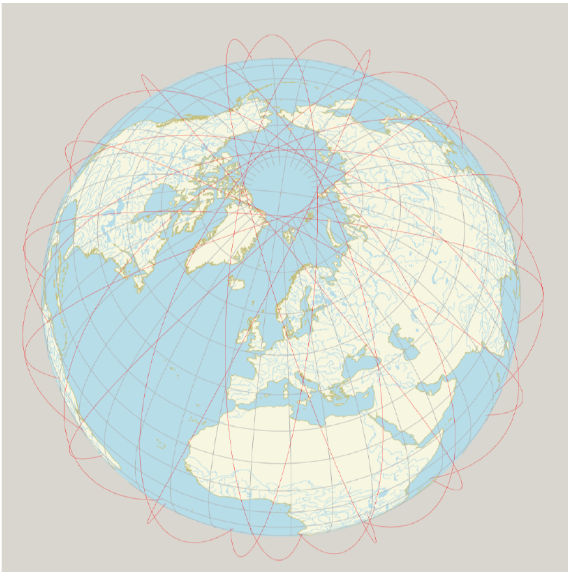


Figure 2.6: Red lines indicates the path for one satellite during a 24 hour period. Figure produced by Ørnulf Jan Rødseth

Chapter 3

General Approach

In this chapter, we will start to present the general approach of the methodology used in this thesis, while a more detailed version is presented in Chapter 5. Usually, a methodological framework is developed and the necessary data sources and their structures are identified based on that. In this study, however, some parts of the methodology are dependent on the type and structure of the data sources at hand, while other parts of the method set the requirements for the data. This makes the process of developing the model and identify the needed data to an iterative process. To convey this process to the reader in a straightforwardly and understandable manner the general methodology will be presented in this chapter, the data sources in Chapter 4 and the detailed description of the methodology in Chapter 5. In addition, the final part of this chapter will present the case study conducted in Chapter 6.

3.1 Methodology Approach

Converting AIS data into OSV activity includes several complex steps and can be approached from many angles. In this thesis, a method is developed and the key steps will be presented in this section. Figure 3.1 illustrates the model flow together with all data sources that are used and in which chapter to find further information.

First of in the process is to access the AIS data. AIS data can be obtained from several sources with different pre-processing needs. The data in this project is acquired from PortVision and stored in a Rystad Energy database. The data is already decoded which simplifies the data handling process a lot. In order to extract the data, one has to select the fleet, in terms of IMO numbers, the frequency of the AIS messages and the time span one would like the data to cover. The fleet selection process and vessel data source are presented in 4.1. Before the AIS data is structured into database tables, additional information provided form Rystad Energy is added. The additional information consists of GIS shapefiles outlining the international maritime boundaries and vessel specific information such as vessel name, owner and type. The boundary information is used to calculate each positions' distance to shore and the country the AIS messages are sent from. Adding this

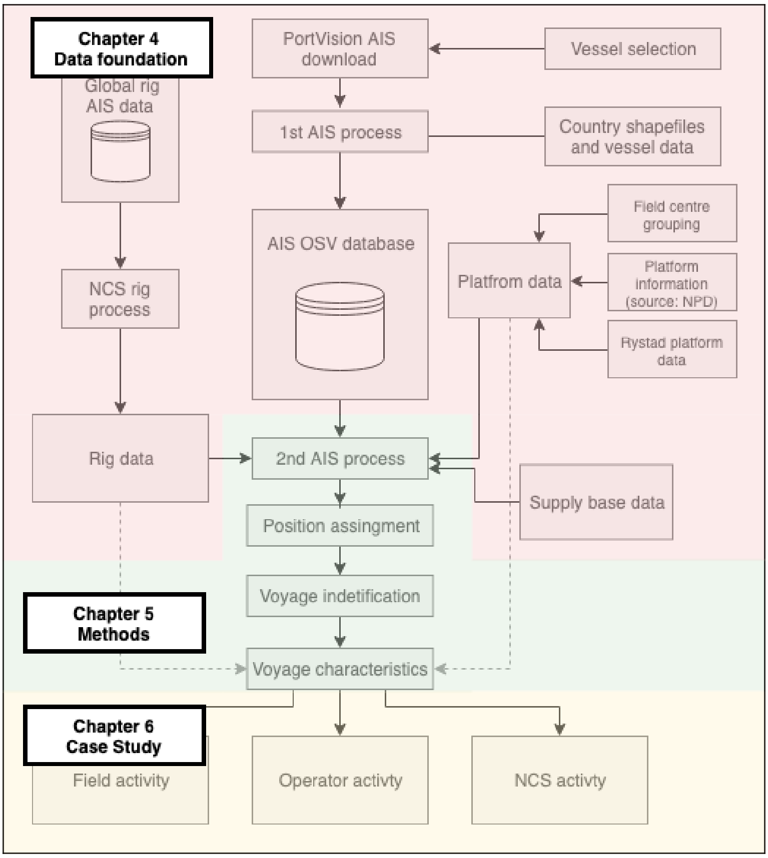


Figure 3.1: Flowchart with the main steps used in this thesis for converting AIS data to OSV activity and the structure of the report

information is referred to as the *1st AIS process* in Figure 3.1.

Once the data is structured into a database table the characteristics and qualities of the AIS data are evaluated. This is done in Chapter 4. The aim of this process is to identify the actions necessary to apply to the AIS data in the *2nd AIS process* in order to obtain the wanted structure and completeness. The calculation methods used in this thesis rely on a data structure with hourly information on each vessel. Where it is identified that this is not met, methods are developed for adding and filling the missing data points. These are presented in Chapter 5. The *2nd AIS process* also consists of merging the AIS data together with additional data sources. The method mainly relies on three data sets; platform, rig and supply base data. Obtaining and structuring these data sets is a process on its own and is further explained in Section 4.2. By adding these data sets to the AIS data each position's distance to shore and the nearest platform, rig and supply base is known. Based on these distances and speed information obtained from the AIS messages all positions are assigned to groups indicating if the vessel is close to shore, in transit or at an offshore installation (called *On site*). This is referred to as *Position assignment* in Figure 3.1. Each vessel's event history is reconstructed by chronologically order all data points. The position assignments are then used to divide each voyage from each other, by the use of *voyage ids*. This process is described in detail in Chapter 5 and is referred to as *Voyage identification* in Figure 3.1. The nature of each voyage is then categorised based the sailing route mainly identifying if the voyages are coastal or non-coastal voyages and whether the voyages are headed to one of the infrastructures in the data sets. Furthermore, details about the voyages' destinations, the voyage operator and the sailing pattern are identified for each voyage. This is referred to as *Voyage characteristics* in Figure 3.1.

Based on the characteristics of the voyages the OSV activity is studied in Chapter 6. The model can be used to study several topics where those listed in Figure 3.1 only are some of them. The content of the case study in Chapter 6 will be presented in the last part of this chapter.

To build the model and perform the analysis the Python programming environment, SQL database language and excel tools are utilised. PowerPoint is used for illustration of the results. Several scripts have been created to carry through the complex calculations. The contents of these scripts are provided in Table 3.1. All scripts are also included in Appendix E.

3.2 Case Study Definition

To investigate whether the proposed approach is applicable for understanding OSV activity levels, a case study has been carried through. The aim of the study was in line with the thesis objective; to investigate whether AIS data coupled with market data from the offshore oil and gas industry can be used to understand offshore support vessel activities.

The case study will focus on OSV activities on the NCS during the period mid-2013 to

Table 3.1: List with description of Python scripts created for this study

File name	Description
process.py	All codes applying the logic in the model are found as functions in this scrips. Includes all steps from data processing to voyage characterisation.
run_process.py	Run the processing and apply logic on the AIS data. Construct the final data set that is further used for analysis.
run_analysis.py	Codes used to analyse the data through the case study
plot_codes.py	Codes used to plot the spatial distribution of messages and other map related features

end-2018. OSV activities are analysed in terms of the number of voyages and time spent on these voyages. The case study consists of two main studies. In the first part, referred to as the *micro study*, the model will be applied to the Ekofisk field. This is an important field on the NCS and a field with known OSV activities during the period. Through this field study, the properties of the model are exemplified and the model's capability to recognise field specific events are tested. In the second part, referred to as the *macro study*, the aim is to use the model to gain general insight into the NCS OSV activities. This is done by studying the vessel days and number of voyages servicing the shelf during the period, divided by PSV and AHTS vessels. In the remaining parts of the macro study, the fleet, operators and installations on the NCS are analysed with the goal to both verify known truth and to discover new findings.

Activity in the case study is only based on the number of voyages going offshore and the time spent on these voyages. The focus is on activities related to production and drilling units located above the sea-level and not subsea infrastructure. Activity in port is neither a part of this study. The data used are AIS messages from a predefined set of vessel assumed to be all PSVs and AHTS vessels working on the NCS. However, global positions from these vessels are extracted. The infrastructure data only include infrastructure located on the NCS.

Chapter 4

Data Foundation

This chapter will present the data foundation used in this thesis. The sections that will be covered are the highlighted part of the method flow chart in Figure 4.1. Common for all sections in this chapter is that they cover the part of the overall methodology that consists of structuring and eventually merging the multiple data sources together. The combination of the data sources presented in this chapter will be used to apply logic to the model as described in Chapter 5.

The first part of this chapter will present each data source type, how they are obtained and if relevant, how they have been processed. The final part will explore the outcome of the *1st AIS process* (see Figure 4.1) and identify model requirements, limitations and further processing that need to be included in the *2nd AIS process*.

4.1 Fleet Data

In several transportation research cases, it is vital to identify ship types and groups on a more detailed and accurate level than what is provided in the AIS messages. This is also the case for this study, were only OSVs working on the NSC is of interest and is not accessible through the AIS ship type tag as seen in Section 2.2.1. Smestad et al. (2017) studied the possibility of developing heuristics for identification of specific ship types by the use of information retrieved from AIS data alone. The motivation was to avoid the additional cost of acquiring commercial ship data. As OSVs were not a part of their study, and Rystad Energy already has access to a database containing information on a large part of the global OSV fleet, heuristics for ship identification will not be necessary in this study.

The Rystad Energy vessel database contains information such as IMO number, vessel owner and manager, vessel type, vessel age and vessel size (length, breadth etc.) The information is gathered by mining through the different vessel owners' ship specification sheets. The data is stored in multiple database tables connected to each other by keys[1].

[1] Database keys are used to generate relationship among different database tables

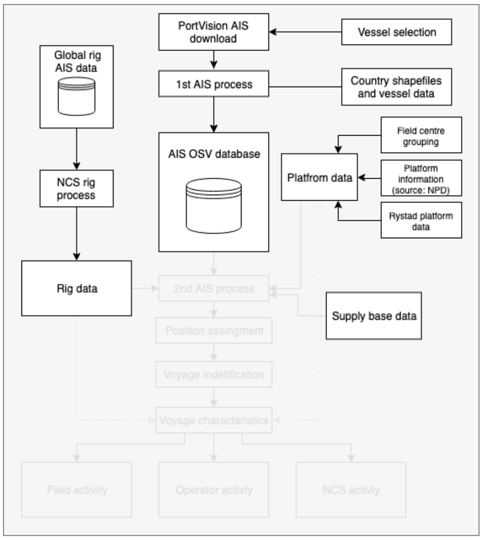


Figure 4.1: Sub-flowchart of thesis flow in *Data Foundation*. Flow of all data sources and the connections between them

These tables will be used to identify and obtain the IMO number for the vessels relevant for this study.

The relevant fleet is defined as the PSVs and AHTS vessel Rystad Energy know have been working on the NSC during the past 10 years and all PSVs and AHTS vessels in the Maersk fleet. The list consists of 443 vessels and can be found in Appendix B.

4.2 Infrastructure Data

With the model being based on the vessels' distance to offshore installations for identification of offshore activity, coordinates of every installation are needed. The data is divided into three different data sets; the platform, rig and supply base data.

4.2.1 Platform Data

The platform data was obtained from the Norwegian petroleum directorate (NPD) fact pages[2]. The NPD data were filtered to only include offshore installations in service or under installation located above sea level. Further were all installation marked as *loading systems* excluded and the longitude and latitude coordinates were converted from degrees North and East to decimal values by the use of Equation 4.1.

[2]The "installation" file from: https://www.npd.no/fakta/faktasider-og-faktasider/geografiske-datasett/ (15.03.2019)

$$\text{Decimal degree} = Degree + \frac{Minute}{60} + \frac{Second}{3600} \tag{4.1}$$

Only the installation name, type, location, current operator and water depth were kept from the NPD fact page. In the cases where the operator data were missing it was scouted and added to the table. Based on the installation name the number of beds on each platform were added from a Rystad Energy platform database. Lastly, the NPD's fact maps were used to group platforms located at the same field centre together. This was done by evaluation of whether the platforms could be connected together by bridges or not. As seen in Section 2.1 platforms may be located close. The movement between such platform clusters could be used to analyse the fleet's sailing pattern. The name chosen for the field centre is not the actual field centre name, but rather a name indicating where it is placed compared to other installations on the same field. The final platform information is included in Appendix C.

4.2.2 Rig Data

The rig locations are identified by the rigs' AIS signals. Daily AIS signals from 609 distinct drilling rigs were collected for the entire period. By merging rig AIS data with data from Rystad Energy RigCube the positions, rig name, and rig owner is given for each AIS message. Rystad Energy also poses information on rig contracts indicating when each rig has been on contract and whom it was contracted by. This information is also added to the rig AIS data. Since rigs are not required to have their AIS transmitter on while moored the data set is observed to be incomplete, with several days for each of the rigs missing reports while they seem to be active (i.e. not stacked). To overcome this issue the rig days with missing observations are filled by using the forward fill method (described in Section 5.1). This means that when a rig turns off its AIS sender the model will assume that the rig is located at the same spot until another signal is observed. There was a concern that the rigs would have time to change their position and turn off the AIS sender within one day so that the updated position would not be registered. However, it was observed that the rigs often kept their sender on at shore (see red stars along the coast on Figure 6.6) and that they usually waited some days before turning it off once located offshore. Based on this it was assumed that the forward fill method was applicable for the rig AIS data. The completion of the rig AIS data is crucial for the model as OSV-rig activity would only have been recorded for some parts of the total time a rig was located offshore if no processing had been done. Lastly, only positions sent from the NCS are extracted and stored in its own DataFrame[3]. The process of forward filling, adding operator information and extracting NCS positions is done in the *rig_process* function found in the *process.py* script.

The operator information for both platforms and rigs can be quite complex and changes a lot over time with merges and acquisitions. The operator data used in this study is static. This means that a platform is defined to be operated by the current operator for the entire period (2013-2018) even if the operator has changed during those years. For the rigs,

[3] A 2-dimensional labelled data structure with columns of potentially different types used for data storing in Python

the operator is somewhat more dynamic. During each contract period, the operator of the contract is defined as the rigs' operator, meaning that it changes over time. However, if there have been company mergers it is the latest company name that is used for all years. Furthermore, it should also be mentioned that the *field centre* information is only added to the platform data and not to the rig data.

4.2.3 Supply Base Data

Rystad Energy has provided information on the supply bases along the Norwegian coast. A list containing all the supply bases and their locations can be found in Appendix D.

4.3 Geographical Data

The longitude and latitude vessel positions are compared to a GIS shapefile that outlines the international maritime boundaries and the coastlines. This file is used to locate the country of each AIS message and calculate its distance from shore. If a vessel is located within international waters, this is set as the country. The shapefile is provided by Rystad Energy.

4.4 PortVision AIS Data Provider

There are several ways of accessing AIS data, but most applications are built on data bought from commercial providers. Rystad Energy subscribes to AIS data from Oceaneering's AIS solution *PortVision 360 Entreprise*. The establishment of the solution started in 2006 when four refineries in the Sabein-Neches waterway took the initiative to use AIS signals to monitor vessel traffic in their terminals. Today PortVision is a web-based service with a visual display of real-time activities world-wide, where costumers can track vessels, set alerts on various activities and filter out unnecessary data (Oceaneering). The data is collected from several PortVision owned terrestrial receivers as well as commercial Satellite-AIS data providers. In addition to the web-based solution, it is possible to extract historical data from 2013 and towards today with a given time frequency for a desired part of the global fleet. The main way to query the vessels' positions is through their IMO number. PortVision mainly provides the dynamic message type and not the static and voyage specific messages as presented in Section 2.2.1. Table 4.1 lists the information provided in each AIS message by PortVision. These were some of the data types that Shelmerdine (2015) found to be the most reliable (less prone to human errors) and essential when using AIS signals to estimate vessel activity.

As seen in Table 4.1 the IMO number is connected to the dynamic messages. Recall from 2.2.1 that all dynamic information, such as position data and speed, is connected to the vessels by the MMSI number and not IMO number. This means that the translation of MMSI number into IMO number is done by PortVision as a part of their service. The

Table 4.1: Data provided by PortVision

Data Types
IMO number
Vessel Name
Latitude position
Longitude position
Time-stamp
Speed
Heading
Course
Call sign

work of decoding the raw AIS data and translate it into logic information is also done by PortVision. An arbitrary AIS message, obtained from Næss (2018), is visualised in Table 4.2 and shows the need for a decoding process.

Table 4.2: Structure of raw AIS message

Arbitrary message
/s:ASM//Port=669//MMSI=,c:1439078400*7D/!BSVDM,1,1,,A,1:UF6@001OMO>0au3G5mbDT2081<,0*5E

4.5 OSV AIS Database

Given that vessels send dynamic AIS messages up to 1800 times per hour (see Section 2.2.1) the data size can be large and challenging to work with even for a small part of the fleet. In order to minimise running time, only the necessary data should be extracted. The reporting interval for the ship to ship safety cases (original use case of AIS data) is much higher than what is needed for this study. OSVs are large vessels with operations that, in most cases, lasts more than one hour, as seen in Section 2.1. Hourly reporting intervals are thus considered to be sufficient to identify vessel activities.

Hourly global positions from 2013 and to end of January 2019 for a large part of the OSV fleet is extracted from the PortVision service and stored in a Rystad Energy internal database. In this database, each recorded AIS messages is also connected to a country and the location's distance to shore (see Chapter 5). From this database table, a new table that only contains messages sent from the relevant part of the fleet is extracted. In addition, owner and vessel type information is included in the new table by using the IMO number as key for connection between the AIS data and vessel tables mentioned in Section 4.1. The SQL code doing this is shown in Figure 4.2. The process described above (extracting, processing and merging AIS data) is referred to as the *1st AIS process* in Figure 4.1.

```sql
select * from tblnCSMvessel

SELECT DISTINCT Vessel.imo,
                                Vessel.name as name,
                                vesselOwner.name as owner_name,
                                vesseltype.vessel_group as vessel_group,
                                vesseltype.vessel_category as vessel_category,
                                vesseltype.vessel_detail as vessel_detail,
                                vesselposition.timestamp as timestamp,
                                vesselposition.lat as lat,
                                vesselposition.lon as lon,
                                vesselposition.speed as speed,
                                vesselposition.location as location,
                                vesselposition.heading as heading,
                                vesselposition.course as course,
                                vesselposition.on_offshore as on_offshore,
                                vesselposition.distance_to_shore as distance_to_shore,
                                vesselposition.country as country
INTO tblNCSMaerskPosition_
FROM   vessel
       INNER JOIN vesseltype
               ON vessel.vessel_type_id = vesseltype.id
       INNER JOIN tblNCSMvessel
               ON vessel.imo = tblNCSMvessel.imo
       INNER JOIN vesselposition
               ON vessel.id = vesselposition.vessel_id
       INNER JOIN vesselOwner
            ON vessel.vessel_owner_id = vesselowner.id
```

Figure 4.2: Script creating the OSV AIS database table in SQL database language

The new table will from now be referred to as the *OSV AIS database*. The table has 7,126,780 rows that each represent one position report from one vessel. A row will be referred to as *a message* or *a data point*. The table has the 16 columns listed in Table 4.3.

In the two following subsections, the data in the OSV AIS database will be explored and the quality will be evaluated. The aim of doing this is firstly to get an understanding of what is included in the data and how it can be used and secondly, to identify the further processing needs in order to have a data set suited for understanding the OSV activities.

4.5.1 Data Exploration

Out of the 443 vessels that were defined as the relevant fleet in Section 4.1 (Appendix B), 367 vessel have been identified by their AIS signals in the PortVision data. Out of the 367 identified vessels, 141 are AHTS and the remaining 226 are PSVs. This is shown in Figure 4.3.

Smestad (2015) pointed out that there can be variations in the AIS data from different time periods due to enhanced technology leading to increased coverage both globally and locally. Næss (2018) point however out that this issue applies mostly to data sets including pre-2013 AIS messages. To study if this can affect our research the count of messages per month for each year is shown in Figure 4.4. January to March 2013 and January 2019 clearly has fewer messages than what is observed in the other months. No data is found from April 2013, but the number of messages in each month during 2013 increases after this drop. To avoid technical issues to affect our study only messages sent between May 2013 and end-December 2018 will be included in the analysis.

Table 4.3: Columns included in the AIS OSV Database

Data Types
imo
name
owner_name
vessel_group
vessel_category
vessel_detail
timestamp
lat
lon
speed
location
heading
course
on_offshore
distance_to_shore
country

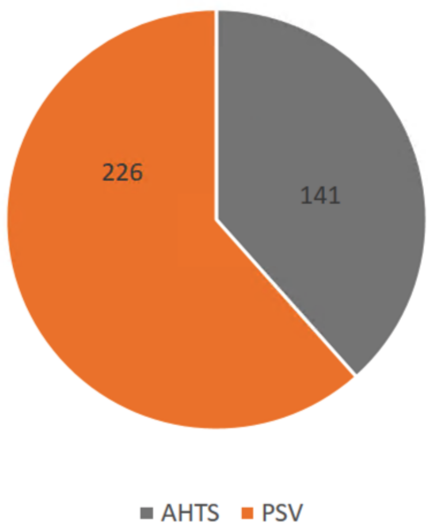


Figure 4.3: The distribution between PSV and AHTS vessels included in the OSV AIS Database

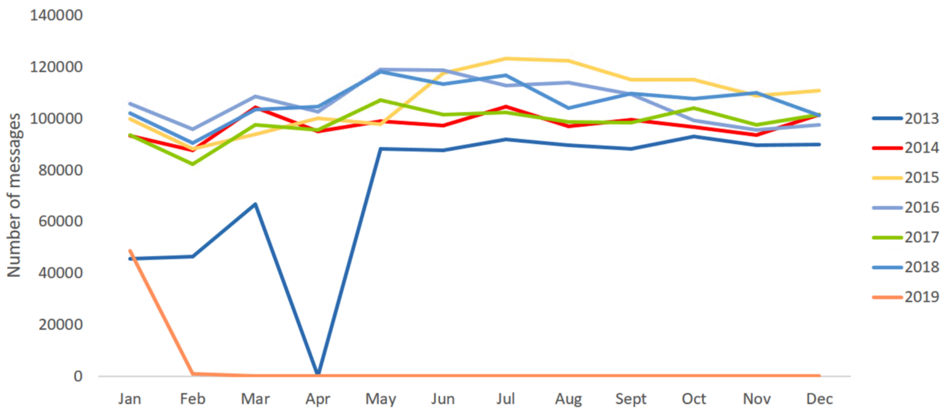


Figure 4.4: Monthly count of data points for each year

The yearly geographical distribution of the data is shown in Figure 4.5 where the total number of messages each year is referred to as 100%. Between 40% to 50% of the messages are sent from Norway each year and another 20% from the United Kingdom. Positions outside of the NCS is found due to the dynamic movements of the fleet. A vessel working in Norway one year may work in Brazil the next year. Also, the Maersk fleet, included in the vessel list, is global.

