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A Study of the Operational Patterns of LNG Carriers from AIS Data

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Preface

This is a master thesis from the Department of Marine Technology at the Norwegian University of Science and Technology, and is the final part of my Master Degree in Engineering with specialization in Marine System Design. The work has been carried out during the spring semester of 2018, and corresponds to 30 ECTs. The thesis is directed towards a general technical audience with basic knowledge of shipping and data analysis.

The thesis is inspired by and building on the work done in the project thesis, *Exploration of Methods for Analysing AIS Data*, from the fall semester of 2017. Although the master thesis builds on theory and data addressed in the project thesis, it can and should be read as an independent piece of work.

Trondheim, 20.06.18

Jørgen Jensen Axelsen

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I would like to thank the following persons for their great help during this work:

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Bjørnar Brende Smestad and Jon Hovem Leonhardsen, for their work with AIS Data which represents the foundation of the data sets.

My office mates, for their daily support and our open discussions.

J.J.A.

Abstract

This thesis investigates the operational patterns of LNG carriers from Automatic Identification System (AIS) Data. AIS was created for vessels as a safety-enhancing supplement to the radar, and over the last decade satellites have recorded data that enables new use of it. The overall objective of the thesis is to increase the decision support for stakeholders within the LNG industry.

The work is based on two parts, shipping knowledge and data analysis, and they serve as a foundation for the analyses of the operational patterns.

The most important findings are that LNG carriers sail slower than their design speed, and that the spot part of the fleet does not adjust its speed significantly more than the total fleet from a year of peak rates (2012) to a year of low rates (2015). The work also shows that from 2011 to 2015, an increasing part of the fleet visits more oceans per month. This could imply that the spot market is increasing, which again could indicate that vessels should be designed for a broader range of LNG terminal configurations.

The commoditization theory, which postulates that the increasing LNG spot market will serve to balance the cost differences between the regions and establish a global LNG price, is investigated to see if any leverage for the theory can be found in the data. The work finds weak support for the theory, but numerous assumptions make the results ambiguous.

Further, the thesis suggests that future work should obtain more comprehensive AIS Data, and that the inefficient design speed compared to the actual sailing speed should be investigated. The thesis also suggests other applications of AIS Data to increase the decision support for the participants in the industry, e. g. port calls and shipping distances.

In conclusion, the findings can increase the decision support for the stakeholders in LNG industry. It is emphasized that the numerous assumptions and potentially erroneous data make the analyses incomplete, underscoring that the results should be treated accordingly.

Keywords: AIS Data, LNG, Operational Patterns, Design Speed, Freight Rates

Sammendrag

Denne oppgaven undersøker operasjonsmønstre for LNG-skip ved bruk av Automatisk Identifikasjonssystem (AIS) Data. AIS ble opprettet for skip, og er et sikkerhetstiltak som supplementerer radaren. Det siste tiåret har satelitter registert dataene, noe som muliggjør ny bruk av dem. Formålet med oppgaven er å gi økt beslutningsstøtte for aktørene i LNG-industrien.

Arbeidet er basert på to deler, som er kunnskap om shipping og dataanalyse. Sammen er de grunnlaget for analyse av operasjonsmønstre.

De viktigste funnene er at LNG-skip seiler saktere enn designhastigheten, og at spotdelen av flåten ikke forandrer farten sin signifikant mer enn hele flåten, fra et år med høye rater (2012) til et år med lave rater (2015). Arbeidet viser også at fra 2011 til 2015 besøkte en økende del av flåten flere hav per måned. Det kan tyde på at spot markedet øker, som igjen kan indikere at skip bør designes for et større spekter av LNG terminal konfigurasjoner.

Commoditization-teorien, som postulerer at et økende LNG spotmarked vil balansere kostnadsforskjellene mellom regionene og at en global LNG-pris vil etableres, er undersøkt for å se om det finnes støtte for teorien i datasettet. Arbeidet finner svak støtte for teorien, men en rekke antagelser gjør resultatene tvetydige.

Videre foreslår oppgaven at fremtidig arbeid burde ta for seg mer omfattende AIS Data, og at den ueffektive designhastigheten sammenlignet med den virkelige hastigheten bør undersøkes nærmere. Oppgaven foreslår også andre bruksområder av AIS Data for å øke beslutningsstøtten til aktørene i industrien, for eksempel havneanløp og shipping-distanser.

Funnene i oppgaven kan gi økt beslutningsstøtte for aktørene i LNG-industrien. Oppgaven fremhever at en rekke antagelser og potensielt feilaktig data gjør analysene ufullstendige, og at resultatene må tolkes deretter.

Nøkkelord: AIS Data, LNG, Operasjonsmønstre, Designhastighet, Fraktrater

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Acronyms

AIS Automatic Identification System

DFDE Dual Fuel Diesel Electric

DWT Deadweight Tonne

ETA Estimated Time of Arrival

FID Final Investment Decision

FLNG Floating Liquefied Natural Gas

FSRU Floating Storage and Regasification Unit

GT Gross Tonnage

HFO Heavy Fuel Oil

IoT Internet of Things

LNG Liquefied Natural Gas

MEGI M-type, Electronically controlled Gas Injection

MMBtu Million British thermal units

MMSI Maritime Mobile Servicy Identity

NBP National Balancing Point

SOLAS Safety of Life At Sea

SQL Structured Query Language

ST Steam Turbine

S-AIS Satellite Automatic Identification System

TC Time Charter

TEUkm Twenty-foot Equivalent Unit kilometer

TFDE Tri-Fuel Diesel Electric

VHS Very High Frequency System

VLCC Very Large Crude Carrier

WTI West Texas Intermediate

Chapter 1

Introduction

1.1 Background

We live in a time age of digitization with an increasing amount of data being generated daily. Some of the largest corporations in the world base their income on exploiting this data. In shipping, the digitization age and its opportunities are relatively unexplored terrain. With more or less all existing merchant vessels being online in real time through AIS, new possibilities are emerging. These opportunities were explored in the project thesis during fall 2017, and are further expanded in this master thesis.

The motivation for looking into AIS Data is the opportunity to provide useful insight for design requirements of ships and the nature of maritime transportation. For the stakeholders in shipping, including but not limited to shipowners and shipyards, the data appears to be a relatively untapped resource. AIS Data can provide important knowledge regarding operational patterns, trends, and trade.

Operational patterns are important for the stakeholders in the maritime industry. If shipowners, yards and design offices can have a better understanding of operational patterns, they can increase their decision support. Increased decision support is an added value for the stakeholders.

The motivation for choosing LNG carriers as case study is as follows. First, the segment is a niche and the fleet size is small compared to dry bulk, tank, and cargo. This enables easier data handling, and makes manual reviews possible due to the size. Second, the author has some experience with the LNG market from earlier internships. Third, the LNG market is going through a rapid development. From historically being a pure industrial market, the short-term and the spot market are increasing fast both in share and in absolute figures. The fleet size has almost doubled the last decade, and new trade routes are emerging.

However, the main reason is that operational LNG patterns are not well investigated compared to the larger segments. To the author's knowledge, there has not been a study investigating the operational patterns of LNG carriers from AIS Data.

The reader of this thesis is expected to have a basic knowledge about shipping and data analysis. However, the topic would be interesting for industry professionals as well as academics with a background in engineering or economics.

1.2 Objective

How can AIS Data incorporate superior information about the operational patterns of LNG Carriers? With this research question in mind, the following research objectives will be conducted

- Obtain the LNG fleet and identify its spot trading part
- Analyze operational patterns in terms of speed distribution and areas
- Identify any patterns that strengthen or weaken the theory of the commoditization of the LNG market

The thesis will investigate a data set of AIS Data from the Norwegian Coastal Authorities, and extract the necessary data to conduct the analysis. Figure 1.1 presents the structure of the data set and the objectives, where level 5 and 6 have been conducted by Smestad (2015), Leonhardsen (2017), and during the project thesis from the fall semester of 2017 (Næss et al., 2017). This thesis will work in the domain of level 4, where the methods are applied, and through 3 and 2 before reaching level 1.

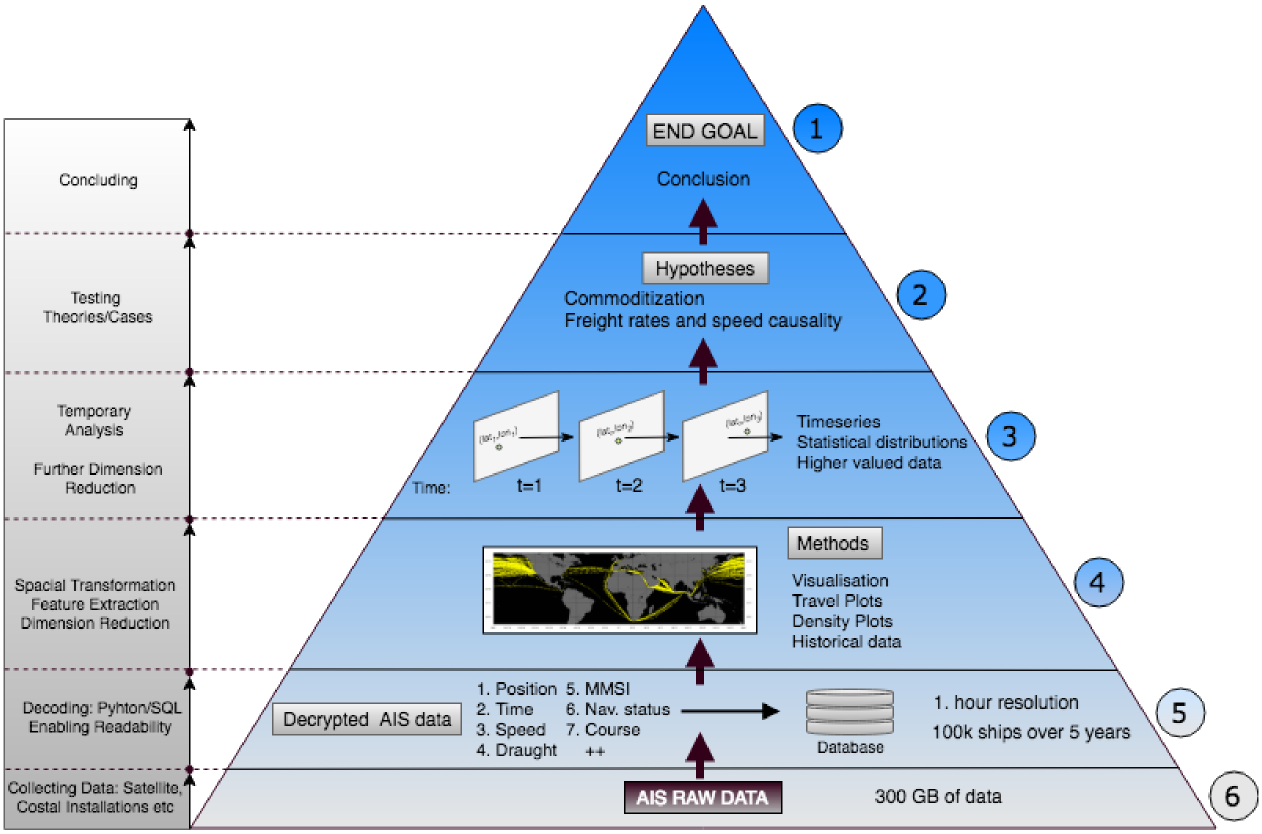

Figure 1.1: Objective structure

1.3 Limitations

The most important limitation of this work has been the data set. A situation with more frequent records of AIS messages would lift the possibilities of the analyzes, especially in terms of Message type 5. The data set is also restricted by the Norwegian Coastal Authorities, where single vessels cannot be made public. However, the latter did not affect the opportunities to do analyzes.

1.4 Structure of the report

The master thesis is structured as follows. Chapter 2 gives insight to the literature that has been reviewed. The first part of the literature review, regarding AIS Data, is heavily inspired by the project thesis.

Chapter 3 gives an introduction to natural gas and LNG shipping. For those who are not familiar with the LNG segment, this chapter will give a review of its characteristics. The Methodology is presented in Chapter 4. It is divided into two, whereof the first presents the data set and its applications. The second part presents the process in which the necessary and relevant data is obtained and extracted.

Chapter 5 presents the case studies, which aims to conduct the objectives from 1.2. The last part of the thesis is a general discussion part, found in chapter 6, and concluding remarks, chapter 7. The conclusion aims to summarize the findings, and verify whether the objective of the thesis is met. Lastly, some recommendations for further work are presented.

Appendix A contains the code, while Appendix B presents details within AIS Data. Appendix C shows an overview of the AIS part of the literature review. A signed copy of the problem description can be found in Appendix D, and a list of the electronic appendices can be found in Appendix E.

Notice that the detailed discussions are carried out continuously throughout the thesis, e.g. the results of the case studies are discussed where they are presented.

Chapter 2

Literature Review

The literature review is divided into two main parts, and summarized at the end. The first part is heavily inspired by the project thesis (Næss et al., 2017), where about 50 papers were reviewed to obtain the state-of-art within AIS Data. The second part connects to the LNG part in chapter 3, and to the case studies in chapter 5.

2.1 Part I - AIS Data

About 50 papers have been reviewed as a part of the work done in the project thesis. The papers represent the foundation for the work and give an understanding of the currently existing methods and applications within AIS Data exploitation. In this section, a description of the most important papers and their topics can be found.

The thesis has included three figures visualizing the distribution of the papers within AIS Data that have been reviewed. Figure 2.1 shows the different topics, and figure 2.2 shows the distribution of the domain of methods used in the papers. The last figure, 2.3, shows the distribution by vessel types, and we see that the majority have not obtained a specific vessel type. An overview of all the papers that have been reviewed during the project thesis can be found in Appendix C.

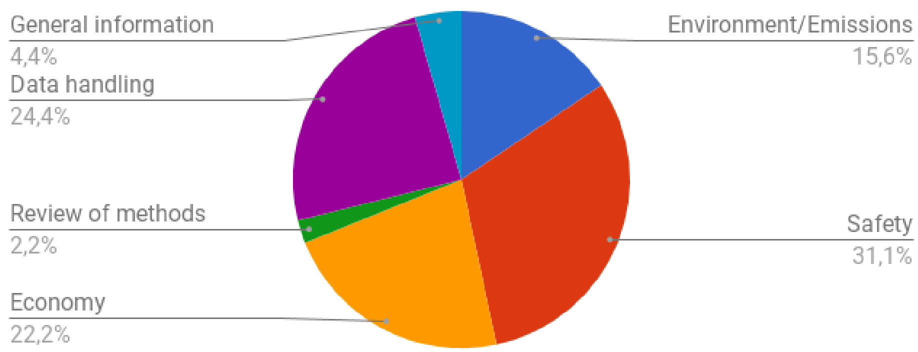

Figure 2.1: Study sections of previous literature

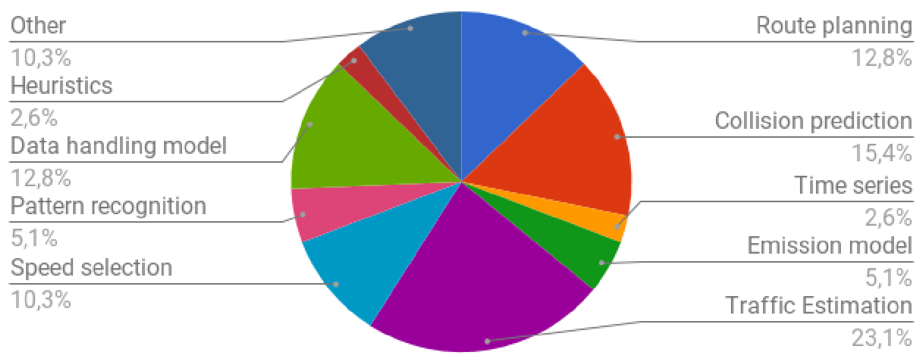

Figure 2.2: Method domain of previous literature

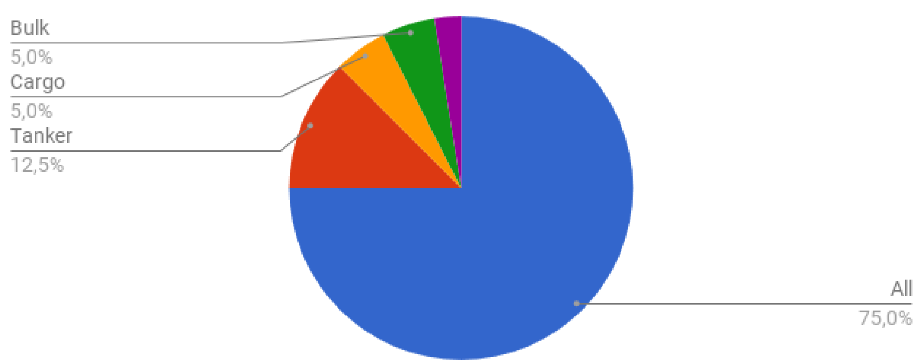

Figure 2.3: Vessel specification of previous literature

2.1.1 Safety

The AIS system was originally developed for safety precautions, and the comprehensive survey done by Tu et al. (2016) is a thorough review of the opportunities within safety in AIS Data. The methods they present are traffic anomaly detection, route estimation, collision prediction and path planning.

Wang et al. (2014) develop a clustering algorithm called Density-based Spatial Clustering of Applications with Noise considering Speed and Direction (DBSCAN_SD) and applies it to AIS Data. The purpose is to verify if data points are normal or abnormal, and then use the labeled data in the Parallel Meta-Learning (PML) algorithm on Hadoop. The overall goal of their work is to enhance safety in marine applications.

2.1.2 Data Handling and Networks

Arguedas et al. (2014) develop an algorithm to construct maritime shipping lanes from AIS Data. The lanes are detected by behavioral changes, such as course (COG) and port calls. The results can be used in Maritime Situational Awareness applications, such as track reconstruction from missing AIS Data points.

Kaluza et al. (2010) present an interpretation of the global cargo ship movements as a complex network. The world's merchant ships are classified into three categories, dry bulk, container vessels, and oil tankers. Each of these three has different mobility patterns and networks, and the goal is to improve current assumptions based on gravity models of ship movements. The overall purpose is to understand the global trade patterns and the influence they have on bioinvasion.

Spiliopoulos et al. (2017) present a four-step approach on how to transform AIS Data into information for understanding global trade patterns. The number of data points is large, and the authors have developed a method to evaluate 500 GB of data with only 3 hours of data processing time. The results can be used to see changes in shipping trade patterns, which again is connected to the global trade patterns.

Haji et al. (2013) present the development of a model capable of representing container flows at a global level, hence the global container trade. AIS Data is utilized to detect the positions and sizes of container vessels, and this is used to estimate container flow (TEUkm).

2.1.3 Economy

Jia et al. (2017) identify empirically how VLCCs can save fuel and emissions by implementing Virtual Arrival, which is an operational agreement that involves reducing speed when there is known delay at the discharge port. AIS Data is used to determine the operational status of each vessel, and to see how long the excess time in port is. They showed that if a reduction of 25% of the excess time is gained through slow steaming, it leads to a 7% reduction in fuel consumption.

Smestad et al. (2017) show how to use heuristics to establish specific ship type, with sole use of AIS Data. The purpose of predicting ship type without additional data is to avoid the cost of acquiring commercial ship data. S-AIS Data is used as a basis to create the heuristics, and a data cleaning process is carried out to exclude vessels that have conflicting and inaccurate data. To verify the accuracy of the heuristics, AIS Data is matched with data from Clarksons Ship Register, and the results show that Panamax bulk carriers can be established with a 98% certainty.

Leonhardsen (2017) investigates through his master thesis the possible fuel savings from rapidly re-configurable bulbous bows. A large amount of historical speed records from AIS Data is analyzed. The results are used to confirm significant variations in speed during transits, and from transit to transit. A stochastic representation of the speed is proposed, and used in further work to analyze the possible fuel savings.

Both Smestad et al. (2017) and Leonhardsen (2017) were central to the application of methods for the project thesis, and their work is also a part of the foundation for this master thesis. A more detailed description of their work and how it is applied for this master thesis is further described in chapter 4.1.

Wu et al. (2017) apply methods for mapping the global vessel density and traffic density. Vector-based and grid-based methods are utilized for traffic density, and the latter one has some of the same characteristics as geo-fence. The usage of geo-fence is briefly discussed in the case studies, in section 5.2.1.

Millefiori et al. (2016b) and Millefiori et al. (2016a) show in their work how a Kernel Density Estimation (KDE) algorithm can be used to estimate a seaport operational area, utilizing AIS Data and MapReduce. This is interesting for decision making regarding port investments and policymaking. The port of Rotterdam is used to show the results. The possibilities to find ports is as well briefly discussed in section 5.2.1.

2.1.4 Summary AIS Data

This part of the literature review gives a fundamental understanding of the different methods and applications within exploitation of AIS Data. The methods and applications reviewed should not be considered a complete list, but instead a basis for the work done in this thesis.

Tu et al. (2016) show the opportunities within safety in AIS Data, presenting methods as anomaly detection, route estimation, collision prediction and path planning. Wang et al. (2014) develop a clustering algorithm which is important to find ports, while Kaluza et al. (2010), Spiliopoulos et al. (2017) and Haji et al. (2013) expand on methods for generating networks. Both Jia et al. (2017) and Leonhardsen (2017) combines methods for exploitation of AIS with resistance estimations, and Smestad et al. (2017) shows how heuristics can be developed for the purpose of recognizing ship types.

AIS Data is a relatively recent development, and the literature review shows that even though several methods and applications already are explored, opportunities to expand the area are present.

2.2 Part II - Shipping

2.2.1 LNG Shipping

Nikhalat-Jahromi et al. (2017) present a thorough analysis of the LNG trade, outlining the characteristics of the industry and its long-term contracts. They also identify the spot market, explaining how it is connected to the long-term contracts and trade. The authors also claim that a surge of new supply will decrease the global LNG prices over the next 5 years.

Makholm and Olive (2016) argue that a global LNG market where the spot market trading will balance the huge costs differences between the regions, will not develop in the future, in contrast to the oceangoing crude oil and the oil market where it already exists. The main reasons are the large costs of shipping LNG (compared to oil), and the regulations outside North America which preclude competitive entry of new suppliers. They therefore argue that the long-term price and supply contracts will dominate the future of LNG trade.

Fretheim and Bondevik (2014) show the possibilities for buying and selling LNG with profit, using LNG carriers to ship from seller to buyer. They develop two optimization models to show the profit scenarios, and review the necessary conditions for applying this to the real world.

The LNG shipping and the usage of the literature above are covered in chapter 3. The global LNG market discussed by Makholm and Olive (2016) will be covered in this thesis, in section 5.3.

2.2.2 Freight rates: Spot and Time-Charter

Zhang and Zeng (2015) show the relationship between the time charter and the spot freight rates. Their study shows that there is a two-way lead-lag relationship between the TC and spot rates, and that the TC contracts have a discovery function.

