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AIS-Data For Increased Insight Into Navigational Impacts Post Installation of Man-made Structures at Sea

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Submission date: June 2019
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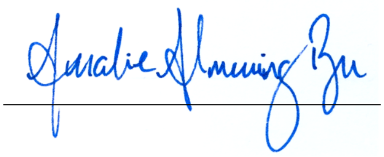
Preface

This thesis is written as the final work to complete my Master of Science degree in Marine Technology, with a specialisation in Marine Systems Design and Logistics. The work corresponds to 30 ETC and has been carried out at the Department of Marine Technology (IMT) at the Norwegian University of Science and Technology (NTNU) during the spring of 2019. My supervisor throughout the work has been Prof. Bjørn Egil Asbjørnslett.



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My fellow students, for two memorable years.

My office, C1.085, for all the help and motivation.

My family and friends, for always supporting me.

A.A.B.

Summary

The objective of this study is, through analysis of AIS-data, to investigate the navigational effects post installation of man-made structures at sea, in an attempt to provide increased insight into the resulting effects. The motivation behind the study is the current and expected development in ship traffic and marine activities in Norwegian waters. There is, according to literature, little understanding as to whether the modelling performed in navigational risk assessments prior to the development of for example wind farms accurately reflects the effects post construction. In addition are many of the risk calculation methods used sensitive to traffic changes. Small changes in the traffic post installation, can therefore result in large variations between the modelled and actual traffic risk.

A case study of several locations along the coast of Norway is conducted. Information from AIS-data has been extracted and analysed through codes/programs developed for visualisation and statistical analyses. The data is used to visualise and present statistics for the traffic density, the longitudinal and latitudinal traffic distribution, vessel speed and type, as well as the distance and angle between vessels and the investigated objects, for both pre- and post installation scenarios.

Due to the unfortunate reason that only a limited AIS-database was available for this study, the objects investigated are oceanographic buoys. The size and location of these objects create challenges with respect to how the results should be interpreted, and the applicability of these, with respect to other larger structures, such as wind turbines and aquaculture facilities.

Although the results from the case study are a bit ambiguous, they do indicate some repeating trends in vessel behaviour when new obstacles are introduced. It seems like a reasonable distance to the new objects is kept, also for small objects such as met-ocean buoys, even if the mean distance of the traffic decreases. The results also show examples where the traffic is ”compressed” due to circumnavigation or alterations in course by the vessels closest to the object. This may lead to a growth in vessel density, which again can result in increased ship-ship collision risk. Additionally, for some of the cases, increased activity near the object is detected. This introduces new situations that can be interesting to investigate in further studies. Also, for further studies, investigation of the correlation between size and degree of traffic is interesting.

Sammendrag

Målet med denne masteroppgaven er gjennom analyse av AIS-data, å undersøke endringer i den maritime trafikken som følge av installasjon av menneskeskapte konstruksjoner på sjøen. Motivasjonen bak studien er å forsøke å skape økt innsikt i disse effektene, grunnet den nåværende og forventede utviklingen i skipstrafikk og marine aktiviteter i norske farvann. Det er ifølge litteraturen lite forståelse rundt hvorvidt modelleringen som utføres ved risikovurderinger før for eksempel vindmølleparker bygges, gjenspeiler effektene etter bygging. I tillegg er mange av metodene som brukes til risikoberegninger sensitive med tanke på trafikkendringer. Små endringer i trafikken etter installasjon kan dermed resultere i store variasjoner mellom den modellerte og faktiske trafikkrisikoen.

En case-studie av flere lokasjoner langs norskekysten er gjennomført. Informasjon fra AIS-data er hentet ut og analysert ved hjelp av koder laget for visualisering og statistisk analyse av AIS data. Dataene er brukt til å visualisere og presentere statistikk for trafikktetthet, traffikkfordeling langs lengde- og breddegrader, hastighet og typer fartøy, samt avstanden og vinkelen mellom fartøyene og de undersøkte objektene, både for pre- og postinstallasjonsscenarier.