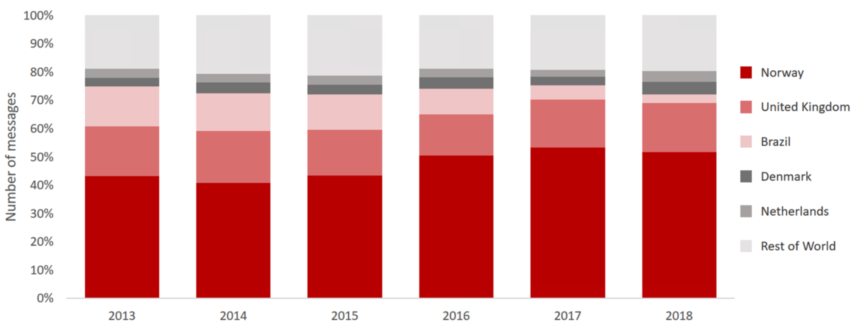


Figure 4.5: Geographical distribution of data points

4.5.2 Data Quality

There are several issues regarding the quality of AIS data. In this section, some of the most important issues, in addition to those outlined in Section 2.2 (interference), will be discussed. This has also been covered by Næss (2018), Smestad et al. (2017) and Leonhardsen (2017).

As seen in 2.2 static (e.g. ship identity and dimensions) and voyage related data (e.g. navigational status) are entered manually during equipment installation or before each sailing. Several previous works have observed these (static and voyage related) data types to be more prone to errors. Næss (2018) found several data points with the combination of navigational status equal to *moored* or *at anchor* and higher speed than 5 knots, which is an impossible combination and are likely due to crew forgetting to change the navigational status. Smestad et al. (2017) found more than 40 vessels in their data set with a length above 460 m, which is more than the length of the world's longest ship, SeaWise Giant. The vessel length is entered manually when the AIS equipment is installed on the vessel.

Technical errors occurring during the installation of the AIS equipment can also lead to erroneous reporting of dynamic data e.g. erroneous positions or vessel speeds. Since the PortVision data set only contains dynamic information these are the errors it would be likely to observe in the OSV AIS Database, in addition to interference and coverage issues. Erroneous coordinates can be identified by searching for coordinates outside the valid range of $\pm$ 90 (latitude) and $\pm$ 180 (longitude).

The following query was executed:

```
SELECT *
FROM tblNCSMaerskPosition
WHERE
lat < -90 OR lat > 90 OR
lon < -180 OR lon > 180
```

Only four data points were found with this query. Two of the data points had latitude positions close to $\pm$ 90 while the third and fourth data point had latitude position equal to -109 and -196 respectively. Compared to the size of the data set, this is considered negligible.

According to Aas et al. (2009) the maximum speed of modern offshore vessels is around 17-18 knots. Figure 4.6 shows the speed for each data point distributed over the years from 2013 to 2019. The vast majority of the speed observations lies between 0 and 20 knots, as expected. However, there are some observations where the speed values greater than 20 knots, even all the way to 100 knots. The following query counts the number of data points with speed above 20 knots:

```
SELECT count(*)
FROM tblNCSMaerskPosition
WHERE speed > 20
```

The query returns 534 data points from 98 different IMO numbers. Comparing to the number of messages in the table and the fact that speed is not a very important parameter for this model, no effort is put into removing these from the data set.

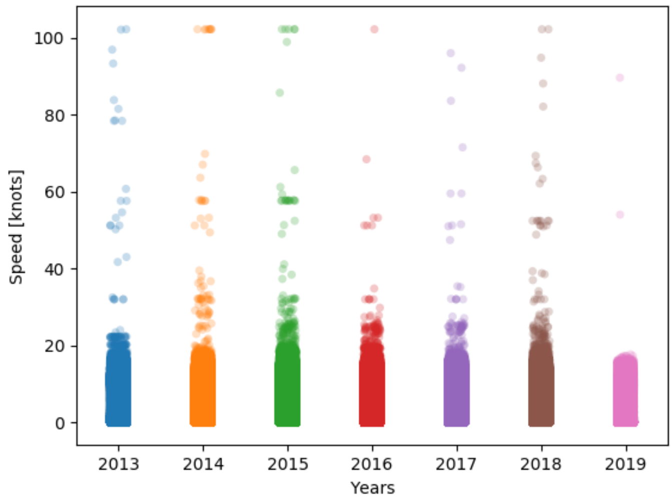


Figure 4.6: Yearly distribution of speed for all data points

In Table 4.4 the number of vessels observed in the AIS OSV database each year is listed together with the maximum and the actual number of data points from each year. The maximum number of messages is found by taking the number of vessels in each year (imo count) and multiply it with the total number of hours in each year/period. The last column, deviation, is the difference between the maximum observable and the count of registered AIS messages. Each year, less than 50% of the possible messages are reported. Indicating that a large part of the fleet has had its sender turned off during the period (e.g. if stacked) or that there are some coverage issues in the data set.

Table 4.4: Unique vessels observed each year together with the actual and maximum number of AIS messages

Period	IMO count	Maximum count	Actual count	Deviation
May-Dec 2013	267	2338920	876131	-63%
Full year 2014	293	2566680	1168679	-54%
Full year 2015	313	2741880	1292534	-53%
Full year 2016	313	2749392	1278725	-53%
Full year 2017	309	2706840	1179106	-56%
Full year 2018	311	2724369	1281972	-53%
January 2019	178	132432	49633	-63%

Figure 4.7 shows the distribution of the duration of these data gaps. We see that the duration's of the gap varies between 1 to 25000 hours, where the latter represent gaps lasting for almost three years. From the zoom-in, it is verified that the wide part of the gaps only

lasts for 1-5 hours.

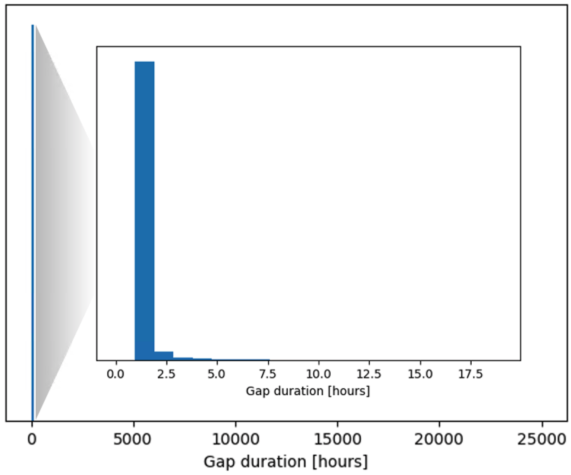


Figure 4.7: Histogram showing the distribution of the duration of the data gaps

Chapter 5

Methods

In this chapter, the methodological framework used to convert AIS messages into OSV activities will be elaborated in detail. The calculation methods and the final processing of the OSV AIS database, referred to as the *2nd AIS process* in Figure 5.1, will also be described.

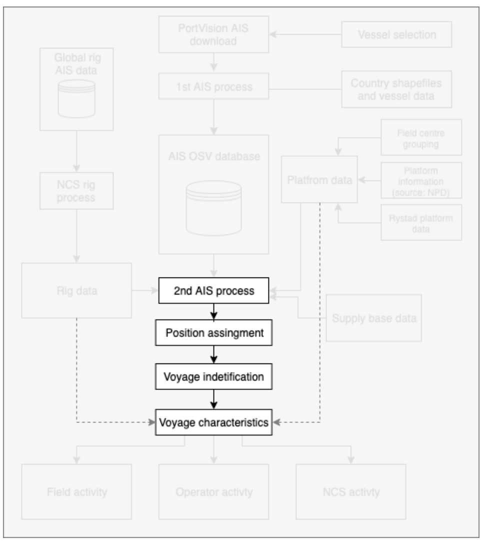


Figure 5.1: Sub-flowchart of thesis flow in *Methods*. General sequence for applying logic to the AIS data used to build the model

5.1 Processing and Calculation Methods

5.1.1 Missing AIS Data

For calculation purposes, it was desirable to have one row in the table representing every hour for each vessel, as if there had been hourly records over the entire period for all vessels. Chapter 4.5.1 showed that this was not the case. In order to obtain the desired structure, the table was re-indexed, so that each hour with missing data points were added to the table. This is done in the *adding_missing_datapoints* function in the *process.py* script (see Appendix E). A column, named *reporting_group*, is added to provide information to each row on whether the datapoint is a recorded AIS message or not.

The hours with missing AIS messages need to be filled. There exist several approaches for treating the missing AIS data points. According to Goldsworthy (2017) a simple shortest path or straight line interpolation can in most cases be used to fill shorter time gaps. Where these methods do not give acceptable results they present a more advanced method for steering paths around land. Goldsworthy and Goldsworthy (2015) provide an extrapolation method to fill gaps with longer duration. The first and last reported course and speed are used to extrapolate both forward and backward in the gap. In addition length and time restrictions were used to ensure proper gap-filling. In this master thesis, there has not been put much effort in developing or implementing a sophisticated method for estimating the vessels' non-reported positions. As seen, doing so may be very complex and even construct more erroneous data, such as creation of voyages that crosses land. In addition, there is an expectation that there exist more complete data sources, and if not, that the quality will increase in short time. Thus, in this model, all non-reported positions are assumed to have the same properties as the last reported AIS message (same method as for the rig positions, as described in Section 4.2). Meaning that a vessel is assumed to be located at a certain position until another position is reported. This is done with a forward fill method. Forward fill is used over backwards fill so that vessels are not given positions before the first time the vessels are observed in the AIS data. This is to avoid assigning positions for vessels not yet in service. This method will inevitably in many cases assigning erroneous hourly positions, the impact of this will be discussed in Chapter 7.

The process of filling missing data points is illustrated in Figure 5.2. The data gap filling process is done in the function *filling_missing_datapoints* in the *process.py* script (Appendix E).

5.1.2 Calculation of Distances

In order to identify the nearest platform, rig and supply base a nearest neighbour algorithm were used. This was done by defining a neighbour data set, which in our case was the installation data. Then, for each unique combination of longitude and latitude positions in the OSV AIS database the nearest neighbour for the three installation types were found. This was done by the functions *nearest_port*, *nearest_rig_append*, *nearest_infra*

imo	timestamp	....	reporting_group	position_group
9254381	2013-05-01 00:00		Missing	NaN
	2013-05-01 01:00 : 2013-05-07 04:00		Missing : Missing	NaN : NaN
	2013-05-07 05:00		Reported	At shore (other)
	:		:	:
	2018-06-08 21:00		Reported	At shore (other)
	2018-06-08 22:00		Missing	At shore (other)
	2018-06-08 23:00		Missing	At shore (other)
	2018-06-09 00:00		Missing	At shore (other)
	2018-06-09 01:00		Missing	At shore (other)
	2018-06-09 02:00		Reported	In transit

Figure 5.2: Illustration of the gap filling method (forward fill method)

and *nearest_neighbour* which can be found in the *process.py* script in Appendix E.

There exist several algorithms for such applications. The most simple one is to calculate the distance to every installation for each of the OSV AIS positions, called the *Brute-force* method (Rohin, 2018). This is time consuming and not applicable for large data sets. Instead a tree construction method called *BallTree* method were used. This method is well described in a lecture from the computer science program at Cornell Univeristy[1]. The most essential steps of the method are to construct a tree by space partitioning coordinates into sub-circles and then use the sub circles to efficiently calculate the nearest neighbour of any given position. The tree construction method is illustrated in Figure 5.3 obtained from Rohin (2018). In our case, each of the blue positions in the figure will represent either the platform, rig or supply base data.

The second step of the algorithm consists of finding the nearest neighbour for positions in an additional data set, which means the nearest platform, rig and supply base to all positions in the OSV AIS database. This is, simply explained, done by identifying the sub-circle closest to the current position (OSV AIS position) and then calculating the distance to all data points within the sub circle. Some additional steps for reassuring that the nearest position actually is found is also a part of the algorithm and is well explained in the Cornell University lecture.

The geographical positions of vessels and offshore installations are given in longitude and latitude coordinates. Since the earth's surface is curved, proper means must be implemented to calculate the distance between coordinates. In this thesis the Haversine formula is used, a formula well-known for calculation of distances between to coordinates on a sphere, ignoring the earth's ellipsoidal form. Mahmoud and Akkari (2016) compared different calculation methods and concluded that the Haversine method was not the most accurate, but fast to solve and well suited for shorter distances. In this thesis, the distance

[1]https://www.youtube.com/watch?v=E1_WCdUAtyE&t=5s, (19.05.2019)

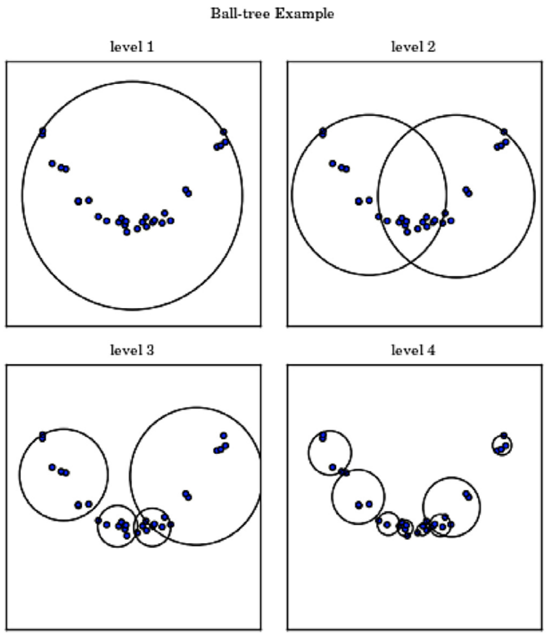


Figure 5.3: BallTree creation for a 2D sample distribution at different levels of the tree construction process. Figure obtained from Rohin (2018)

accuracy is only necessary for short distances, e.g. if a vessel is very close to an installation or not. The general Haversine equation is defined by Equation 5.1.

$$Haversine(\theta) = sin^2\frac{\theta}{2} \tag{5.1}$$

Using Equation 5.1 the distances between two coordinates $[\theta, \lambda]$, with θ and λ representing the latitude and longitude position respectively can be calculated from Equation 5.2.

$$d = 2 \cdot R \cdot arcsin\sqrt{sin^2(\frac{\theta_1 - \theta_2}{2}) + cos(\theta_1) \cdot cos(\theta_2) \cdot sin^2(\frac{\lambda_1 - \lambda_2}{2})} \tag{5.2}$$

Where R is the radius of the chosen sphere, in our case the earth, and d is the distance measured in km between the coordinates $[\theta_1, \lambda_1]$ and $[\theta_2, \lambda_2]$.

In python, there is a built in function through the scikit-learn package that will construct the BallTree and find the nearest neighbours between two data sets based on the Haversine formula.

The distance calculation method is used to find the distance to shore. The distance to shore is calculated as its nearest shore, meaning that the distance to shore may be to the UK coastline even if the vessel is located on NCS waters.

5.1.3 2nd AIS Process

The process of adding and filling the data gaps as described in these sections is the first part of what is referred to as the 2nd AIS process in Figure 5.1. The last part consists of assigning the nearest platform, rig and supply base to every AIS message and calculate the distances between them. This is further used for the position assignment, as will be described in the next sections.

5.2 Description of Model

In order to study OSV activity, the model classifies each AIS position into different position groups, construct voyages, identify voyage legs and assigns different characteristics to each voyage. All of these elements will be used to study the OSV activity. In the following sections, the logic applied to the data will be described in detail and the reasoning for all choices and model parameters used will be presented. A more general description of the model is presented in Section 3.1.

5.2.1 Offshore and At Shore Definition

Several of the model characteristics are defined as either being Offshore or At shore. According to LovData (2009)'s law regarding regulations on trading areas, there are two definitions on what is considered as at shore/inshore; 5 and 25 nautical miles ($\sim$ 10 or 45 km) of open sea. Based on this, all positions located further from shore tan 10 km are defined as offshore positions, the same hold for voyages; all voyages crossing a 10 km line from shore will be defined as offshore voyages. The definition of the is illustrated in Figure 5.4.

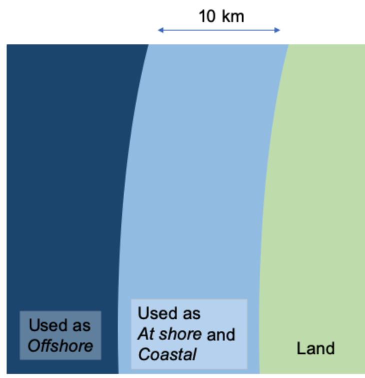


Figure 5.4: Illustration of the definition of the *At shore* and *Offshore* limit

5.2.2 Position Assignment

To construct voyages all AIS positions are divided into different categories. The categorisation is done on several detail levels, as illustrated in Figure 5.5. The second column in the figure is the column name in the DataFrame used for the analysis and the last column lists the different categories the AIS messages are assigned to. On the most detailed level, the AIS messages are split into 9 collectively exhaustive position categories, these are illustrated in Figure 5.6.

Positions	on_offshore	Land Offshore
	position_group	At base On site In Transit At shore (other) Offshore (other)
	position_detail	At base At shore (other) Coastal transit On site (rig) – active On site (platform) – active On site (rig) – waiting On site (platform) – waiting Transit offshore Offshore (other)

Figure 5.5: Overview of the detail levels in the categorisation of positions. The middle column is the column names used in the DataFrame. The last column shows the position types the AIS messages are given in each detail level

The aim of categorising each AIS message is to use the positions to represent the complex working pattern of OSVs in an understandable manner. The model does not focus on the exact operations of the vessels (e.g. towing or mooring assistance), but rather the vessels' more general operational status. The positions are categorised based on location, speed and duration. The code assigning each AIS message to a position category can be found in Appendix E in the functions *tag_position* and *tag_positions_detail* in the *process.py* file. The remaining of this section will explain how the model parameters (position, speed and duration) are used to categorise the positions.

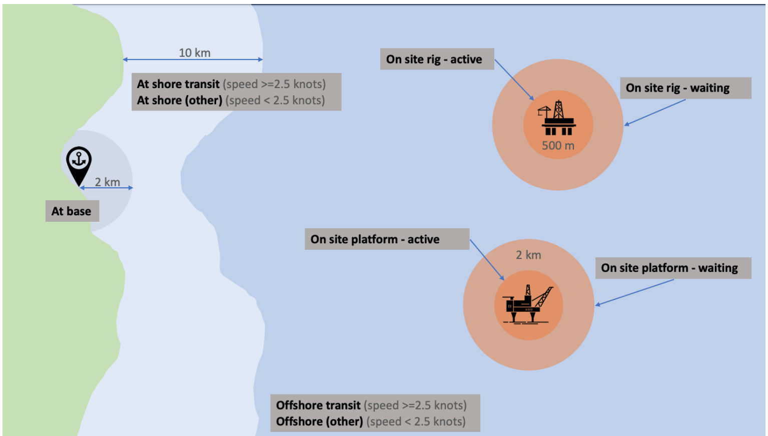


Figure 5.6: Illustration of the 9 different positions a vessel can have in the most detailed level

The methodological framework is based on the assumption that it is possible to identify whenever an AIS message is sent from a vessel working at an offshore installation. The OSV working pattern at installation may be complex and varied and thus difficult to identify solely by the use of AIS messages. The method will therefore depend on the AIS messages' distance from infrastructure. The distance used to identify working OSVs must be chosen with care as it should be able to distinguish working vessels from vessels just passing by.

The industry works with something called the *safety zone* (Marine Safety Forum, 2017). A safety zone is a zone extending out from any part of an offshore oil and gas installation and can only be entered by vessels if a job is planned (Marine Safety Forum, 2017). By the completion of a job or if a longer delay is identified, the vessels are supposed to leave the zone. Figure 5.7 shows the speed limitations within the zone. As seen the maximum speed is 3 knots for the outer bound and only 0.5 knots closest to the installation. Before entering the 200 m zone the vessels have to acquire a stable position and allow a dynamic positioning model to build up. This can take up to 30 minutes. The time a vessel spends inside the safety zone will vary with the work task, but with the speed limitations, there is an upper bound on how fast a job can be completed. It is assumed that no work tasks will be executed without the vessel staying at least one hour inside the safety zone. With the data frequency at hand (hourly messages), all on site working activities should be identifiable. Based on the industry's strict rules for allowing vessels to be located in the zone it is assumed that all vessels within 500 meter from an offshore installation is performing a work task. These positions will be categorised as *On site - active* positions.

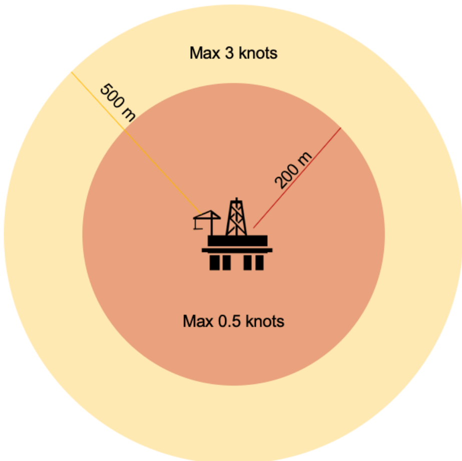
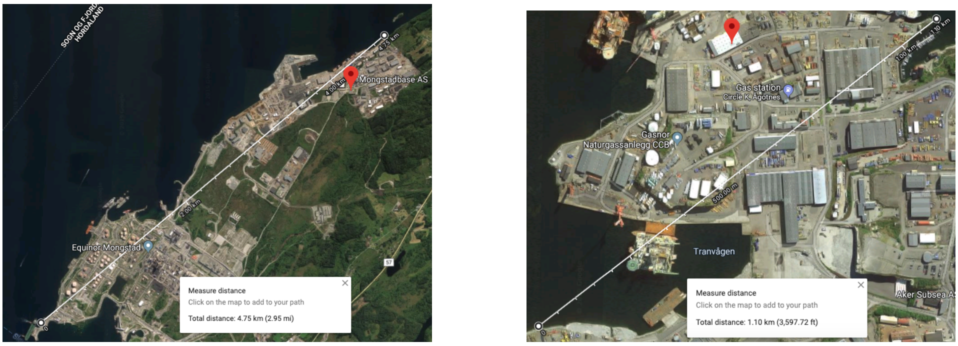


Figure 5.7: Safety zone and speed limits around offshore installations. Vessel inside this zone is defined as actively working

Only using the On site - active definition for calculating offshore activity would probably undercount the duration and number of activities and voyages. There are several incidents where the work may be interrupted e.g. due to weather conditions, unforeseen events at the platform or even as basic events as meal pauses (Marine Safety Forum, 2017). If the work is delayed the working vessel is supposed to exit the safety zone while waiting to restart the work. These waiting events are included in the model as *On site - waiting* positions and are defined when a vessel is 500 m to 2 km from any offshore installation for more than two following hours, or right after or before an on site - active event. The time restriction is included to avoid the coincidences where a vessel is just passing by. On the less detailed level, all positions defined as either on site active or waiting will be referred to as *On site* positions. In addition, the model will also indicate whether the vessel is on site a platform or a rig. In situations where rigs and platforms are located close to each other, the position will be assigned to the nearest installation type.

At base is the term used to tag vessels located close to a supply base. The supply bases along the Norwegian coast may vary in size, and it is not known exactly where on the supply base the longitude and latitude coordinates are given. The size difference of two supply bases is illustrated in Figure 5.8 based on satellite images obtained from Google maps. The images show one supply base covering approximately 4 km and another about 1 km of the coast. The distances are measured by the use of *Measure distance* application in Google maps. Ideally, the distance parameter defining the at base positions should be set individually for each port but considered out of scope for this thesis. All messages sent from a location with a distance less than 2 km from the given supply base coordinates will in this model be considered as *At base*.



(a) CCB Mongstad base. **(b)** CCB Aagotnes base

Figure 5.8: Comparing the geographical range of two Norwegian supply base ports

Positions not defined as on site or at base will be categorised as *In transit* if the observed speed is above 2.5 knots. Most vessels will have a transit speed in the range of 11-13 knots when sailing to installations (Aas et al., 2009), however, the speed limit is set low to include the start of the voyage and also to filter out the messages sent from vessels standing still outside the on site/at base range. The transit messages are further divided into *Coastal transit* and *Offshore transit* depending on the position's distance to shore. The remaining messages will be categorised as *At shore other* or *Offshore other* depending on the distance to shore. The at shore other positions may represent vessels being stacked away from known bases and the offshore other positions may be vessels working on offshore infrastructure not included in our infrastructure data.