Alizadeh and Nomikos (2011) also investigate the relationship between the time-varying freight rates, with focus on volatility. They argue that TC rates in fact are a form of forward freight rates. They find that when the freight market is in backwardation (spot rates higher than forward rates), volatility is higher compared to periods when the market is in contango (spot rates lower than forward rates).

Both studies have investigated larger segments like the tanker and dry bulk market with a more liquid spot market, while this thesis uses LNG carriers as the case study. It is reasonable to assume that the results in terms of the relationship between spot and TC rates could hold for the LNG market, since they share some the same fundamentals. However, to this authors knowledge, there has not been a study showing the relationship between spot and TC freight rates in the LNG market.

The distribution of the spot and TC freight rates will be covered in chapter 3.

2.2.3 Operational patterns: Speed analysis

The vessel speed in response to freight market has been investigated by academics through time with inconsistent results. The hypothesis has been that vessels speed up under conditions of high freight rates and low bunker prices, justified that by a rationale that vessels should rush for the next job if freight rates are high. In her master thesis, Assmann (2012) finds that this does not hold for the VLCCs for a given time period and route, and in a later published paper

Assmann et al. (2015) also argue that the evidence are weak. Their study also shows that the speed alteration is larger on ballast trips than laden.

Adland and Jia (2018) have studied the same phenomena in terms of bulk carriers, and the results suggest that high freight rates and low fuel prices do not influence the chosen speed. This is in line with Assmann (2012), and a earlier published paper by Adland and Jia (2016).

These papers relate to the case study in section 5.1.

2.3 Summary of literature review

The supportive literature has been various web-pages, especially with regards to the data analyses side of the thesis. The web-pages are given as footnotes in the report where it is required.

Part I and Part II of the literature are connected in the following way. Part I reviews the work that has been done regarding AIS Data, and connects to Methodology part I in chapter 4. Part 2 is utilized in chapter 3. They both are the foundation for the case studies.

Chapter 3

Natural Gas and LNG shipping

This section will give the reader a basic introduction to natural gas and LNG shipping. The fundamentals of the industry will be presented and reviewed. The value chain, its supply and demand, and the characteristics of the LNG market will be covered. The distinctiveness of LNG shipping and its dynamics will also be presented.

It is essential to have the fundamentals in mind when the analysis of the operational patterns are carried out in the case study. With an introduction to natural gas and LNG shipping, the interpretation of the case study results can be carried out with a deeper understanding.

If the reader has a knowledge of the LNG industry and its shipping characteristics in advance, this chapter can be reviewed briefly.

3.1 Intro

Natural gas is the third largest energy source in the world and accounts for around 25% of the world energy demand (ExxonMobil, 2018). Most natural gas is transported through pipelines, but an increasing amount of it is cooled down, turned into liquid and shipped. This is known as liquefied natural gas (LNG). The volume is reduced to $\frac{1}{600}$ of its original gaseous state, while the temperature and normal pressure of LNG is respectively -160°C and slightly below 1 bar.

LNG is the most cost-efficient way to transport natural gas over long distances. Above 1100 km, the cost of liquefying, shipping and regasifying outperform the cost of building and operating offshore pipelines (Nikhalat-Jahromi et al., 2017).

3.2 Value Chain

Figure 3.1 shows the LNG value chain, which starts at the gas field, where the natural gas is produced. Next, it is sent through pipelines to the gas processing facility and further to the liquefaction plant. The natural gas is cooled down to below its boiling point and stored or loaded directly onto an LNG carrier. At the receiving terminal, the LNG is regasified and sent to the end user. The regasification process can be carried out by an Floating Storage and Regasification Unit (FSRU) or a land-based terminal. The typical end users are power plants, industrial processes, and heating applications.

When considering a natural gas value chain where only pipelines are used for the transport, the gas is sent directly from gas processing facilities to end users through pipelines.

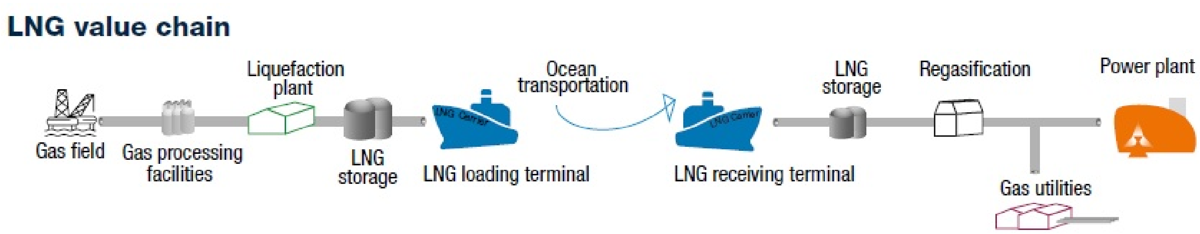

Figure 3.1: Value chain (IMO, 2010)

Liquefaction is the most capital intensive part of the LNG value chain. The break down of capital costs can be approximated as follows:

Table 3.1: Capital costs in the LNG value chain (Maxwell and Zhu, 2011)

Type	Percentage
Exploration and production	15 - 20%
Liquefaction	30 - 45%
Shipping	10 - 30%
Regasification and storage	15 - 25%

When considering the value chain of LNG, the typical total costs from the gas field to the end user is \$2-4 per MMBtu [1] (Nikhalat-Jahromi et al., 2017). The number depends on various pa-

[1] Million British thermal units

rameters where shipping distance and field size are the most important. Shipping contributes $0.5-1 per MMBtu, depending on the distance.

3.3 Supply and demand

The supply and demand for natural gas are expected to grow significantly over the next decades (ExxonMobil, 2018). Traditionally, the largest suppliers have been North America, Russia, and the Middle East. These regions are also expected to dominate the natural gas supply in the future. On the other side, the main demand for natural gas is in North America, Europe, and Asia/Pacific. Mainly, the gas is either consumed within its own region or sent through pipelines to a different region. A minor, but increasing portion of the total natural gas production is cooled down to LNG and shipped to its consumers.

Figure 3.2 shows the actual supply and demand for natural gas in different regions for the years 2000 and 2016, and projections for 2025 and 2040. Europe and Asia/Pacific have been the main importers of natural gas historically, and they will also be the most important ones in the future, according to the projections.

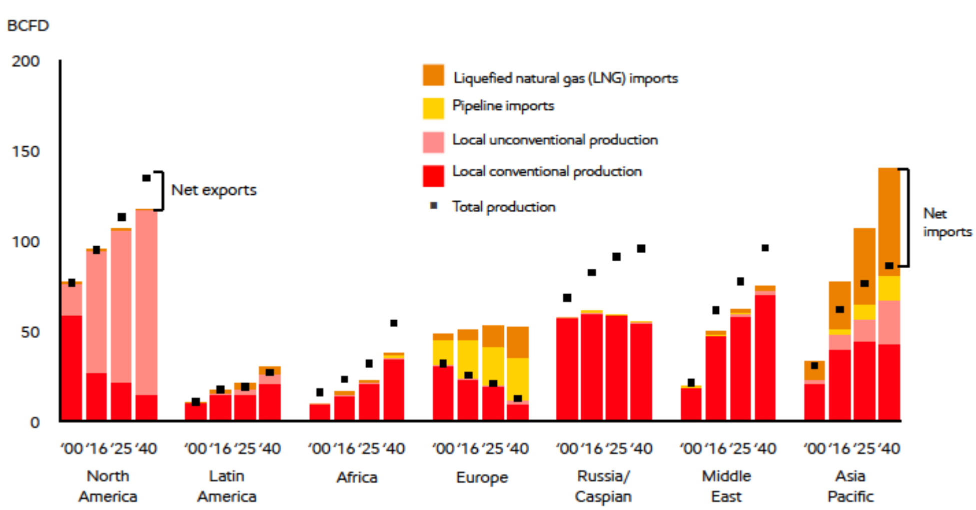

Figure 3.2: Supply and demand (ExxonMobil, 2018)

Figure 3.2 and 3.3 shows the increasing importance LNG play in the global natural gas market. While being a small and unimportant part of the market in 2000, LNG will increase to be a significant player in the future. Almost half of the consumption in Asia/Pacific in 2040 will come from imported LNG. The chart shows that more than one-third of the total natural gas growth from 2016 to 2040 will come from LNG, which indicate the that the annual growth in LNG will be substantially larger than the annual growth in natural gas.

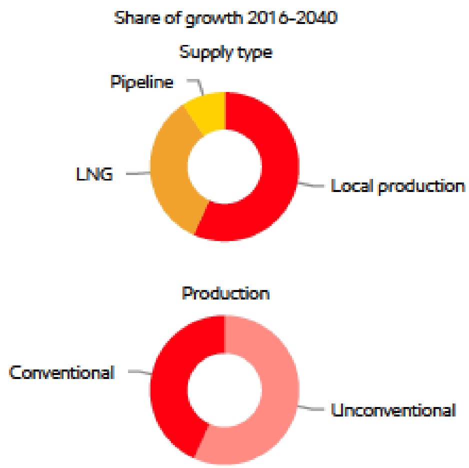

Figure 3.3: Share of growth 2016-2040 (ExxonMobil, 2018)

For the LNG trade itself, the supply and demand picture remains quite different. Figure 3.4 shows that the largest suppliers in 2015 were Australia, Indonesia, Malaysia, and Qatar. On the demand side, China, Japan, and South Korea were the largest.

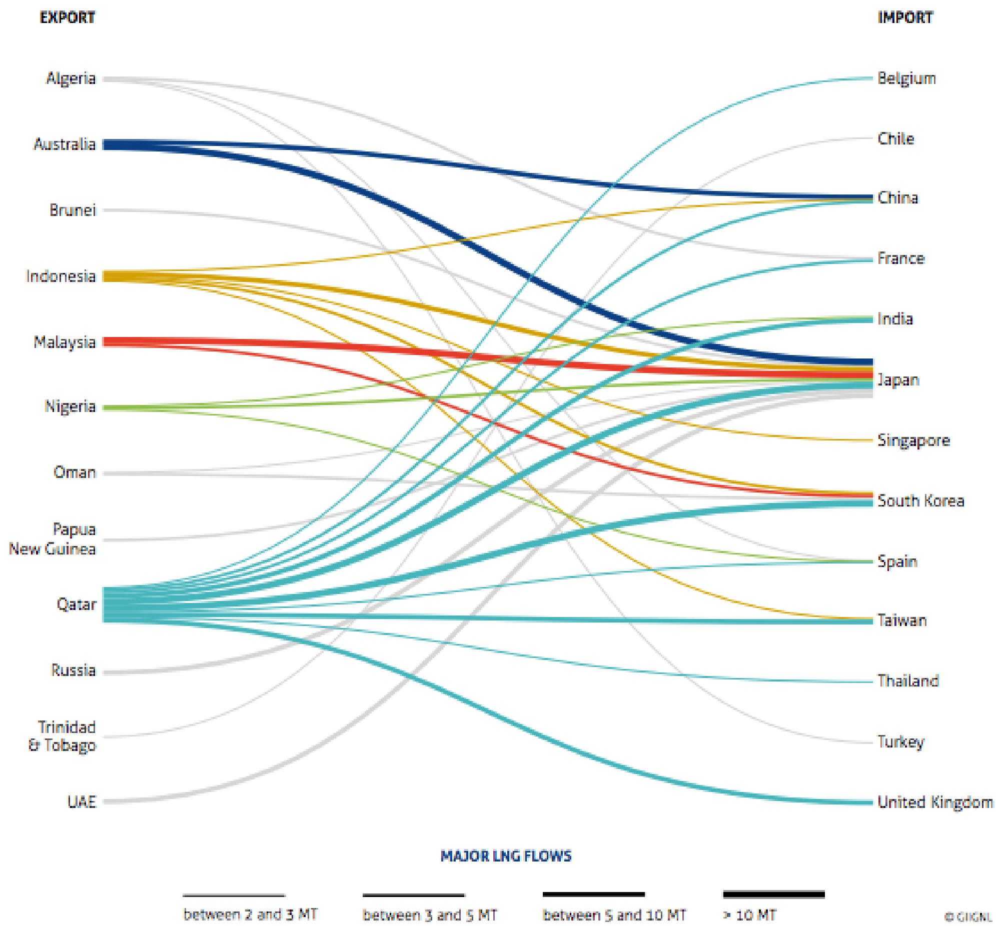

Figure 3.4: LNG importers and exporters 2015 (GIIGNL, 2016)

3.4 Characteristics of the LNG market

The LNG market is rapidly changing. The vital infrastructure is being built at a higher pace and new technology is evolving. The number of stakeholders is increasing, and major market shifts like the US shale gas revolution disrupts the original trade routes. An important technological innovation is the Floating Liquefied Natural Gas (FLNG) projects, where Golar LNG was the first company to convert an LNG carrier to an FLNG (Golar LNG, 2018). Another important innovation is Shell's Prelude FLNG (Shell, 2018). Prelude FLNG is the largest offshore facility ever built, with a maximum displacement of 600 000 MT, and measuring 488m x 74m x 105m (length, width, height). Despite the innovations, onshore liquefaction and regasification facilities are still the governing types of terminals. Another innovation, Floating Storage and Regasification Units (FSRU), have opened new smaller markets for the import of LNG.

Figure 3.5: Golar's first FLNG (Hine, 2018)

The different parts of the LNG value chain have an important factor in common, which is that they are capital intensive. The cost of liquefaction plants and import terminals are usually in hundreds of millions $ or even more than a billion $. This requires the corresponding gas fields to be large to be competitive on costs. These assumptions changes if a gas field is located close to existing pipeline infrastructure which is connected to the end users. In that case, the need for converting to LNG and the corresponding capital-intensive facilities would not be necessary.

The contracts in LNG trade are mainly long-term. Both the sellers and the buyers of the LNG face enormous risk, and from a final investment decision (FID) it might take 4 years before the facilities generate revenue. The sellers, buyers and the facility operators need predictability to maintain a reasonable funding and to keep their risk as low as possible. A liquefaction terminal without a buyer of the LNG could potentially be in a dangerous financial position.

According to Fretheim and Bondevik (2014), the long-term contracts normally include a take-or-pay clause shifting some of the volume risks to the buyer. The buyer has to receive the volumes given in the contract, and still pay if he refuses to take delivery. Destination clauses are also common, meaning that the buyer cannot resell the LNG and ship it somewhere else.

The short-term contracts in natural gas are slowly increasing its part of the total trade, from 25% in 2013 to 27% in 2017 (GIIGNL, 2018). Short-term gas contracts are defined as three years or less. Traditionally, short-term contracts have been used to make up for imperfect long-term planning. Flexible contracts are also an evolving part of the LNG trade. These contracts allow the stakeholders to adjust the cargoes if profitable opportunities present, and the cargo can be sent to other ports.

3.4.1 Regulations and liberalization

In the European Union, gas markets are gradually being liberalized (Brakman et al., 2009). The trend is shared by other regulators around the world, with regulations gradually softening up. The expectation is that liberalized gas will lead to lower prices and higher volumes, which again gives higher welfare. Energy markets in general are often characterized by imperfect competition and capacity constraints. These two applies to the natural gas market, and they could be limiting the effect on the liberalization process and its projected benefits.

The LNG-carriers-to-FLNG conversion projects could speed up the market liberalization process on the supply side. Obviously, with half the building time compared to land-based liquefaction terminals they provide a competitive advantage. They also cost less than the land-based facilities, and can be relocated to a new gas field when the current production declines. These competitive advantages make exploitation of smaller and remote gas fields feasible, and they are expected to play an increasing role in the future LNG market. In figure 3.6, a simplified value chain is presented, where the left-hand side of the original LNG value chain in figure 3.1 is merged into the FLNG facility.

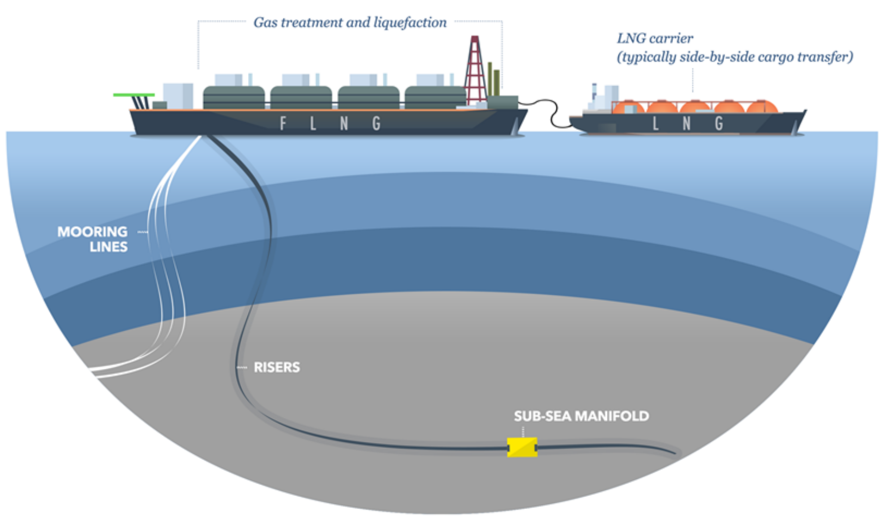

Figure 3.6: FLNG to LNG carrier (Golar LNG, 2018)

3.4.2 Natural gas pricing

In terms of gas pricing, an international pricing regime that typifies the oil market does not exist for natural gas. Where oil has an international pricing in terms of Brent Crude and WTI, the LNG market has regional prices. The most important regions are North America, the U.K, the European Continent and Northeast Asia. As described in 3.4.1, some markets have developed further in the deregulation process. Both the U.K. and North America have developed a short-term market, while the other two regions still rely on long-term contracts. In addition, long-term contracts are usually linked to oil price while short-term prices in the U.K. follows the gas price indicators like National Balancing Point (NBP).

The main reasons for the non-existing international gas price are the following (Makholm and Olive, 2016). First, the cost of shipping natural gas as LNG is extremely higher than for other commodities. The cost of liquefaction, shipping and regasification can be as high as 150% of the competitive US gas sales price. In comparison, the cost of shipping oil only amounts to 4% of the sale price. Second, the regulations of the industry majors outside the U.K and North America effectively precludes competitive entry of new supply. This is line with the gas prices outside the U.K. and North America, which remains tied to the oil price rather than the supply and demand of natural gas.

Indications of this pricing regime can be found in figure 3.7. The North-East Asia Spot Price and Japan (based on LNG) fell with more than 60% from Jan 2014 to Jan 2016, corresponding with the steep decline in the oil price. The figure also shows that the US Henry Hub is not correlated to the oil price. The U.K. (NBP) and the German Border Price remains partly tied to the oil price, while slowly decreasing its link. This can be seen in figure 3.8.

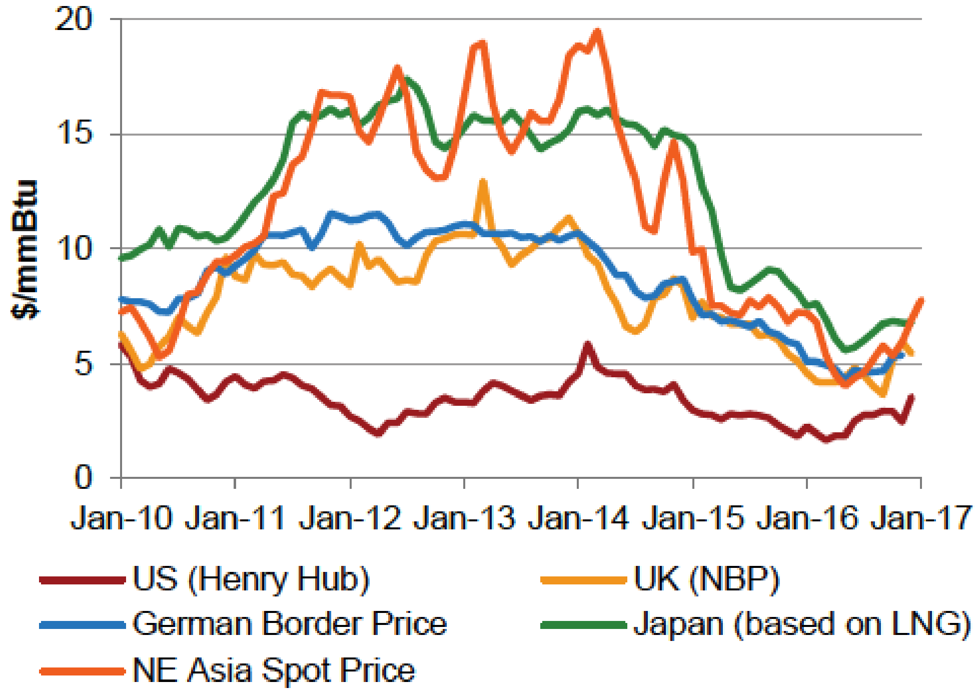

Figure 3.7: Monthly Average Regional Gas Prices, 2010-2017 (IGU, 2018)

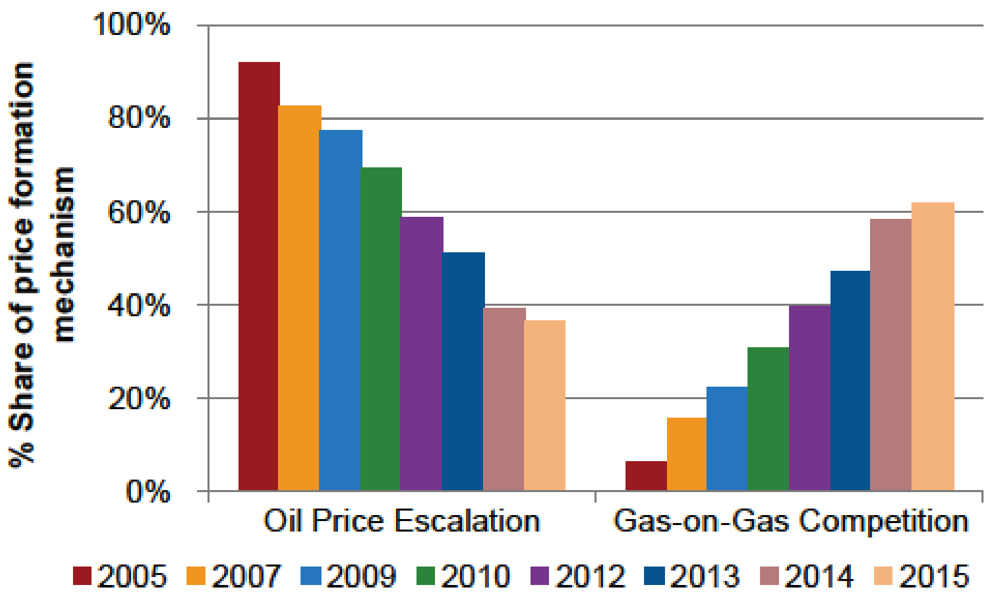

Figure 3.8: European Import Price Formation, 2005-2015. Oil Price Escalation = Prices linked to competeting fuels, usually crude oil. Gas-on-Gas Competition = Prices determined by the interplay of supply and demand (IGU, 2018)

The different pricing regimes lead to arbitrage opportunities. Since the regional prices are determined partly independent of each other, a trader could ship LNG from a high price region to a low price region and profit on the difference, excluding shipping costs.

Figure 3.9 shows the price difference between NBP and the Japan Import from 2009 to 2014. After the earthquake and the following tsunami in Japan in March 2011, the nuclear power plants were closed. A steep rise in demand for LNG occurred to substitute parts of the power gap, and the price increased quickly. While the British gas prices remained at lower levels, the spread, which is the difference between the two prices, increased and arbitrage became a possibility. With shipping costs around $0.5-1 per MMBtu, traders could make huge profits shipping LNG from Britain to Japan (Nikhalat-Jahromi et al., 2017).

Here, a theoretical example with shipping costs of $1 per MMBtu, and an LNG carrier with the capacity of 140 000 m^3, and LNG with heating value 22 MMBtu per m^3, is presented. If the assumption is that the trader gets a spread of $6, the profits will be as follows

$$140,000 m^3 * 22 \text{ MMBtu}/m^3 = 3,080,000 \text{ MMBtu} \tag{3.1}$$

$$\$6/\text{ MMBtu} - \$1/\text{ MMBtu} = \$5/\text{ MMBtu} \tag{3.2}$$

$$3,080,000 \text{ MMBtu} * \$5/\text{ MMBtu} = \mathbf{\$15{,}400{,}000} \tag{3.3}$$

This calculation is a highly theoretical example, and a real-world calculation will include a lot more factors. The example assumes that costs of liquefaction and regasification have already occurred, and that all costs related to boil-off (decreasing payload) are included in the shipping costs. The example is just meant to show the possible profits made through arbitrage.

However, arbitrage is not something every trading company could do. The trading company would need to have access to buy LNG from an existing liquefaction plant, charter a vessel and have a willing buyer at the receiving terminal. Considering the market characteristics outlined in this chapter, this could be hard to establish.

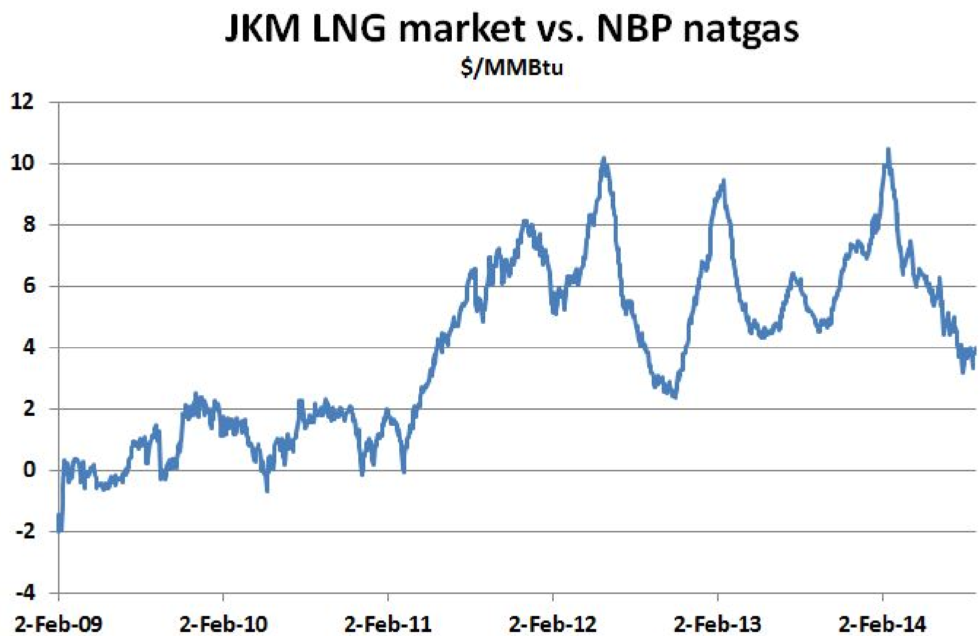

Figure 3.9: Price spread between Japan and NBP (Robinson, 2014)

3.5 LNG Shipping

From the first LNG carrier was built in the late 1950s, the LNG shipping industry has gone through a rapid change. The vessels have increased in size, and today the largest carriers can ship more than 200,000 m^3 LNG in each leg. The industry has also turned more cost-efficient, driven by both competition and new technology. While the largest LNG carriers cost up to $280 million in the 2008 and 2009, the same size cost less than $200 million today (DNVGL, 2018).

3.5.1 Technical

LNG carriers are categorized by two main design systems, the Moss System and the Membrane System. These can be viewed in figure 3.10. The Moss System can carry the load at different levels without concerns of stability, while the Membrane System can only sail at full load or close to empty. The reason for this is the free surface effect, where the liquid LNG could make the Membrane carrier unstable. The Membrane System utilizes the hull better, and can therefore carry more payload compared to the Moss System with the same main dimensions. Today, most

LNG carriers are designed as the Membrane System. The reason for this might be that a majority of LNG carriers sail on long-term charters, where they fully load at one liquefaction plant and fully unload at the regasification terminal.

Figure 3.10: Moss system and Membrane system(Xun Yao Chen, 2014)

A unique aspect with the LNG carriers is the boil-off that occurs continuously. The LNG carriers can be interpreted as gigantic thermoses, and a fraction of the LNG will continuously evaporate from the loaded tanks. The boil-off, which is methane in a gaseous state, can be used directly in the machinery for propulsion. If the vessel has a system for it, the other option is to re-liquefy the gas to LNG and pump it back in the tanks. If none of the above can be carried out, or if the vessel is in an emergency, direct discharge to air is possible. From a cost and environmental standpoint this is not desirable. The boil-off has gone from 0.25% per day of the total payload in the 1970s to below 0.1% of for the newest LNG carriers today (DNVGL, 2018).

Another aspect is that LNG carries are configured, through their loading systems, to a given set of loading and regasification terminals. This is a prerequisite from the shipowners and charterers, and the configuration is done during the building process at the shipyard. For a vessel that is going to sail on a 20 year fixed contract, from one given terminal to another, the flexibility of being configured to all terminals in the world might not be as valuable as for a vessel trading in the spot market.

3.5.2 The fleet

The total LNG carriers fleet consisted of 416 LNG carriers by end-2015 (IGU, 2018), considering those above 30,000 m^3 in payload. The fleet is young compared to other segments, with an over-weight of vessels less than 10 years old. Most vessels are built with a design speed of 19.5 knots plus a sea margin, which according to Johan Petter Tutturen in DNV GL is because of the initial design of vessel Hilli and her sister vessels built in 1970s (DNVGL, 2018). They were designed for shipping LNG from Abu Dhabi to Tokyo on a 20 years contract, and the design speed was optimized for their high boil-off (0.25%) and the storage capabilities. This relatively high speed could be held without a corresponding high external fuel consumption because the boil-off was used directly in the machinery for propulsion. 19.5 knots plus a sea margin was established as an industry standard and has been that since. According to Tutturen, this is pointless since the technology has lowered the boil-off, which makes around 16-18 knots a more suitable speed. This is also the speed most LNG carriers sail in today.

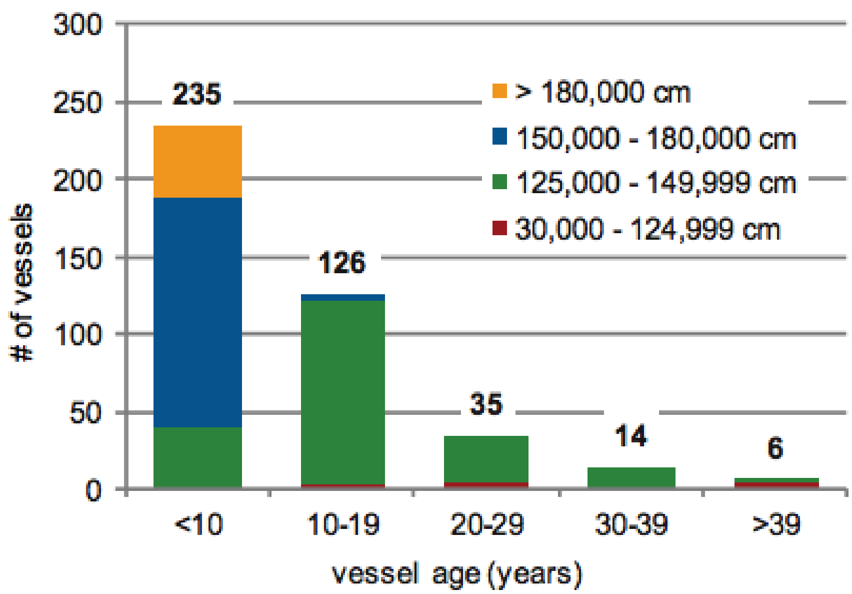

Figure 3.11: LNG carrier fleet (end-2015), by capacity and age (IGU, 2018)

A majority of today's existing fleet have steam turbine powered propulsion, while vessels built the last decade are mostly dual or tri-fuel diesel electric (DNVGL, 2018). Some of the youngest vessels, built in 2017 and 2018, have MEGI (M-type, Electronically controlled Gas Injection) engines which reduce greenhouse gas emission with 22% compared to fuel oil (DNVGL, 2018). The reduced fuel consumption and emissions are a competitive advantage over the older part of the fleet.

3.5.3 Costs

A breakdown of the costs for LNG shipping is presented in figure 3.12. The vessels are assumed to sail at 19 knots, and the numbers include a non-paid voyage back to the original port, as well as port costs. The vessels are also assumed to have a loading capacity of 160,000 m^3, and the Dual Fuel Diesel Electric (DFDE) Carrier's machinery is fed by boil-off while the Steam Turbine (ST) Carrier burn a combination of HFO and boil-off to maintain 19 knots. Also, the actual charter rates of July 2017 is used in the example.

The costs are divided into charter costs, fuel costs, canal costs and other costs. Charter costs are the payment to the owner for hiring the vessel, and fuel costs are assumed to be paid by the charterer. The other costs include port costs.

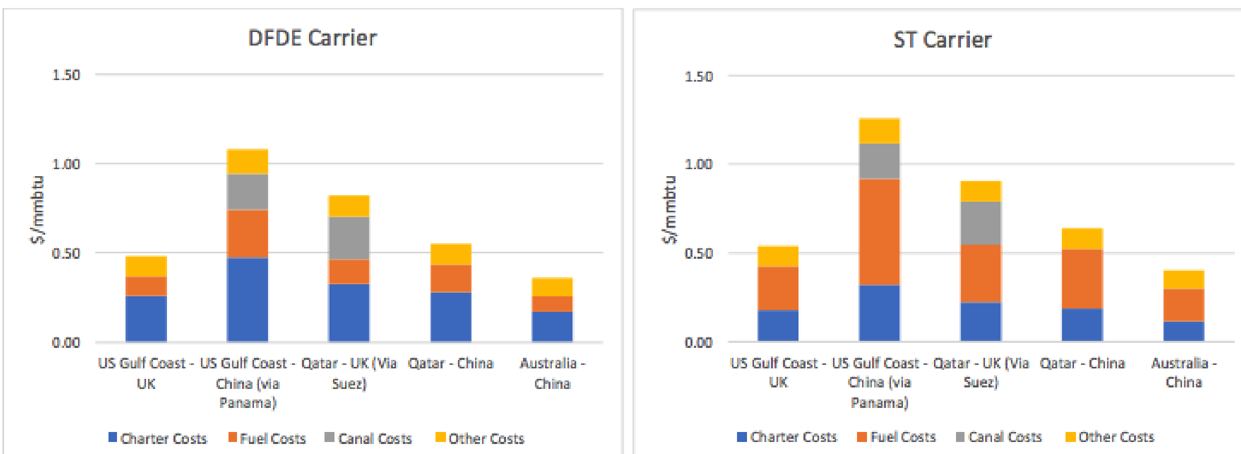

Figure 3.12: Cost of LNG Shipping for Dual Fuel Diesel Electric and Steam Turbine, and 5 different routes in 2017 (Rogers, 2018)

It is shown that depending on the length of the sailing leg, either the charter costs or the fuel costs are the main contributors. This holds for both carriers. For the ST Carriers, which have an older technology and a larger fuel consumption, the fuel costs are the governing cost when the sailing leg is long. Considering the example in subsection 3.4.2, it is shown that a shipping cost of $1 per MMBtu is not an unreasonable estimate.

3.6 Shipping dynamics

The market dynamics in the different shipping segments have a lot in common, and the most important aspects are outlined here. The supply in shipping is the product of (Stopford, 2009)

- The world fleet
- The fleet productivity
- The shipbuilding production
- The scrapping and losses
- The freight revenue

while the demand is a product of

- The world economy
- The seaborne trade
- The average haul
- Random shocks
- The transport costs

Both the supply and demand can be estimated in ton-miles, which makes them comparable. In a market where the demand is increasing faster than the supply, the freight rates will increase, and vice versa.

The shipping market follows cycles, and an average historical cycle has been 8 years long (Stopford, 2009). A new cycle can have similarities with the historical ones, but they are never identical. Through the cycles, the shipowners have two jobs. They must operate their vessels, and make the right decisions. The decisions to be made can be divided into four segments: the newbuilding market, the freight market, the sales and purchase market, and the demolition market. Continuously during the cycles, the shipowners have to consider these markets and their possibilities within each.

These aspects also hold for the owners of LNG carriers. A random shock disrupted the demand for LNG in Japan in 2011, when the earthquake and tsunami hit the country. This again led to an increase in demand for LNG shipping, and the spot freight rates skyrocket in late 2011 and 2012. Naturally, the other supply and demand factors still applied, but the earthquake was the main event that disrupted the balance.

Figure 3.13 shows the relationship between freight rates and ton-miles in a simplified way, hence supply and demand for shipping. With a low demand and a high supply the rates will be low, and if the demand increases while supply remains the same the rates will slowly recover. The curve is elastic, and the vessels could increase speed, decrease port time, postpone maintenance and thereby the fleet productivity increases. At some point, there is no more productivity to gain, and ordered vessels cannot be delivered before they are built, which makes the supply fixed. At this point, the supply and demand curve turns inelastic, and the rates could skyrocket. This is a simplified example of what happened from 2010 to 2012, which can be reviewed in figure 3.14.

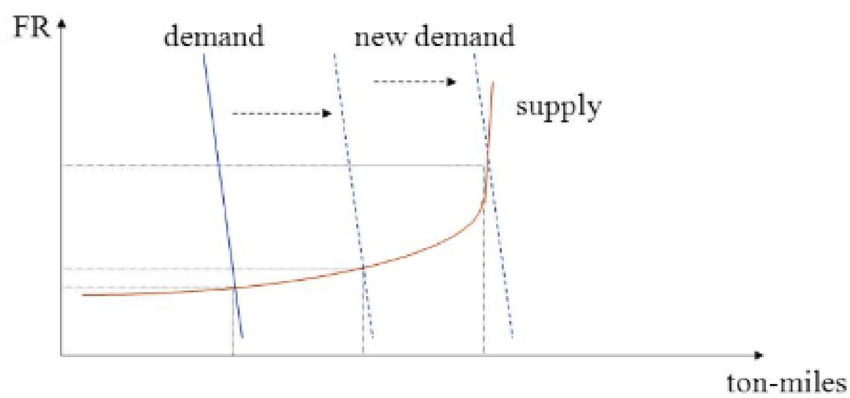

Figure 3.13: Supply and demand curve (Stopford, 2009)

In the same figure, 3.14, it can also be seen that the number of available vessels decreased to less than 5 vessels during the peak rates in 2011 and 2012. For a segment with several hundreds of vessels, this small fraction of available vessels was a serious threat for charterers that immediately needed shipping services. Since an overfilled storage at the liquefaction terminal could force a production stop at the gas field, hence a revenue loss and potential costly production restart, this is something a charterer would avoid at almost all cost.

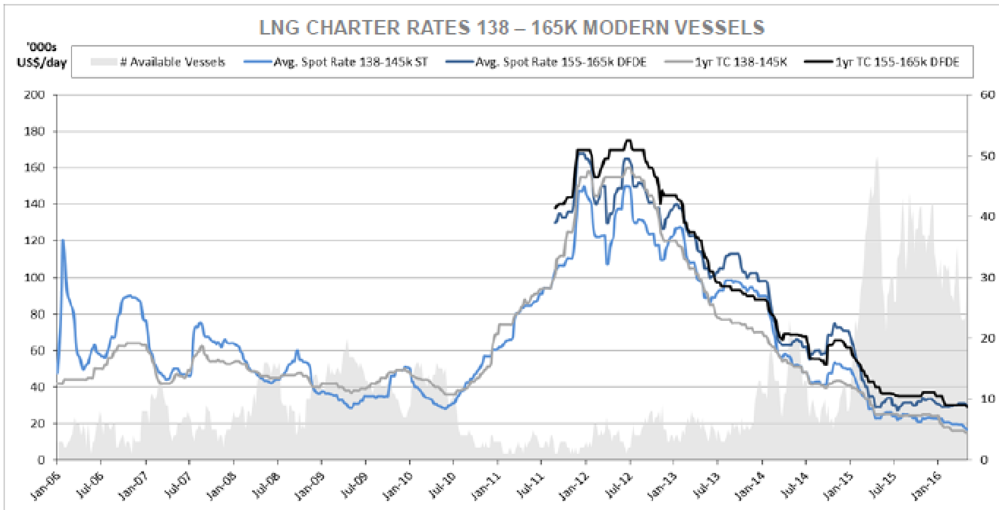

Figure 3.14: LNG Freight rates 2005-2016 (Catlin, 2017)

3.6.1 Contracts

As outlined in section 3.4, the contracts in LNG are mainly long-term contracts. For this research, long-term is considered more than 10 years, while medium-term is 3-10 years. Short-term is shorter than 3 years. Figure 3.15 shows the distribution of loaded LNG in 2016 and 2017, and we see that still around 80% of the LNG is shipped on long-term contracts. The reasons for this is described in section 3.4.

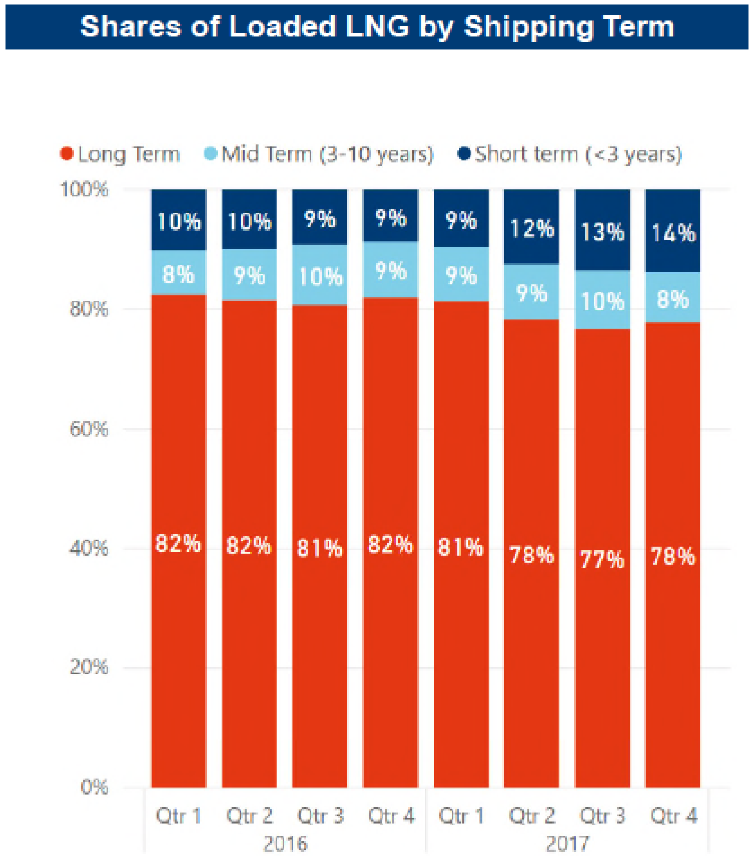

Figure 3.15: Shares of loaded LNG by shipping term (DNVGL, 2018)

However, the spot market has been increasing its share of the total trade in the last decade (DNVGL, 2018). It is also expected that this share will continue to increase. The spot market and the commoditization theory is further discussed in the case study and discussion part, in chapter 5 and chapter 6.

Chapter 4

Methodology

This chapter is structured as follows. Part I presents the data, how it was constructed and how it was obtained. A brief description of the section is done in the intro.

Part II shows how an LNG fleet list was obtained, and how the AIS Data for the same fleet was created. Further, the method for creating a spot fleet is presented, and how the corresponding spot fleet database is established. The databases are the basis for the analyses conducted in the case study.

4.1 Part I

This part is heavily inspired by our project thesis from 2017 (Næss et al., 2017).

The part presents the data used in the thesis. In the first section, 4.1.1, the content and its history are presented. In the same section the different methods for collecting AIS data is described. In section 4.1.2 the decryption method is given, and section 4.1.3 presents the kind of quality issues encountered in the data.

The AIS Data set, obtained by Smestad (2015) and Leonhardsen (2017), originally comes from the Norwegian Coastal Authorities, and the work is mainly built on the work done by the two graduated naval architects. Parts of the databases utilized are already created to extract the necessary data for different analysis. Because of the data set size and corresponding running time, the importance of extracting only the necessary data cannot be understated. Even after the work done by Smestad (2015) and Leonhardsen (2017), the challenge remains to only select the useful information for running algorithms on the AIS Data.

4.1.1 AIS Data

Automatic Identification System (AIS) is an automatic tracking system based on Very High Frequency (VHS) system, installed on more or less all merchant vessels. AIS Data from vessels can be exchanged with other vessels nearby, AIS base stations and satellites (S-AIS). The information within AIS messages includes static data such as navigational data, dynamic data such as speed, and voyage related data such as draught and estimated time of arrival.

AIS was developed with the purpose of enhancing safety, more specifically to avoid collisions. It remains as a supplement to the marine radar, which is considered the main instrument to avoid collisions. The AIS technology itself was developed in the 1990s, and from the early 2000s it became mandatory to have AIS on board most vessels above 300 GT. Around 2008 S-AIS was introduced, meaning that satellites can receive the messages in addition to base stations and other vessels. AIS messages can only reach around 70 kilometers horizontal at sea level, but up to 400 km in vertical direction (Skauen et al., 2013). This enabled the collection of the data with low orbiting satellites, and allowed a more coherent investigation of marine traffic.

Guidelines for Use of AIS Data

The International Convention for the Safety of Life at Sea (SOLAS) requires AIS to be fitted aboard all ships of 300 gross tonnages and upwards engaged on international voyages, cargo ships of 500 gross tonnages and upwards not engaged on international voyages and all passenger ships regardless of size.[1]

Message Types and Content

The International Telecommunication (ITU) has defined 27 different AIS message types, and the 5 most common ones can be found in table 4.1 (ITU, 2014). The information included in message type 1 is presented in table 4.2. According to Smestad (2015), message type 1 contributes to 72,5 % of all AIS messages. Message type 5, which include more information, is presented in table 4.3.