5.2.3 Voyage Generation

Even though the operating pattern of OSVs can be very complex, the general operational characteristics of service vessels are straight forward (Kaiser and Narra, 2014). A shore based location can be set as the point of origin. From here the vessel departs to a destination located offshore where cargo is delivered or an activity is performed. From an offshore location, the vessel will either complete the trip by returning straight to port or sail to another offshore location before returning to shore. In some cases, vessels may go straight from one port to another port. Each vessel's event history is reconstructed by chronologically order all data points belonging to the vessel. A voyage is then defined to start whenever the vessel's position changes from *At base* or *At shore other* to one of the other position groups, most likely to Coastal or Offshore transit. The voyage is defined to last until a new *At base* or *At shore other* position is observed. All data points between the two shore events are assigned the same voyage id, indicating that the positions are part of the same voyage. This method is illustrated in Figure 5.9, where the last column indicates the voyage id. As seen the id changes each time a At base or On shore other event is observed. This logic is implemented to the AIS data by the the function *tag_voyages* in the *process.py* file found in Appendix E.

imo	timestamp	....	position_group	voyage_id
9254381	2013-05-01 12:00		At base	1
	2013-05-01 13:00 : 2013-05-02 14:00		In transit : In transit	2 : 2
	2013-05-02 15:00		On site	2
	:		:	:
	2013-05-02 21:00		In transit	2
	2013-05-02 22:00		In transit	2
	2013-05-02 23:00		At shore other	3
	:		:	:
	2013-05-20 08:00		In transit	4
	2013-05-20 09:00		In transit	4

Figure 5.9: Illustration of the process of assigning the voyage ids to each AIS message in the DataFrame

In order to understand the OSV sailing pattern, the positions making up each voyage are grouped together and given a segment leg tag. 8 unique segment legs are defined and listed in Figure 5.10. The segment legs connect each *at base* and *on site* events together by shore-to-site, shore-to-shore, site-to-shore and site-to-site events. Site-to-site defines the segments of the voyages that are not transit to and from shore. This segment is split into two groups; *site to site - same* and *site to site - new*. The site to site - new will be the most important one as this leg identify voyages that visits more than one field centre. The site to site - same can in some cases be considered as an on site waiting event. The definition of the segment legs is illustrated in Figure 5.11.

Figure 5.10: List of *segment* groups defined in the model

The segment legs are assigned to the OSV AIS database by the *tag_segments* function in the *process.py* file. The function starts with identifying and assigning the At base and At site segments in each voyage. The positions in between are then assigned a segment based

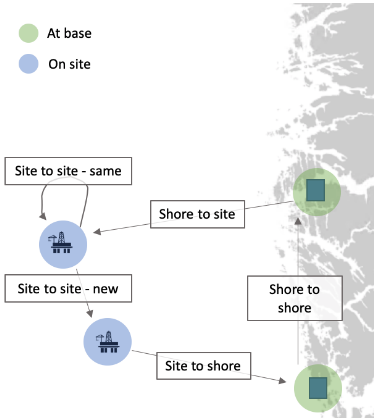


Figure 5.11: Illustration of the segment group definitions

on the previous and next segment leg observed, such that e.g. *shore to site* always will be assigned to the data points between At base and On site events. Figure 5.12 provide an example of how this may look in the OSV AIS database.

imo	timestamp	....	position_group	segment_group
9254381	2013-05-01 12:00		At base	At base
	2013-05-01 13:00 : 2013-05-02 14:00		In transit : In transit	Shore to site : Shore to site
	2013-05-02 15:00		On site	On site
	:		:	:
	2013-05-02 21:00		In transit	Site to site - same
	2013-05-02 22:00		On site	On site
	2013-05-02 23:00		In transit	Site to shore
	:		:	:
	2013-05-20 08:00		In transit	Site to shore
	2013-05-20 09:00		At base	At base

Figure 5.12: Illustration of the process of assigning the segment group to each AIS message in the DataFrame

5.2.4 Voyage Characteristics

Furthermore, all voyages are assigned different characteristics. As for the position assignment, the voyages are categorised on different levels. In the most general level, the voyages are defined as either *coastal*-voyages or *offshore*-voyages, depending on how far from shore they sail. Coastal voyages are defined as voyages not sailing further than 10 km from shore. The offshore voyages are further split into *On site*-voyages and *Offshore other*-

voyages. This definition is dependent on whether the voyage contains *on site*-positions or not. On the most detail level the on site-voyages are further split into *on site rig*- and *on site platform*-voyages. The categorisation of the voyages is illustrated in Figure 5.13 where the grey boxes indicate the most detail level.

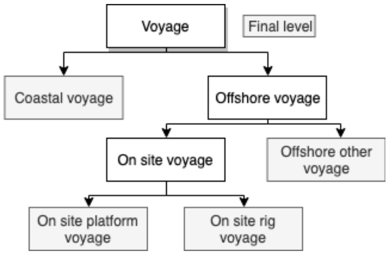


Figure 5.13: Illustration of how voyages are categorised into different voyage types

For each voyage the field centre(s) visited is given together with a number indicating how many field centres that were visited on each trip. Figure 5.14 shows an illustration of the Ekofisk field (obtained from Norwegian Petroleum Directorate's Ekofisk factmap[2]) where two different types of voyages are illustrated. The black voyage has positions defined as on site on both the northern and central field centre whereas the blue voyage only visits one of the field centres. Recall that field centres are only assigned to the platform data sets. This means that voyages only visiting rigs will not be assigned a field centre. They will, however, be assigned an operator.

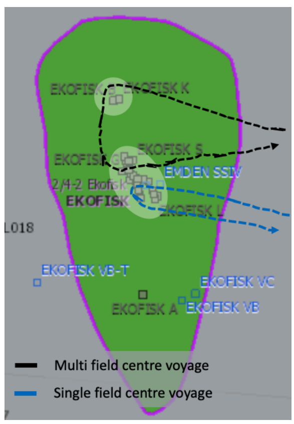


Figure 5.14: Illustration of voyages visiting one (blue) and two (black) field centres

The final parameter assigned to the voyages is the operator(s) of the voyage. When a vessel is chartered it is the oil companies that fully operates the vessel. This means that if a vessel is working on an installation operated by Equinor, it is most likely Equinor that operates

[2] http://gis.npd.no/factmaps/html_21/ (20.05.2019)

the vessel on the entire voyage. We saw in Section 2.1 that some oil companies share their OSV fleet in so-called vessel pools. So in the cases where a vessel visits field centres with different operators during the same voyage both operators are assigned as *voyage operator* and the voyage will be referred to as a *multi operator voyage* or as a *shared vessel voyage*. Figure 5.15 illustrates how voyages are assigned operators.

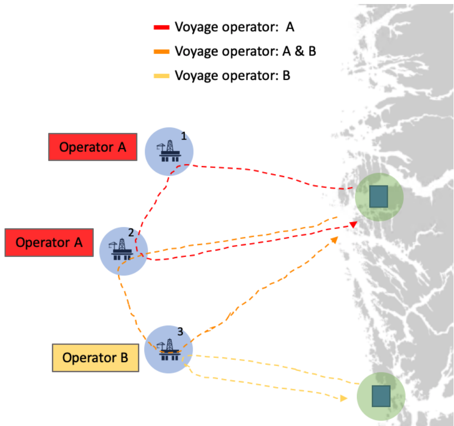


Figure 5.15: Illustration of how voyages are assigned operators

imo	voyage_id	....	segment_group	voyage_operator	voyage_destination
9254381	205		Shore to site	A & B	Field centre 2 & 3
	205 : 205		On site : Site to site - new	A & B : A & B	Field centre 2 & 3 : Field centre 2 & 3
	205		On site	A & B	Field centre 2 & 3
	:		:	:	:
	205		Site to shore	A & B	Field centre 2 & 3
9709876	1104		Shore to site	B	Field centre 3
	1104		On site	B	Field centre 3
	:		:	:	:
	1104		Shore to site	B	Field centre 3

Figure 5.16: Illustration of the process of assigning the voyage operator and voyage destination to each AIS message in the DataFrame

5.2.5 Activity Definition

To understand the OSV activity one needs to define what OSV activity is. In this thesis, it will be defined as the number of voyages sailing offshore and the time spent on these voyages. Recall that a voyage starts with the first transit observations meaning that time in port will not be a part of OSV activity as defined in this study. It should, however, be kept in mind that the vessel owners are paid for mobilisation and demobilisation activities at port. These operations may take up to several days depending on what is to be transported and the efficiency of the logistics.

Chapter 6

Case Study

The model's capability to understand the OSV activities will be tested through a case study presented in this chapter. The model will be used to analyse activity on the NCS from mid-2013 to the end of 2018. This chapter is structured into two main sections consisting of a micro and a macro study. In the micro study, the model is applied to the Ekofisk field. The characteristics of the OSV activities connected to the field are analysed and presented. In the macro study, the model's capability to provide insight on a higher level is tested by studying OSV activities on the entire NCS. A fleet composition, operator and installation study is included in this section. The Python scripts used to perform the analyses in this chapter can be found in Appendix E.3 and E.4.

There are a lot of definitions presented in this master thesis. To increased the readability of the case study some of the most frequently used definitions are presented.

- *Voyage*: A vessel trip, e.g. a vessel leaving shore, going offshore and then returning back to shore. Time in port is not included as a part of a voyage
- *Voyage id*: Each voyage for every vessel is marked with its own id number. Used to count the number of voyages
- *Vessel days*: Total days · total vessels. Often used to characterise the activity level. If nothing else is specified vessel days is used to describe the total duration and number of vessels on a certain voyage type, including time spent in transit and excluding time in port
- *On site-position*: Position within the range of 2 km from an offshore installation
- *On site-voyage*: A vessel voyage containing on site-positions. Also referred to as *Voyages to offshore facilities*
- *Offshore other-voyage*: A vessel voyage containing positions further from shore than 10 km, but no on site-positions
- *Offshore-voyage/Non coastal-voyage*: A collective term for on site- and offshore other-voyages

- *Field centre*: A single, or a group of installations, located with a certain distance to other installations

6.1 Micro Study: OSV Activity at the Ekofisk Field

To be better suited to evaluate the model results on an aggregated level the model will be illustrated by studying the Ekofiks field. The Ekofisk field was discovered in 1969 and was the first commercial field being developed on the NCS. The field is located in the southern part of the North Sea, 290 km from the Norwegian coast and is operated by ConocoPhillips (Norsk Oljemuseum, 2018a). The main supply base is located in Tananger, Stavanger. Production started in 1971 and the development of the field has consisted of several phases. In 1994 the plans for further development were approved assuring operations on the field for the coming years. Since then, new installations intended for a lifetime of 30 years have been installed, replacing the old ones. According to Norsk Oljemuseum (2018a) a total of 14 platforms on the Norwegian side will be shut down as new installations will replace them. In 2013 a new wellhead platform and two sea-bed installations started operations. In 2014 a new living quarter, 2/4 L, were installed replacing two old ones.

Figure 6.1 shows a map over the field and its installations, obtained from the Norwegian Petroleum Directorate. We observe three field centres whereas the central one consists of most installations and serves as the field centre. Ekosfisk A, the most southern installation is no longer in operation, and therefore not included in our infrastructure data. The two remaining field centres will be referred to as Ekofisk North and Ekofisk Central.

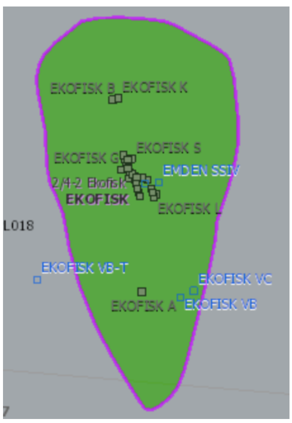


Figure 6.1: Overview of the Ekofisk field. Obtained from NPD FactMaps

With the model established, we can find both the number of voyages departed to the field and the time spent on these voyages. Figure 6.2 shows how this is distributed between the two field centres when data from the entire period of study is included. About 50% of the vessel days are dedicated solely to Ekofisk Central, another 45% are dedicated to both field centres while only 5% of the total vessel days are observed servicing the north field centre alone. In terms of the number of voyages 50% have the destination set to both of the centres, the remaining 45% and 5% are headed to the central and northern centre respectively.

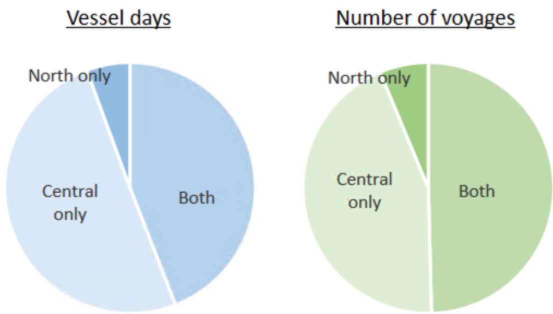


Figure 6.2: Distribution of vessel days (blue) and number of voyages (green) headed to each of the field centres

In Figure 6.3 the yearly activity at the Ekofisk field is presented. The number of voyages and vessel days spent on these voyages are correlated from year to year. From May - December 2013 about 200 voyages departed with the field as the destination, in comparison, only 170 did so during the entire year of 2014. In fact, 2018 is the first year where the activity levels are above the 8 first month of 2013 (recall that the AIS data set starts in May 2013). From 2013 and to 2017 the activity levels have decreased steadily, reaching the lowest levels in 2017 with about 100 voyages headed to the field. The activity observed in Figure 6.3 is from both PSVs and AHTS vessels.

Figure 6.4 shows how the yearly activity in 6.3 is distributed over the months for both PSVs and AHTS vessels. The total activity level fluctuates during each year, with most activity peaks taking place during the summer months (Q2 and Q3). The high activity levels observed in 2013 are due to steady high activity in all months, with an exception for December. In 2014 on the other hand, the activity levels only peak in March and June while the rest of the months have low levels with only about 20 vessel days each month from August to December. The lowest levels are observed in January 2015 where output from the model shows that no vessels are servicing the field. Except for three activity peaks during the summer months in the following years, the activity remains low. In 2018 however, the activity levels are increased from February and throughout November with 100 to 130 vessel days being observed each month. Recall that these are not only vessel days spent at the field, but includes the time spent sailing back and forth. Time in port is however not included. The activity levels described are almost solely PSV vessel days. AHTS activity is only observed during some of the months in 2013 and 2014. As seen in Section 2.1 AHTS vessels are more likely to be observed at site under non-normal circumstances, such as installation phases or by the presence of a rig at the field. Potential

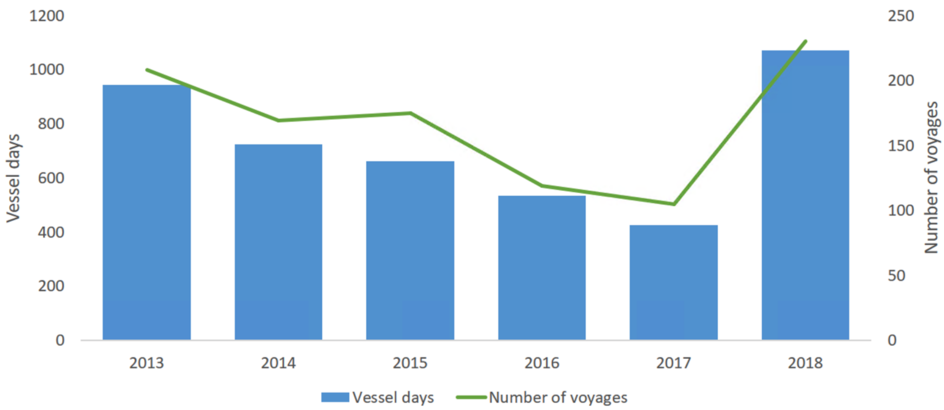


Figure 6.3: Yearly activity at the Ekofisk field. Blue columns are vessel days (left y-axis) and green line is number of voyages (right y-axis) where one of the Ekofisk field centres have been defined as the destination of the voyage

events coinciding with the observed AHTS activities are identified by scouting through ConocoPhillips websites[1] and placed on the figure. In addition, a larger decommissioning phase on the field, with four platforms with a total of 36.000 tons to be removed, taking place from 2107 to 2022 have been reported by Petro.no[2].

The vessel days spent on the voyages headed to the field can be grouped into different segment legs. This is illustrated in Figure 6.5 by showing the share of vessel days spent in each segment each year. 100% on the chart refers to the total vessel days spent on the voyages where the destination has been one of the Ekofisk field centres. The red sections indicate transit between site and shore and the light blue indicate the time spent on site. The darker green and purple segments represent the time spent between the *on site*-observations. The difference between the two segments is an important part of the model. Whereas the purple part indicates events where a vessel has been sailing between two *different* sites, the darker green segments indicate the time spent outside of the 2 km zone between operations performed at the *same* site. The darker green can thus be treated as an extended waiting area and the purple segments as an indication of voyages visiting multiple field centres without returning to shore in between. The purple segments on Figure 6.5 can either be transit between the two field centres at the Ekofisk field or between Ekofisk and other nearby fields. The distribution of the segments seems to vary cyclically each year, with transit segments making up a larger part of the voyages during the winter months than in the summer months. Furthermore, there seems to be more time spent in transit *to* site than on the way back to shore. The bar for January 2015 is empty due to no voyages being registered to the field during the entire month.

[1] http://www.conocophillips.no/nn/vare-norske-operasjoner/ekofisk-omradet/ekofisk/, (29.05.2019)

[2] https://petro.no/nyheter/heerema-af-decom-fjerne-fire-plattformer-pa-ekofisk, (29.05.2019)

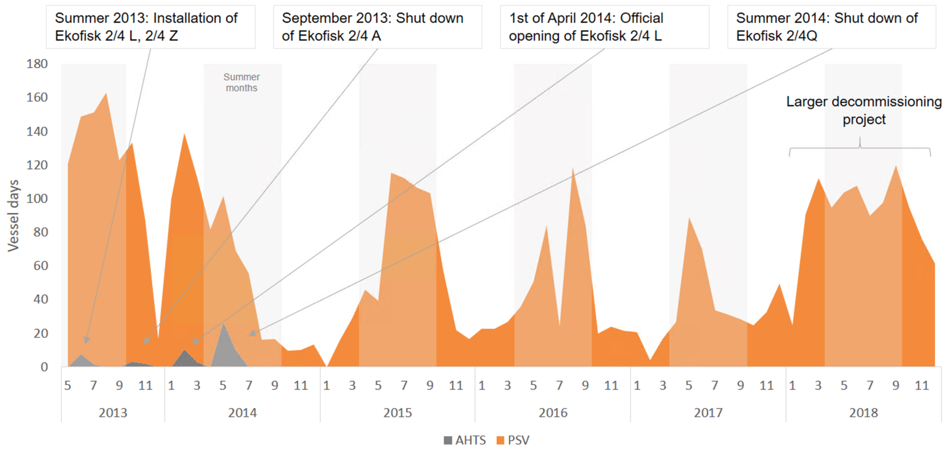


Figure 6.4: Monthly vessel days from voyages headed to one of the Ekofisk field centres with colour split by vessel type and information boxes showing ConocoPhillips reported activities on the field

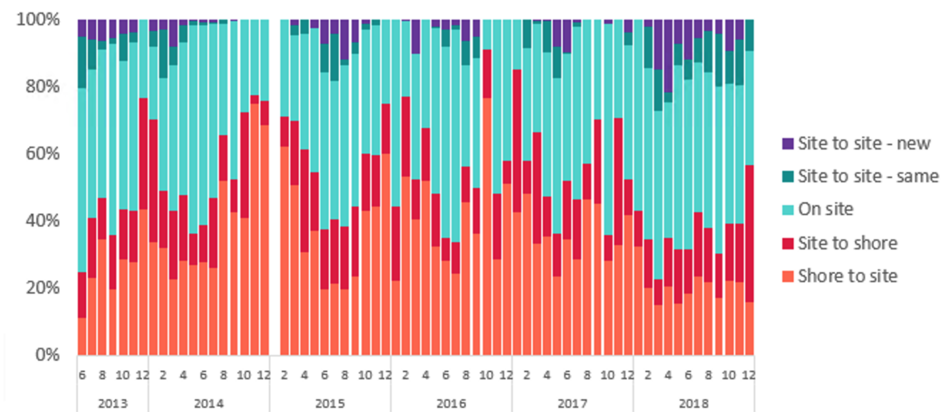


Figure 6.5: Distribution of vessel days spent in each segment legs on voyages with destinations to one of the Ekofisk field centres each month

Figure 6.6 shows the location of the AIS messages sent from voyages headed to the Ekofisk field during March 2018. The colours indicate the same segment legs as seen in Figure 6.5. Each coloured dot represents a data point (AIS message), and the grey line the connections between them. The data points are made transparent so that areas with layered messages stand out. Layered data points will either indicate areas with more OSV activity or instances where the forward fill method have been used to fill data gaps. Longer stretches with no data points, such as observed right before the Ekofisk field, is also an indication of missing data points. The black diamond- and red star-shaped points represent platforms and rigs receptively. During March 2018 the field is serviced from both Norway and Denmark. When we later will study NCS activity it should be kept in mind that only data points sent from the NCS are counted. In addition to servicing the Ekofisk field, several of the voyages also visit another field named Eldfisk. According to ConocoPhillips, who is the operator on both fields, both Eldfisk and Embla is a part of what is called the *greater Ekofisk area*. The Eldfisk field started production in 1979 and is divided into two field centres, which in this thesis are referred to as Eldfisk North and Eldfisk South. Embla consists of one field centre, started production in 1993 and is, according to Norsk Oljemuseum (2018b), normally unmanned and remotely operated from Eldfisk.

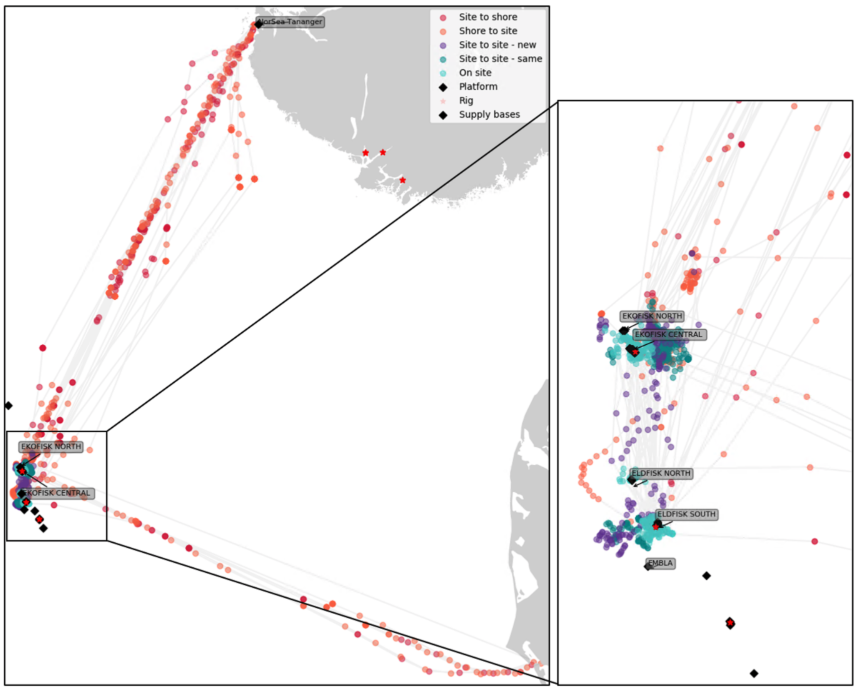


Figure 6.6: Vessel and installation positions during March 2018 from voyages headed to the Ekofisk field with colour codes indicating the segment legs. Right figure is a zoom in on the vessel positions closer to the facilities

In Figure 6.7 the voyages from Figure 6.3 are divided into whether they also are servicing the Eldfisk and Embla fields or not. Out of all voyages visiting the Ekofisk field, more than 50% are found to also visit the Eldfisk field. However, this is not true in 2016 and 2017, the years where the OSV activity at the field is at its lowest. Based on results from the model the reduction in OSV voyages to Ekofisk during 2016 and 2017 is due to the reduction of voyages also visiting Eldfisk. The number of visits only headed to the Ekofisk field seems to have remained stable during the same period. Only a small portion of the voyages visit Embla, as this is an unmanned installation.