Table 4.1: Message types, AIS

ID	Name	Description
1	Position report	Scheduled position report
2	Position report	Assigned scheduled position report
3	Position report	Special position report
4	Base station report	Position, UTC, date and current slot number of base station
5	Static and voyage report	Scheduled static and voyage related vessel data report

Table 4.2: Message type 1

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)

[1] http://www.imo.org/en/ourwork/safety/navigation/pages/ais.aspx

Table 4.3: Message type 5

Information	**Description**
Unixtime	Number of seconds elapsed since 1 January 1970
Vessel specifications	Length and breadth, 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)
Vessel type	Vessel type category

Detailed information on AIS messages is given in table B.1, B.2 and B.3, in Appendix B, for static, dynamic and voyage related messages respectively. The data content is given by 'Guidelines for the onboard operational use of shipborne AIS' by IMO (2002).

The AIS ship type described is reported as a double-digit number between 10 and 99. The first digit represents the ship type, seen in table 4.4. The second digit represents whether a cargo is dangerous, hazardous or a marine pollutant.

Table 4.4: First digit representation of ship types

First Digit	**Ship Type**
1	Reserved for future use
2	WIG (Wing In Ground)
3	Other vessels
4	High-speed carrier, or vessels < 100 Gross Tonnes
5	Special craft
6	Passenger ships > 100 Gross Tonnes
7	Cargo ships
8	Tankers
9	Other types of ships

The frequency of the AIS messages varies with different intervals. Static and voyage data are sent every 6 minutes or upon request, but dynamic data is sent according to speed and operational status. The different intervals can be found in table 4.5.

Table 4.5: Dynamic AIS Data and their general reporting intervals

Vessel Operational Status	**General 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 14-24 knots and changing course	2 sec
Vessel at > 23 knots	3 sec
Vessel at > 23 knots and changing course	2 sec

Collection Methods

AIS data was traditionally collected using land-based receivers able to detect messages up to 40-50 nautical miles off-shore (Skauen et al., 2013). Messages outside this area would not be detected. A solution to this is to utilize satellites to collect the messages. This poses some problems further described in section 4.1.3. Messages collected with satellites, known as S-AIS Data, are collected on a worldwide scale. The Norwegian Coastal Authorities have four satellites collecting data[2], and the data used in this thesis is collected by the two first ones, AISSa-1 and AISSa-2. Since the data spans from late 2010 to year-end 2015, the two last ones, launched after 2015, is not a part of this thesis.

4.1.2 Decryption of AIS Data

Smestad (2015) developed a Python script used to extract data to an SQLite database by an external AIS parser provided by Lane. All the data handling, analysis and visualization in this thesis is done using Python. The verification of the output from various scripts implemented in Python is done with SQL, for instance that the number of unique MMSIs found by the script coincides with the number stored in the database.

[2] https://www.romsenter.no/Bruk-av-rommet/Norske-satellitter

4.1.3 AIS Data Quality

There are several issues to discuss when it comes to the quality of the AIS data. Some of the most important aspects of this will be discussed in this section. This is also covered extensively by Smestad (2015) and Leonhardsen (2017). This section will cover quality issues related to S-AIS data, general imperfection with AIS data and some human errors.

Satellite Coverage and Interference

Smestad (2015) points out that the variations in traffic from different time periods can have increased coverage in an area and therefore the traffic density may look higher. Eriksen et al. (2010) state that over a time span over of 24 hours, the High North and South is covered up to 15 times, while the areas around the equator are covered around two to three times. With the launch of AISSsat-2 the coverage was extended. The satellites can also have interference problems. A satellite will have a much larger coverage area than the AIS system of receivers were designed for, so high traffic areas would cause problems. If combining this with the low orbiting rates over the area, there could be significant gaps in the data.

Erroneous S-AIS Data

There are other possible sources of errors than the ones discussed in terms of the satellites. These errors can either be caused by a failure in the automatic reports or by human errors. Regarding the former, Smestad (2015) discovered that there were several thousands of vessels that had at least some erroneous data. This includes for instance wrong IMO numbers. However, that only affects the static messages, so the total number of distinct IMO numbers do not reflect the total number of vessels present in the S-AIS data. Leonhardsen (2017) discovered that the total number of unique MMSI numbers in the database exceeded the total number of vessels in the world fleet at that time. This may be caused by vessels changing owners over the time period for the data set. Other errors may include wrongly reported ship dimensions and erroneous ship positions. Some of these errors were fixed by Smestad (2015) and Leonhardsen (2017) in constructing the database.

Human Error

There are several kinds of human errors with regards to the AIS data. This mainly includes manually reported data. The manually reported data include for instance the draught, destination, ETA, route plan and navigational status (see Appendix B for more manually reported data). To illustrate these errors we look at the navigational status. The crew can set the status to 1 or 5 when a vessel is not moving, meaning "at anchor" and "moored", respectively. It happens that the crew forgets to change the status while sailing. This can be seen in figure 4.1, where the data plotted is for speeds above 5 knots and navigational status 1 or 5, for a set of ships.

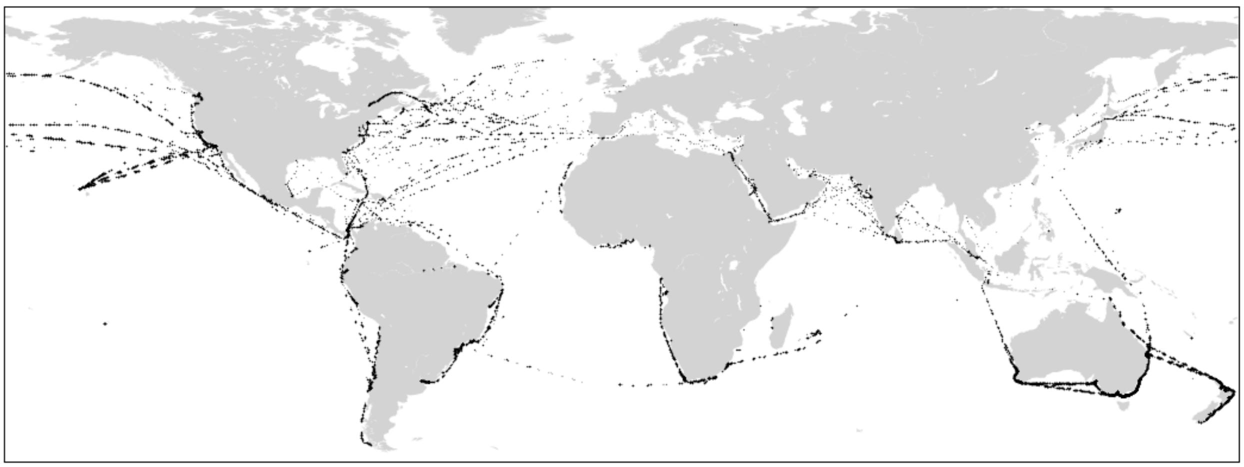

Figure 4.1: Vessels with speeds above 5 knots and navigational status 1 or 5

4.1.4 Summary

The foundation of the work were done by Leonhardsen (2017), utilising heuristics from Smestad (2015). Their approach and results have been presented for the reader to get a good understanding of the data being used for further analysis.

As for this thesis, the cleaning, filtering, and the methods used further will be presented in the next part.

4.2 Part II

4.2.1 Obtaining LNG fleet list

To start the work of investigating the LNG carriers, a fleet list of the today's existing carriers was obtained from Thomson Reuters. The subscription is kept by NTNU Business School, and the fleet list was exported in excel. The list includes IMO number, name, year built, callsign, size (DWT), flag and status. This amounted to a total of 614 vessels at the time of download (March 2018), which included LNG carriers of all sizes and new-builds (on order and under construction).

A data cleaning and filtering process started to obtain the vessels relevant to the case study. The AIS Data had an upper time limit of December 2015, hence vessels delivered after this month was filtered out. Carriers smaller than 10 000 DWT was also excluded, as they most likely have a different operational pattern and therefore are not relevant for the case study.

After this filtering, the number of vessels in the fleet was 416. A total of 198 vessels were either smaller than 10 000 DWT and/or built after December 2015.

It is important to note that the LNG carriers scrapped in the time period from 2011 until the time of download (March 2018) will not appear in the fleet list from Thomson Reuters. However, the scrapping was low in these years. The total number of vessels sold to scrap was 22 vessels during the time period, while around 20 vessels were sent to the yards for conversion to FSRUs or FLNGs (GIIGNL, 2018).

Since the AIS Data spans from December 2010 to January 2016, it is interesting to understand the fleet composition during this time period. 87 vessels have a newbuild date (delivered) inside this time period, which means that the fleet considered for the case study increased from 329 vessels to 416 during the time span. However, since the fleet list obtained does not consider scrapped vessels (they are deleted when they are scrapped), the real world fleet of LNG carriers was somewhat higher in both 2011 and 2015. This is further discussed in section 6. The fleet obtained and used in the case study is presented in figure 4.2, plotted by size (DWT) and year built.

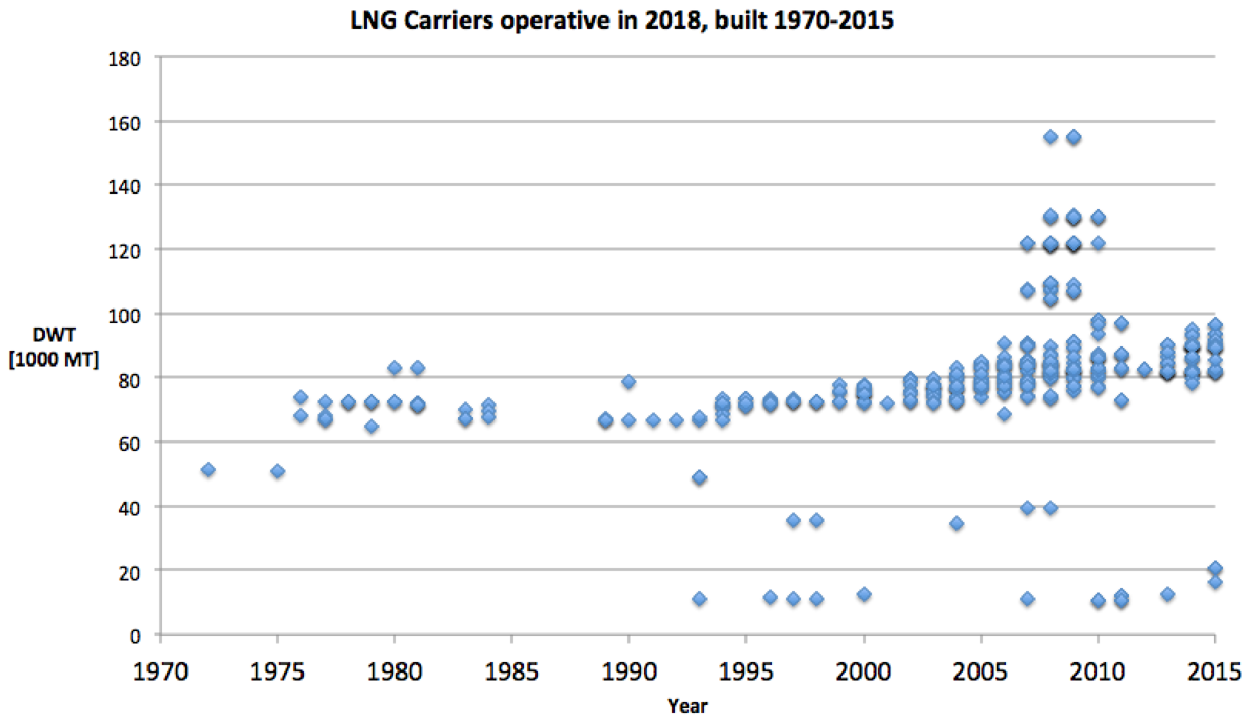

Figure 4.2: LNG Carriers in 2018, built 1975-2015

A simplified flowchart expressing this process can viewed in figure 4.3.

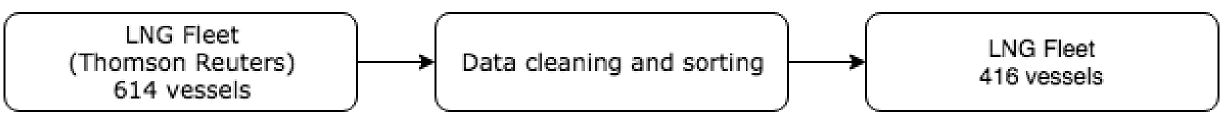

Figure 4.3: Obtaining LNG fleet list, flowchart

4.2.2 Obtaining AIS Data for LNG fleet

The fleet list consisting of the 416 vessels was used to extract the relevant AIS Data from the main database file from the Norwegian Coastal Authorities. The main database file, which included all vessels and therefore had a size of approximately 300 GB, was unpractical to do analysis with because of long running time and challenging data handling. This is elaborated in Part I.

Therefore, the AIS Data corresponding to the LNG fleet was extracted and a separate database file was created. The process was conducted as follows. First, the list of MMSI-numbers was obtained by matching IMO numbers from LNG fleet list with the IMO-numbers in Message type

5 in the main database file. For more information about message type 5, see 4.1.1. The list of MMSIs amounted to 437 numbers, which is higher than 416 because the vessels might have more than one MMSI-number during their lifetime. Second, the list of MMSI-numbers was used to create a table of LNG carriers with the information from Message type 1. This table was saved as its own database file, with a size of approximately 1 GB. This smaller file was saved locally which simplified data handling and analysis.

A script, written in Python, in combination with commands in SQL was executed to obtain the local database file. This script and the SQL commands can be found in Appendix A.

A flowchart presenting the process can be viewed in figure 4.4.

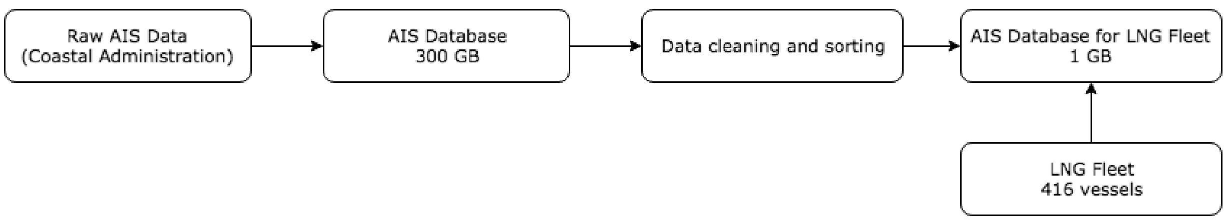

Figure 4.4: Obtaining AIS Data for LNG fleet, flowchart

4.2.3 Creating spot fleet database

As outlined in the introduction of this thesis, and for the purpose of the case study, creating an LNG fleet consisting of spot-trading vessels through the time period of 2011 to 2015 was necessary. This section outlines the methods that have been used, and the potential shortcomings of them. While it would be natural to present a list of the vessels, this is not done. The reason is explained in section 1.3.

The identification of the spot trading vessels was done as follows. First, the original fleet list of LNG carriers was used as a basis. As described in 4.2.1, the list included their names and their IMO numbers. From this, their owner groups could be identified through online research of public information. The sources were mainly online newspapers that cover the LNG market[3]. Also, searching for the name of the vessels often gave hits directly on the companies' websites. As an example, the majority of Nakilat's (Qatar Gas Transport Company) LNG carriers starts with "Al", making research faster and easier. Similar recognizing methods were applied for the other shipowner groups, and the author's prior knowledge to the industry was an advantage. As

[3] e. g. http://www.tradewindsnews.com/ and https://www.lngworldnews.com/

mentioned in the introduction, the size of the total fleet made this manual approach feasible. If the same approach were applied on larger segments like (crude) tank, dry bulk or cargo, the work would be very time-consuming.

With this method, the owner groups were identified, and a list of them was obtained. For the 416 vessels, this amounted to around 30 groups. Included in this list was both pure LNG shipowners and larger energy companies and conglomerates. The LNG market, like other shipping segments, is characterized by complicated corporate structures. A common usage is the single purpose vehicles, where each vessel is its own entity. The parent company is the real owner, and therefore the term owners groups make more sense when characterizing the owners. Shipowners organize their companies in this way to minimize risk exposure, especially in terms of financial liabilities, and sometimes for tax purposes. If the vessel is its own legal entity and the legal framework do not include parent guarantee, the real owner could abandon the liabilities in a situation of default. However, the last decade the ship finance actors usually include this parent guarantee before they provide any funding (Lee and Pak, 2018).

While identifying owners groups was trivial and straightforward, the next task was to find out which vessels traded in spot in which time periods. Without access to detailed shipping intelligence, this had to be solved in other ways. In the general business world, companies often disclose their risk profiles. This is important for the stakeholders, like investors and debt holders, because they want to adjust their investments after their own risk preferences. Therefore, transparency is often a requirement from the stakeholders. To some extent, this also holds for shipping companies, even though the industry itself is not considered being transparent. The individual shipowners often disclose what kind of risk exposure their companies aim to have. This is closely linked to chartering, where spot and short-term markets are more volatile and therefore higher risk than long-term charters. With this in mind, it is reasonable to assume that many of the shipowners want to disclose their risk exposure, and therefore their chartering strategies. Those of them who are listed on a stock exchange have to publish quarterly and annual financial reports, and a majority of them include what kind of markets their vessels have traded in. For the reasons expanded above, the non-listed companies also to some extent disclose what kind of markets their vessels trade in.

The process was therefore uncomplicated after considering these assumptions. The spot fleet was obtained from the public available information. However, the shipowners might not want to disclose their operations for several reasons. They could be aiming for the combination that they believe gives the best risk-adjusted return, and they might want to hide this from their competitors. If their stakeholders are not public entities, and not demanding transparency, they could have an interest in hiding their business model.

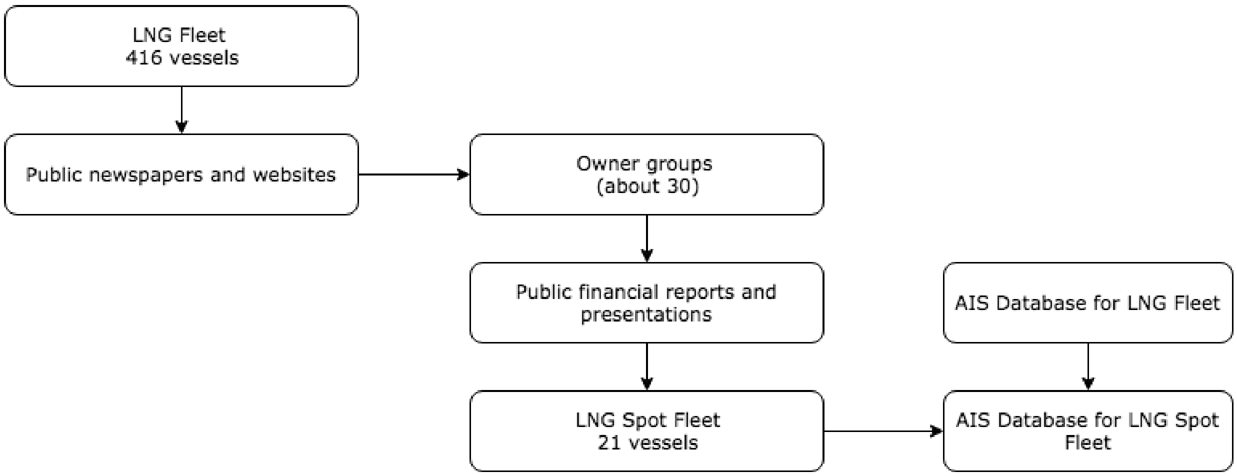

Figure 4.5: Creating spot fleet database, flowchart

However, with this method, a name list of confirmed spot trading vessels from 2011 to 2015 was created. The number of vessels trading spot through the time period of the AIS Data, which is 1 December 2010 to 1 January 2016, was found to be 21 vessels. After the list was obtained, the same procedure as in section 4.2.2 was executed for the spot list, and the AIS Data for LNG carriers trading spot was saved locally. The procedure can be reviewed schematically in figure 4.5, which presents a flowchart of the method. The most time-consuming parts were identifying the owner groups and going through their financial reports and presentations.

Potential shortcomings

There are some shortcomings related to this method. Mainly, the public listed companies disclose their vessel operations in a detailed manner making it trivial to find out which vessels traded in spot. However, some of the shipowners are not listed, and do not disclose what market their vessels trade in. These unconfirmed vessels could be sailing at long-term contracts, spot or a combination of them. As known from the industry review in chapter 3, a great majority of the fleet trade in long-term contracts. When considering the spot fixtures presented in figure 5.2 in the case studies, chapter 5, the number of spot vessels in our spot fleet list appears to be too low. The reason might be that the actual spot vessels have not been included, but it could also be that long-term chartered vessels have occasionally done spot fixtures.

For the purpose of the case study, a complete and accurate list of the spot vessels is desirable, but not crucial. The operational differences between an incomplete spot fleet and the long-term fleet would still be observable, and the time-varying parameters would still be present. The reason for this is that the spot trading vessels amounts to less than 10% of the total fleet for the given time period.

A quick example can explain this. Imagine a total fleet of 500 vessels, where 50 trade in spot and 450 sail on long-term charters. The analysis only verifies half of the actual spot trading vessels, thus 25 vessels. If the actual spot fleet sails faster than the long-term chartered fleet, you would still observe a difference in speed distribution even though you are only considering half of the actual spot fleet. On the other hand, if the spot trading vessels amounted to a lot larger size of the total fleet, for example 50%, the differences in operational patterns would be harder to observe.

Chapter 5

Case studies

This chapter presents the different case studies conducted. The first case study presents the findings related to speed distributions, both of the spot fleet and the total fleet.

The second case study presents the results of an area and draught analysis, and how they are connected to the overall objective of the thesis.

The third case study is a more qualitative part, where it is discussed if the results from the two other case studies can be any support for the hypothesis of the LNG market turning commoditized.

The discussion of the results is mostly carried out where they are presented. However, the overall and general discussion is covered in the next chapter, 6.

The codes used in the case studies can be found in Appendix A.

5.1 Speed cases

In this section, the speed distribution is investigated. The AIS Data of the spot fleet obtained in 4.2.3 is compared to AIS Data from all LNG carriers. This spot fleet speed case aims to investigate the differences in speed patterns by the two fleets, and provide theories explaining the differences.

Why is speed interesting? As outlined in the introduction, the stakeholders in shipping have an interest in the speed patterns of their vessels. Design offices, shipyards and shipowners could increase their decision support if they have a better understanding of the speed patterns. The sailing speed directly affects the operational costs. Vessels optimized for the actual speed they sail in, will in general have lower fuel consumption than those who are not, all else being equal. If the vessels sail slower than their design speed, which often their hull and machinery are optimized for, they could scale down the machinery in future newbuilds. However, this could also affect the flexibility of the vessels.

The speed is also interesting in terms of whether the vessels is supposed to trade in the spot or the long-term market. If differences in the speed distribution between the two fleets are identified, this should be taken into account when dedicated spot shipowners, like Oslo-based Flex LNG, order new vessels.

5.1.1 Spot fleet speed

From 2.2.3 in the literature review, we remember the theory proposed by both academics and industry insiders, which claims that vessels speed up during high rates and slow down during weaker market. In the time period from 2011 to 2015, the LNG spot market experienced both very high freight rates in 2012 and low rates in 2015. The rates can be view in figure 5.1. The hypothesis is further investigated in this section.

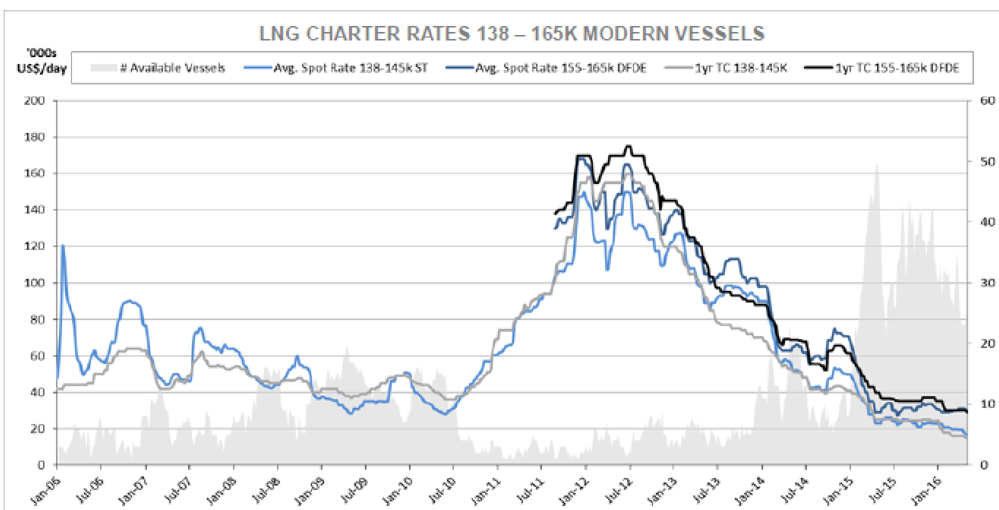

Figure 5.1: LNG Freight rates 2005-2016 (Catlin, 2017)

In 2012, the confirmed spot fleet consisted of 6 vessels, and the total number of messages from these 6 vessels amounted to 65,632. However, in 2015, the fleet consisted of 17 vessels and counted 253,331 messages. The reason for this change is that many of the spot trading vessels were delivered in 2013 and 2014, and the fleet increased at a high pace these years. Also, 4 vessels of the spot fleet were either scrapped or converted by year-end 2015, making the total spot fleet consistent with the number in 4.2.3, which was 21 vessels.

It is important to remember that this spot fleet does not include all vessels traded in spot, but instead all vessels that have been confirmed and disclosed that they traded in spot. Figure 5.2 shows the spot fixtures, which is the number of single spot loads, monthly from 2012 to 2017. The total number of fixtures were about 80 in 2012 and about 180 in 2015, which is an increase of 125%. While a spot vessel could ship 4-8 loads through a year (DNVGL, 2018), heavily depending on the sailing distance and idle time, it is reasonable to assume that the confirmed spot fleet is missing some vessels from the actual spot fleet. However, another reason might be that the flexibility described in 3.6, allows vessels which normally sail on long-term contracts to trade occasionally in the spot market. Hence, the potential missing vessels in the confirmed spot fleet versus the real spot fleet could be those. It is also likely that a charterer on long-term contract temporally relocate its vessels to the spot market when the rates are high, like we see in 2012 in figure 5.1.

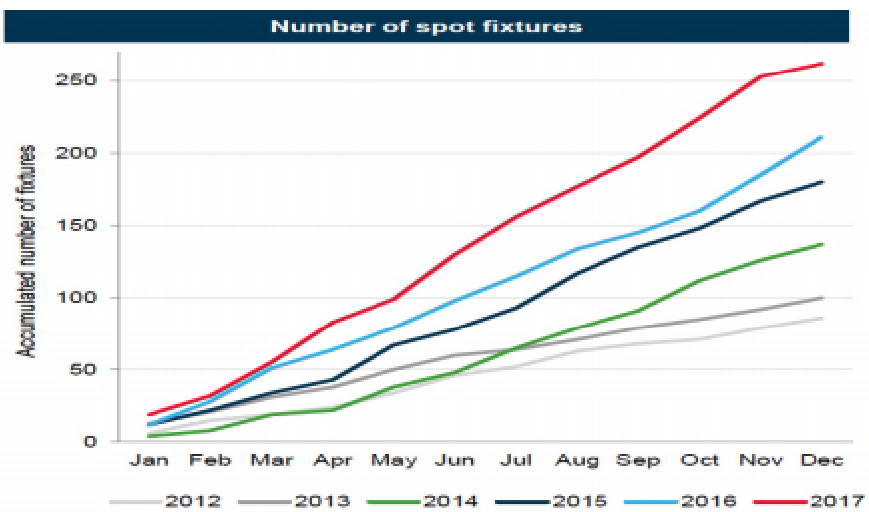

Figure 5.2: Number of spot fixtures 2012-2017 (DNVGL, 2018)

Figure 5.3 and figure 5.4 show the speed distribution of the different LNG carriers that were confirmed to trade in the spot market during 2012 and 2015. We see a shift from higher speed in 2012 to lower speed in 2015.

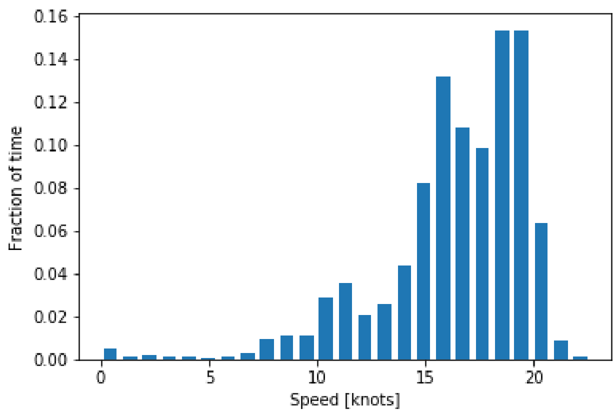

Figure 5.3: Speed distribution 2012

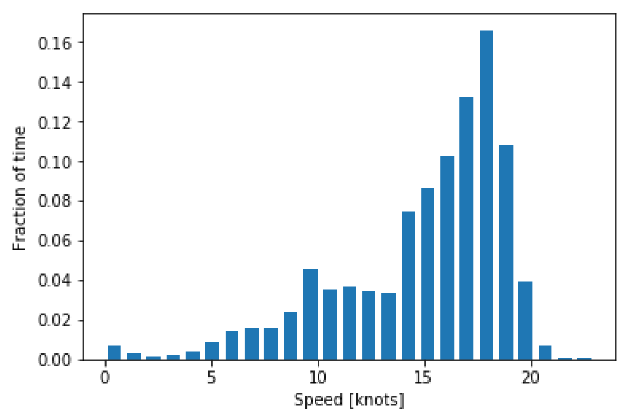

Figure 5.4: Speed distribution 2015

To investigate this further, we choose to only consider AIS messages where the speed is more than 10 knots. The speed at open sea is the most interesting, since vessels sailing close to land or through straits might be constrained by other factors, e. g. speed restrictions. The speed at open sea would not be restricted by third parties, and the captain, hence the shipowner or the charterer, would be free to choose his sailing speed. The results are presented graphically in figure 5.5 and figure 5.6, while the numbers are presented in table 5.1.

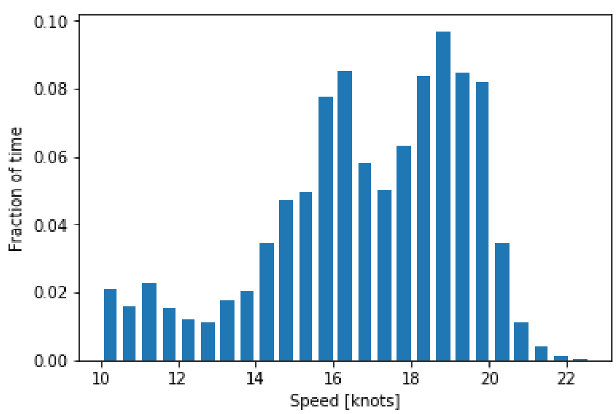

Figure 5.5: Speed distr. over 10 knots, 2012

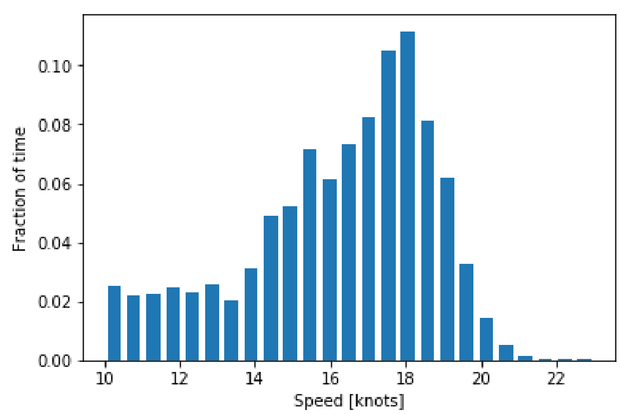

Figure 5.6: Speed distr. over 10 knots, 2015

Table 5.1: Speed distribution over 10 knots, spot fleet

Type	**2012 (full year)**	**2015 (full year)**	**Dec. 2010 to Jan. 2016**
Number of messages	62,506	218,985	616,856
Vessels	6	17	21
Average speed [knots]	16.82	16.19	16.32
Standard deviation [knots]	2.57	2.49	2.48

For the messages above 10 knots, in the years 2012 and 2015, respectively, the average speeds were 16.82 knots and 16.19 knots. The decline was 0.63 knots from 2012 to 2015, and the corresponding standard deviation decreased slightly from 2.57 to 2.49 knots.

There could be several reasons for this decline in the average speed, one of them being the initial hypothesis about vessels speed up during time periods with higher rates. The number of vessels used in this speed case is small, only 6 vessels in 2012 and 17 vessels in 2015. There could be that the 6 vessels in general have a higher operating speed due to their design, e. g. machinery, propulsion or hull. However, the number of messages is high, 62,506 versus 218,985. A relatively high number of messages is important to substantiate that the speed distributions are close to the actual speed during the voyages.

Another aspect to have in mind is that the speed obtained is the speed over ground, meaning that wind, waves and currents are not taken into account. The speed through water is the governing for the operational costs, since the resistance relies on it. Figure 5.5 and figure 5.6 show the same messages plotted on a world map, where the map is reduced to only present the messages detected. In the first figure, 5.5, showing the smallest amount of messages, not a single vessel has sailed north of Great Britain. In the second figure, 5.6, one or several vessels have been sailing to the LNG terminal in Norway, Melkøya. The weather outside Norway is known for being harsh, and this could affect the sailing speed in a negative way. Therefore, the weather could contribute to an offset of the actual speed compared to the recorded speed distribution.

In section 4.1.3, this offset is addressed from another perspective. Because of their orbiting pattern, the Norwegian Coastal Authorities' satellites cover the north and south of the globe more extensively than the areas around equator. If the vessels generally sail faster closer to equator due to weather, this could pose an offset in the speed distribution.

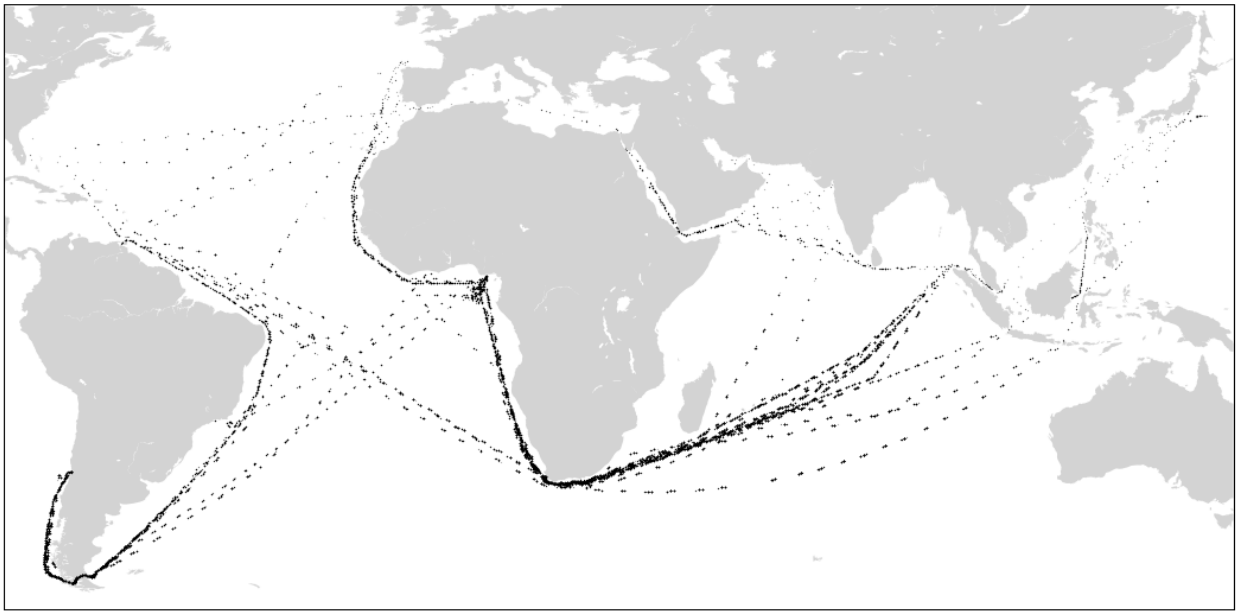

Figure 5.7: All 62,506 messages plotted, 2012

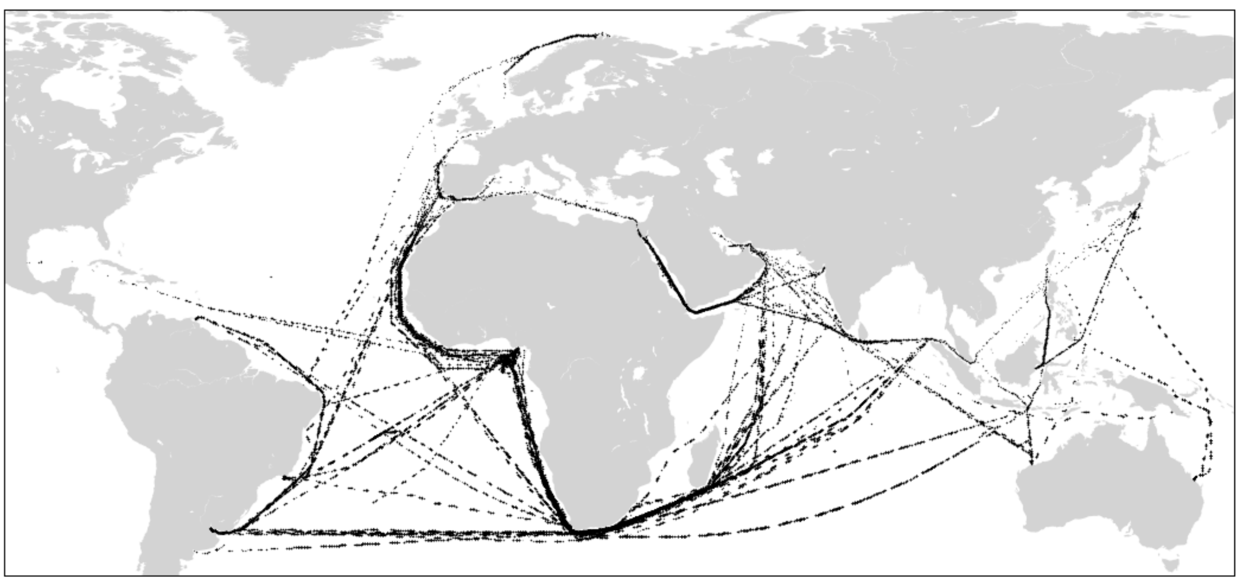

Figure 5.8: All 218,985 messages plotted, 2015

The fuel prices are also a factor in the hypothesis regarding speed and freight rates. While high rates could make vessels to speed up, a low fuel price could also contribute to an increasing speed, as described in the literature review 2.2.3. However, we could argue that LNG carriers are less affected by fuel prices than other shipping segments. The reason for this is their boil-off. While fuel prices for shipping in general are tightly linked to the oil price, the prices of LNG are set regionally, as outlined in section 3.4.2. In some regions it is linked to the oil price, while in other the price could be interpreted as a function of supply and demand of natural gas, and not oil. Since the LNG carriers mainly sail on a combination of their boil-off and diesel, they are less linked to the oil price.

With all these factors in mind, it is hard to evaluate which of them are the most important for the shipowners and charterers when they decide the sailing speed. The rates could be a governing factor, but not necessarily. This will be further discussed in chapter 6.

5.1.2 Total fleet speed

With the spot fleet speed analysis in mind, it would also be interesting the check the speed for all LNG carriers through the year of the peak rates (2012) and the year of low rates (2015). This is interesting because we can compare the years against each other, to the spot fleet, and also against their design speed.

As outlined in section 3.5.2, most LNG carriers are built with a design speed of 19.5 knots plus the sea margin. Traditionally, and in general, vessels have been built with a sea margin of 15% (Magnussen, 2017). If the vessels were sailing at their design speed, the speed should be around 19.5 knots at a considerable part of the time. From 5.9, we see that the vessels rarely sail at this speed. When only considering the AIS messages where the speed over ground is more than 10 knots, the average speed is 16.27 knots, and the standard deviation is 2.46 knots.

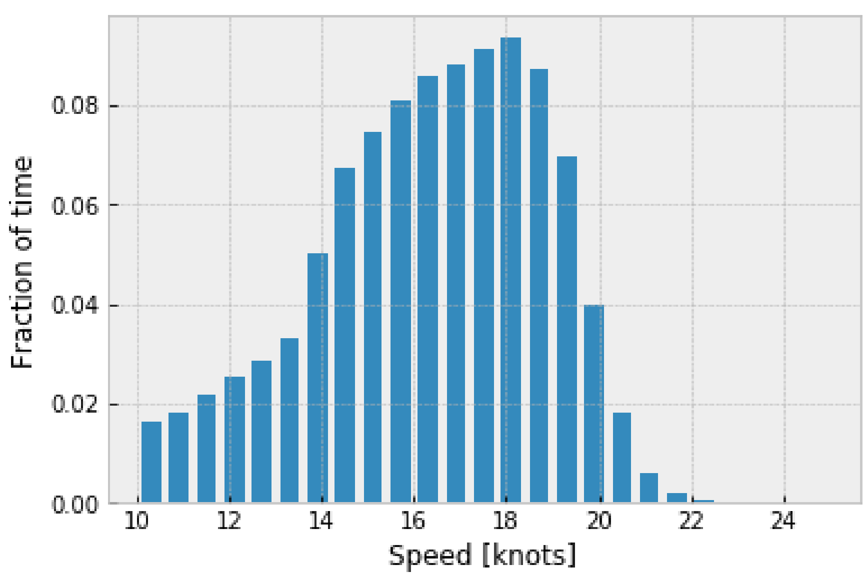

Figure 5.9: Speed distribution over 10 knots, Dec. 2010 to Jan. 2016

Table 5.2: Speed distribution over 10 knots, total fleet

Type	2012 (full year)	2015 (full year)	Dec. 2010 to Jan. 2016
Number of messages	1,315,349	3,999,033	11,740,898
Vessels	348	409	437
Average speed [knots]	16.60	16.03	16.27
Standard deviation [knots]	2.42	2.47	2.46

Although the speed is not an even normal distribution, it has some of the characteristics of it. The vessels sail at 19.5 knots or above at less than 8% of the time period. This implies that the vessels are not operating according to their design speed, and that potential savings could apply if the vessels were designed differently.

Since the design speed of 19.5 knots plus the sea margin remains as an industry standard (DNVGL, 2018), it could be interesting to look at potential savings for retrofitting the bulb. If the speed profile obtained here holds for the future, designing a bulb for a service speed in the range of 16 to 18 knots could be more cost-effective in the long run.

Further, it is also interesting to look at the change in speed distribution from 2012 to 2015 for the total fleet, as conducted for the spot fleet. In table 5.2, we see that the fleet average speed also decrease significant from 2012 to 2015. This could indicate that not only the spot fleet is decreasing their speed, but also all LNG carriers in general. We see that the decrease is slightly lower than for the spot fleet in table 5.1. The possible reasons are discussed further in chapter 6.

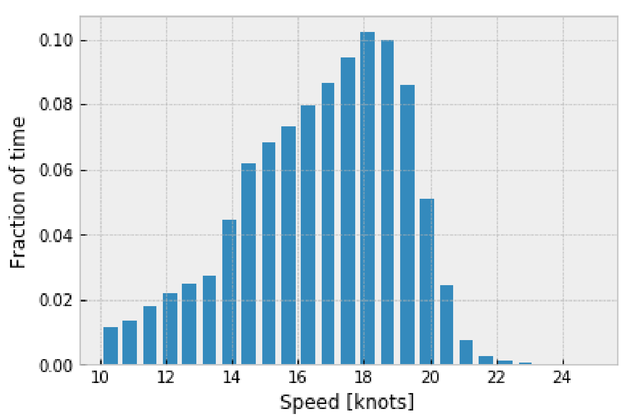

Figure 5.10: Speed distr. over 10 knots, 2012

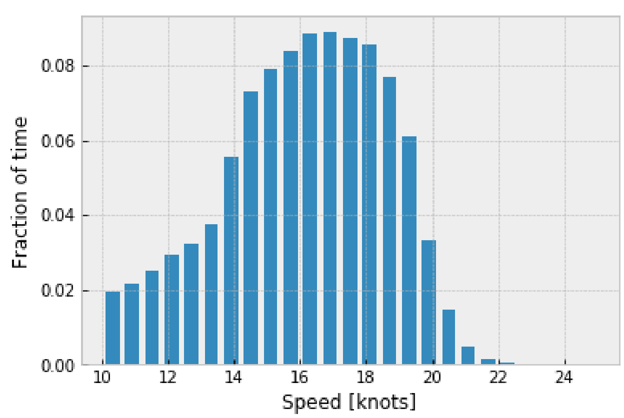

Figure 5.11: Speed distr. over 10 knots, 2015

To validate the AIS messages and the speed distribution, a plot presenting the message intervals is included in figure 5.12. We see that the time between messages is mostly less than 15 seconds.