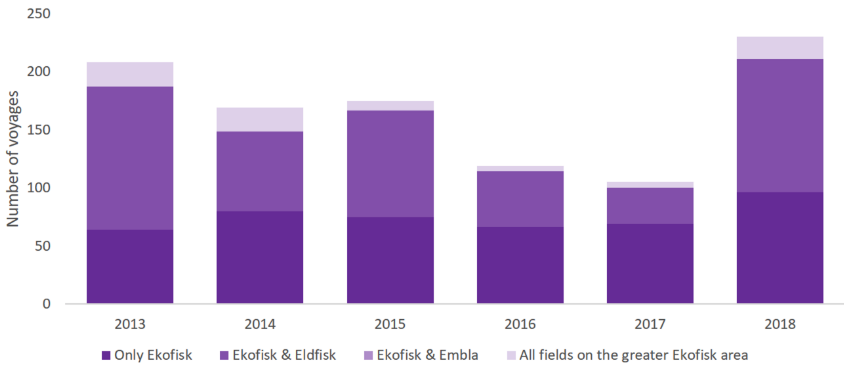


Figure 6.7: Number of voyages headed to the Ekofisk field each year, split by voyage pattern in terms of the other fields visited on the same voyage

In Figure 6.8 we illustrate a single *on site*-voyage with the aim to show how a certain field is set as the destination of a voyage. The positions shown in the figure belong to a PSV and are from a voyage sailed during September 2018. The vessel is observed leaving the Tananger supply base at midnight on the 10th of September and returning on the 24th of September. It is observed on site, within the light blue circles in figure 6.8, on the evening the 11th of September. All voyages with positions defined as on site are labelled *on site*-voyages, and the destination is set to be the or those field centre(s) the vessel is visiting on the voyage. For this voyage, Ekofsik North and Ekofisk Central are defined as voyage destination, as positions are observed within the 2 km range of both field centres. By studying the figure it is observed that the two field centres are separated from each other with about 2 km, leading the on site areas to intersect with each other. The vessel is observed close to the installations on the central part of the field, leaving little doubt that the vessel was servicing the installations here during the voyage. Even though the vessel is defined as to be on site at the northern field centre, no observations indicate that the vessel was located next to the installations on this part of the field. The vessel is located at the field for about two weeks with multiple positions indicating both types of site to site transit. The figure indicates that messages sent further from the installations than the on site definition probably also are connected to work at the field, as no other nearby rigs or installations can explain the activities. Some positions are observed inside the *on site* range without being defined as on site. On the figure, these can be observed as the purple and dark green positions within the light blue circles of Ekofisk north. These are positions staying within this zone for less than two hours.

Common for all the voyages included in the Ekofisk study is that we can know their destination with some certainty. However, not all voyages are headed to a destination recognised by the model. Those voyages may either just be crossing the 10 km border for displacement, working on installations not covered by the infrastructure data sets, supporting activities on subsea equipment or working for other industries e.g. offshore wind projects. The offshore voyages with unknown destinations are labelled *offshore other*-

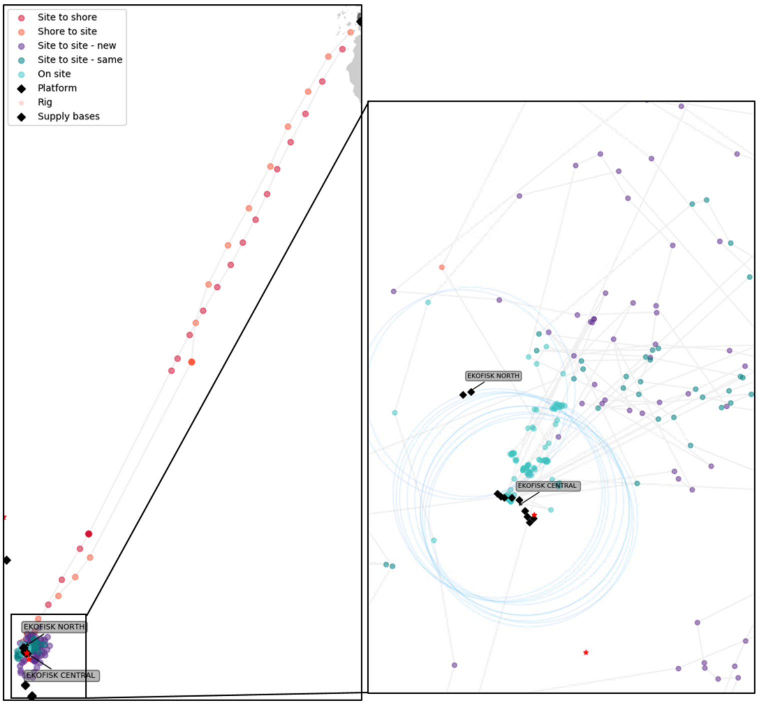
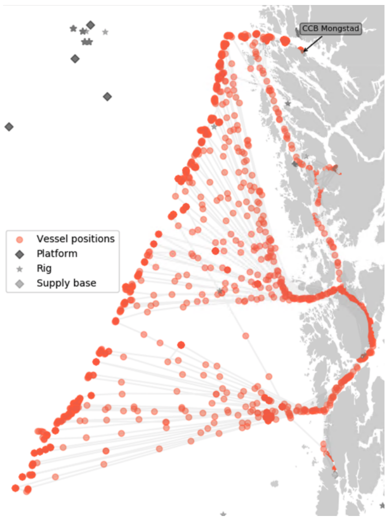
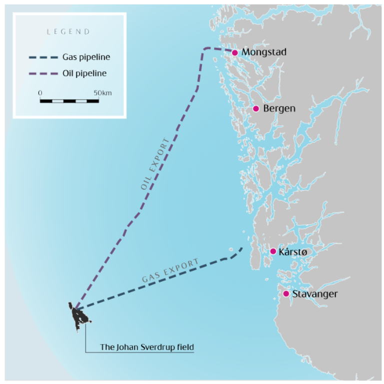


Figure 6.8: PSV voyage to the Ekofisk field from 10 of September to 24th of September with colour codes indicating segment legs and blue circles indicating the range of the on site definition

voyages. Figure 6.9 shows a vessel sailing multiple times to the same area, staying there for some time and then returning to shore without being defined as on site. The sailing pattern does, however, indicate that the vessel is working. According to Sysla[3] the vessel observed was reactivated from stacked status to support pipe-laying activities between the Johan Sverdrup field and the Mongstad delivery base during summer 2018. Comparing the vessel's working pattern with the location of the oil export line confirms this.



(a) AIS messages from vessel working on the oil export line



(b) Illustration of the export lines from the Johan Sverdrup field. Obtained from Equinor.

Figure 6.9: Voyages defined as offshore other together (a) with subsea infrastructure not included in the model (b).

6.2 Macro Study: OSV Activity on the NCS

This section contains multiple studies where the model is used to understand and describe different aspects of the activities on the NCS. The first part focuses on the general activity, in terms of vessel days, while the remaining parts will use the model to study the fleet, operators and installations on the NCS.

6.2.1 General NCS Activity

To study the general OSV activity on the NCS all voyages with positions sent from Norway were included. However, only the part of the voyage spent on the NCS was counted when analysing the activity in terms of vessel days. Since January to April 2013 is not included

[3] https://sysla.no/maritim/far-de-endelig-offshore-baten-ut-av-opplag/, (29.05.2019)

in the data set, the year is excluded from these analyses. Figure 6.10 shows the yearly vessel days and number of voyages observed on the NCS. Output from the model shows that 2014 was the most active year both in terms of vessel days and number of voyages. About 22500 vessel days were spent on offshore voyages, where about 15000 of these had a destination recognised by the model. In general, more than two-thirds of the vessel days are spent on voyages with a known installation set as the voyage destination. We observe some reduction from 2014/2015 to 2016/2017 in both vessel days and number of voyages. The lowest activity level is observed in 2016 with about 20000 vessel days from offshore voyages. The vessel days spent on *on site*-voyages decreased the most going from 2015 to 2016, where the reduction was 15%.

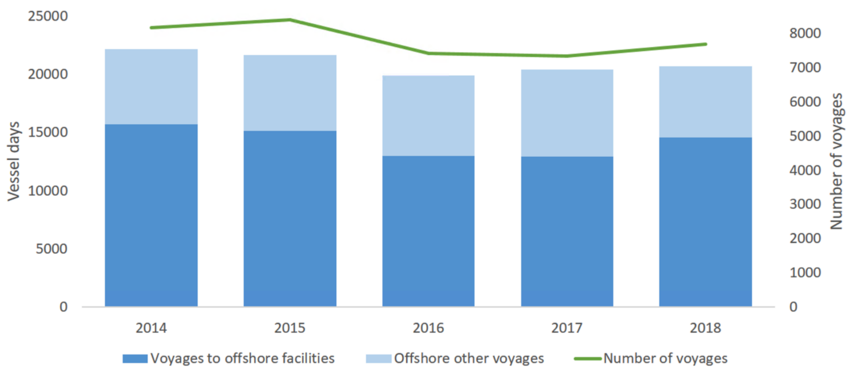


Figure 6.10: Yearly activity on the NCS. Blue columns are vessels days (left y-axis) and green line is number of voyages (right y-axis). Vessel days divided between voyages headed to a known facility (dark blue) and voyages with unknown destinations (light blue)

Figure 6.11 shows the vessel days in Figure 6.10 for each month. Activity peaks are observed during the summer months. 2016 seems to have low activity levels due to low levels in all months, i.e. no noticeable peak during the summer months.

As seen in Section 2.1, PSVs and AHTS have different work tasks and activity drivers. Where AHTS vessels primarily are used to tow and moore rigs, PSVs provide supplies to both platforms and rigs. Figure 6.12 shows the total vessel days from offshore voyages sailed by AHTS vessels. In addition, the contracted rig days, obtained from Rystad Energy RigCube, and the offshore rig days observed by AIS signals are plotted as the solid and dashed line respectively. AHTS vessels only stand for about 4300 vessel days in 2014, compared with the total number of 225000 from Figure 6.10. About 55% of these vessel days are from voyages with a recognised destination. Both rig activity sources show a solid reduction in the number of rig days. From 2014 to 2017 the contracted rig days have been reduced with about 40%. The model shows that AHTS vessel days from voyages with a known destination follow this trend more than the other offshore voyages. From 2014 to 2016 the vessel days from on site AHTS voyages decreased with about 40% and remained low into 2018. The AHTS vessel days from offshore other voyages, on the other

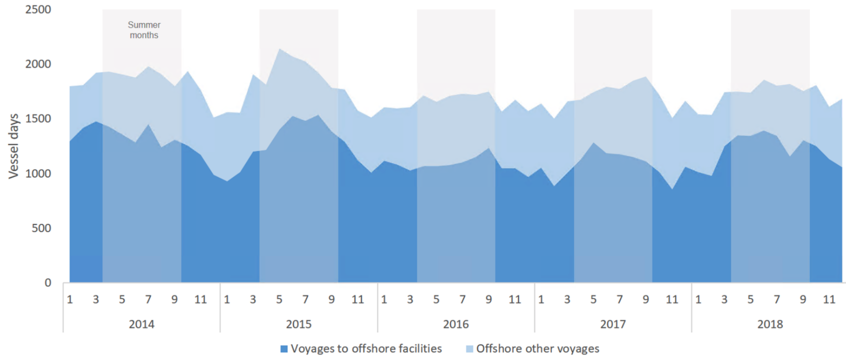


Figure 6.11: Monthly vessel days on the NCS. Vessel days divided between voyages headed to a known facility (dark blue) and voyages with unknown destinations (light blue)

hand, only saw a decrease of 6% from 2014 to 2016.

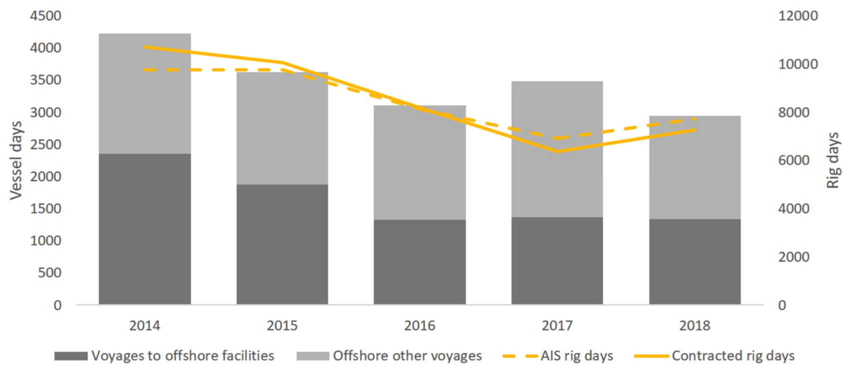


Figure 6.12: Yearly AHTS vessel days from the NCS (columns) on the left y-axis and number of rig days each year (line) on right y-axis. Vessel days divided between voyages headed to a known facility (dark grey) and voyages with unknown destinations (light grey). Rig days divided between contracted days from Rystad RigCube (solid line) and offshore AIS rig positions (dashed line)

In Figure 6.13 the yearly modelled PSV vessel days spent on non-coastal voyages are shown together with the number of facilities installed and the corresponding cumulative number of offshore beds on the NCS. The number of platforms increased with about 15% from 2014 to 2018, and the number of offshore beds with about 10% during the same period. Despite this increase, the vessel days spent on voyages to offshore facilities are seen to slightly decrease. 2015, being the peak year, saw a total of 18000 PSV days while there in 2017 were observed about 17000 PSV days. For the PSVs we notice that about 70% of all vessel days are from voyages where the destination is found to be one of the installations in the infrastructure data sets.

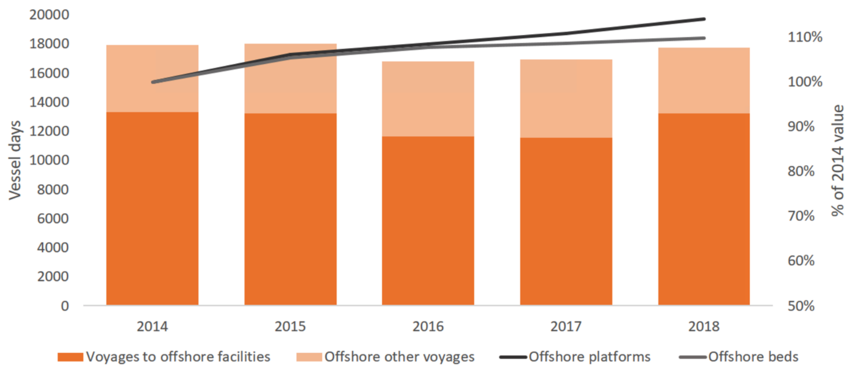


Figure 6.13: Yearly PSV vessel days from the NCS (columns) on left y-axis and percentage increase in number of facilities installed (black line) and corresponding cumulative number of offshore beds (gery line) on the right y-axis. Vessel days divided between voyages headed to a known facility (dark orange) and voyages with unknown destinations (light orange)

6.2.2 The NCS OSV Fleet

In section 2.1 we saw how the OSV fleet consists of vessels with different work tasks requiring the vessels to be offshore a varied amount of time. In Figure 6.14 the observed number of vessel days spent on offshore voyages for each vessel in the fleet in 2018 is shown, with the x-axis being each vessel in the fleet. The vessel days are found by counting the number of data points (hours) connected to offshore-voyages for each vessel and then translate the hours into days. There are a handful of vessels being on offshore voyages 365 days out of 365 possible days in 2018. The remaining part of the fleet is split between vessels with almost none offshore recordings and those with around 250 to 100 offshore vessel days. The vessels with most offshore reporting may be standby vessels that are located close to site for longer periods, while those with almost none may have been stacked during the year. All the vessels in between may be vessels sailing to and from ports either on long-term contracts or in the spot market.

Figure 6.15 shows that, on an average basis, the NCS is serviced by 65 PSVs and 17 AHTS vessels each month. If the fleet is well defined and all offshore voyages actually are dedicated to working, this number can be interpreted as the average fleet size necessary to cover the shelf activities. However, the OSV fleet is not designed to handle average demand. The fleet size is more likely to be driven by the demand peaks occurring in the summer months, which is easier handled by a fleet with excess capacity. A large fleet will also make logistics planning easier, but the obvious disadvantage is increased charter cost and environmental issues Aas et al. (2009).

Comparing the number of working vessels with the number of vessels available in the fleet, as done in Figure 6.16, gives an estimation on the fleet's *working utilisation*. Working utilisation should not be mixed with *contracted utilisation*. As operators do not manage to have a 100% utilisation of their chartered fleet, the working utilisation will always be

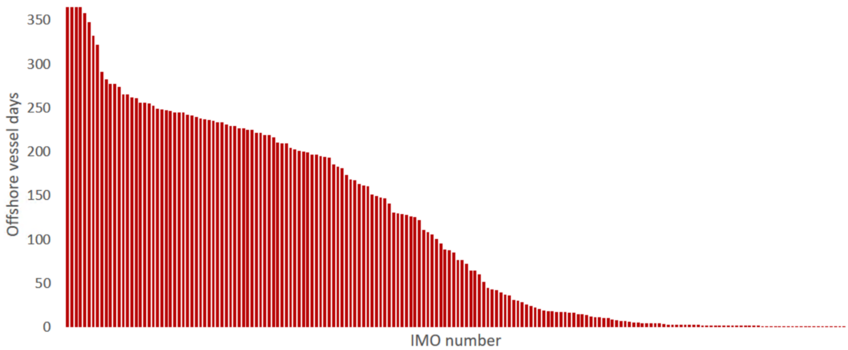


Figure 6.14: Number of days spent on voyages going offshore during 2018 for each vessel in the fleet

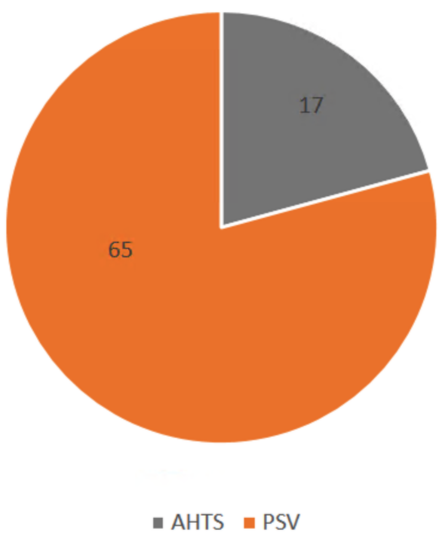


Figure 6.15: Monthly average number of working AHTS vessels (grey) and PSVs (orange) on the NCS. Average for all months all years

lower than contracted utilisation and represent the part of the fleet that is actively working. The number of working vessels is defined as all vessels observed on offshore-voyages each month, including voyages with unknown destinations. The available fleet is defined to be the part of the pre-defined fleet (Appendix B) that were identified in the AIS data and each of these vessels' first service year. The dynamic effect of some vessels being added and other being scraped during the period is incorporated in a simplified manner. The fleet data only provides information on the year a vessel entered the fleet and not whether it has been scraped during the period or not. This means that the size of the available fleet is only updated once a year and the effect of vessels leaving the fleet is excluded from the analysis. Based on this the OSV fleet is observed to grow over the period with 6% and the fleet utilisation is reduced with about 15% when comparing 2017 with 2014.

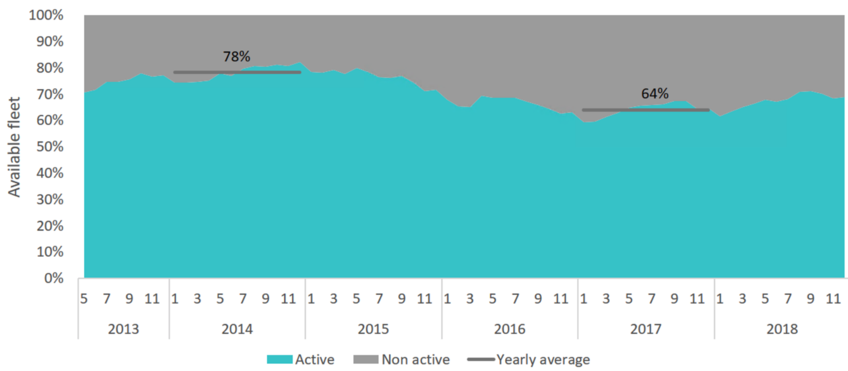


Figure 6.16: Monthly working utilisation for the fleet included in the AIS data set

Modern vessels are rather expensive to chart and according to Aas et al. (2009) it has gradually become more important for oil companies operating on the NCS to maximise the OSV utilisation in order to reduce costs. One reason for this is stated to be falling production rates and increasing unit costs on mature fields. A way to reduce OSV costs could be to charter older and less expensive vessels, which may be an easier approach than to restructure and optimise the OSV operations. Figure 6.17 aims to show how the age of the fleet has evolved over the years. 100% represents the total vessel days from offshore-voyages each year. The total vessel days are split between the different age groups of the fleet. To keep the age parameter static over the period the ages are represented as the vessels' first year in service. In 2018 10% of the vessel days are coming from new builds, these vessels represent the vessels added to the fleet as described in the previous paragraph. In all years, vessels entering the fleet between 2010 and 2014 have accounted for the largest portion of the offshore vessel days. Their share is also observed to steadily increase from 2013 to 2015 taking shares from the oldest part of the fleet. After 2015 their share has remained fairly stable as the new builds have accounted for the reduced activity in the older parts of the fleet.

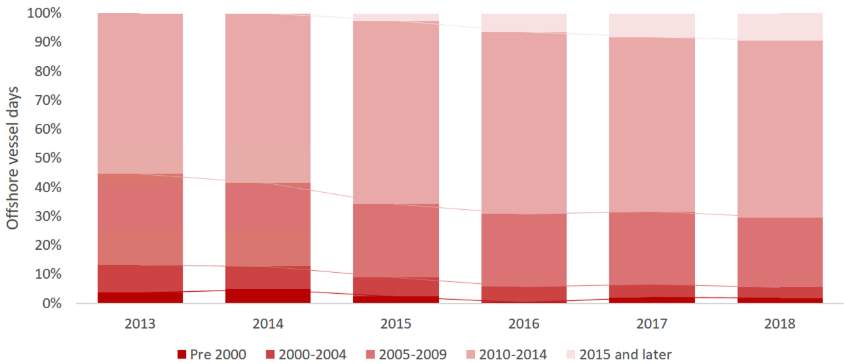


Figure 6.17: Yearly working share in terms of vessel days by each vessel age group in the fleet

6.2.3 The NCS Operators

This part of the case study is focused on the operators on the NCS. To study this, the *voyage operator* parameter of the model is used. Recall, from Chapter 5, that a voyage is assigned to one, or multiple, operator(s) based on the operators on the platforms and rigs visited during each voyage. In addition, it should be kept in mind that the operator parameter is static during the entire study, meaning that the effects of mergers and acquisitions are not included. Each platform and rig is set to be operated by their current operator as of 2018 during the entire period.

Figure 6.18 ranks the operators in terms of vessel days spent on voyages where they are labelled as voyage operators. Equinor is observed with most vessels days, a total of 40 000, during the entire time span (May-2013 to end-2018). Aker BP is found to be the second-largest operator, in terms of vessel days, with a total of about 15 000 vessel days over the same time span. As Aker BP was established in 2016 as a merger between BP Norway and Det Norske Oljeselskap [4] the vessel days operated by any of these two operators before 2016 is included in the Aker BP numbers. Other than Eqionor and Aker BP, the NCS seems to be operated by a large group of smaller players (small in terms of vessel days on the NCS).

By the use of the *segment leg*-parameter, the operators can be characterised by how they sail their OSV fleet. In Figure 6.19 the distribution of the vessel days spent in the different segment legs for both Equinor and Aker BP is presented. For both companies, about 85% of the time is spent either on site or in transit to and from site, while the remaining time is divided between the two site to site definitions. By comparing them, we observe that Aker BP has a larger on site share and that Equnior spends more time in transit to and from site.

The literature review pointed out that there are lots of potential cost savings in the optimisation of sailing pattern. In 2013 Equinor reported[5] that they would change their sailing

[4] https://www.akerbp.com/historien-om-aker-bp/, (30.05.2019)
[5] https://www.equinor.com/en/news/archive/2013/11/01/1NovSailing.html,

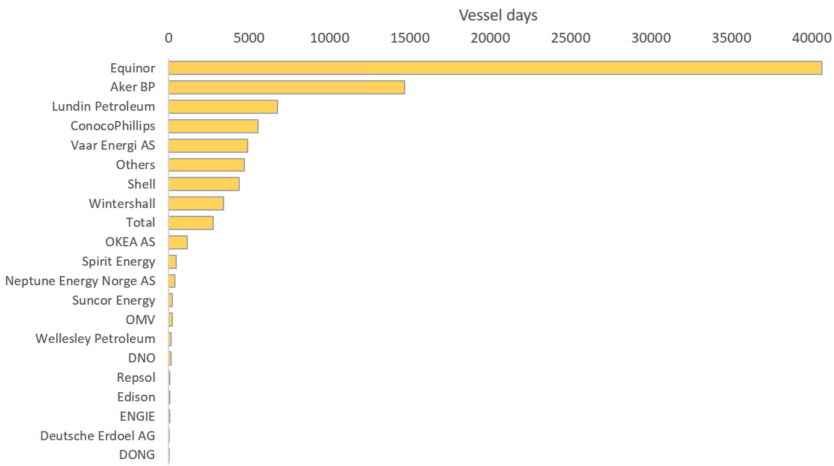


Figure 6.18: Total vessel days during all years for each operator (including vessel days from multi-operator voyages)

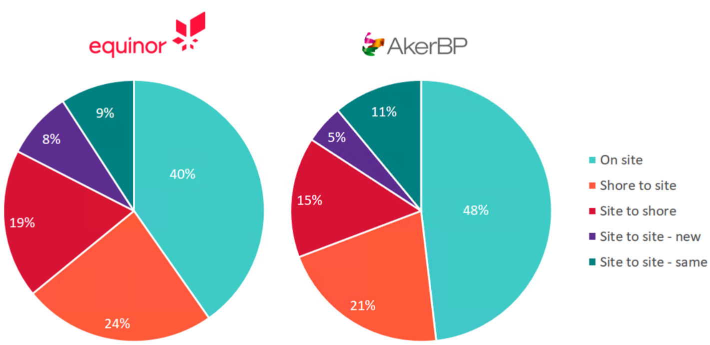
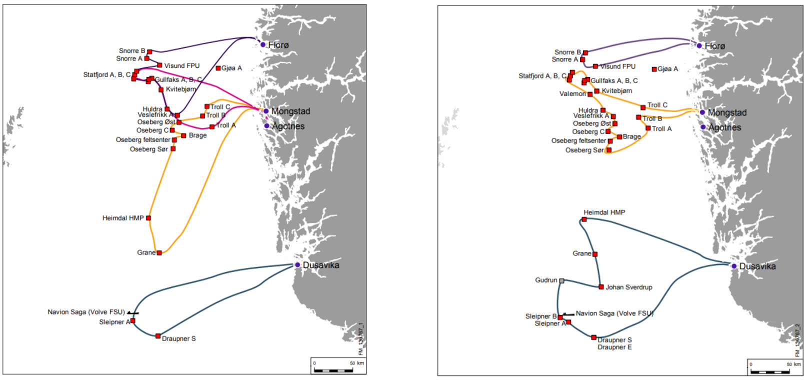


Figure 6.19: Distribution of vessel days spent in each segment leg during the entire period (mid-2013 to end-2018) for Equinor and Aker BP

routes on the NCS and expected the routes to be fully implemented by 2015. Equinor reported cost saving in the order of NOK 250 million per year along with a reduction in CO2 emissions. The changes consisted of more supply activity from Dusavik and Mongstad, and less from the bases in Florø and Ågotnes as seen in Figure 6.20, obtained from Equinor.



(a) Old sailing routes

(b) New sailing routes

Figure 6.20: Illustration of Equinor's changed sailing pattern introduced in 2013. Figure obtained from Equinor

In Figure 6.21 the monthly average vessel days operated by Equinor in each year is shown. To include 2013 the average does only include the months from May to September and can be seen as the monthly average during peak season. The model shows that Equinor has reduced its monthly sailing time with 150 days each month, however, only a little portion seems to be due to less time spent in transit.

In Figure 6.22 we look at the vessel days spent on site-to site-transit between *different* field centres for each of the operators. The time spent in this segment leg has been noticeably reduced during the period. In 2013 a total of 1300 vessel days were observed, whereas only about 700 were observed in 2017. Equinor stands for most of the vessel days in this segment each year with 600 vessels days in 2014. Aker BP had about 150 vessel days in this segment the same year and seems to have been one of the operators with the largest reduction during the downturn with only about 50 vessel days in 2016. The time spent in the segment increased in 2018, almost back to 2014 levels. The increase was mostly driven by Equinor, Aker BP and ConocoPhillips. With Aker BP being established in 2016, the increased vessel days may be synergies resulting from this merge.

In Section 2.1 we saw that vessel pools (operators sharing vessels) previously had proven to cut operational costs. In Figure 6.23 the share of the total vessel days in each year that is operated by more than one operator is shown. From the figure, we observe that less than

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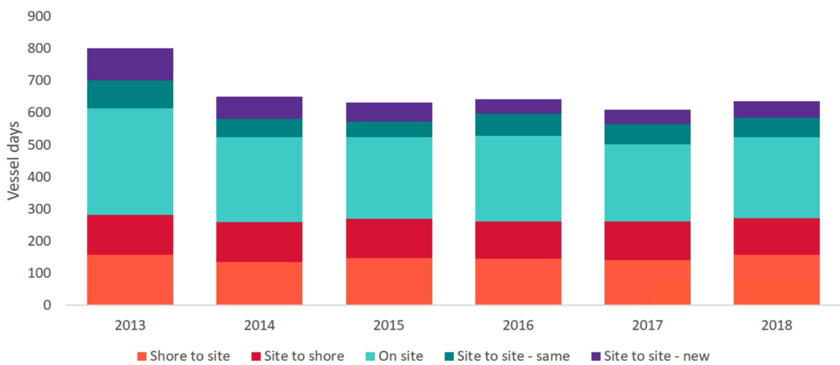

Figure 6.21: Monthly average vessel days spent in each segment leg during peak season (May-September) in each year for Equinor

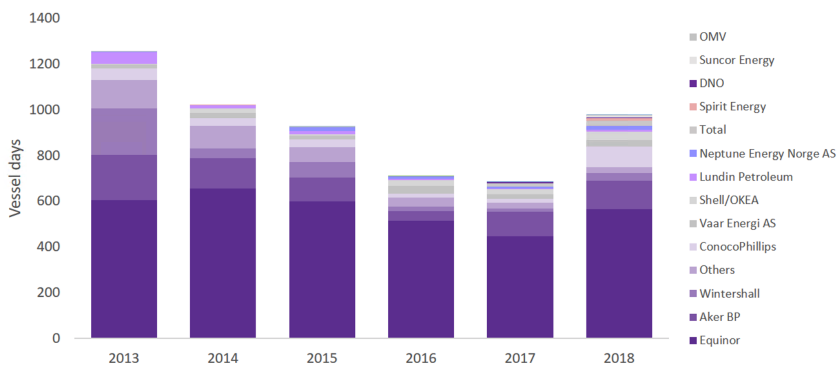

Figure 6.22: Vessel days spent on site-to-site transit between different field centres for each operator during the study period

10% of the vessel days each year are from voyages operated by multiple operators. This share seems to have stayed fairly stable during the entire period of study. In Figure 6.24 the voyage operators of the vessel pools are shown. Red sections indicate that Equinor is part of the vessel pool and green that Aker BP is. The orange represents vessel sharing between Equinor and Aker BP. We observe that Equinor is included in multiple vessel pools and that the voyages seem to be operated by multiple combinations of the operators rather than one structured collaboration between some of them.

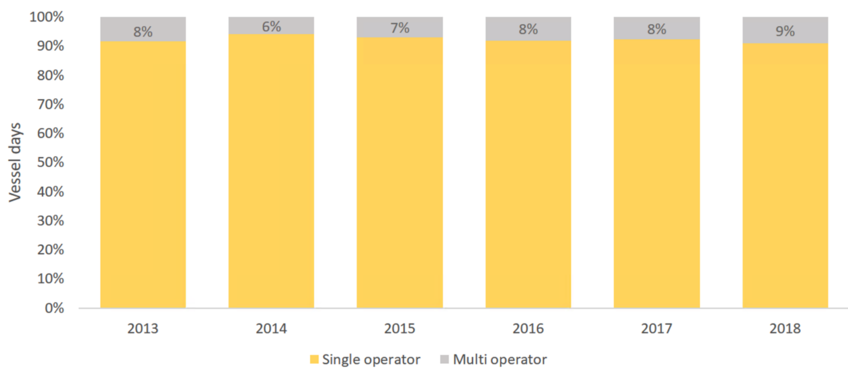

Figure 6.23: Share of vessel days spent on voyages with single (yellow) and multi (grey) operators

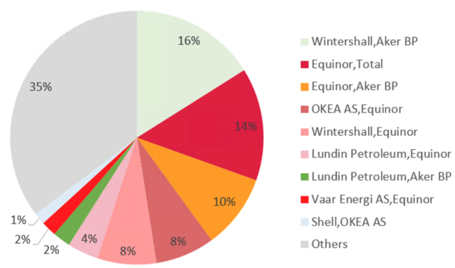

Figure 6.24: Pie showing total vessels days spent on multi operated voyages divided between operator collaborations

6.2.4 The NCS Installations

In this part of the study, we will focus on OSV activity related to production platforms and drilling rigs respectively, meaning that only the on site voyages will be included. In general, drilling rigs have more fluctuating and uncertain demand for supplies than production platforms, due to the complex nature of offshore drilling operations (Aas et al., 2009). The installation types also differ in the type of support needed. A general assumption is that platforms are mainly dependent on PSV support whereas drilling rigs are the main driver for AHTS activity but also dependent on support from PSVs.

Platform support

Figure 6.25 shows the average number of PSV visits per field centre each month. A visit differs from a voyage in the way that *one* voyage consist of several visits when servicing multiple field centres without returning to shore. The number of visits is found by counting the number of unique voyage ids observed at each field centre. If a field centre is visited twice on the same voyage this will only be counted as one visit. The analysis shows that the average fluctuates each month, with peaks often observed during the summer months. By calculating the monthly average for each year (grey line), we observe that the mean required support varies between 11 and 8 PSV visits each month per field centre. Note that only the 8 last month in 2013 is included, probably increasing the average as the low activity months of Q1 is excluded. Comparing 2015 with 2017, the model estimates that about 1 to 2 PSVs less per month were used in the latter year.

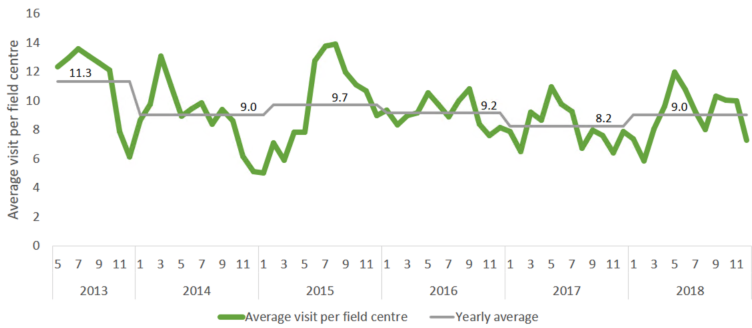

Figure 6.25: Monthly average number of visits of PSVs per field centre each month (green) and each year (grey)

From Section 2.1 we know that the required support varies between fields and installation types. In Figure 6.26 the average number of monthly PSV visits for each field centre is shown. The field centres are divided into three groups depending on the number of off-shore beds. The field centres with green bars are those with less than 50 beds located at site, while those with light and dark blue bars are field centres with 50-200 and more than 200 beds at site respectively. Gullfaks A, B and C are found to be the most PSV intensive field centres, with Gullfaks A requiring an average of 20 visits per month. The unmanned installation at the Embla field, mentioned in the Ekofisk study, is found in the lower part of the chart, with less than 5 visits per month.

In Figure 6.27 we aim to study the characteristics of the vessel days spent on site. The figure shows the average number of hours spent in the *on site*-zone per voyage sailed by PSVs. This is not distributed on each field, meaning that voyages servicing several field centres without returning to shore probably will have a higher duration on site. Further-

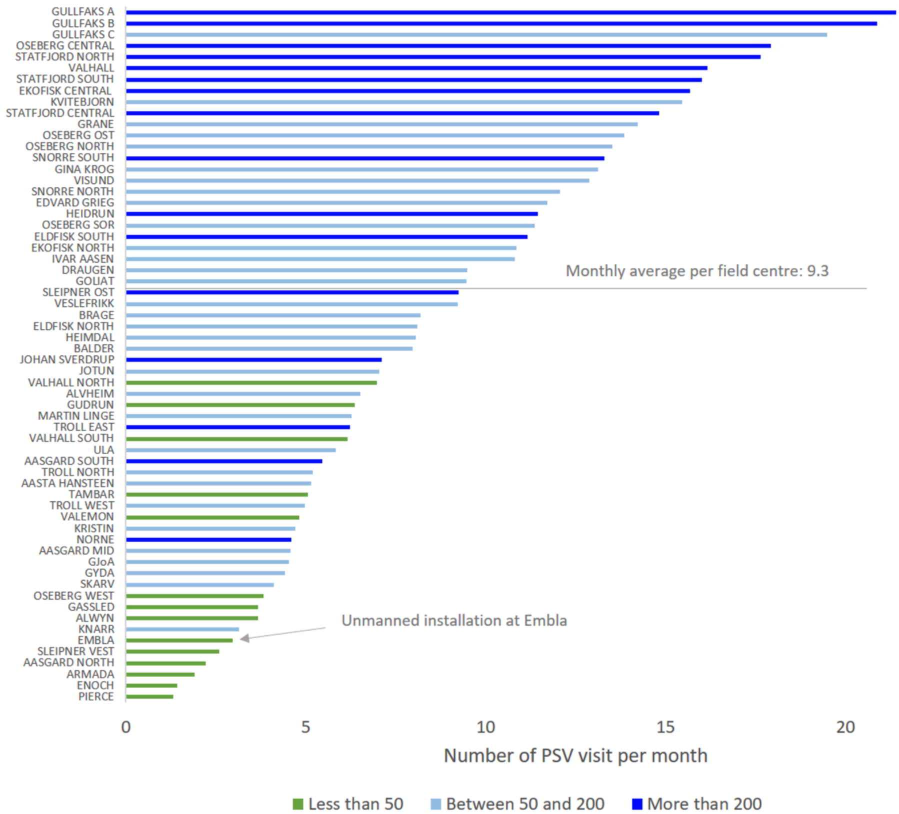

Figure 6.26: Monthly average number of PSV visits for each field centre with colour coding indicating number of offshore beds at each field centre

more, are the time spent on site divided between the active and waiting zones. Recall from Chapter 5 that the on site definition is divided into active and waiting, where active positions are located within 500 m from installations and waiting between 500 m and 2 km from installations. Results from the model show that about 10 hours are spent inside the safety zone each voyage and the time seems to be fairly stable during the entire period. The time spent in the waiting zone fluctuates more heavily but seems also to be centred around 10 hours. If anything, there seems like the time spent in the waiting zone have increased when comparing 2014/2015 with 2017/2018.

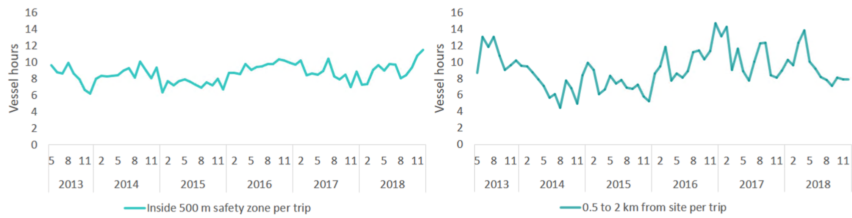

Figure 6.27: Monthly average vessel hours spent in the safety zone (left) and in the waiting zone (right) of platforms by PSVs

Rig support

With rigs being dependent on support from both AHTSs and PSVs, this section will include both vessel types. Figure 6.28 shows the monthly average number of PSV and AHTS visits per active rig. The average values were found by counting the number of unique voyage ids visiting each rig each month and divide the total count of visits on the number of *active* rigs in each month. The rigs were defined to be active in the months where PSVs were observed servicing the rig. This is based on the assumptions that a rig cannot operate without supplies and support from PSVs. Output from the model indicates that the rigs are visited 10 times a month by PSVs and 1 time a month by AHTS vessels. The number seems to be stable during the entire period.

As seen in Section 2.1, not all drilling units need both mooring and towing support. Some drilling rigs will be able to move by its own propulsion system and stay in place by the use of dynamic positioning (DP). Figure 6.29 shows the monthly average number of AHTS visits for each rig, with colour codes indicating the different rig station-keeping technologies. The rigs on the NCS are found depend on mainly 3 different station-keeping technologies: Mooring, DP and jack-up legs. We notice that all moored rigs in the data set, except from one, are visited more often than the average, the support need of DP rigs varies a lot within the group and that all jack-up rigs are visited rarer than the average.

In Figure 6.30 the number of AHTS visits have been grouped together by station-keeping technology. The model shows that rigs depending on anchors for station-keeping require about 2-3 AHTS vessels each month. Jack-ups rig require least with an average of less

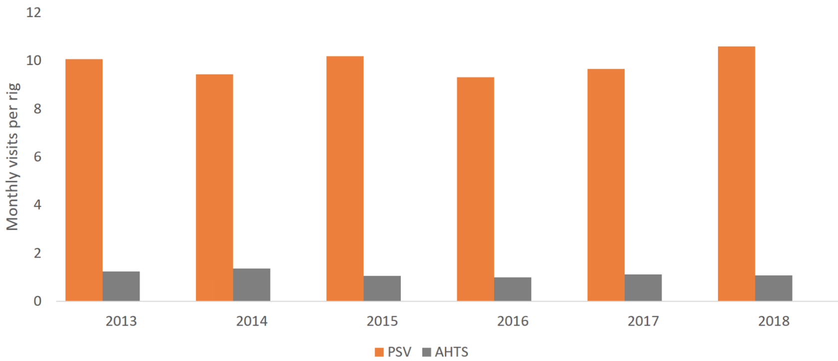

Figure 6.28: Monthly average need of PSVs (orange) and AHTS vessels (grey) per rig each year

than 1 per month.

In Figure 6.31 we are studying the PSV activities related to the drilling units in the same manner as what was done for platforms (Figure 6.27). The chart to the left shows the time spent within the safety zone while the right chart shows time in the waiting zone per PSV voyage. The time spent within the safety zone remains fairly stable around 6/7 hours per trip over the entire period. The time spent in the waiting zone seems, however, to have been reduced. When comparing 2013/2014 with 2016/2017 a reduction of 55% is found.

6.3 Case Study Summary

In this chapter a case study investigating the potential of the model has been conducted through several sub-studies. Other than providing model results used for evaluating the model in Chapter 7, the aim of this case study was to outlay the potential applications and insight such a model as the one developed in this thesis can provide.

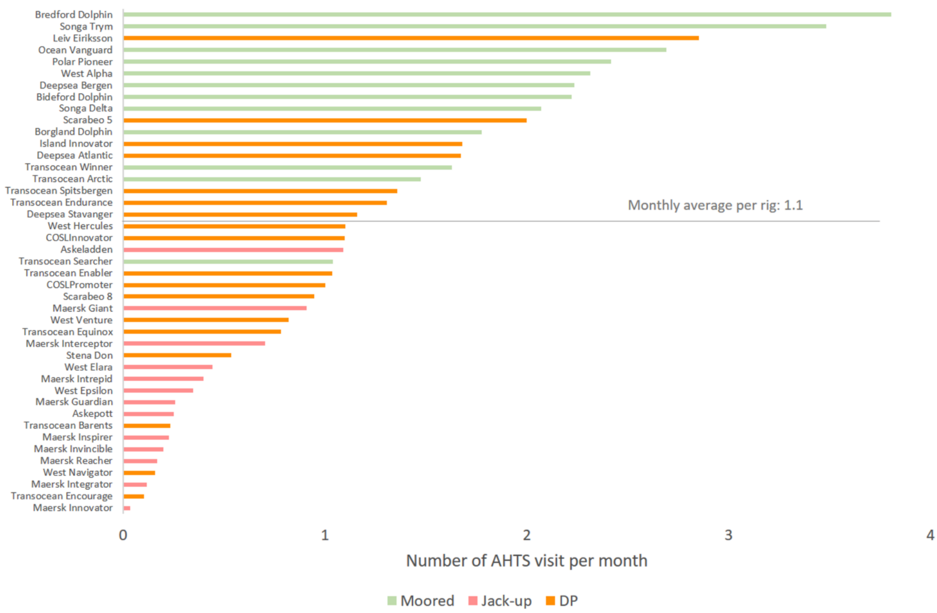

Figure 6.29: Monthly average number AHTS vessel visits for each active rig with colour coding indicating the rig station-keeping technology for each rig

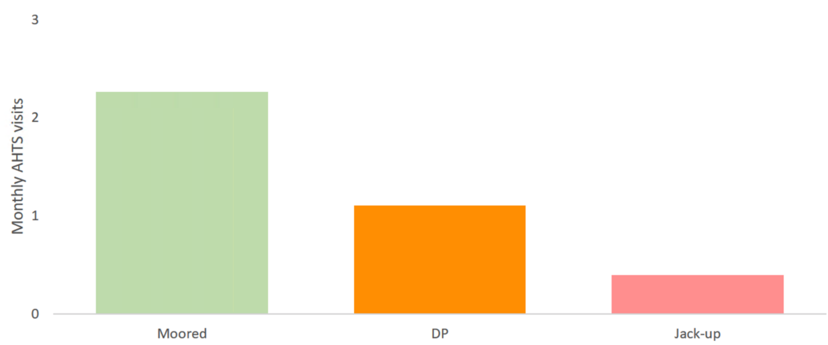

Figure 6.30: Monthly average AHTS vessel need per rig for each rig type, grouped by station-keeping technology

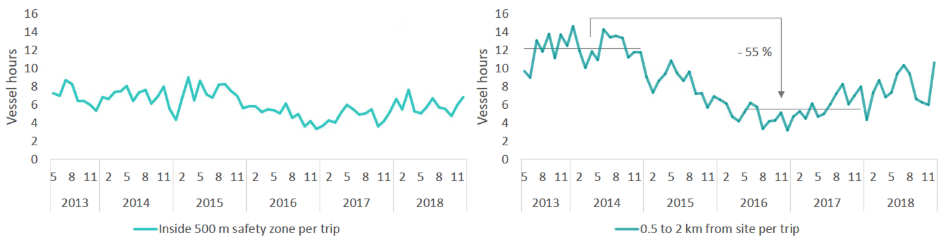

Figure 6.31: Monthly average vessel hours spent in the safety zone (left) and in the waiting zone (right) of rigs by AHTS vessels

Chapter 7

Discussion

The chapter will be organised in three main parts: Firstly, the case study results are discussed and evaluated, secondly, the assumptions and methodology building up the model are discussed and lastly, the chapter is summed up and commented in the light of the thesis objectives.