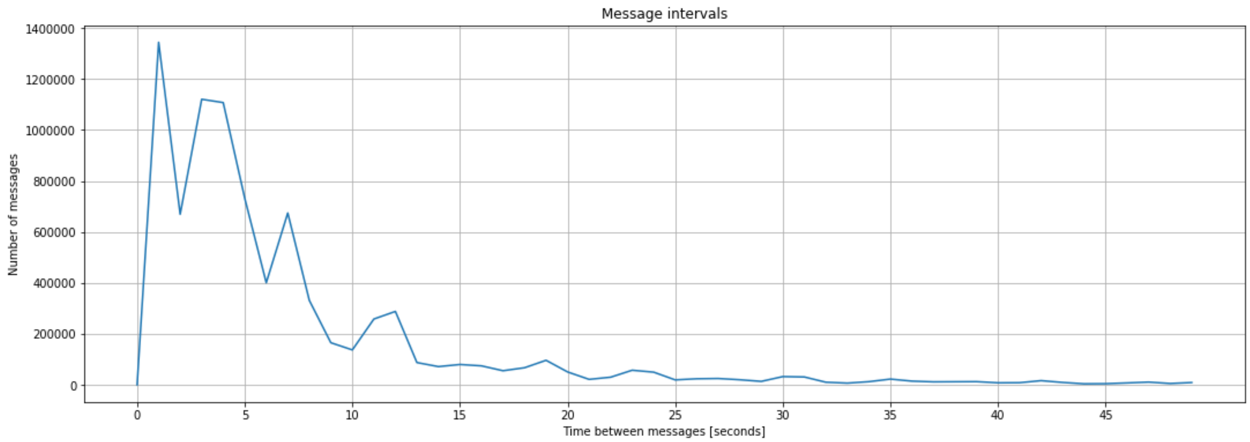

Figure 5.12: Message intervals, Dec. 2010 to Jan. 2016

However, a simplified calculation presented in formula 5.1 shows that for each vessel, on average, 17 messages per day is recorded throughout the time period of 5 years from 2011 to 2016. The number of messages is taken from Table 5.2. The weighted fleet, thus the number of vessels, is an average of the fleet at year-end 2010 and year-end 2015.

$$\frac{11,740,898 \text{ (messages)}}{371 \text{ (weighted fleet)} * 5 \text{ (years)} * 365 \text{ (days per year)}} = 17 \text{ (messages per vessel per day)} \tag{5.1}$$

The two reviews of the message intervals are linked in the following way. The area under the graph in figure 5.12 is equal to the total number of messages, 11.7 million. The graph is reduced to only include message intervals up to 50 seconds, and if all the existing message intervals were to be included, the graph would not be readable. So, why are the two reviews showing such different results? A message interval of 15 seconds or less equals almost 6000 messages per day or more, far above the 17 messages recorded. The reason is that the messages often are collected burst-wise, where many messages are recorded closely in time and then a longer interval waits before the next appears. This can be seen in the map in figure 5.7. At open sea in the Atlantic and the Indian Ocean, it is clearly seen that the black dots, which is the position data, are concentrated before a longer time interval and the next concentration appears. The nature of the orbiting satellites and the collection methods are the reason for this, and they are explained in section 4.1.1.

5.2 Area and draught cases

This section of the case study is investigating the areas that the LNG carriers are sailing in. In terms of the objective of the thesis, which is investigating operational patterns, the areas sailed are of importance because of the following. LNG carriers are prepared from the shipyard for a given set of loading configurations, since the worldwide terminals utilize different loading systems. If the carriers increasingly sail to new areas, hence new terminals, a configuration of more terminals could be weighted stronger in the design process of the vessels. This is explained in section 3.5.1. This analysis could therefore increase the decision support for the stakeholders in LNG shipping.

A basic analysis of the draught is also conducted at the end of this section. The background of not utilizing the draught data in a more comprehensive way is also reviewed.

5.2.1 Area case

To analyze the areas sailed, the world is split up into 7 different zones, represented in figure 5.13. These are the main oceans, from west to east, Pacific, Atlantic, North Sea, Mediterranean, Indian, South East Asian and Oceania.

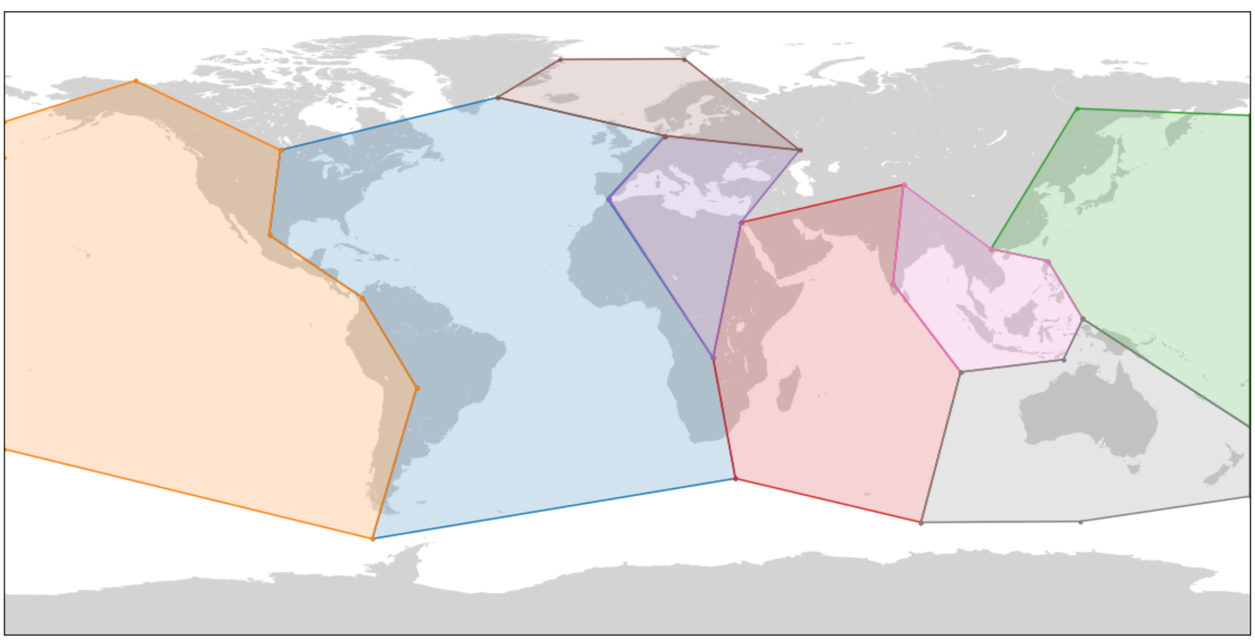

Figure 5.13: Area zones

The approach on how to observe vessels in each zone is important for the analysis. For the area case, the messages recorded in each zone each month were a suitable method. The messages imply that the single vessels have been in that zone, but not necessary at a port. However, if an increasing part of the fleet is visiting more zones this could imply that new and more terminals are being visited in general.

Figure 5.14 and figure 5.15 present the percentage share of the total LNG fleet visiting each zone per month, for 2011 and 2015, respectively. The results should be understood in the following way. If an increasing part of the fleet sails to more oceans over time, the vessels visit more areas on the same time compared to earlier. There might be several reasons for this. An obvious is that new terminals are opening, and new routes are emerging. Another, which is tightly linked to the first, is that the spot and short-term market are increasing, as indicated figure 5.2. While long-term contracts usually are from one distinct terminal to another, also known as bus routes, spot-trading vessels are expected to sail to a greater amount of different terminals over time.

All the zones change from 2011 to 2015, but some more significant than others. The part of the fleet observed in Oceania each month, increase from below 10% in 2011 to more than 15% by year-end 2015. The part that is observed in the Pacific also increases, from around 25% in early 2011 to around 50% early in 2015.

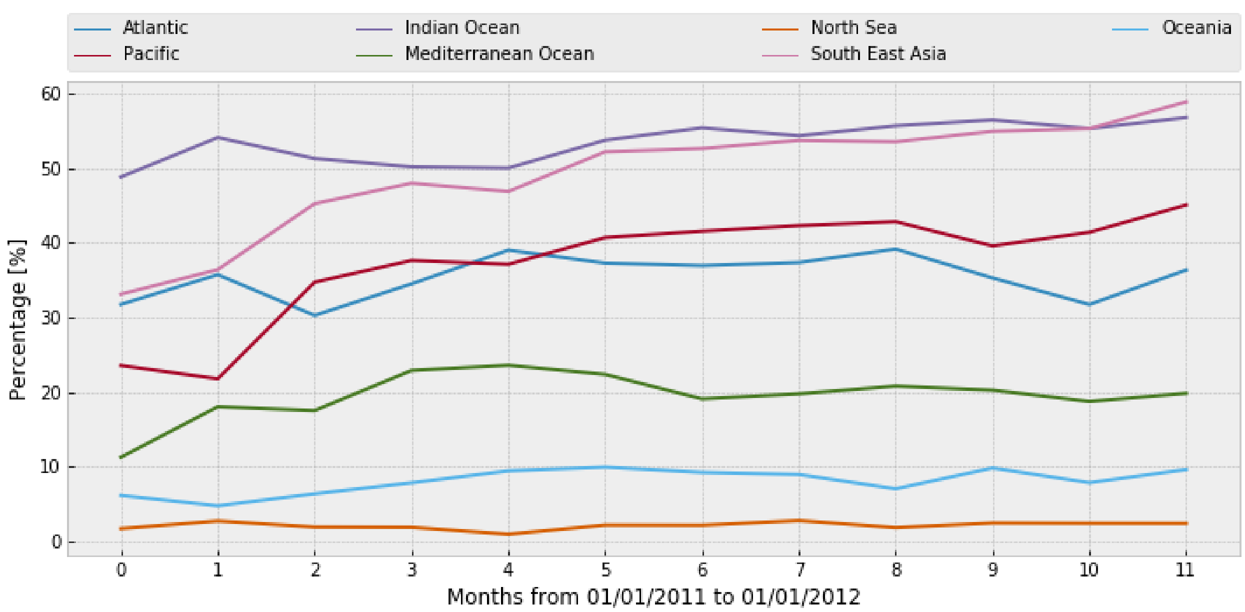

Figure 5.14: Percentage of fleet in zones, monthly, 2011

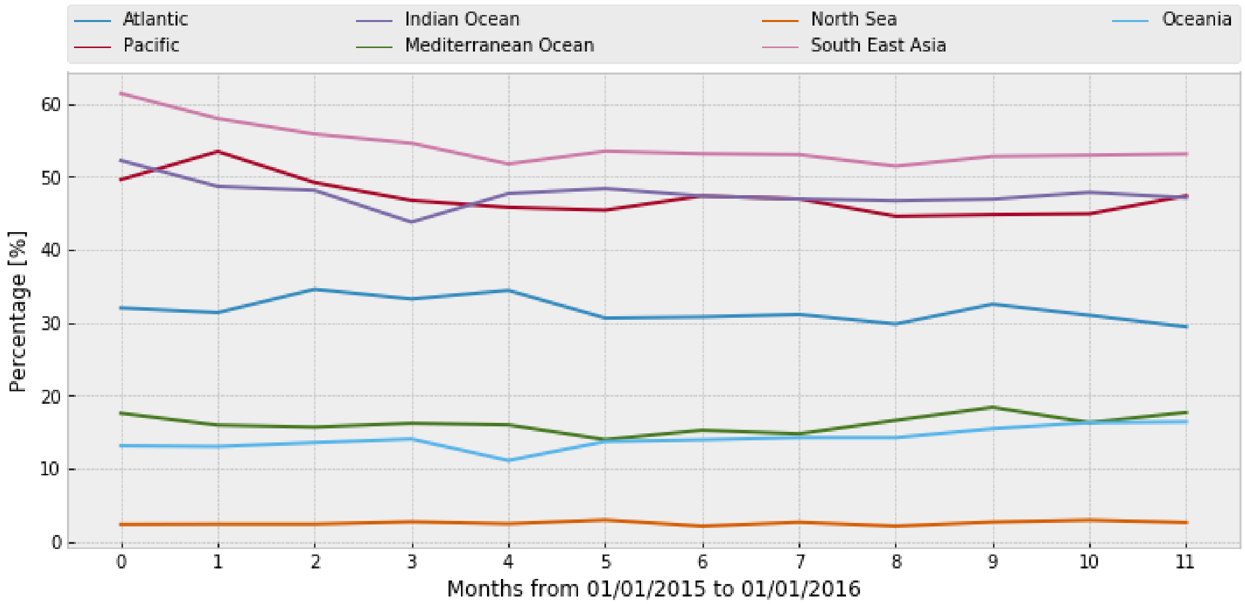

Figure 5.15: Percentage of fleet in zones, monthly, 2015

This could imply that the LNG carriers are visiting more ports per month than earlier, which again could indicate that a large number of port configurations should be valued stronger in a design process of a vessel. However, for this hypothesis to hold the assumptions needs to be accurate.

First of all, most LNG carriers are configured for a grand majority of the LNG terminals. Second, the newly opened terminals have a self-interest of being compatible with most of the carriers. It usually breaks down to costs. How do you value the flexibility versus the extra cost of being compatible?

Another way to verify the different terminals being visited by each vessel could be to analyze the AIS Data with different algorithms. The ports could be obtained by public sources [1], and a geo-fence could be set up around each port. Further, counting the vessels sailing in or out of each geo-fence could determine the number of unique port calls per vessel per month. This solution is feasible, but the manual work of setting up geo-fences would be very time-consuming.

A third way to solve port calls through AIS Data, could be to analyze the draught of the LNG carriers. A large increase in draught indicates that the carrier is being loaded, and unloaded if vice versa. The draught information is a part of Message type 5, and therefore recorded less frequent than Message type 1. This is elaborated in section 4.1.1. The less frequent recording of

[1] https://en.wikipedia.org/wiki/List_of_LNG_terminals

the draught data could make an analysis challenging, and this is therefore not conducted in this thesis.

An example can explain these challenges. The total number of Message type 5 for the time period of 2011 to year-end 2015 for all LNG carriers, is 139,579. By utilizing the same simple calculation as earlier, we get an average of 0.21 messages per vessel per day throughout the time period. See formula 5.2. Roughly, this equals one message per vessel every fifth day. Since Message type 5 is transmitted every 6 minutes from each vessel, it is reasonable to assume that a considerable part of the messages are recorded closely in time and have a time between messages of approximately 6 minutes. If so, the rest of the messages will have a time between messages of more than 5 days.

$$\frac{139,579 \text{ (messages)}}{371 \text{ (weighted fleet)} * 5 \text{ (years)} * 365 \text{ (days per year)}} = 0.21 \text{ (messages per vessel per day)} \quad (5.2)$$

5 days or more between each draught message would be challenging to analyze for port purposes. Since an LNG carrier can fully unload or load in about 1 day, you could miss the visiting port if only considering the draught data.

For further discussion regarding these issues, see chapter 6.

5.2.2 Draught analysis

Figure 5.16 presents the draught of all LNG carriers during the time period of the AIS Data. The data is from Message type 5, as outlined at the end of section 5.2.1. The plot shows that the carriers have a draught between 8.5 and 12.5m more than 95% of the time.

As described earlier, these results can be used as decision support when designing an LNG carrier, especially if they are broken down into vessel sizes. On the other hand, since the time between each message is 5 days, on average, the results should be handled with care. The data should therefore be considered inapplicable for detailed analysis.

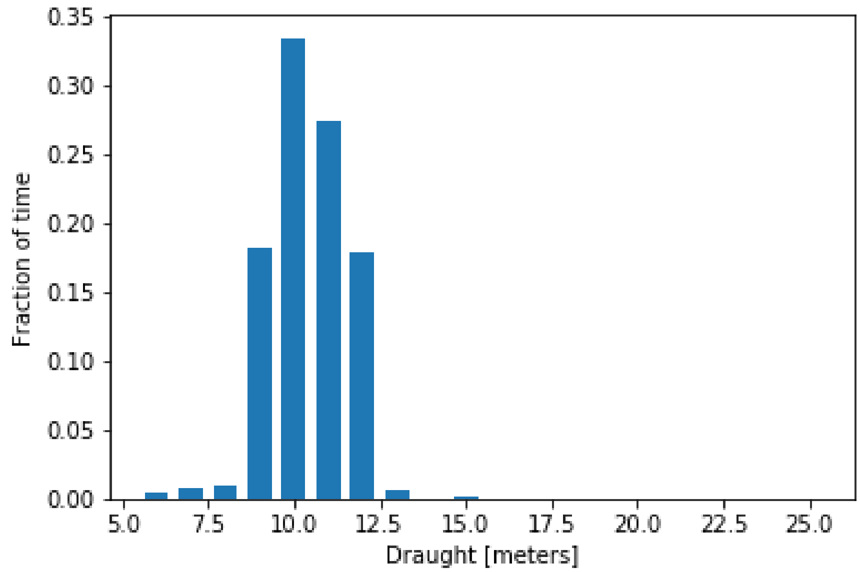

Figure 5.16: Draught of all LNG carriers, 2011-2016

5.3 Commoditization case

As stated in the introduction, the hypothesis about the LNG shipping market turning commoditized is investigated. This part of the case study investigates if we can find any support of this in the conducted case studies.

As outlined in the literature review, section 2.2.1, both academics and industry stakeholders are discussing if the LNG shipping market is showing signs of turning commoditized. By definition, the expression commoditization is the process by which goods that have economic value and are distinguishable in terms of attributes (uniqueness or brand), end up becoming simple commodities in the eyes of the market or consumers[2]. Related to LNG, the interpretation is somewhat different. A more precise question would be the following. Does the LNG market trade serve to balance the cost differences in the global gas market, as crude oil does for oil markets? Or, put in another way, will there be established a global gas price, similar to Brent Crude and WTI for oil?

This is linked to the areas where the vessels sail in the following way. As the spot and short-term trade increase, indicated by figure 5.2, it is expected that the oceans visited by each vessel per month will increase. The results from the area case study imply that these two happens at the

[2] https://en.wikipedia.org/wiki/Commoditization

same time. With an increasing global spot trade, the regional prices, described in section 3.4.2, should be balanced to a greater extent than earlier. The rationale is that when the spot trading vessels exchange the LNG between the regions, the worldwide supply and demand will be more governing, and the regional will be less. Since the supply and demand will be affected by the spot cargoes, the prices will to a greater extent correlate. This could be interpreted as support for the commoditization theory. But there are numerous assumptions in this assertion. The results should therefore be interpreted as weak, and treated accordingly. This is further discussed in section 6.2.

Chapter 6

Discussion

This chapter contains the general discussion of the methodology and the case studies. As stated earlier, most of the discussions are carried out where they are presented.

6.1 Methodology

The discussion regarding the data is mainly carried out in Methodology part I ,4.1, where the AIS Data set is presented and investigated. The data spans from late 2010 to year-end 2015, and two satellites from the Norwegian Coastal Authorities have been collecting the data in this time period. Obviously, with large time gaps in the records of Message type 1 and 5, more satellites would increase the foundation of the analyses. Today the Coastal Authorities have four satellites, while the commercial companies like Spire operate more than 40 [1]. With more data, more precise analyses could be conducted.

The time period of the AIS Data is also an interesting matter of discussion. The LNG spot rates increased in 2011, spiked in 2012, and fell from 2012 to 2015. This could be a full shipping cycle, but also only a part of it, as the rates continued to fall after 2015. Since the objective of the thesis is to investigate operational patterns, the ideal would be to have data from more than one full cycle. If the data analyzed fall within the same cycle, a temporary analysis could give misleading results.

In Methodology part II, 4.2, the total fleet and the spot fleet are obtained, and the relevant data is extracted. The total fleet during the time period from late 2010 to year-end 2015 is created

[1] http://spacenews.com/spire-40-cubesats-in-orbit-competing-more-directly-in-space/

by obtaining a list of today's existing vessels, and excluding the ones delivered after year-end 2015. The list is incomplete, because the vessels scrapped in the time period from late 2010 until today will be missing. This is not posing a problem, because the scrapping is very low in these years, with a total of 22 vessels sold to demolition. A small number of vessels is also converted to FSRUs or FLNGs, and the fleet withdrawal is low compared to the fleet size. On the other hand, many carriers are delivered in the time period, and has to be taken into account during the analyses.

Another solution to obtain the total LNG fleet, could have been to utilize the heuristics created by Smestad et al. (2017). However, these were not perfect, and in that case a data cleaning process to filter out erroneously identified vessels had to be conducted. Therefore, obtaining the database through IMO-numbers from a reliable source seemed more appropriate.

Some issues and potential errors posed when the list of spot trading vessels was obtained. Since a large part of the work were manual checking reports, human errors could occur during this work. As elaborated in section 4.2.3, some shipping companies do not disclose their operations, making it hard to obtain the total spot trading fleet. However, as explained, a sufficient list was obtained.

6.2 Case studies

The first case study presents a decline in speed distribution from 2012 to 2015, both for the total fleet and for the spot fleet. As elaborated in the chapter, there might be many reasons for this decline. While the hypothesis was that the decline in spot and short-term rates was the governing factor, other factors like weather, fuel prices and newbuilds could be of great importance. Since around 100 vessels, or about 25% of the fleet was delivered between 2012 and 2015, they could affect the fleet speed if they have different design parameters than the original fleet. In general, newer LNG carriers have a lower boil-off, which could affect the service speed in a negative way. The rationale is that with a lower boil-off, the vessels have less natural gas they need to burn and therefore can sail slower. However, this is not a clear relationship, since the chosen speed depends on many factors. Also, if the change in the rates was the governing factor for the speed decline in those years, the decline should have been significantly larger for the spot fleet than for the total fleet in general. However, the decline was barely larger for the spot fleet, and the proposed hypothesis was that this market is where the change should be the largest.

A longer time series of the speed distribution could increase the basis of the analysis, e. g. obtaining the speed after 2015 and until today. Maybe the average speed has increased, or the standard deviation has increased? According to Johan Petter Tutturen (DNVGL, 2018), this is not the case, and the vessels continue to slow steam. This again indicates that the vessels sail in a significant lower speed than their design speed, which implies that the design speed is set too high and potential environmental and economic costs savings might apply. However, the shipowners and charterers might value the flexibility over the possible savings, and continue to order newbuilds with a relatively high design speed. Another reason might be that some vessels are designed with a sub-optimal design speed, where they can hold a wide range of speed and still be effective. However, industry individuals claim that this is not the case (DNVGL, 2018).

The area case study shows that from 2011 to 2015 an increasing part of the world fleet travels to more of the world's ocean per month. Assuming that this also means that the vessels have more unique port calls per month, this could imply that designing a vessel with more flexible port configurations should be higher valued. However, this is not necessarily the case, and it requires the assumptions from the case study to be thoroughly understood and evaluated correctly.

The usage of draught data, from Message type 5, as parameters to analyze port calls was investigated. The data was found to not be sufficient for this kind of analysis, and therefore disregarded in this work. On the other hand, if more data from more satellites were obtained, this could be a feasible way to analyze port calls.

The last case study investigated whether information retrieved from the other case studies could strengthen or weaken the theory about the commoditization of the LNG market. Weak support was found, but the assumptions are to some extent speculative, and the results should therefore be treated accordingly. While the spot and short-term market increases, this do not necessarily mean that a commoditized market will be achieved.