For readability the thesis objectives, as presented in Section 1.3, will be repeated here:

The main objective of this thesis is to investigate whether AIS data coupled with market data from the oil and gas industry can be used to understand offshore support vessel activities in order to gain more insight into the sector from a region, operator and field point of view in different market situations.

7.1 Discussion of Case Study Results

The case study conducted in Chapter 6 indicated that the model developed were able to capture some of the known and expected characteristics of OSV operations. However, the study also showed relevant OSV activities not being recognised by the model and indications of erroneous activity assignments. No solid data sources have been available, but annual reports, news articles and general industry insight have been used to evaluate the model results.

7.1.1 Discussion of the Micro Study Results

The Ekofisk study illustrated the different attributes of the model together with the model's capability of capturing OSV activities on a field level. The Ekofisk field was analysed as two separate field centres; North and Central. The activity levels, both in terms of vessel days and number of voyages, identified the central field to be most OSV demanding. This is considered to be in line with the reality as the central field has more installations and beds located at site. However, the voyage plotted in Figure 6.8 was shown to be defined as servicing both the north and central part of the field, while the positions indicated that the vessel only serviced the central field centre. Based on this it is uncertain whether the voyages defined to visit the two field centres (see Figure 6.2) actually were servicing both or if positions were assigned to both centres because the vessels were located within a certain distance. With this in mind, it seems that the only result we can see for sure is that the central field centre is serviced more often than the northern one, but that a large part of the voyages have unknown destinations, in terms of which Ekofisk field centre they visited. We cannot be sure if the voyages actually serviced both, only the northern or only the central part of the Ekofisk field. This type of issue will, however, only be encountered when field centres are located within a certain proximity from each other.

Furthermore, it was found that the activity on the field varied each month following the seasons, with most activity being present during the summer months. This is also likely to be correct as larger projects often are executed during the summer months when the weather is more likely to be calm. During the period of study, 2013 and 2018 were the most OSV intensive years at the Ekofisk field. No data is found on why the activity was reduced from 2014 to 2017, but there are reports of a larger decommissioning phase taking place in 2017 and lasting until 2022. This is likely to explain the increased PSV levels in 2018. AHTS activity was only observed at the field in 2013 and 2014. Possible events explaining the presence of AHTS vessels were found and presented, strengthening our trust in the results. When studying the sailing pattern of the voyages headed to the field in Figure 6.5, some abnormalities were observed. There were e.g. no voyages visiting the field during January 2015 and during some of the months the time spent to site is multiple times the time spent on returning to shore. This cannot solely be explained by site-to-site transit as the voyages are mainly observed visiting Eldfisk and Embla which are located with approximately the same distance from shore. The reason may be that the vessels leave from Tananger and then head back to the port in Denmark (see Figure 6.6), but it is also likely to be a consequence of the gap-filling method. This issue will be further discussed in the final part of this chapter.

7.1.2 Discussion of the Macro Study Results

The general NCS Activity Study

A tendency of decreased OSV activity during the period of study was observed. With the number of production platforms and the number of offshore beds increasing in the region (see Figure 6.13), the activity reduction may be seen as a consequence of the low oil price environments, which is well in line with industry observations[1,2]. From the motivation section (Section 1.1) we know that the oil companies have reduced their exploration activities and hence their need for drilling rigs, significantly during the downturn. This can also be seen in Figure 6.12 by both the evolution in the number of contracted rig days and

[1] https://www.dn.no/oljeservice/solstad-offshore-skriver-ned-for-milliarder/2-1-554751(04.06.2019)

[2] https://e24.no/energi/oljebremsen/offshore-skip-for-over-20-milliarder-i-opplag/23608017 (04.06.2019)

the offshore rig days from the AIS data. With rigs being the main source of employment for AHTS vessels (Kaiser and Narra, 2014) the decrease in AHTS *on site* vessel days as seen in Figure 6.12 is nothing but expected. During the downturn, a reduction of 40% is observed in the *on site* vessel days from this vessel type (comparing 2014 with 2016).

There have, however, been reports that also the PSV market has led significantly during the downturn. Seaborakers reported already in August 2015[3] that 40 PSVs were stacked in the North Sea alone and that several vessel owners were struggling to survive due to low vessel rates. The model does however only indicate a reduction of about 10% in the vessel days spent on *on site*-voyages by PSVs. PSVs are mainly supporting already existing production units, and as seen this base have increased during the period. PSVs do however also provide supplies to drilling activities and the 10% reduction may be due to the reduction in the number of rig days. The suffer felt from the PSV owners may be due to a combination of oversupply[4,5] and less work available, rather than a large structural shift in the PSV demand. Another finding may be that the operators, due to the focus on reducing costs, have been able to charter vessels on more precise contracts. Meaning that the vessels perform the same amount of work, but on shorter contracts. To further evaluate this, one would need to have access to vessel contract data.

About 75% of the time spent offshore by PSVs were recognised as belonging to one of the infrastructures in the data set. For the AHTS vessels, this was only true for about 40% of offshore vessel days. This may indicate that the platform data is more complete than the rig data or that AHTS vessel operations are not as connected to the given infrastructures as what the PSV operations are. There are larger uncertainties connected with the rig data since their movements are more complex than the still-standing production platforms. Also, the rig data is daily forward filled positions. This means that if an AHTS is towing a rig this activity may not be recorded as the rig is defined to have the same position during the entire day while the AHTS vessel is moving. Information on how the daily positions are gathered is not provided, meaning that the positions may be daily averages. If so, it will be hard to capture all cases where the vessels and rigs are connected. To fully understand the AHTS activity data sources containing information on subsea infrastructure should be included and the rig AIS data should be of a higher frequency.

The NCS OSV Fleet Study

The NCS OSV fleet study aimed to describe the composition of the fleet servicing the NCS offshore oil and gas activities. The distribution of offshore messages sent from the fleet (see Figure 6.14) indicated some vessels being offshore 365 out of 365 possible days in 2018. The remaining part of the fleet consisted of a larger portion (about 30% of the

[3] `https://www.seabrokers.no/wp-content/uploads/Seabreeze-August-2.pdf`, (03.06.2019)

[4] `https://www.osjonline.com/news/view,uk-north-sea-psv-market-at-risk-of-shooting-itself-in-the-foot_56750.htm` (03.06.2019)

[5] `https://www.osjonline.com/news/view,area-report-north-sea-road-to-recovery-blocked-by-oversupply_54272.htm` (03.06.2019)

fleet) of vessels observed offshore 250 to 100 days, while the remaining 50% of the fleet were observed less than 100 hours on offshore voyages during 2018. Vessels being on offshore voyages 365 out of 365 possible days is not considered likely. Even standby vessels are required to go back to shore at least a few days a year for maintenance purposes (Aas et al., 2009). The over-count of offshore messages may be a consequence of the gap-filling method. The large portion of the fleet with few messages may be explained by the multiple reports of vessels being stacked during the downturn.

Furthermore, 65 PSVs and 17 AHTS vessels were identified as the average fleet size required for servicing the region. These numbers are however likely to be too low as the winter months, with low activity levels, are included in the calculations. In any case, the structure of the OSV demand forces the fleet to have a certain amount of overcapacity during the winter season, as operators tend to do most of their work during the summer. Also, due to the high value of keeping the production from the NCS facilities at maximum uptime, the OSV fleet is not designed to handle average demand with queuing of jobs, but rather to handle demand peaks (Aas et al., 2009). The value of stopping production or drilling operations due to non-sufficient supplies is much higher than the day rate of PSVs and AHTS vessels.

In Figure 7.1, Clarksons Platou (2017) has analysed the contracted utilisation of both PSVs and AHTS vessels in the North Sea from 2009 to 2017, where a reduction in utilisation of both vessel types can be observed. Although the contracted utilisation decreases this does not imply that the working utilisation must follow. As discussed in the previous section, the operators may have been able to optimise the contracts, leading to the same vessel activity but for fewer contracted days. When we analysed the working utilisation with the model, a decrease of about 15% was observed when comparing 2014 with 2017 (Figure 6.16), meaning that the model does not necessarily indicate that an optimisation of the vessel contracts can fully explain the suffering felt by the vessel owners. Furthermore, we observe that the utilisation numbers are not equal which can be explained by the difference in working and contracted utilisation. It should also be mentioned again that the utilisation is defined to be 100% if all the 367 vessels observed in the AIS data are working, neglecting the rest of the 443 vessels that initially were defined as the relevant OSV fleet. Thus, the magnitude of the reduction is not certain and probably very sensitive to the way the working and total fleet is defined. The case study defined the working fleet to be all vessels observed further from shore than 10 km. It is not unlikely that vessels moving between ports will sail further than 10 km from shore, and thus be considered as a part of the working fleet.

The last part of the vessel study showed that the younger part of the fleet is doing a larger portion of the work in 2018 compared with the previous years (see Figure 6.17). There have been mixed expectations on how the age of the fleet would evolve during the downturn. Some have argued that with low vessel rates operators are more likely to chose a modern but still relatively cheap vessel. Others state that in periods where cost efficiency is a priority the operators would go for the cheapest vessels capable of performing the job. Another factor that may explain why the second theory does not seem to hold is that new

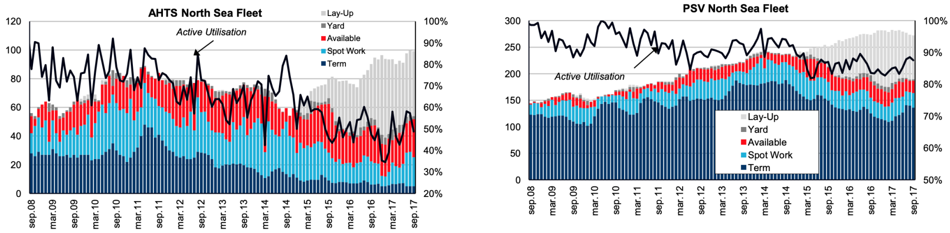

Figure 7.1: Contracted fleet utilisation (black line) presented by Clarksons Platou. Obtained from Clarksons Platou (2017)

builds will often be delivered with an existing contract in the other end, forcing the older part out of the fleet.

What must not be forgotten regarding this study is that the AIS messages are extracted for a predefined set of vessels, making out the so-called fleet. The results will therefore only be capable to quantify the vessel utilisation and estimating the required fleet size on the NCS if the predefined fleet includes all vessels servicing the region. This study can, however, be used by e.g. vessel owners to analyse the operations of a given set of vessels.

The NCS Operator Study

Equinor and Aker BP were found to be the two major operators on the NCS with Equinor being assigned almost three times as many vessel days as Aker BP. The remaining vessel days are shared between multiple smaller (in terms of vessel days) operators. Equnior's position is well in line with the real situation as Equinor in 2018, according to Rystad Energy UCube, produced almost 75% of all the resources coming from the NCS (see Figure 7.2). In line with the model results, the remaining resources are produced by a large group of smaller (in terms of NCS production) operators with Aker BP being the most important one.

Equinor and Aker BP were found to have quite similar sailing patterns. Aker BP spent a slightly larger portion of its vessel days on site compared to Equinor. On the other hand, Equinor was observed with a slightly larger portion of its vessels days in transit between different sites. This may indicate that Equinor is more efficient during the offshore off/on-loading operations or that the company have longer sailing distances to reach sites. Also in this study the time spent *to* site is observed to be somewhat larger than the time spent *from* site for both operators. The situation may be that the companies' sailing routes are of such a character that site-to-site transit stands for a part of the site-to-shore transit. This can be the case if the routes are servicing other field centres on the way back to shore. The uneven distribution of transit segments may also be an effect of waiting times. Recall that the shore-to-site segment will include all the time spent from the beginning of a voyage and until the first *on site*-observation. In some situations, the vessels will have to wait before they are allowed to perform their work tasks. This can be due to events such as delays

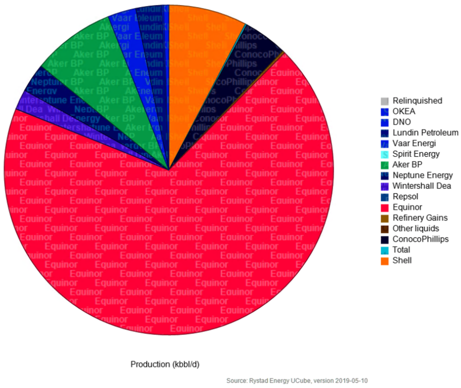

Figure 7.2: Resources produced on the NCS in 2018 by operator

or unsafe weather conditions. Vessels can be seen leaving supply bases in heavy weather with the aim to time the arrival at site with the beginning of a weather window. As the weather in the North Sea may change quickly and is hard to predict correctly, situations forcing vessels to wait offshore may arise. Figure 6.5 from the Ekofisk study supports this theory as the shore-to-site segment is observed to increase its share during the winter months. Still, this may also just be another consequence of the gap-filling method.

Output from the model showed that Equinor has reduced their monthly vessel days with about 150 days during the summer months when comparing 2013 with the following years (see Figure 6.21). Since the reduction also is observed during summer 2014, this reduction is not assumed to be explained by the oil price downturn. The timing coincides well with the reported change in Equinor's sailing routes. The reduction seems to be due to reduced time spent on site and transit between sites, and not from transit between shore and site. Looking at the changed sailing patterns in Figure 6.20 the distances between sites visited on the same route seems to have been reduced, supporting the results from the model.

The definition of the *on site*-segment stretches 2 km out from any installation and includes all speed values. This means that the site-to-site segment will not be recorded before the vessels are located further than 2 km away from the installations. The same will happen when approaching a second site; the recording of the site-to-site segment will end when the vessels are closer than 2 km to the new installation. This means that the site-to-site segment will be assigned a too low portion of the total voyage-time. This will not have any impact when comparing the time spent in the segment from year to year or between operators, as the definition will remain the same. However, it will have an effect on the magnitude of hours spent within this segment and the distribution between the segment legs.

The time spent in the segment sailing between sites increased in 2018, almost back to 2014 levels (Figure 6.22). The increase was mostly driven by Equinor, Aker BP and ConocoPhillips. With Aker BP being established in 2016 as a merger between BP Norway and Det Norske Oljeselskap[6], the increased vessel days in this segment may be synergies resulting from this merge. Comparing operators over several years, as done in Figure 6.22, may be challenging as the sector is affected by mergers and acquisitions. The operators used in this study is always the current operator name. This means that Aker BP will be used as the operator name for installations that actually were operated by BP Norway and Det Norske Oljeselskap before the merger took place. When studying the vessel days spent within this segment for each operator, as done in Figure 6.22, it should also be noted that if a voyage is found to have multiple operators, the site-to-site time will be counted multiple times; once per voyage operator.

However, in Figure 6.23, it is shown that less than 10% of the yearly voyages are defined to have multiple operators. In further analysis of the multi-operated voyages (Figure 6.24) no evident collaborations are identified. The voyages seem to be operated by a large variety of companies, with Equinor being observed in collaborations with multiple operators. Sharing OSV fleet is assumed to be a somewhat complex logistical issue rather than a coincidence as the model seems to indicate. One of the few vessel sharing agreements that have been discovered when browsing through news articles, is an agreement between BP Norway (now Aker BP) and Equinor in 2015. This vessel sharing consisted of one vessel supplying both the Skarv and the Norne field[7]. Other than that, these results are assumed to be uncertain as the allocation of voyage operator is solely based on the position group assignment with no further evaluation. It should also be kept in mind that as the model does not include a dynamic operator status, there may be missed events of voyages with multiple operators in the cases where two companies have merged into one during the time period covered by the study.

The NCS Installation Study

The model showed that on a yearly average the production platforms on the NCS require about 9 PSV visits per month. As discussed in Section 2.1, the need of support vary among the different installation types and especially with the number of offshore beds, as more people require more supplies. This seems to be captured by the model as the field centres with most beds also are the ones that are visited most frequently (Figure 6.26). For rigs, model results showed that about 1 AHTS vessel and about 10 PSVs were needed per month. The model showed that the most AHTS intensive rigs were those that depend on mooring for station keeping and that jack-up rigs required the least amount of AHTS-support with an average of less than 1 for every second month. The process of lowering the jack-up legs can be challenging and time-consuming. It was therefore not expected that jack-ups would be the rig type with less AHTS demand. However, the case study investigates the *number* of AHTS visits and not the vessel days spent on operations. Another explanation may be that, as jack-up rigs are applicable for drilling operations on wells

[6] https://www.akerbp.com/historien-om-aker-bp/ (30.05.2019)
[7] https://petropuls.no/index.php/13-nyheter/185-to-er-blitt-til-en, (01.06.2019)

located underneath fixed installations[8], they are more often used for longer development drilling, intervention or plugging campaigns. Fewer rig moves are expected under such operations than for exploration drilling, where the rigs are towed between each well location.

One of the more challenging parts in these studies was to define the number of rigs to take the average of, especially when studying the AHTS need per rig. First, it was assumed that the number of rigs visited each month by AHTS vessels would be the right proxy. This was found to generate a too high number of monthly visits as the months where the rig was kept in place, not needing AHTS support, were excluded. The number of active rigs was then decided to be the number of rigs visited by PSVs each month, as it was assumed that all active rigs would depend on PSV support each month in order to maintain operations. One could also have defined all rigs with a certain distance from shore to be active. However, the forward fill methodology has also been used on the AIS rig data and PSV visits were therefore considered to be a more accurate measure.

The average number of both PSVs and AHTS vessels required per rig and platform remained fairly stable during the period, even though the activity level has decreased. This makes sense as each operation still will need the same amount of support. Only if the oil companies have put some efficiency measures to play, this average could be reduced. However, it is probably more likely that increased efficiency can be observed in the *time* spent on operations rather than in the number of vessel visits each month. The time spent by PSVs in what has been referred to as the waiting zone in this thesis (500 m to 2 km from installation) around rigs seems to have been reduced noticeably. Over the same period in 2013/2014 and 2016/2017, a time reduction of 55% was observed. If the time spent within this zone can be interpreted as waiting time, the results indicate that the PSV-rig operations have become more efficient during the downturn. For platforms, the case study did not identify any such efficiency signs. Tests should, however, be conducted before relying on these efficiency numbers as they probably are very sensitive to the definition of the waiting zone. Also, the size of the vessels servicing the installations has not been included in these analyses. If the vessels have become smaller, but the number of visits remains the same, there may have been some efficiency in the operations as the capacity of each vessel is likely to be better utilised.

The numbers presented in this study are relying on the fleet data to be complete. If that is not the case, the numbers only indicate how many visits are needed from the fleet at hand and not the actually required support per installation.

7.2 Methodology

Numerous assumptions have been made during the process of developing the model presented in this thesis. The impact of the most important assumptions will be discussed in

[8] https://petrowiki.org/PEH:Offshore_Drilling_Units#Picking_the_Right_Unit_for_the_Job (03.06.2019)

this section.

7.2.1 Model Variables

The model depends on several proxy decision variables for determination of vessel events. As the model is based on analysing voyages created by connecting these vessel events together the robustness of the model is sensitive to the choice of these proxy variables. The most crucial variable is the one defining the *on site*-events. On site-events are used to identify the destination, operator and sailing pattern of the voyages. If a position is wrongly categorised the entire voyage will be connected to both the wrong field centre and operator in addition to a misleading sailing pattern being assigned to the voyage. An example of this is observed in Figure 6.8 where the voyage has positions defined to be on site on both field centres at the Ekofisk field. By analysing the positions closer it seems more as if the voyage only is servicing the central part of the field. The wrong position assignment seems to happen due to the two field centres being located relatively close to each other, about 2 km. This issue could have been solved by making the on site definition more strict. The requirement could be set so that the voyages must include positions within the safety zone of an installation in order to be categorised as *on site*-voyages. However, from the same figure (Figure 6.8) we observe several positions being located further from the installation than 2 km that seems to be a part of the working pattern. In addition, in real-life, the safety zone is defined to be 500 meters from *any* point at an offshore installation. In the model, the safety zone is defined as 500 from the given longitude and latitude coordinates of each installation. The modelled safety zone is thus likely to be too strict, as the size of the installations them self are not included. Also, a vessel may be supporting the field centre without being inside the safety zone. This holds e.g. for standby vessels that are used, among others, for guarding the safety zone.

To avoid categorising vessels just sailing by as on site-events, a duration variable is also introduced. If the duration requirement was increased some of the positions in Figure 6.8 defined as on site at the northern field centre may have been avoided. However, with the installations on the NCS, usually, located quite far from each other, vessels being located close to site for more than two hours are likely to work on that field. To overcome this issue a third parameter, taking into account other nearby field centres or rigs, before assigning the on site positions could be considered.

A second important variable is the parameter distinguishing *at shore* and *offshore* events from each other. The events are distinguished from each other by the use of a distance to shore parameter. In the NCS OSV fleet study, the definition of the active fleet, and hence the results, are dependent on this variable. If the distance is set to be too large OSV activities located closer shore would not have been included, but by setting the variable too low one risk to include voyages that in reality only are e.g. displacements between ports. To evaluate how sensitive the results from the case study could be to changes in this parameter the maximum distance on each *offshore other*-voyage was analysed. This is shown in Figure 7.3, where 100% represents the total number of *offshore other*-voyages during the entire period. The voyages are grouped based on their furthest position from shore. We see that about 70% of these voyages have positions further from shore than 20 km, indicating that the vessels are headed offshore and probably should be included as a part of the active fleet. However, we also observe that about 10% of the voyages barley passes the 10 km limit used in the model, and are probably not a part of the active fleet.

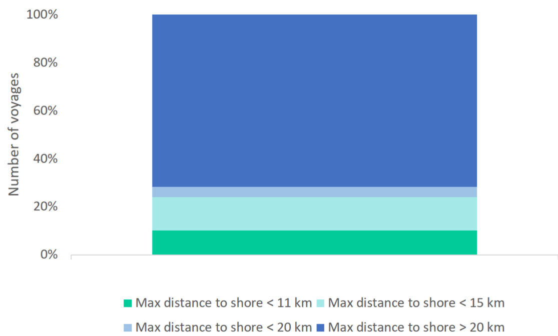

Figure 7.3: Distribution of maximum distance from shore on voyages with unknown destinations

A third model parameter is used to categorise positions located at supply bases. For the scope of this thesis, and the analysis conducted in the case study, the parameter will not affect the results in any large ways but should be kept in mind if the model is to be used for port activity investigation.

The way of analysing the activity levels is chosen so that the variables would have the least power over the results. It was first considered to study vessel activity as the time spent inside the safety and waiting zone, i.e. only the time spent within the distance of 2 km from any installation. These studies would have been largely dependent on the choice of distances. The way activity is analysed now the results only depend on the distance parameters for identification of the voyages to be included in the analysis. All vessels days from these voyages are included, meaning that changing the model parameter form e.g. 2 to 1 km is not likely to affect the results as much as if only the time within the zone were studied. As vessels on contract are operated by the oil companies during the entire voyage, this definition seems to be a more relevant measure for vessel activity. It should be noted that activity in port is not included in any of the activity studies even if loading and unloading also is a part of the OSVs work scope.

7.2.2 AIS Data Quality and Gap Filling Method

From Chapter 4 it is evident that the AIS data are missing reports. The missing data have been referred to as data gaps and is clearly visualised in Figure 6.1 and 6.8 presented in the case study. In these figures, a long stretch with no data points (coloured marks) can be observed on the voyages approaching the Ekofisk field from the Norwegian coast. Missing observations are observed on the same location for all the voyages during March

2018 and indicate low coverage on this exact location. These kinds of errors may impact the results, especially if low-coverage regions are found closer to installations, causing *on site*-positions to not be recorded.

The data gap issue has, in this thesis, been met by the use of a simple forward fill method. With this method, the model will assume that the vessels are located on the exact same position until a new report indicate something else. In transit segments, this method will in most cases assign erroneous positions. This can be observed in Figure 6.8. Right before and after the long stretch with no recordings, several recordings at the exact same spot is observed. Messages with the exact same location are identified by darker dots, as each data point is shown with transparency. The vessel in Figure 6.8 is obviously in transit before the gap and there are no reasons for the vessel to suddenly stop. A more clever gap-filling method, interpolation, could have been used. Then the missing positions would have been spread along the area with no records. However, as we in this analysis base activity measures on the time spent on the entire voyage and in each segment, smaller gaps where the operational status before and after the gap is identical will not affect the results.

If data is missing over a period where the vessels change their operational status, the forward fill method will, however, affect the results. This may be what has happened when we in the case study saw vessels being on offshore voyages 365 out of 365 days a year. If a vessel is headed to port, and the last report received before the vessel turns off its AIS transmitter is part of an offshore voyage, the model will define the vessel to be on this voyage until a new data point is recorded. In the most severe cases, the vessel may have been scraped and the model will assume the voyage to continue. As the analysis define activity as the time spent on offshore voyages, such cases may disturb the results significantly. A way to avoid this could be to only count the hours spent outside the 10 km line for each voyage. This will however only exclude the cases where the last observation is within the 10 km line. Another issue is if field centres or rigs are located within a region with low coverage. Such cases may lead to *on site*-positions not being recorded at all so that voyages are defined as *offshore other*-voyages while they, in reality, support the installations in the infrastructure data. Another case may be that the transition between two segment groups is not be recorded immediately, leading to an erroneous distribution of segments. Such errors can explain the instability of transit times to and from site as were observed in Figure 6.5.

Wrong position and voyage assignment may not only happen due to data gaps but can also be a consequence of the hourly data frequency. There may be situations where the vessels have time to change their operational status *and* turn off the AIS transmitter within one hour. If a vessel turns off its AIS transmitter within one hour after e.g. approaching port the vessel's location at port will never be recorded. This issue can be met by increasing the data frequency as it is unlikely that the vessel will have time to enter the 2 km zone of a supply base (defined as *At base*) and turn off its sender within e.g. 15 minutes. However, in talks with the industry[9], it was reported that vessels do not turn off their AIS transmitter during loading and unloading at port. It is neither believed that turning off the AIS sender

[9]E-mail conversation with a large vessel owner company (22.03.2019)

will be the first thing done when stacking a vessel. Based on this one can assume that if the coverage is good the vessel will send AIS signals from the *At base* position before turning the transmitter off and thus the forward filling of positions will be correct. It is, however, not certain that increasing the data frequency will help solve this issue as coverage may be weak in some shore regions. Shelmerdine (2015) discovered that some areas near Shetland had low coverage due to high elevation of land blocking AIS signals to the receivers, called shadow areas. If this was observed on Shetland it may also be found in the Norwegian fjords.

As most of the data gaps were found to be less than 5 hours (see Figure 4.7) the erroneous positions will only last for a few hours before they are updated with a new correct position report. If the data gaps occur randomly in time and space one may assume that one or two hours with wrong positions may not impact the results significantly. Problems will, however, arise if the data gaps follow a specific structure such as no AIS messages being collected from one area avoiding important activities to be recorded. In any case, it would have been desirable to obtain data with better coverage and extract data at a higher frequency. If not possible a more intelligent filling method could have been used and is considered as a low hanging fruit for the shorter gaps.

7.2.3 Infrastructure and Fleet Data

Even if the model parameters are set to describe the real world perfectly the results will not be good if the data sources the model is based upon are not complete and accurate. In this study, we have mainly used four data sources in addition to the vessel AIS data. These are the data sources containing information about the platforms, rigs, supply bases and the fleet. Out of these, the rig information is considered to be the most uncertain and complex source. Supply bases and production platforms are fixed in space over medium time periods, as in this study, whereas offshore demand from drilling rigs are from variable locations (Kaiser and Narra, 2014) making the process of locating the rigs in space and time much more complex.

Since the rig data is obtained from AIS signals sent from drilling units all uncertainties and issues regarding the AIS data discussed in 7.2.2 also applies to this source. Information on how the daily rig positions are extracted is not provided, thus we do not know if we are working with average positions or an actual position from a certain hour each day. If the given positions are the average values, recording vessel activity at this location at all may be hard and somewhat arbitrary. The dynamic aspect of the rigs makes it also more difficult to assign field centres to the rigs' positions. This means that the analysis based on field centres, such as the Ekofisk study, will not include the voyages only assigned to rigs located at the field. However, if rigs are located at a field centre it is seen, from e.g. Figure 6.8, that some of the positions are likely to be assigned to one of the platforms located at the field centre which then automatically will assign the entire voyage to the field centre. For the same reason, it may be challenging to study voyages headed to rigs and platforms separately as done in the NCS installations study. The positions will be defined as on site whatever installation type they are closest to. It is not hard to imagine situations where e.g. an AHTS vessel is working on mooring a rig close to a platform and at some point during the voyage is located closer to one of the platforms than to the rig. This will define the voyage to work on the platform as well as the rig, while it in reality only supported the rig mooring process. Based on this it is hard to know whether the PSV per rig relationship found in the NCS installations study actually is representing that, or if several of the PSV-rig observations actually just were PSVs supporting nearby platforms. This may also be the reason for why the PSV time spent inside the waiting zone of a rig has been reduced. With fewer rigs being located at field centres, there are fewer incidents where PSV-rig events are recorded per trip and therefor the time inside the waiting zone has decreased.

The fleet data is also a key part of this study that needs to be complete in order to trust the results. The completeness of the data is decisive for the model's capability to estimate the general activity in the region on all levels. If the fleet data does not include all vessels servicing the region one aim to study, the analysis cannot convert the *observed* activity levels to *required* activity levels. The way the fleet is defined in this study may exclude vessels that usually not have been working on the shelf, but are introduced due to e.g. low vessel rates. The introduction of new vessels into the market as a consequence of changed vessel rates is probably more likely to be observed in other regions. The fleet of vessels capable of operating on the NCS are likely to have been built to work in this region, due to the challenging weather conditions, and therefore likely to be included in the pre-defined fleet (see Appendix C). However, this effect should not be excluded and proper ways to ensure that AIS messages from the entire fleet are included should be developed. In our study, we also encountered the issue where about 15% of the fleet defined as relevant did not have any messages in the AIS data. Work should be done to identify these.

The quality of the platform and supply base data is less discussed as the platform data is considered to come from a reliable and complete source and the supply data does not affect any of the results in a large way. If the model is to be used to estimate port activity the supply data must also be complete and the variable identifying *at base* events should be reviewed.

7.3 Discussion in Light of Thesis Objectives

The thesis objectives can be divided into 3 sub-objectives where the first one is to answer whether AIS data coupled with market data from the offshore oil and gas industry can be used to understand the OSV activities. Even if the micro case study showed some voyages being assigned wrongly and others not being recorded as activity at all, the overall impression is that we are able to connect vessel days to fields and identify the presence of different vessel types at site. On a general level, this can be translated into understanding OSV activities as we can track vessels voyages and identify when the vessels were active and not. Thus the result from the case study is that, on a general level, AIS Data combined with market data can be used to understand OSV activities.

The second sub-objective is to evaluate whether the understanding of OSV activities can be used to gain more insight into the sector from a region, operator and field point of view. Through the NCS, operator and Ekofisk study we illustrated how this kind of insight can be provided with the model. In all three cases, we saw that with the properties of the model we are able to provide information on all three levels, but that the validness of the results are dependent on the input data. We are only able to provide a complete insight on these levels if the entire fleet and all infrastructure data are included.

The last sub-objective is to answer whether the model can provide insight into the sector in different market situations. With a relatively short time-span and limited data before and after the downturn, this objective was less touched upon. In the NCS general activity study, we saw a reduction of offshore activity during low oil price environments, especially for AHTS vessels, compared to periods with higher oil prices. In the fleet study we also observed a reduction of utilisation, but if this reduction is solely due to low oil prices or an effect of new vessels entering the fleet is hard to know. With longer time spans on both sides of the oil price downturn more analysis regarding this could be done, and hence it is considered that the model itself is capable of providing such insight.

Chapter 8

Conclusion

8.1 Concluding Remarks

The main objective of this thesis has been to investigate whether AIS data coupled with market data from the offshore oil and gas industry can be used to understand offshore support vessel activities. Specifically, if understanding the OSV patterns could be used to gain insight into the sector from a region, operator and field point of view in different market situations. Trough the master thesis this issue has been attacked systematically. Relevant literature describing OSV operations and the exploitation of AIS data has been reviewed. Despite the importance of the OSV sector, the literature revealed few studies focusing on understanding and analysing the OSV operations. To meet this information gap a model combining AIS data with other infrastructure sources were developed and tested through a case study focusing on activities on the NCS.

The proposed model was developed by reviewing the literature for necessary methods, especially methods for working with AIS data. Secondly, a deep understanding of the structure of OSV operations was necessary, both to develop the model but also to evaluate the model results in a proper way. As the offshore OSV operations were found to be complex and difficult to identify solely by the use of AIS data, the vessels' distance from infrastructure was found to be a good proxy. These distance calculations were used as a foundation in the development of the model. All AIS messages were given a position group that further was used to reconstruct the sailing routes of every vessel. Each voyage was characterised based on their destination and sailing pattern. To understand the OSV activities these voyages were analysed through a case study providing insight into the operations on the NCS.

Overall, the case study showed promising results as the model were able to capture some of the well-known trends and expectations regarding OSV operations. Some of the results were the model's capability to capture the seasonal variations, the dependency between rig and anchor handling tug supply (AHTS) vessel activity and assigning vessel days to each of the fields on the NCS. There seemed also to be a consistency in modelled OSV activities and the reported operations on a field level, indicating that combining vessel positions with infrastructure data, as done in this thesis, is a good approach for identifying OSV operations. However, the results also shed light on the complexity of the logistical patterns. Especially, it was found hard to distinguish active work from offshore waiting. It was also found that the fleet's activities cannot fully be described solely based on the offshore infrastructures included in this study. Based on the case study results and the discussion provided in Chapter 7 it is concluded that by coupling AIS data with detailed market data from the offshore oil and gas industry it is possible to understand OSV operations within a certain level of detail. Further, it is concluded that by understanding the OSV operations correctly one could gain more insight into the industry from a region, operator and field point of view in different market situations.

Even though the model shows promising results, we acknowledge that the model is far from a perfect description of the real OSV activities. The model has to be further refined and evaluated in order to quantify the activity levels correctly. As is, the model seems applicable for identifying underlying trends and stating the obvious, such as seasonality, activity reduction during the downturn and Equinor being the main NCS operator, more than as to quantify e.g. the exact number of vessel days servicing the central part of the Ekofisk field. We also acknowledge that there are limitations to the research performed in this thesis. This is especially concerning the quality of the AIS data, and the completeness of the infrastructure data. The quality of the AIS data at hand varies and the frequency of the messages was kept low due to processing times. Ideally, a more complete AIS data set with higher frequency for all vessels servicing the fleet should be used. Accordingly, as more AIS data is acquired and the collection reflects a longer part of the history, the potential advantage of using AIS data to understand and analyse the OSV operations increases. Furthermore, to get a wider understanding of the OSV operations data containing subsea infrastructure should also be included.

8.2 Recommendations for Further Work

Further research within the topic of understanding and analysing the operations of OSVs is recommended. Based on the findings in this study, and the relatively unexplored field of describing, understanding and quantifying OSV operations, there is a potential in exploiting the information incorporated in AIS-messages, and especially in combination with other data sources. This study only incorporated production platforms and drilling units, further studies should aim to include a wider part of the offshore infrastructure, such as pipelines and wells. With the inclusion of more infrastructure, adding the remaining part of the OSV fleet into the study, such as construction and pipe-laying vessels, will make more sense. Further studies should also aim to acquire a more complete AIS data set or use more advanced gap-filling methods. It is also recommended to further evaluate the model results, ideally by comparing results with operational vessel data for a selected part of the fleet.

We acknowledge that with the scope of this study being wide, further development in each of the event identification steps should be conducted. The variable identifying port activities may be selected individually for each supply base, the At shore/ Offshore distance may be changed between different regions and the definition of *On site*-events may be further investigated so that only the correct *on site*-events are recorded. Ideally, the model could be of such a detail level that towing, mooring and loading operations could be identified as separate events.

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Appendices

A AIS Data Contents

Detailed information of the AIS messages transmitted by a vessel, as issued by IMO (2002).

A.1 Static Message Information

Table A.1: Information on static messages

Information item	Information generation
MMSI	Set on installation
Call sign and name	Set on installation
IMO number	Set on installation
Length and beam	Set on installation
Type of ship	Select from pre-installed list
Location of position-fixing antenna	Set on installation

A.2 Dynamic Message Information

Table A.2: Information on dynamic messages

Information item	Information generation
Ships's position with accuracy indication and integrity status	Automatically updated from the position sensor connected to AIS. The accuracy indication is for better or worse than 10 m
Position Time stamp in UTC	Automatically updated from the ship's main position sensor connected to AIS
Course over ground (COG)	Automatically updated from the ship's main position sensor connected to AIS, if that sensor calculates COG. This information might not be available
Speed over ground (SOG)	Automatically updated from the position sensor connected to AIS
Heading	Automatically updated from the ships's heading sensor connected to AIS
Navigational status	Navigational status information has to be manually entered by the crew and changed, as necessary, for example: • underway by engines • at anchor • not under command (NUC) • restricted in ability to manoeuvre (RIATM) • moored • constrained by draught • aground • engaged in fishing • underway by sail In practice, since all these related to the COLREGS, any change that is needed could be undertaken at the same time that the lights or shapes were changed
Rate of turn (ROT)	Automatically updated from the ship's ROT sensor or derived from the gyro. This information might not be available

A.3 Voyage Related Message Information

Table A.3: Information on voyage related messages

Information item	Information generation, type and quality of information
Ship's draught	To be manually entered at the start of the voyage using the maximum draught for the voyage and amended as required. (e.g. - result of de-ballasting prior to port entry)
Hazardous cargo (type)	To be manually entered at the start of the voyage confirming whether or not hazardous cargo is being carried, namely: • DG (dangerous goods) • HS (Harmful substances) • MP (Marine pollutants) Indications of quantities are not required
Destination and ETA	To be manually entered at the start of the voyage and kept up to date as necessary
Route plane (way-points)	To be manually entered at the start of the voyage, at the discretion of the master and updated when required.

B List of Vessels

List of vessels defined as the relevant NCS fleet + Maersk vessels. All these vessels are not observed in the AIS data.

	A	B	C
1	IMO Numb	Vessel Name	Vessel Type Group
2	7400807	Ocean Sky	AHTS
3	7400819	Sentinel Prince	AHTS
4	7402544	Ocean Sprite	PSV
5	7404229	Sea Pilot	AHTS
6	7412020	Eide Fighter	AHTS
7	7414262	Sea Meadow 06	PSV
8	7415137	Eide Wrestler	AHTS
9	7434690	Sea Meadow 02	PSV
10	7508881	Eide Traveler	AHTS
11	7814864	Retriever*	AHTS
12	7825473	Ocean Fighter	PSV
13	7905273	NSO Champion	PSV
14	7914470	Diavlos Pride	AHTS
15	8108107	CSC Nelson	AHTS
16	8108781	Beta	AHTS
17	8110992	Gaira Trader	PSV
18	8111001	African Spirit	PSV
19	8116099	Maersk Clipper*	AHTS
20	8116104	Maersk Cutter*	AHTS
21	8119596	Sentinel Ranger	AHTS
22	8119601	Karadeniz Powership Refakat Sultan	AHTS
23	8119649	NSO Fortune	PSV
24	8203141	Thetis	AHTS
25	8204937	Cerro El Centinela	AHTS
26	8204949	Maersk Gabarus	AHTS
27	8206961	Agat Zejt III	AHTS
28	8211863	Eagle Fjord	PSV
29	8213897	Mainport Elm	AHTS
30	8224470	NSO Crusader	AHTS
31	8302088	Lev Twister	AHTS
32	8304816	VN Sapeur	AHTS
33	8316900	Ocean Troll	AHTS
34	8401432	Valiant Energy	PSV
35	8401949	Blue Antares	AHTS
36	8401951	Maersk Champion	AHTS
37	8401963	Blue Aries	AHTS
38	8401975	Maersk Chancellor	AHTS
39	8406470	Normand Draupne	AHTS
40	8406482	GSP Antares	AHTS
41	8409379	Butler Favour	AHTS
42	8409381	Maersk Mariner*	AHTS
43	8501098	Ocean Investigator	AHTS
44	8501103	Karadeniz One	AHTS
45	8516952	Resolve Blizzard	AHTS
46	8912364	FS Taurus	PSV

	A	B	C
47	9000625	Ocean Zephyr	PSV
48	9000637	Tek-Ocean Spirit	PSV
49	9007142	Karadeniz Powership Arda Bey	AHTS
50	9007154	Maersk Pacer	AHTS
51	9007166	Karadeniz Powership Faruk Bey	AHTS
52	9007178	Amazon Chieftain Z	AHTS
53	9031076	FS Pisces	PSV
54	9034767	Maersk Frontier	PSV
55	9034779	Karadeniz Powership Metin Bey	PSV
56	9034781	Karadeniz Powership Nezih Bey	PSV
57	9034793	Karadeniz Powership Goktay Bey	PSV
58	9043067	Ocean Tay	PSV
59	9086203	Karadeniz Powership Koray Bey	PSV
60	9086215	Han Ji 2	PSV
61	9104017	Maersk Norseman	PSV
62	9104029	Maersk Nascopie	PSV
63	9106431	VN Partisan*	PSV
64	9121053	Normand Neptun	AHTS
65	9121845	Karadeniz Powership Goskel Bay	PSV
66	9122978	Eurus Express	PSV
67	9123673	TAG 17	PSV
68	9126039	TAG 20	PSV
69	9126455	Havila Fortress	PSV
70	9127320	Heimdal R	PSV
71	9128350	Far Supporter	PSV
72	9134531	Carrier Express	PSV
73	9144330	Maersk Battler	AHTS
74	9144342	Maersk Beater	AHTS
75	9150224	Stril Power	AHTS
76	9151577	Maersk Boulder	AHTS
77	9151589	Maersk Blazer	AHTS
78	9155054	Normand Atlantic	AHTS
79	9157820	Far Sailor	AHTS
80	9158666	Strilborg	AHTS
81	9158678	North Stream	PSV
82	9163025	Scotian Sea	PSV
83	9165906	Halani 6	PSV
84	9166364	Sea Leopard	AHTS
85	9166546	Karadeniz Powership Baris Bey	PSV
86	9166613	Sar Loke	AHTS
87	9169392	Alegria	PSV
88	9169471	Zhengli 18000	AHTS
89	9169483	Maersk Shipper	AHTS
90	9171620	Umka	AHTS
91	9171747	Sea Panther	AHTS
92	9171876	Far Senior	AHTS

	A	B	C
93	9177844	Olympic Princess	PSV
94	9179751	Normand Pioneer	AHTS
95	9180683	Maersk Supplier	AHTS
96	9180695	Maersk Seeker	AHTS
97	9182344	Felicity	PSV
98	9185023	Skandi Admiral	AHTS
99	9186675	Far Sovereign	AHTS
100	9191369	Maersk Searcher	AHTS
101	9191371	Maersk Server	AHTS
102	9193783	Maersk Assister	AHTS
103	9193795	Maersk Attender	AHTS
104	9194103	Far Star	PSV
105	9196503	BB Ocean	AHTS
106	9196515	Server	AHTS
107	9198044	Esvagt Connector	AHTS
108	9198056	Esvagt Dee	AHTS
109	9198068	Esvagt Don	AHTS
110	9198484	Offshore Energy	AHTS
111	9199622	Tor Viking	AHTS
112	9199634	Balder Viking	AHTS
113	9201786	Stril Neptun	PSV
114	9203203	BB Troll	AHTS
115	9229477	Normand Borg	AHTS
116	9235672	Olympic Hercules	AHTS
117	9239343	Highland Fortress	PSV
118	9239769	Highland Navigator	PSV
119	9239771	Far Scotia	PSV
120	9240952	Normand Ivan	AHTS
121	9243370	Stril Myster	PSV
122	9244568	Viking Dynamic	PSV
123	9245902	Maersk Achiever	AHTS
124	9245914	Maersk Winner	AHTS
125	9246114	Edda Fjord	PSV
126	9246724	Maersk Handler	AHTS
127	9246736	Maersk Helper	AHTS
128	9249350	Normand Mariner	AHTS
129	9249465	Highland Eagle	PSV
130	9249520	Island Frontier	PSV
131	9254379	Maersk Asserter	AHTS
132	9254381	Maersk Advancer	AHTS
133	9255141	Deep Wave	PSV
134	9257929	Olympic Pegasus	AHTS
135	9258430	Stril Pioner	PSV
136	9258442	Viking Energy	PSV
137	9263514	Skandi Buchan	PSV
138	9263631	Normand Flipper	PSV

	A	B	C
139	9266451	Normand Master	AHTS
140	9272412	Bourbon Surf	AHTS
141	9272436	Bourbon Borgstein	AHTS
142	9276391	Skandi Sotra	PSV
143	9276896	Bourbon Tampen	PSV
144	9281657	Skandi Caledonia	PSV
145	9283473	Skandi Texel	PSV
146	9284324	Skandi Captain	PSV
147	9285299	Conti	PSV
148	9288253	Far Symphony	PSV
149	9294006	Far Splendour	PSV
150	9294082	Maersk Vega	PSV
151	9294094	Maersk Ventura	PSV
152	9297797	Geo Energy	PSV
153	9298909	Maersk Dispatcher	AHTS
154	9205720	Maersk Detector	AHTS
155	9306914	Viking Avant	PSV
156	9307114	Belle Carnell	PSV
157	9312119	KL Arendalfjord	PSV
158	9319985	Energy Swan	PSV
159	9325738	Island Patriot	PSV
160	9325829	Bourbon Topaz	PSV
161	9328546	Strilmoy	PSV
162	9329435	Normand Aurora	PSV
163	9331268	Normand Skipper	PSV
164	9334131	Tan Cang 66	PSV
165	9339492	Olympic Promoter	PSV
166	9341251	Carlo Magno	AHTS
167	9342724	Normand Trym	PSV
168	9343766	Normand Corona	PSV
169	9344332	Dina Merkur	PSV
170	9348974	Nor Star	AHTS
171	9350238	Martin	PSV
172	9350240	FS Kristiansand	PSV
173	9350795	Island Spirit	PSV
174	9351969	Stril Odin	PSV
175	9352377	Bourbon Orca	AHTS
176	9355771	Olympic Octopus	AHTS
177	9356189	Island Vanguard	AHTS
178	9356191	Island Valiant	AHTS
179	9356995	Edda Fram	PSV
180	9361770	Normand Ferking	AHTS
181	9362009	Bourbon Mistral	PSV
182	9362011	Bourbon Monsoon	PSV
183	9363728	Standard Viking	PSV
184	9363778	Standard Supplier	PSV

	A	B	C
185	9364033	North Promise	PSV
186	9364253	Havila Mars	AHTS
187	9364265	Havila Mercury	AHTS
188	9366809	Viking Athene	PSV
189	9367011	Olympic Elena	PSV
190	9370070	Siddis Sailor	PSV
191	9371385	Normand Titan	AHTS
192	9371696	Island Challenger	PSV
193	9372169	Far Sapphire	AHTS
194	9372896	Skandi Flora	PSV
195	9372901	Viking Queen	PSV
196	9374193	Kailash	PSV
197	9381691	Far Seeker	PSV
198	9382944	Havila Foresight	PSV
199	9383871	Skandi Mongstad	PSV
200	9384461	Siem Hanne	PSV
201	9385104	FS Braemar	PSV
202	9386691	Bourbon Sapphire	PSV
203	9388584	Maersk Topper	AHTS
204	9388596	Maersk Trader	AHTS
205	9388601	Maersk Tackler	AHTS
206	9388613	Maersk Tracer	AHTS
207	9388625	Maersk Trimmer	AHTS
208	9388637	Maersk Tracker	AHTS
209	9388649	Maersk Transporter	AHTS
210	9388651	Maersk Tender	AHTS
211	9388663	Maersk Traveller	AHTS
212	9388950	Far Searcher	PSV
213	9388962	Far Sabre	AHTS
214	9390549	Standard Princess	PSV
215	9390551	Havila Fortune	PSV
216	9392951	Sea Pollock	PSV
217	9392975	Sea Witch	PSV
218	9393400	Havila Neptune	AHTS
219	9395408	Normand Vibran	PSV
220	9395458	FS Crathes	PSV
221	9396593	Caspian Challenger	AHTS
222	9397274	Caspian Supplier	PSV
223	9399155	Normand Provider	PSV
224	9402342	Island Endeavour	PSV
225	9404259	Stril Herkules	PSV
226	9407897	Stril Merkur	PSV
227	9408229	Far Serenade	PSV
228	9409663	Island Commander	PSV
229	9409675	Viking Lady	PSV
230	9409730	Edda Frende	PSV