Chapter 7

Conclusion

7.1 Concluding remarks

The objective of this thesis is to investigate the operational patterns of LNG carriers from AIS Data. The findings can be summed up in

- The LNG fleet and its spot trading part is identified
- The operational patterns are analyzed in terms of speed distribution and areas. We find that the LNG carriers sail slower than their design speed, and that the spot fleet does not adjust their speed significant more than the total fleet from the year of peak rates in 2012 to the year of low rates in 2015.
- We also find that an increasing part of the fleet visits more oceans per month, which could be interpreted as weak support for the commoditization theory.

The overall objective is to increase the decision support for the stakeholders in LNG shipping. The results can be utilized as decision support to the stakeholders, and therefore, the objective is considered to be met. The results indicate that operational knowledge regarding the LNG segment can be obtained from AIS Data.

There are more opportunities to explore, and these will be briefly discussed in the last section.

7.2 Recommendations for further work

The findings show that the LNG carriers are sailing significant slower than their design speed. While designed for 19.5 knots plus the sea margin, most of them maintain a service speed between 16 and 18 knots at open sea. If the machinery, propulsion and the hull were designed for the actual speed, potential savings could occur. An interesting topic would be to investigate these savings. The research would involve several part of the marine study, and could be a cooperation between master students with different specializations, e. g. hydrodynamics and design systems.

As discussed in section 5.2.1, the data set is not suitable for analysis of the draught data to estimate ports and port calls. The messages are recorded with large time between messages, making port calls hard to find. With the 4 orbiting satellites operated by the Norwegian Coastal Authorities today, the time between messages will be decreased significantly. Since this is a critical parameter for such analysis, newer AIS Data could open this domain.

The domain can also be used to evaluate shipping distances, which originally was an idea of the co-supervisor of this thesis, Dr. Carl Fredrik Rehn. A hypothesis of decreasing shipping distances for cargo vessels can be tested, with the objective to increase decision support for the stakeholders in shipping.

An interesting domain to investigate in future work would be to use machine learning to understand and forecast patterns from AIS Data. This domain is huge, from forecasting freight rates to forecast potential safety problems or accidents.

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Appendix A

Code

A.1 MainMenu.py

This script runs the analyses by selection of inputs and methods of interest.

```
#!/usr/bin/env python3
# -*- coding: utf-8 -*-
"""
Created on Fri May  4 10:56:59 2018

@author: Axelsen
"""

import AIS_Analysis as AIS
import datetime

Database = '/Users/Axelsen/Desktop/spot_fleet.db'
#Database = '/Users/Axelsen/Desktop/LNG_fleet01.db'
#Database = '/Users/Axelsen/Desktop/LNG_fleet05.db'
#Database = '/Volumes/LaCie/NTNUfilesMac/SAISGlobalFinal.db'

#All methods are run from this script, 1 = run
Analysis = 1 #1 = extract data of intrest from database
LocalMap =0 # Plot all data on map
DataClusterPorts = 0 # Cluster ports
PortAnalysis = 0 # Compare with LINNERLIB
GeoFencePorts = 0 # Geofence ports
Network = 0 # Network of port-to-port
WorldOceanAnalysis = 0 # Polygon
SpeedForAnalysis = 1 # Message interval
DraughtAnalysis = 1 #Draught analysis
DraughtHistogram = 1 # Draught histogram
```

```
SpeedHistogram = 0 #Speed histogram

Pacific = [-120,63,12,28]
Atlanter = [0,53,-80,33]
MexAu = [180,7.75,-180,-26.10]
Global = [180,90,-180,-90]
asEur = [120, 50, -15, 0]
CapeAfrica = [60,24,-30,-42]
Panama = [-79,9.8,-81,8.5]
Suez = [40,40,30,27]
Norway = [30,80,0,55]

#east, north, west, south

#Choose location of intrest:
Loc = 4

if Loc == 1:
    Pos = Pacific
elif Loc == 2:
    Pos = Atlanter
elif Loc == 3:
    Pos = MexAu
elif Loc == 4:
    Pos = Global
elif Loc == 5:
    Pos = asEur
elif Loc == 6:
    Pos = CapeAfrica
elif Loc == 7:
    Pos = Panama
elif Loc == 8:
    Pos = Suez
elif Loc == 9:
    Pos = Norway

#Time window of intrest:
lowtime = '01/01/2011'
hightime = '01/01/2012'

#unixtimelow = 1291236214 = 1 des 2010
# 01/01/2010
#unixtimehigh = 1443651368 = 1 jan 2016
# 01/01/2016

#Speed of interst:
maxspeed = 25
minspeed = 0

#Convert from date to unixtime:
unixlow = datetime.datetime.strptime(lowtime, "%d/%m/%Y").timestamp()
unixhigh = datetime.datetime.strptime(hightime, "%d/%m/%Y").timestamp()
```

```
#PV calls PlotVessels.py, which essentially does all data extracting, initial analyses,
#and visualizations of AIS data.
if Analysis == 1:
    plotlon, plotlat = AIS.ExtractData(Database,Pos[0],Pos[1],Pos[2],Pos[3],
                    unixlow,unixhigh,maxspeed,minspeed,Analysis)

if DataClusterPorts == 1:
    clusterlat, clusterlon, labels = AIS.ClusterPorts()

if SpeedForAnalysis == 1:
    AIS.SpeedForAnalysis()

if DraughtAnalysis == 1:
    AIS.DraughtAnalysis()

if PortAnalysis == 1:
    portdata = AIS.Checkports(ports)

if WorldOceanAnalysis == 1:
    BigD = AIS.PolygonAnalysis(unixlow,unixhigh)

if GeoFencePorts == 1:
    labels = AIS.GeoFencePorts()

if Network == 1:
    route,G = AIS.ShippingNetwork(labels)

if LocalMap == 1:
    AIS.LocalMap()

if SpeedHistogram == 1:
    AIS.SpeedHistogram()

if DraughtHistogram == 1:
    AIS.DraughtHistogram()
```

A.2 AIS_Analysis.py

This script contains all the methods and runs which is selected in the MainMenu-script.

```
#!/usr/bin/env python3
# -*- coding: utf-8 -*-
"""
Created on Tue May  8 10:56:07 2018

@author: Axelsen
"""


import sqlite3
import matplotlib.pyplot as plt
import time
import datetime
from mpl_toolkits.basemap import Basemap
import numpy as np
from scipy import stats
import pandas as pd
import loc_check as LC
from pylab import boxplot


#######################################################
## THE FOLLOWING PART EXTRACT DATA FROM THE DATABASE ##
#######################################################

def ExtractData(filepath,a,b,c,d,lowtime,hightime,maxspeed,minspeed,Analysis):
    global draughttime
    global useridDraught
    global draught
    global plotlat
    global plotlon
    global speeds
    global timestep
    global mmsi
    global navstat

    speeds = list()
    plotlat = list()
    plotlon = list()
    timestep = list()
    mmsi = list()
    navstat = list()
    draughttime = list()
    draught = list()
    useridDraught = list()

```

```
    conn = sqlite3.connect(filepath)
    cur = conn.cursor()

    # For nav-igation status, insert in '':
    #portstatus = 'and (nav_status==1 or nav_status ==5)'

    SQLstring1 = "SELECT unixtime,sog,latitude,longitude,userid,\
        nav_status FROM %s WHERE longitude<= %s and latitude <= %s\
        and longitude >= %s and latitude >= %s and sog >= %s and \
        sog <= %s and unixtime >= %s and unixtime <= %s %s ORDER BY UNIXTIME \
        ASC" % ('LNG_fleet',str(a),str(b),str(c),str(d),str(minspeed),\
        str(maxspeed),str(lowtime),str(hightime),'')

    # Extract data from database:
    A = time.time()
    with conn:
        cur = conn.cursor()
        if Analysis == 1:
            cur.execute(SQLstring1)
        VesselData = cur.fetchall()

        for i in range(0,len(VesselData)):
            Datastrip = VesselData[i]
            timestep.append(Datastrip[0])
            speeds.append(Datastrip[1])
            plotlat.append(Datastrip[2])
            plotlon.append(Datastrip[3])
            mmsi.append(Datastrip[4])
            navstat.append(Datastrip[5])

    cur.close()

    conn = sqlite3.connect(filepath)
    cur = conn.cursor()

    SQLstring2 = "SELECT unixtime,draught,userid from %s where \
        unixtime >= %s and unixtime <= %s" % ('LNG_fleet5',str(lowtime),\
        str(hightime))

#    # Extract draught data from database:
    with conn:
        cur = conn.cursor()
        if Analysis == 1:
            cur.execute(SQLstring2)
        draughtdata = cur.fetchall()

    for i in range(0,len(draughtdata)):
        draughtstrip = draughtdata[i]
        if draughtstrip[1]/10 > 5:
            draughttime.append(draughtstrip[0])
            draught.append(draughtstrip[1]/10)
            useridDraught.append(draughtstrip[2])
```

```

    print('Database extraction time is: ' + str(time.time()-A) + ' s')
    return plotlon, plotlat


#################################################
## THE FOLLOWING PART PLOTS HISTOGRAM FOR SPEED ##
#################################################

def SpeedHistogram():
    plt.figure()
    hist, bins = np.histogram(speeds, bins=25)
    width = 0.7 * (bins[1] - bins[0])
    center = (bins[:-1] + bins[1:]) / 2
    plt.bar(center, hist, align='center', width=width)
    plt.show()

    plt.figure()
    plt.title('')
    histval1, binsval = np.histogram(speeds, bins=25)
    histval = histval1/sum(histval1)
    width = 0.7 * (binsval[1] - binsval[0])
    center = (binsval[:-1] + binsval[1:]) / 2
    plt.bar(center, histval, align='center', width=width)
    plt.xlabel('Speed [knots]')
    plt.ylabel('Fraction of time')
    plt.show()


    messages = len(speeds)
    unique_mmsi = len(set(mmsi))
    average_speed = np.mean(speeds)
    std_speed = np.std(speeds)

    print('The number of messages in the time period is: ' + str(messages))
    print('The number of unique MMSI in the time period is: ' + str(unique_mmsi))
    print('The average speed in the time period is: ' + str(average_speed) +' knots')
    print('The standard deviation in the time period is: ' + str(std_speed) +' knots')


#################################################
## THE FOLLOWING PART DOES THE POLYGON ANALYSIS ##
#################################################

def PolygonAnalysis(lowtime,hightime):
    # Creating DataFram for analytical easiness
    df = pd.DataFrame({'Speed': speeds, 'MMSI': mmsi, 'Unixtime': timestep, \
                             'Lat': plotlat, 'Lon': plotlon})

    polygons = LC.generate_polygons()

    #Creating empty column in the dataframe
```

```
df['Zone'] = pd.Series({'Zone': range(len(df['MMSI']))})

#Taking time:
A = time.time()
for i in range(0,len(plotlat)):
    if LC.point_inside_polygon(plotlon[i],plotlat[i],polygons[0]):
        df.set_value(i,'Zone','Atlantic')
    elif LC.point_inside_polygon(plotlon[i],plotlat[i],polygons[1]):
        df.set_value(i,'Zone','Pacific') #East Pacific
    elif LC.point_inside_polygon(plotlon[i],plotlat[i],polygons[2]):
        df.set_value(i,'Zone','Pacific') #West Pacific
    elif LC.point_inside_polygon(plotlon[i],plotlat[i],polygons[3]):
        df.set_value(i,'Zone','Indian Ocean')
    elif LC.point_inside_polygon(plotlon[i],plotlat[i],polygons[4]):
        df.set_value(i,'Zone','Mediterranean')
    elif LC.point_inside_polygon(plotlon[i],plotlat[i],polygons[5]):
        df.set_value(i,'Zone','North Sea')
    elif LC.point_inside_polygon(plotlon[i],plotlat[i],polygons[6]):
        df.set_value(i,'Zone','SE Asia')
    elif LC.point_inside_polygon(plotlon[i],plotlat[i],polygons[7]):
        df.set_value(i,'Zone','Oceania')
    else:
        df.set_value(i,'Zone','Outside Zones')
print('Polygon iteration time is: ' + str(time.time()-A) + ' s')

#Defining dataframes for each zone
Atlantic = df[df['Zone'] == 'Atlantic']
Pacific = df[df['Zone'] == 'Pacific']
IndianOcean = df[df['Zone'] == 'Indian Ocean']
Mediterranean = df[df['Zone'] == 'Mediterranean']
NorthSea = df[df['Zone'] == 'North Sea']
SEAsia = df[df['Zone'] == 'SE Asia']
Oceania = df[df['Zone'] == 'Oceania']

Timestamps = LC.get_timevector(lowtime,hightime)
#print(Timestamps)
dates = [datetime.datetime.fromtimestamp(u).strftime('%d/%m/%Y') for u in Timestamps]
#print(dates)

#Filter data for monthly basis
A = time.time()
speeds_monthly_Atlantic,monthly_stdev_Atlantic,unique_vessels_monthly_Atlantic,interval_Atlantic \
    = LC.monthly_filter(Atlantic,Timestamps)
speeds_monthly_Pacific,monthly_stdev_Pacific,unique_vessels_monthly_Pacific,interval_Pacific \
    = LC.monthly_filter(Pacific,Timestamps)
speeds_monthly_IndianOcean,monthly_stdev_IndianOcean,unique_vessels_monthly_IndianOcean,
 interval_IndianOcean \
    = LC.monthly_filter(IndianOcean,Timestamps)
speeds_monthly_Medittarnean,monthly_stdev_Mediterranean,unique_vessels_monthly_Medittarnean,
 interval_Medittarnean \
    = LC.monthly_filter(Mediterranean,Timestamps)
speeds_monthly_NorthSea,monthly_stdev_NorthSea,unique_vessels_monthly_NorthSea,interval_NorthSea \
```

```
        = LC.monthly_filter(NorthSea,Timestamps)
    speeds_monthly_SEAsia,monthly_stdev_SEAsia,unique_vessels_monthly_SEAsia,interval_SEAsia \
        = LC.monthly_filter(SEAsia,Timestamps)
    speeds_monthly_Oceania,monthly_stdev_Oceania,unique_vessels_monthly_Oceania,interval_Oceania \
        = LC.monthly_filter(Oceania,Timestamps)
    speeds_monthly_World,monthly_stdev_World,unique_vessels_monthly_World,interval_World \
        = LC.monthly_filter(df,Timestamps)
    print('Monthly filtering time is: ' + str(time.time()-A) + ' s')

#    Percentage of fleet observed in zone each month
    prcentage_Atlantic = LC.percentageMonthly(unique_vessels_monthly_Atlantic,
                                              unique_vessels_monthly_World)
    prcentage_Pacific = LC.percentageMonthly(unique_vessels_monthly_Pacific,
                                              unique_vessels_monthly_World)
    prcentage_IndianOcean = LC.percentageMonthly(unique_vessels_monthly_IndianOcean,
                                              unique_vessels_monthly_World)
    prcentage_Medittarnean = LC.percentageMonthly(unique_vessels_monthly_Medittarnean,
                                              unique_vessels_monthly_World)
    prcentage_NorthSea = LC.percentageMonthly(unique_vessels_monthly_NorthSea,
                                              unique_vessels_monthly_World)
    prcentage_SEAsia = LC.percentageMonthly(unique_vessels_monthly_SEAsia,
                                              unique_vessels_monthly_World)
    prcentage_Oceania = LC.percentageMonthly(unique_vessels_monthly_Oceania,
                                              unique_vessels_monthly_World)
#
    #Plotting the vessel distribution
    timeperiod = list(range(0,(len(Timestamps)-1)))
    plt.style.use('bmh')

    #Plotting number of unique vessels
    fig, ax = plt.subplots(figsize=(12,5))
    #plt.title('Number of unique vessels in zone')
    plt.xlabel ('Months from %s to %s' % (str(dates[0]),str(dates[len(dates)-1])))
    plt.ylabel('Vessels in zone')
    ax.plot(timeperiod,unique_vessels_monthly_Atlantic,label = 'Atlantic')
    ax.plot(timeperiod,unique_vessels_monthly_Pacific,label = 'Pacific')
    ax.plot(timeperiod,unique_vessels_monthly_IndianOcean, label = 'Indian Ocean')
    ax.plot(timeperiod,unique_vessels_monthly_Medittarnean, label = 'Mediterranean Ocean')
    ax.plot(timeperiod,unique_vessels_monthly_NorthSea,label = 'North Sea')
    ax.plot(timeperiod,unique_vessels_monthly_SEAsia, label = 'South East Asia')
    ax.plot(timeperiod,unique_vessels_monthly_Oceania, label = 'Oceania')
    ax.plot(timeperiod,unique_vessels_monthly_World, label = 'World')
    #Placeing the legend outside the plot box:
    legend = ax.legend(bbox_to_anchor=(0., 1.02, 1., .102),ncol=4,loc=3,mode="expand",borderaxespad=0.)
    frame = legend.get_frame()
    frame.set_facecolor('0.90')
    for label in legend.get_lines():
        label.set_linewidth(1)
    plt.show()

    #Percentage of fleet observed in zone each month
    fig, ax = plt.subplots(figsize=(12,5))
```

```
    #plt.title('Percentage of fleet observed in zone each month')
    plt.xlabel ('Months from %s to %s' % (str(dates[0]),str(dates[len(dates)-1])))
    plt.ylabel('Percentage [%]')
    ax.plot(timeperiod,prcentage_Atlantic,label = 'Atlantic')
    ax.plot(timeperiod,prcentage_Pacific,label = 'Pacific')
    ax.plot(timeperiod,prcentage_IndianOcean, label = 'Indian Ocean')
    ax.plot(timeperiod,prcentage_Medittarnean, label = 'Mediterranean Ocean')
    ax.plot(timeperiod,prcentage_NorthSea,label = 'North Sea')
    ax.plot(timeperiod,prcentage_SEAsia, label = 'South East Asia')
    ax.plot(timeperiod,prcentage_Oceania, label = 'Oceania')
    #Placeing the legend outside the plot box:
    legend = ax.legend(bbox_to_anchor=(0., 1.02, 1., .102),ncol=4,loc=3,mode="expand",borderaxespad=0.)
    frame = legend.get_frame()
    frame.set_facecolor('0.90')
    for label in legend.get_lines():
        label.set_linewidth(1)
    plt.show()

    #Plotting mean speed of vessels
    fig, ax = plt.subplots(figsize=(12,5))
    #plt.title('Average speed per month per zone')
    plt.xlabel ('Months from %s to %s' % (str(dates[0]),str(dates[len(dates)-1])))
    plt.ylabel('Speed [knots]')
    ax.plot(timeperiod,speeds_monthly_Atlantic,label = 'Atlantic')
    ax.plot(timeperiod,speeds_monthly_Pacific,label = 'Pacific')
    ax.plot(timeperiod,speeds_monthly_World, label = 'World')
    #Placeing the legend outside the plot box:
    legend = ax.legend(bbox_to_anchor=(0., 1.02, 1., .102),ncol=3,loc=3,mode="expand",borderaxespad=0.)
    frame = legend.get_frame()
    frame.set_facecolor('0.90')
    for label in legend.get_lines():
        label.set_linewidth(1)
    plt.show()

    #Plotting world speed with standard deviation
    fig, ax = plt.subplots(figsize=(12,5))
    plt.xlabel ('Months from %s to %s' % (str(dates[0]),str(dates[len(dates)-1])))
    plt.ylabel('Speed [knots]')
    boxplot(monthly_stdev_World,0,'')
    plt.show()

    #Plotting mean message interval of vessels
    fig, ax = plt.subplots(figsize=(12,5))
    #plt.title('Average message interval')
    plt.xlabel ('Months from %s to %s' % (str(dates[0]),str(dates[len(dates)-1])))
    plt.ylabel('Time [hours]')
    #ax.plot(timeperiod,interval_Atlantic,label = 'Atlantic')
    #ax.plot(timeperiod,interval_Pacific,label = 'Pacific')
    ax.plot(timeperiod,interval_World, label = 'World')
    #Placeing the legend outside the plot box:
    legend = ax.legend(bbox_to_anchor=(0., 1.02, 1., .102),ncol=2,loc=3,mode="expand",borderaxespad=0.)
    frame = legend.get_frame()
```

```
    frame.set_facecolor('0.90')
    for label in legend.get_lines():
        label.set_linewidth(1)
    plt.show()

    #SPeed histogram
    SpeedHistogram(Atlantic['Speed'].tolist(),'Atlantic')
    SpeedHistogram(Pacific['Speed'].tolist(),'Pacific')

    LC.plot_inside_polygons(Atlantic['Lon'].tolist(),Atlantic['Lat'].tolist())

    return df

#####################################################
## THE FOLLOWING PART PLOTS HISTOGRAM OF SPEED DIST ##
#####################################################

def DraughtHistogram():
    plt.figure()
    histval1, binsval = np.histogram(draught, bins=20)
    histval = histval1/sum(histval1)
    width = 0.7 * (binsval[1] - binsval[0])
    center = (binsval[:-1] + binsval[1:]) / 2
    plt.bar(center, histval, align='center', width=width)
    plt.xlabel('Draught [meters]')
    plt.ylabel('Fraction of time')
    plt.show()

    draughts = len(draught)
    print('The number of draughts in the time period is: ' + str(draughts))

###############################################
## THE FOLLOWING PARTS PLOTS POSITIONS ON MAP ##
###############################################

def LocalMap():
    minlon = max(-180,min(plotlon)-5) #-5
    minlat = max(-90,min(plotlat)-5) #-5
    maxlon = min(180,max(plotlon)+5) #+5
    maxlat = min(90,max(plotlat)+5) #+5
    lat0 = (maxlat+minlat)/2
    lon0 = (maxlon+minlon)/2
    lat1 = (maxlat+minlat)/2-20

    fig=plt.figure(figsize=(18,18))
    fig.add_axes([0.1,0.1,0.8,0.8])
    m = Basemap(llcrnrlon=minlon,llcrnrlat=minlat,urcrnrlon=maxlon,urcrnrlat=maxlat,\
            rsphere=(6378137.00,6356752.3142),\
            resolution='l',projection='cyl',\
            lat_0=lat0,lon_0=lon0,lat_ts = lat1)

    m.drawmapboundary(fill_color='white')
```

```
    m.fillcontinents(color='lightgray',lake_color='white',zorder=0) #,zorder=0
    x, y = m(plotlon,plotlat)
    #Ships:
    m.scatter(x,y,0.01,marker='o',c='black')
    #m.drawcoastlines()
    #plt.legend(handles=[data])
    #plt.title('Ship movements')
    #m.drawparallels(np.arange(-90,90,20),labels=[1,1,0,1])
    #m.drawmeridians(np.arange(-180,180,20),labels=[1,1,0,1])
    #m.bluemarble()
    #plt.saveffig('/Users/PatrickAndreNaess/Desktop/PyPlots/current_plot.eps',\
    #            format='eps', dpi=1000)

############################################################################
## THE FOLLOWING PART CALCULATES INTERVALS OF MESSAGES AND PLOTS HISTOGRAM #
############################################################################

def SpeedForAnalysis():
    global logdiff
    global UpDiff
    global UpTime
    global UpSpeed
    global AnSpeed
    global AnTime
    global AnSteps
    global AnDiff
    global AnLat
    global AnLon
    logdiff = list()
    logdiff = np.diff(timestep)
    UpDiff = list()
    UpSpeed = speeds
    UpTime = timestep
    UpDiff = logdiff
    UpLat = plotlat
    UpLon = plotlon

    for i in range(0,len(logdiff)):
        if logdiff[i] < 1:
            logdiff[i] = logdiff[i]
            UpSpeed[i+1] = 101010
            UpTime[i+1] = 101010
            UpDiff[i] = 101010

    AnSpeed = [x for x in UpSpeed if x != 101010] #AnDiff = Message intervals for analysis
    AnTime = [x for x in UpTime if x != 101010]
    AnLat = [x for x in UpLat if x != 101010]
    AnLon = [x for x in UpLon if x != 101010] #AnSpeed = Speed for analysis
    AnDiff = [x for x in UpDiff if x != 101010] #AnTime = Time for analysis
    AnDiff.append(1)
    AnSteps = list()
    for i in range(0,len(AnTime)):
```

```
        Unixconv = datetime.datetime.fromtimestamp(AnTime[i])
        AnSteps.append(Unixconv)

###############################################
## THE FOLLOWING PART PLOTS INTERVAL FREQUENCY #
###############################################

    Count = list()
    Number = list()
    for i in range(0,50):
        Count.append(i)
        Number.append(AnDiff.count(i))

    xaxis=np.arange(0,50,5)
    plt.figure(figsize=(18,6))
    plt.plot(Count,Number)
    plt.grid(True)
    plt.xticks(xaxis)
    plt.title('Message intervals')
    plt.xlabel('Time between messages [seconds]')
    plt.ylabel('Number of messages')
    plt.show()

    plt.figure(figsize=(18,6))
    plt.scatter(AnSteps,AnSpeed,c='k',s=0.1)
    plt.xlabel('Speed [knots]')
    plt.ylabel('Year')
    #plt.plot(IncSteps,AvSpeed,'k')
    plt.show()

    messages = len(speeds)
    unique_mmsi = len(set(mmsi))
    #average_speed = np.mean(speeds)
    #std_speed = np.std(speeds)

    print('The number of messages in the time period is: ' + str(messages))
    print('The number of unique MMSI in the time period is: ' + str(unique_mmsi))
    #print('The average speed in the time period is: ' + str(average_speed) +' knots')
    #print('The standard deviation in the time period is: ' + str(std_speed) +' knots')

def DraughtAnalysis():
    global AnDraught
    global AnCat
    global DSpeed
    global DTime
    global Dcat
    global slope
    global intercept
    global r_value
    global p_value
    global std_err
    Drange = max(draught)-min(draught)
```

```
    Intervals = 3
    Dsteps = Drange/Intervals
    Dcat = [0]*len(draught)

    for i in range(0,len(draught)):
        for j in range(0,Intervals-1):
            if  min(draught) + Dsteps*j <= draught[i] <= min(draught)+(j+1)*Dsteps :
                Dcat[i] = j+1

    AnDraught = list()
    AnCat = list()
    DSpeed = list()
    DTime = list()
    for j in range(0,len(Dcat)-1):
        for i in range(0,len(AnTime)):
        #if AnTime[i]
            if AnTime[i]>=draughttime[j] and AnTime[i]<draughttime[j+1]:
                AnDraught.append(draught[j])
                AnCat.append(Dcat[j])
                DSpeed.append(AnSpeed[i])
                DTime.append(AnTime[i])
    slope, intercept, r_value, p_value, std_err = stats.linregress(AnDraught,DSpeed)

    draughts = len(draught)
    print('The number of draughts in the time period is: ' + str(draughts))
```