	A	B	C
231	9413432	Normand Ranger	AHTS
232	9413444	Siem Ruby	AHTS
233	9413468	Maersk Terrier	AHTS
234	9417684	Siem Pearl	AHTS
235	9417696	Siem Sapphire	AHTS
236	9417701	Siem Emerald	AHTS
237	9417713	Siem Topaz	AHTS
238	9417725	Siem Aquamarine	AHTS
239	9417749	Siem Diamond	AHTS
240	9417816	Far Scorpion	AHTS
241	9417828	Far Sagaris	AHTS
242	9417830	Skandi Bergen	AHTS
243	9418030	Havila Venus	AHTS
244	9418042	Havila Jupiter	AHTS
245	9418664	Havila Aurora	PSV
246	9419761	Island Chieftain	PSV
247	9420007	Sea Jackal	AHTS
248	9420150	Siem Commander	AHTS
249	9420174	Siem Challenger	AHTS
250	9420186	Sea Trout	PSV
251	9422108	Normand Tonjer	PSV
252	9422213	Troms Castor	PSV
253	9423815	Loke Viking	AHTS
254	9423827	Njord Viking	AHTS
255	9423839	Magne Viking	AHTS
256	9424728	Olympic Zeus	AHTS
257	9424730	Skandi Hera	AHTS
258	9424778	Maersk Nomad	PSV
259	9424780	Maersk Nexus	PSV
260	9425423	Amber II	AHTS
261	9425710	Maersk Leader	AHTS
262	9425722	Maersk Logger	AHTS
263	9425734	Maersk Lifter	AHTS
264	9425746	Maersk Launcher	AHTS
265	9425849	Maersk Lancer	AHTS
266	9426647	Normand Supplier	PSV
267	9430753	Havila Borg	PSV
268	9439022	Troms Pollux	PSV
269	9439462	North Purpose	PSV
270	9442419	Siem Opal	AHTS
271	9442421	Siem Garnet	AHTS
272	9442433	Siem Amethyst	AHTS
273	9447639	Skandi Emerald	AHTS
274	9447641	Skandi Saigon	AHTS
275	9447653	Skandi Pacific	AHTS
276	9447952	Normand Prosper	AHTS

	A	B	C
277	9447964	Normand Drott	AHTS
278	9451422	Eldborg	PSV
279	9455404	Maersk Laser	AHTS
280	9459759	Skandi Skansen	AHTS
281	9462770	Havila Crusader	PSV
282	9463126	Nor Chief	AHTS
283	9463504	African Vision	PSV
284	9468190	Normand Baltic	PSV
285	9470466	KL Sandefjord	AHTS
286	9470478	KL Saltfjord	AHTS
287	9475181	Siddis Mariner	PSV
288	9475791	Brage Viking	AHTS
289	9479967	Havila Clipper	PSV
290	9480722	Troms Capella	PSV
291	9482342	KL Brisfjord	PSV
292	9482354	KL Brofjord	PSV
293	9482366	KL Barentsfjord	PSV
294	9489467	Dina Alliance	AHTS
295	9489479	Opal	AHTS
296	9489481	Rem Star	PSV
297	9489493	Stril Mariner	PSV
298	9494618	A.H. Valletta	AHTS
299	9499644	Kamarina	AHTS
300	9499656	Eraclea	AHTS
301	9508067	Skandi Gamma	PSV
302	9510307	Siem Pilot	PSV
303	9513945	Ocean Clever	AHTS
304	9521655	Rem Hrist	PSV
305	9521667	Rem Mist	PSV
306	9526021	Ocean Pride	PSV
307	9529920	Brage Supplier	PSV
308	9529932	Brage Trader	PSV
309	9530101	Bourbon Front	PSV
310	9530113	Bourbon Clear	PSV
311	9530125	Bourbon Calm	PSV
312	9530137	Bourbon Rainbow	PSV
313	9534353	Far Server	PSV
314	9535292	Saeborg	PSV
315	9538529	Stril Mermaid	PSV
316	9544413	Boa Bison	AHTS
317	9544425	Boa Jarl	AHTS
318	9544437	Boa VS491 AHTS TBN03	AHTS
319	9544449	Boa VS491 AHTS TBN04	AHTS
320	9544487	Boa VS495 MPSV TBN03	PSV
321	9544499	Boa VS495 MPSV TBN04	PSV
322	9544516	Vestland Artemis	PSV

	A	B	C
323	9546021	Cristal	PSV
324	9546605	Anne Risley	PSV
325	9547415	Olympic Electra	PSV
326	9575620	Sea Tantalus	PSV
327	9579470	Island Centurion	PSV
328	9579482	Island Captain	PSV
329	9584554	Stril Orion	PSV
330	9585742	VOS Theia	AHTS
331	9589607	Solvik Supplier	PSV
332	9590565	Stril Polar	PSV
333	9591856	Normand Server	PSV
334	9591868	Normand Supporter	PSV
335	9591870	Normand Naley	PSV
336	9591882	Normand Falnes	PSV
337	9591923	Sjoborg	PSV
338	9592812	Normand Arctic	PSV
339	9596296	Viking Prince	PSV
340	9602514	Island Crusader	PSV
341	9602526	Island Contender	PSV
342	9603829	Olympic Energy	PSV
343	9607693	Skandi Feistein	PSV
344	9608271	Lundstrom Tide	PSV
345	9608738	Fanning Tide	PSV
346	9608740	Demarest Tide	PSV
347	9611840	Viking Princess	PSV
348	9613692	NAO Fighter	PSV
349	9613707	NAO Prosper	PSV
350	9613824	Skandi Kvitsoy	PSV
351	9616175	Far Solitaire	PSV
352	9616187	Far Scotsman	PSV
353	9617313	Olympic Orion	PSV
354	9620982	Vestland Mistral	PSV
355	9623025	Viking Fighter	PSV
356	9625425	Skandi Aukra	PSV
357	9627772	Normand Leader	PSV
358	9628386	Troms Sirius	PSV
359	9629005	Far Spica	PSV
360	9631400	Pacific Dolphin	AHTS
361	9631747	Far Senator	AHTS
362	9631759	Far Statesman	AHTS
363	9631890	Havila Charisma	PSV
364	9634347	Vestland Insula	PSV
365	9638123	World Pearl	PSV
366	9640231	C-Viking	PSV
367	9643465	North Pomor	PSV
368	9644342	Vestland Cetus	PSV

	A	B	C
369	9644445	Torsborg	PSV
370	9645683	Sea Falcon	PSV
371	9645932	Island Duke	PSV
372	9645944	Island Duchess	PSV
373	9645956	Island Dawn	PSV
374	9645968	Island Dragon	PSV
375	9647758	Ben Nevis	PSV
376	9648025	World Diamond	PSV
377	9648166	World Peridot	PSV
378	9649184	Troms Lyra	PSV
379	9649562	Evita	PSV
380	9649926	Maersk Clipper	AHTS
381	9649938	Maersk Cutter	AHTS
382	9651852	Sayan Princess	PSV
383	9651890	NAO Power	PSV
384	9653989	Vestland Mira	PSV
385	9654098	North Cruys	PSV
386	9656644	Sea Spider	PSV
387	9656656	Sea Springer	PSV
388	9656735	Sea Frost	PSV
389	9657648	NS Orla	PSV
390	9657650	NS Frayja	PSV
391	9659062	Far Sigma	AHTS
392	9659074	Far Sirius	AHTS
393	9660073	Skandi Iceman	AHTS
394	9663025	Dina Scout	PSV
395	9664380	Makalu	PSV
396	9664433	World Opal	PSV
397	9665011	Juanita	PSV
398	9665102	NAO Thunder	PSV
399	9665114	NAO Guardian	PSV
400	9665126	NAO Protector	PSV
401	9665786	Far Sun	PSV
402	9665798	Far Sygna	PSV
403	9666546	Stril Luna	PSV
404	9667241	Ocean Star	PSV
405	9667253	Ocean Art	PSV
406	9667760	Kongsborg	PSV
407	9668647	Rem Eir	PSV
408	9683659	Normand Fortune	PSV
409	9690066	Siem Symphony	PSV
410	9690949	Polarsyssel	PSV
411	9694000	Troms Arcturus	PSV
412	9695042	Island Condor	PSV
413	9695937	Stril Barents	PSV
414	9703526	Olympus	PSV

	A	B	C
415	9703679	Siem Pride	PSV
416	9714214	Vestland Cygnus	PSV
417	9720720	Aleut	AHTS
418	9722510	NAO Storm	PSV
419	9722522	NAO Viking	PSV
420	9722871	Island Clipper	PSV
421	9731250	Normand Skude	PSV
422	9732204	Kasteelborg	PSV
423	9732216	Blue King	PSV
424	9732838	Bourbon Arctic	AHTS
425	9740354	Stril Mar	PSV
426	9740732	Fafnir Viking	PSV
427	9741279	Island Defender	PSV
428	9741281	Island Discoverer	PSV
429	9741542	FS Cygnus	PSV
430	9741554	C-Warrior	PSV
431	9742766	North Barents	PSV
432	9745615	Island Victory	AHTS
433	9747493	NAO Horizon	PSV
434	9748344	NAO Galaxy	PSV
435	9752400	Onyx	AHTS
436	9759903	Island Diligence	PSV
437	9761035	Maersk Master	AHTS
438	9761047	Maersk Mariner	AHTS
439	9761059	Maersk Mover	AHTS
440	9764336	Pomor	AHTS
441	9764348	Normann	AHTS
442	9765469	Maersk AHTS SALT 200 TBN04	AHTS
443	9765471	Maersk AHTS SALT 200 TBN05	AHTS
444	9765483	Maersk AHTS SALT 200 TBN06	AHTS

C Production Facilities on the NCS

Data obtained for the Norwegian Petroleum Directorate with added field centres and number of beds from Rystad Energy's Platform database.

	A	B	C	D	E	F	G	H
1	name	operator	hub	lon	lat	beds	depth	startup_year
2	ALVHEIM FPSO	Aker BP ASA	ALVHEIM	1.99845	59.56752	120	125	2008
3	ALWYN NORTH B	Total	ALWYN	1.735242	60.81012	0	126	1987
4	ARMADA	Shell	ARMADA	1.845911	57.95744	0	110	1997
5	BALDER FPU	VAAr Energi AS	BALDER	2.387417	59.19161	60	127	1999
6	BRAE A	Repsol Sinopec North Sea Limited	ENOCH	1.28195	58.69248	0	111.862	1983
7	BRAGE	Wintershall Norge AS	BRAGE	3.046797	60.54256	122	136	1993
8	DRAUGEN	OKEA AS	DRAUGEN	7.782606	64.35317	140	252	1993
9	DRAUPNER E	Gassco AS	GASSLED	2.472672	58.18999	0	69.3	1995
10	DRAUPNER S	Gassco AS	GASSLED	2.472792	58.18887	48	70	1985
11	EDVARD GRIEG	Lundin Norway AS	EDVARD GRIEG	2.248339	58.84273	100	109	2015
12	EKOFISK B	ConocoPhillips Skandinavia AS	EKOFISK NORTH	3.203689	56.56535	0	74	1974
13	EKOFISK BS3	ConocoPhillips Skandinavia AS	EKOFISK CENTRAL	3.214517	56.54835	0	72	1974
14	EKOFISK C	ConocoPhillips Skandinavia AS	EKOFISK CENTRAL	3.215517	56.54784	0	76.8	1974
15	EKOFISK J	ConocoPhillips Skandinavia AS	EKOFISK CENTRAL	3.221283	56.5472	0	76.8	1998
16	EKOFISK K	ConocoPhillips Skandinavia AS	EKOFISK NORTH	3.206106	56.5658	182	74	1987
17	EKOFISK L	ConocoPhillips Skandinavia AS	EKOFISK CENTRAL	3.224403	56.54339	552	79	2014
18	EKOFISK L-BS	ConocoPhillips Skandinavia AS	EKOFISK CENTRAL	3.223708	56.54433	0	79	2013
19	EKOFISK M	ConocoPhillips Skandinavia AS	EKOFISK CENTRAL	3.223044	56.54538	0	78.4	2005
20	EKOFISK M-BS	ConocoPhillips Skandinavia AS	EKOFISK CENTRAL	3.223044	56.54538	0	78.4	2005
21	EKOFISK X	ConocoPhillips Skandinavia AS	EKOFISK CENTRAL	3.218944	56.54764	0	76.8	1997
22	EKOFISK X-BS	ConocoPhillips Skandinavia AS	EKOFISK CENTRAL	3.216569	56.54765	0	76	1997
23	EKOFISK Z	ConocoPhillips Skandinavia AS	EKOFISK CENTRAL	3.225658	56.54405	0	79	2013
24	ELDFISK A	ConocoPhillips Skandinavia AS	ELDFISK SOUTH	3.265803	56.37688	112	71	1979
25	ELDFISK B	ConocoPhillips Skandinavia AS	ELDFISK NORTH	3.218394	56.41933	96	71	1979
26	ELDFISK B-FL	ConocoPhillips Skandinavia AS	ELDFISK NORTH	3.219447	56.41824	0	70	1979
27	ELDFISK E	ConocoPhillips Skandinavia AS	ELDFISK SOUTH	3.265206	56.37509	0	72	2000
28	ELDFISK FTP	ConocoPhillips Skandinavia AS	ELDFISK SOUTH	3.265933	56.37572	0	76.8	1979
29	ELDFISK S	ConocoPhillips Skandinavia AS	ELDFISK SOUTH	3.262697	56.37374	154	72	2015
30	EMBLA	ConocoPhillips Skandinavia AS	EMBLA	3.248264	56.33323	12	70.2	1993
31	GINA KROG	Equinor Energy AS	GINA KROG	1.696789	58.57218	70	116	2017
32	GINA KROG FSO	Equinor Energy AS	GINA KROG	1.734325	58.58401	0	116	2017
33	GJOA	Neptune Energy Norge AS	GJoA	3.896819	61.33236	100	360	2010
34	GOLIAT FPSO	Vaar Energi AS	GOLIAT	22.25251	71.31104	120	371	2016
35	GRANE	Equinor Energy AS	GRANE	2.487389	59.16524	130	127	2003
36	GUDRUN	Equinor Energy AS	GUDRUN	1.743722	58.84522	40	109	2014
37	GULLFAKS A	Equinor Energy AS	GULLFAKS A	2.18915	61.17611	330	133	1986
38	GULLFAKS B	Equinor Energy AS	GULLFAKS B	2.2013	61.20292	160	141	1988
39	GULLFAKS C	Equinor Energy AS	GULLFAKS C	2.273869	61.21494	330	216	1990
40	GYDA	Repsol Norge AS	GYDA	3.085197	56.90493	135	66	1990
41	HEIDRUN	Equinor Energy AS	HEIDRUN	7.3175	65.32583	370	345	1995
42	HEIDRUN FSU	Equinor Energy AS	HEIDRUN	7.365869	65.34362	0	0	2015
43	HEIMDAL	Equinor Energy AS	HEIMDAL	2.228806	59.57416	120	120	1985
44	HEIMDAL HRP	Gassco AS	HEIMDAL	2.228306	59.5753	0	120	2000
45	HaeWENE BRIM	Shell	PIERCE	2.294597	57.16144	0	82	1999
46	IVAR AASEN	Aker BP ASA	IVAR AASEN	2.198125	58.92227	70	113	2016
47	JOHAN SVERDRUP DP	Equinor Energy AS	JOHAN SVERDRUP	2.553717	58.83599	0	113.4	2019
48	JOHAN SVERDRUP LQ	Equinor Energy AS	JOHAN SVERDRUP	2.547256	58.83588	560	113.4	2019
49	JOHAN SVERDRUP P1	Equinor Energy AS	JOHAN SVERDRUP	2.550278	58.83663	0	113.4	2019
50	JOHAN SVERDRUP RP	Equinor Energy AS	JOHAN SVERDRUP	2.556944	58.83694	0	115	2018
51	JOTUN A	Vaar Energi AS	JOTUN	2.386358	59.45526	100	126	1999
52	KRISTIN	Equinor Energy AS	KRISTIN	6.551342	64.99396	104	360	2005
53	KVITEBJORN	Equinor Energy AS	KVITEBJORN	2.499719	61.08031	95	190	2004
54	MARTIN LINGE A	Equinor Energy AS	MARTIN LINGE	2.014828	60.50619	95	114	2018
55	NORNE FPSO	Equinor Energy AS	NORNE	8.088358	66.02729	240	378	1997
56	OSEBERG A	Equinor Energy AS	OSEBERG CENTRAL	2.827314	60.49186	320	109	1988
57	OSEBERG B	Equinor Energy AS	OSEBERG CENTRAL	2.828253	60.49334	0	108	1988
58	OSEBERG C	Equinor Energy AS	OSEBERG NORTH	2.775597	60.60834	122	108	1991
59	OSEBERG D	Equinor Energy AS	OSEBERG CENTRAL	2.828986	60.49067	0	109	2000
60	OSEBERG H	Equinor Energy AS	OSEBERG WEST	2.733367	60.54849	0	107	2018
61	OSEBERG SOR	Equinor Energy AS	OSEBERG SOR	2.796961	60.39017	100	101	2000
62	OSEBERG OST	Equinor Energy AS	OSEBERG OST	2.935219	60.7005	62	157	1999
63	PETROJARL KNARR	A/S Norske Shell	KNARR	2.833939	61.77993	100	410	2015
64	RINGHORNE	Vaar Energi AS	BALDER	2.449858	59.26606	110	128.5	2003
65	SKARV FPSO	Aker BP ASA	SKARV	7.651086	65.69778	100	368	2012

	A	B	C	D	E	F	G	H
66	SLEIPNER A	Equinor Energy AS	SLEIPNER OST	1.908614	58.36731	240	83	1993
67	SLEIPNER B	Equinor Energy AS	SLEIPNER VEST	1.717897	58.4179	7	107.6	1997
68	SLEIPNER FL	Equinor Energy AS	SLEIPNER OST	1.912175	58.3694	0	83	1993
69	SLEIPNER R	Equinor Energy AS	SLEIPNER OST	1.910531	58.36856	0	83	1993
70	SLEIPNER T	Equinor Energy AS	SLEIPNER OST	1.906481	58.36861	0	82.5	1997
71	SNORRE A	Equinor Energy AS	SNORRE SOUTH	2.144344	61.44934	220	335	1992
72	SNORRE B	Equinor Energy AS	SNORRE NORTH	2.211506	61.52544	140	350	2001
73	STATFJORD A	Equinor Energy AS	STATFJORD CENTRAL	1.853875	61.25568	206	145	1979
74	STATFJORD B	Equinor Energy AS	STATFJORD SOUTH	1.830636	61.20691	228	145	1982
75	STATFJORD C	Equinor Energy AS	STATFJORD NORTH	1.902547	61.29658	345	145	1985
76	TAMBAR	Aker BP ASA	TAMBAR	2.958781	56.98276	10	70	2001
77	TROLL A	Equinor Energy AS	TROLL EAST	3.726494	60.64564	211	302	1996
78	TROLL B	Equinor Energy AS	TROLL WEST	3.503181	60.77438	100	320	1995
79	TROLL C	Equinor Energy AS	TROLL NORTH	3.611444	60.88632	70	339	1999
80	ULA DP	Aker BP ASA	ULA	2.847331	57.11143	0	71	1986
81	ULA PP	Aker BP ASA	ULA	2.848569	57.11176	0	71	1986
82	ULA QP	Aker BP ASA	ULA	2.845983	57.11108	170	71	1986
83	VALEMON	Equinor Energy AS	VALEMON	2.339008	61.04066	50	133	2015
84	VALHALL DP	Aker BP ASA	VALHALL	3.395331	56.27816	0	74	1981
85	VALHALL FLANKE NORD	Aker BP ASA	VALHALL NORTH	3.352642	56.32436	0	69	2004
86	VALHALL FLANKE SOR	Aker BP ASA	VALHALL SOUTH	3.437394	56.22771	0	66.7	2003
87	VALHALL IP	Aker BP ASA	VALHALL	3.396339	56.27652	0	74	2004
88	VALHALL PH	Aker BP ASA	VALHALL	3.395581	56.27552	180	74	2013
89	VALHALL Q	Aker BP ASA	VALHALL	3.394278	56.27883	209	74	1981
90	VALHALL WP	Aker BP ASA	VALHALL	3.396378	56.27657	0	74	1996
91	VESLEFRIKK A	Equinor Energy AS	VESLEFRIKK	2.897858	60.78271	0	174	1989
92	VESLEFRIKK B	Equinor Energy AS	VESLEFRIKK	2.898611	60.78139	159	176	1989
93	VISUND	Equinor Energy AS	VISUND	2.458917	61.37016	120	335	1999
94	AASGARD A	Equinor Energy AS	AASGARD SOUTH	6.727444	65.06442	240	315	1999
95	AASGARD B	Equinor Energy AS	AASGARD MID	6.791186	65.11037	120	300	2000
96	AASGARD C	Equinor Energy AS	AASGARD NORTH	6.865786	65.13137	0	290	2000
97	AASTA HANSTEEN SPAR	Equinor Energy AS	AASTA HANSTEEN	7.097478	67.06699	100	1315	1900

D Supply Bases Along the Norwegian Coast

Obtained from Rystad Energy.

name	lon	lat
ASCO base	5.597664	58.924
Asco Farsund	6.779857	58.07917
Asco Hammerfest	23.66942	70.66908
Asco Kristiansund	7.672208	63.05665
CCB Agotnes	5.015314	60.41333
CCB Helgelandsbase	12.66581	66.0236
CCB Kirkenes	30.06281	69.7283
CCB Mongstad	5.070793	60.79126
CCB Vardo	31.10454	70.37435
Fjordbase	5.071885	61.61019
NorSea Dusavik	5.662206	58.9978
NorSea Norbase	16.58885	68.78159
NorSea Polarbase	23.66057	70.63445
NorSea Stordbase	5.485715	59.76109
NorSea Tananger	5.59144	58.92755
NorSea Vestbase	7.77762	63.10667
Wergeland base	5.067962	60.85213
Port of Bergen	5.306179	60.40008
Avaldsnes	5.297647	59.33923
Brevik yard	9.686425	59.05451

E Code

E.1 Run Process (run_process.py)

The following code runs the processing, position- and voyage-assignment as well as defining the voyage characteristics. The code is used as a dashboard for the data processing, all codes are defined in E.2.

(CODE NOT PUBLIC)

E.2 Processing Functions (process.py)

In the following code all functions used to process the data is provided. Functions in this code are run from *run_process.py* script found in Appendix E.1

(CODE NOT PUBLIC)

E.3 Run Analysis (run_analysis.py)

The following script provides all codes used to perform the analysis in the Case Study in Chapter 6.

(CODE NOT PUBLIC)

E.4 Plot Codes (plot_codes.py)

The following script provides codes used for plotting purposes.

(CODE NOT PUBLIC)

Celine Mysen

Understanding Offshore Support Vessel Activity by the Use of AIS Data

NTNU
Norwegian University of
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RYSTAD ENERGY