A.3 loc_check.py

This script contains help-functions for the rest of the code.

```
#!/usr/bin/env python3
# -*- coding: utf-8 -*-
"""
Created on Tue May  8 10:58:11 2018

@author: Axelsen
"""


import numpy as np
import matplotlib.pyplot as plt
from mpl_toolkits.basemap import Basemap
from datetime import datetime
import statistics as st
#from geopy.distance import great_circle
#from shapely.geometry import MultiPoint
import pandas as pd


def generate_polygons():
    global polygons
    polygons = list()
    # Atlantic
    polygon_atlantic = [[31.464844,-44.840291],
                        [25,-10],
                        [-5.493164,35.942436],
                        [11.118164,54.110934],
                        [-37.265,65.219],
                        [-100,50],
                        [-103.227539,25.443275],
                        [-76.245117,7.31882],
                        [-60.644531,-18.646245],
                        [-73.476562,-62.267923]]
    polygon_atlantic.append(polygon_atlantic[0]) #Adding the first point
    polygons.append(polygon_atlantic)
    # East Pacific
    polygon_Eastpacific =[[-142,70]  ,
                      [-100,50]  ,
                      [-103.227539,25.443275]  ,
                      [-76.245117,7.31882],
                      [-60.644531,-18.646245]  ,
                      [-73.476562,-62.267923]  ,
                      [-180,-36.315125],
                      [-180,47.989922],
                      [-180,58.077876]]
    polygon_Eastpacific.append(polygon_Eastpacific[0])
```

```
    polygons.append(polygon_Eastpacific)
    # West Pacific
    polygon_WestPacific = [[180,60],
                [130,62],
                [105.292969,21.453069],
                [121.816406,17.978733],
                [131.835938,1.230374],
                [180,-30]]
    polygon_WestPacific.append(polygon_WestPacific[0])
    polygons.append(polygon_WestPacific)
    #Indian Ocean
    polygon_indi = [[33.04687,29.075375],
                    [80,40],
                    [76.992188,11.523088],
                    [96.503906,-14.093957],
                    [85.078125,-57.515823],
                    [31.464844,-44.840291],
                    [25,-10]]
    polygon_indi.append(polygon_indi[0])
    polygons.append(polygon_indi)
    #Mediterranean Ocean
    polygon_medi = [[-5.097,35.960],
                    [11.118164,54.110934],
                    [50,50],
                    [33.04687,29.075375],
                    [25,-10]]
    polygon_medi.append(polygon_medi[0])
    polygons.append(polygon_medi)

    #North Sea
    polygon_northSea = [[11.118164,54.110934],
                        [50,50],
                        [16.699219,76.351896],
                        [-19.160156,76.184995],
                        [-37.265,65.219]]
    polygon_northSea.append(polygon_northSea[0])
    polygons.append(polygon_northSea)
    #South East Asia
    polygon_EA = [[105.292969,21.453069],
                  [121.816406,17.978733],
                  [131.835938,1.230374],
                  [126.210938,-10.487812],
                  [96.503906,-14.093957],
                  [76.992188,11.523088],
                  [80,40]]
    polygon_EA.append(polygon_EA[0])
    polygons.append(polygon_EA)
    #Oceania
    polygon_O = [[131.835938,1.230374],
                 [180,-30],
                 [180,-50],
                 [131.132813,-57.231503],
```

```
                [85.078125,-57.515823],
                [96.503906,-14.093957],
                [126.210938,-10.487812],
                [131.835938,1.230374]]
    polygon_O.append(polygon_O[0])
    polygons.append(polygon_O)

    return polygons


def point_inside_polygon(x,y,poly):

    n = len(poly)
    inside =False

    p1x,p1y = poly[0]
    for i in range(n+1):
        p2x,p2y = poly[i % n]
        if y > min(p1y,p2y):
            if y <= max(p1y,p2y):
                if x <= max(p1x,p2x):
                    if p1y != p2y:
                        xinters = (y-p1y)*(p2x-p1x)/(p2y-p1y)+p1x
                    if p1x == p2x or x <= xinters:
                        inside = not inside
        p1x,p1y = p2x,p2y

    return inside


#Takes an input argument of polygons and plotting them! Should be
def ocean_polygon(polygons):
    fig, ax = plt.subplots(figsize=(20,20))
    m = Basemap(projection='cyl',lon_0=0,resolution='l')
    #m.drawparallels(np.arange(-90,90,20),labels=[1,1,0,1],color='k')
    #m.drawmeridians(np.arange(-180,180,20),labels=[1,1,0,1],color='k')
    m.drawmapboundary(fill_color='white')
    m.fillcontinents(color='lightgrey',lake_color='white')
    #m.drawcountries()
    #m.drawcoastlines()

    for i in range(0,len(polygons)):
        x,y = zip(*polygons[i])
        m.plot(x,y,marker='.')
        ax.fill(x, y,alpha=0.2)
    plt.show()
    #plt.savefig('/Users/erikgrundt/Desktop/currentpoly.eps',\

    polygons = generate_polygons()
    ocean_polygon(polygons)
```

```
def plot_inside_polygons(lon,lat):
    fig, ax = plt.subplots(figsize=(18,18))
    m = Basemap(projection='cyl',lon_0=0,resolution='l')
    #m.drawparallels(np.arange(-90,90,20),labels=[1,1,0,1],color='k')
    #m.drawmeridians(np.arange(-180,180,20),labels=[1,1,0,1],color='k')
    m.drawmapboundary(fill_color='white')
    m.fillcontinents(color='lightgray',lake_color='white')
    x,y = m(lon,lat)
    m.scatter(x,y,0.01,marker='o',c='black')

    x,y = zip(*polygons[0])
    m.plot(x,y,marker='.')
    ax.fill(x, y,alpha=0.2)

    plt.show()

def get_timevector(lt,ht):
    deltatime = ht - lt
    mintime = datetime.fromtimestamp(lt)
    maxtime = datetime.fromtimestamp(ht)

    months= (maxtime.year - mintime.year)*12 + maxtime.month - mintime.month

    increment = deltatime/months
    Timestamp = list()
    Timestamp.append(lt)
    for i in range(1,months):
        Timestamp.append(Timestamp[i-1]+increment)

    Timestamp.append(ht)

    return Timestamp

def monthly_filter(DF,timestamps):
    monthly_mean_speeds = [[] for i in range(0,(len(timestamps)-1))]
    monthly_unique = [[] for i in range(0,(len(timestamps)-1))]
    monthly_message_interval = [[] for i in range(0,(len(timestamps)-1))]
    monthly_stdev_speeds = [[] for i in range(0,(len(timestamps)-1))]

    for j in range(0,len(monthly_mean_speeds)):
        X = DF[(DF['Unixtime'] >= timestamps[j]) & (DF['Unixtime'] < timestamps[j+1])]

        #SPEED
        if len(X['Speed']) == 0:
            monthly_mean_speeds[j].append(0)
            monthly_stdev_speeds[j].append(0)
        else:
            monthly_mean_speeds[j].append(st.mean(X['Speed']))
            monthly_stdev_speeds[j].append((X['Speed']))#st.stdev

        #MESSAGE INTERVAL
        if len(X['Unixtime']) < 2:
```

```
            hours = 24*30 # One month if no messages, in hours
        else:
            time = st.mean(abs(np.diff(X['Unixtime'])))
            hours = (datetime.fromtimestamp(time)-datetime(1970,1,1)).total_seconds()/60/60
        monthly_message_interval[j].append(hours)

        #UNIQUE VESSELS
        monthly_unique[j].append(X['MMSI'].nunique())

    return monthly_mean_speeds,monthly_stdev_speeds,monthly_unique,monthly_message_interval
#
def percentageMonthly(zone, world):
    percent = list()

    for i in range(0,len(world)):
        p = zone[i][0]/world[i][0]*100
        percent.append(p)

    return percent

def get_centermost_point(plotlon,plotlat,n_clusters_,labels):
    df = pd.DataFrame({'lon': plotlon, 'lat': plotlat})
    coords = df.as_matrix(columns=['lon', 'lat'])
    clusters = pd.Series([coords[labels==n] for n in range(n_clusters_)])

    centroid = list()
    for i in range(0,len(clusters)):
        if len(clusters[i]) >=1:
            centroid.append((MultiPoint(clusters[i]).centroid.x, MultiPoint(clusters[i]).centroid.y))

    centermost_point = list()
    for i in range(0,len(clusters)):
        if len(clusters[i]) >=1:
            centermost_point.append(min(clusters[i], key=lambda point: great_circle(point, centroid[i]).m))

    return tuple(centermost_point)
```

A.4 CreateFleet.py

This script contains a code which obtains the MMSI numbers from IMO numbers, through Message type 5. The SQL coding is also included to show how the database was created. The SQL codes can be ran directly in Terminal.

```
#!/usr/bin/env python3
# -*- coding: utf-8 -*-
"""
Created on Mon Apr  9 16:39:37 2018

@author: Axelsen
"""


import sqlite3
import pandas as pd

Database = '/Users/Axelsen/Desktop/LNG_fleet05.db'
#Fleetlist = '/Users/Axelsen/Desktop/Prosjekt og masteroppgave/Filer/LNG_fleet_clean.csv'

imos = list()

import csv
with open('Spot_list_IMO_numbers.csv', newline='') as csvfile:
    mylist = csv.reader(csvfile)
    for row in mylist:
        imos.append(row[0])

skip = imos[1]
imos = imos[2:]

for IMO in imos:
   skip += ','+IMO

imo = list()
mmsi = list()

conn = sqlite3.connect(Database)
cur = conn.cursor()

sql_linje = "select imo,userid from LNG_fleet5 where imo in (%s);" % skip

with conn:
    cur = conn.cursor()

    cur.execute(sql_linje)

    VesselData = cur.fetchall()
```

```

    for i in range(0,len(VesselData)):
        Datastrip = VesselData[i]

        mmsi.append(Datastrip[1])

MMSI = list(pd.Series(mmsi).unique())

#For SQL, for making a new table:
CREATE TABLE spot_fleet AS
    SELECT *
    FROM LNG_fleet
    WHERE userid in (Insert list of MMSIs);

#To create a new .db file, close terminal and reopen it. Then run:
    sqlite3 old.db ".dump mytable" | sqlite3 new.db
 ex: sqlite3 /Users/Axelsen/Desktop/LNG_fleet01.db ".dump GOLAR_fleet" | sqlite3 Golar.db
 ex2: sqlite3 /Volumes/LaCie/NTNUfilesMac/SAISGlobalFinal.db ".dump LNG_fleet" | sqlite3 LNG_fleet01.db
 ex3:sqlite3 /Users/Axelsen/Desktop/LNG_fleet01.db ".dump spot_fleet" | sqlite3 spot_fleet.db
```

Appendix B

AIS Data Contents

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

Table B.1: Information on static messages

Information item	Information generation, type and quality of information
Static	
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

Table B.2: Information on dynamic messages

Information item	**Information generation, type and quality of information**
Dynamic	
Ship'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 ship's main position sensor connected to AIS.
Course over ground (COG)	Automatically updated from 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 ship's heading sensor connected to AIS.
Navigational status	Navigational status information has to be manually entered by the OOW 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 relate to the COLREGS, any change that is needed could be undertaken at the same time that the lights or shapes were changed. [1]
Rate of turn (ROT)	Automatically updated from the ship's ROT sensor or derived from the gyro. This information might not be available

Table B.3: Information on voyage related messages

Information item	**Information generation, type and quality of information**
Voyage related	
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 plan (waypoints)	To be manually entered at the start of the voyage, at the discretion of the master and updated when required.

Appendix C

Literature Review

Literature Review Systemized

Topic	Amount of papers
Environment/Emissions	7
Safety	14
Economy	10
Review of methods	1
Data handling	11
General information	2
SUM	45

Methods (or more specific topic)	Amount of methods
Route planning	5
Collision prediction	6
Time series	1
Emission model	2
Traffic Estimation	9
Speed selection	4
Pattern recognition	2
Data handling model	5
Heuristics	1
Other	4
SUM	39

Type of ship	Amount of type
All	30
Tanker	5
Cargo	2
Bulk	2
Others	1
SUM	40

Paper title	Topic	Type of vessel	Methods
Exploring AIS Data for Intelligent Maritime Navigation: A comprehensive survey From Data to Methodology	Review of methods Safety	All	Route planning Collision prediction
Are AIS-based trade volume estimates reliable? The case of crude oil exports	Economy	Tanker	Time series
An AIS data Visualization Model for Assessing Maritime Traffic Situation and its Applications	Safety Data handling	All	Collision prediction
A Comprehensive Inventory of the Ship Traffic Exhaust Emissions in the Baltic Sea from 2006 to 2009	Environment/Emissions	All	Emission model
Study of Automatic Anomalous Behaviour Detection Techniques for Maritime Vessels	Safety	All	Collision prediction
The complex network of global cargo ship movements	Environment/Emissions	Cargo Tanker	Traffic Estimation
Dynamic speed choice in bulk shipping	Economy	All	Speed selection
Missing in Action? Speed optimization and slow steaming in maritime shipping	Economy	All	Speed selection
Unsupervised learning of maritime traffic patterns for anomaly detection	Safety	All	Collision prediction
Energy efficiency with the application of Virtual Arrival policy	Economy Environment/Emissions	All	Speed selection
Mapping Global Shipping Density from AIS Data	Data handling	Cargo	Other
Spacial and temporal allocation of ship exhaust emissions in Australian coastal waters using AIS data: Analysis and treatment of data gaps	Environment/Emissions	All	Other
Comparison study on AIS data of ship traffic behavior	Safety	Tanker	Pattern recognition
The determinants of vessel capacity utilization: The case of Brazilian Iron Ore exports	Environment/Emissions	Bulk	Other
Maritime traffic analysis of the Strait of Istanbul based on AIS data	Safety	All	Pattern recognition
Geospatial data stream processing in Python using FOSS4G components	Data handling	All	Other
MSARI: A database for large volume storage and utilisation of Maritime Data	Data handling	All	Data handling model
The application of database techniques in the integrated vessel information service system	Data handling	All	Data handling model
Expanding the Possibilities of AIS Data with Heuristics	Data handling	All	Heuristics
Teasing out the detail: How our understanding of marine AIS data can better inform industries, developments, and planning	Environment/Emissions	All	Data handling model

Empirical Ship Domain based on AIS Data	Safety	Others	Route planning
Real-time navigation monitoring system research for LNG-fuelled ship in inland water			
Estimating Vessel Utilization in the Drybulk Freight Market: The Reliability of Draught Reports in AIS Data Feeds			
Automatic Identification System	General information	All	
Analysis of waterway transportation in Southeast Texas waterway based on AIS data	Safety	Tanker	Collision prediction
LNG bunkering demand at Iberian Peninsula ports			
A Document-based Data Model for Large Scale Computational Maritime Situational Awareness	Safety Data handling	All	Data handling model
An automatic algorithm for generating seaborne transport pattern maps based on AIS	Economy	All	Traffic Estimation
An Internet of Things Approach for Extracting Featured Data Using AIS Database: An Application Based on the Viewpoint of Connected Ships			
Discovering Knowledge from AIS Database for Application in VTS	Data handling	All	Traffic Estimation
Environmental accounting for Artic shipping	Environment/Emissions	All	Emission model
A big data driven approach to extracting global trade patterns	Data handling Economy	All	Traffic Estimation
Ship collision risk assessment for the Singapore Strait	Safety	All	
Investigating the Predictive Ability of AIS-data	Economy	Tanker	Traffic Estimation
Shipping in the digital age: how feasible is the application of big data to the maritime shipping industry, and under what conditions can it be developed to become an integral part of its future?	General information Data handling	Bulk	Traffic Estimation
Trajectory Compression-Guided Visualization of Spatio-Temporal AIS Vessel Density	Data handling	All	Data handling model
Design principles of a stream-based framework for mobility analysis			
A distributed approach to estimating sea port operational regions from lots of AIS data	Economy	All	Route planning
Mapping Global Shipping Density from AIS Data	Safety	All	Traffic Estimation
Automatic generation of geographical networks for maritime traffic surveillance	Safety	All	Traffic Estimation Route planning
Scalable and distributed sea port operational areas estimation from AIS data	Economy	All	Traffic Estimation
Online analysis process on Automatic Identification System data warehouse for application in vessel traffic service			
A statistical model for vessel-to-vessel distances to evalute radar interference	Safety	All	Route planning
Shipping in the digital age: how feasible is the application of big data to the maritime shipping industry, and under what conditions can it be developed to become an integral part of its future?			
Study on collision avoidance in busy waterways by using AIS data	Safety	All	Collision prediction
A study of Satelite AIS Data and the Global Ship Traffic Through the Singapore Strait			
Energy efficiency with the application of Virtual Arrival policy	Economy	All	Speed selection
Expanding the Possibilities of AIS Data with Heuristics			

Appendix D

Problem Description

NTNU Trondheim
Norwegian University of Science and Technology
Department of Marine Technology

MASTER THESIS IN MARINE TECHNOLOGY
SPRING 2018

For stud.techn.

Jørgen Jensen Axelsen

A Study of the Operational Patterns of LNG Carriers from AIS Data

Background
We live in a time age of digitisation with an increasing amount of data being generated daily. Some of the largest corporations in the world base their income on exploiting this data. In shipping, the digitisation age and its opportunities are relatively unexplored terrain. With more or less all existing merchant vessels being online in real time through AIS new possibilities are emerging. These opportunities were explored in the project thesis during fall 2017, and are further expanded in this master thesis.

The motivation for looking into AIS Data is the possibility of providing useful insight for design requirements of ships and the nature of maritime transportation. For the stakeholders within shipping, including but not limited to shipowners and shipyards, the data appears to be a relatively untapped resource. AIS Data can provide important knowledge regarding operational patterns, trends and trade.

Operational patterns are important for the stakeholders in the maritime industry. If shipowners, yards and design offices can have a better understanding of operational patterns, they can increase their decision support. Increased decision support is an added value for the stakeholders.

The main reason for choosing the LNG segment is that their operational patterns are not well investigated compared to the larger segments. To the candidate's knowledge, there has not been a study investigating the operational patterns of LNG carriers from AIS Data.

Objective
The overall objective is to investigate the operational patterns of LNG carriers from AIS Data. The thesis will investigate a data set of AIS Data from the Norwegian Coastal Authorities, and extract the necessary data to conduct the analysis.

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

a. Obtain the LNG fleet and identify the spot trading part
b. Analyze operational patterns in terms of speed distribution and areas
c. Identify any patterns that strengthen or weaken the theory of the commoditization of the LNG market

General

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

NTNU Trondheim
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Department of Marine Technology

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 utilize 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.

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 symbols and 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 DAIM:
- 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 DAIM. Any electronic appendages shall be listed in the thesis.

Supervision:
Main supervisor: Prof. Bjørn Egil Asbjørnslett
Co-supervisor: Dr. Carl Fredrik Rehn

Deadline: 27.07.2018

Date: 19.06.18

Prof. Bjørn Egil Asbjørnslett

Jørgen Jensen Axelsen

Appendix E

List of Electronic Appendices

The following files are appended in the zip-file associated with the study:

- Poster.png
- AIS_Analysis.py
- CreateFleet.py
- loc_check.py
- MainMenu.py