Dessverre var AIS-databasen tilgjengelig veldig liten. Objektene undersøkt er derfor oseanografiske bøyer lokalisert i norske farvann. Størrelsen og plasseringen til disse objektene skaper dermed utfordringer med hensyn til tolkning og anvendelighet av resultatene i relasjon til andre større strukturer som for eksempel vindturbiner og akvakulturanlegg.

Selv om resultatene fra casestudien er noe tvetydige, peker de mot noen gjentagende trender i adferd når nye hindringer introduseres. Det ser ut til at fartøyene generelt holder en rimelig avstand til nye objektene, også for små gjenstander som med bøyer, til tross for at den gjennomsnittlige avstanden til trafikken eventuelt minker. Resultatene viser også eksempler på at trafikken "komprimeres" grunnet at de nærmeste fartøyene svinger rundt objektet eller endrer kurs. Dette kan lede til en økning i trafikktettheten for enkelte områder, som igjen føre til økt kollisjonsrisiko mellom to skip. I tillegg, er det ved noen tilfeller oppdaget økt aktivitet nær objektene. Dette introduserer nye situasjoner som kan være interessante å undersøke i videre studier. For videre studier er det også interessant å undersøke sammenhengen mellom størrelse på objektet og grad av trafikkendring.

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Acronyms

AIS	Automatic Identification System
AtoN	Aids to Navigation
COLREGS	Convention on the International Regulations for Preventing Collisions at Sea
COG	Course Over Ground
CPA	Closest Point of Approach
DCPA	Distance to Closest Point of Approach
DWT	Dead Weight Tonnage
ETA	Estimated Time of Arrival
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
GB	Gigabytes
GPA	Global Positioning System
GT	Gross Tonnage
HAT	Highest Astronomical Tide
IMO	International Maritime Organisation
ITU	International Telecommunication Union
Knots	Equivalent to 1.852 km/h
MMSI	Maritime Mobile Service Identity
MSP	Maritime Spatial Planning
mt	Metric Tonne
NRA	Navigational Risk Assessment
OS	Own Ship
RDP	Ramer–Douglas–Peucker algorithm
RIATM	Restricted In Ability To Manoeuvre
ROT	Rate Of Turn
S-AIS	Sattelite-AIS
SOG	Speed Over Ground
SOLAS	International Convention for the Safety of Life At Sea
SQL	Structure Query Language
TSS	Traffic Separation Scheme
UTC	Coordinated Universal Time
VHF	Very High Frequency
VHS	Very High Frequency System
VTS	Vessel Traffic Service
WIG	Wing In Ground
WGS48	World Geodetic system

Chapter 1

Introduction

1.1 Background

Today, Automatic Identification System (AIS) data is exploited for multiple purposes besides collision avoidance, which was the original intention behind the implementation of AIS. It is a great source of information containing data with many possible areas of use, all the way from risk reduction to industrial and economical purposes. From scientific literature, the following are only some of the uses identified: collision and allision risk analysis (Wang (2010), Hassel et al. (2017), Povel (2006), Silveira et al. (2013)), assessment of risk in ice operations (Goerlandt et al. (2017)), marine spatial planning (Shelmerdine (2015), Fiorini et al. (2016)), vessel prediction and analysis of traffic patterns (Pallotta et al. (2013), Pallotta et al. (2014)).

In a sea-safety analysis carried out by DNV GL for the Norwegian Coastal Directory, DNV GL predicts a significant increase in the maritime traffic outside Norway in the following decades (Lasselle et al., 2018). From 2013 to 2040 it is predicted an increase of 41 % in the maritime traffic in Norwegian waters. It is further stated that an increase in marine traffic, seen in isolation, will lead to an increased probability of accidents. Based on the forecasted 41% increase, measured in terms of distance traveled, DNV GL has calculated that the number of annual ship accidents in Norwegian waters can be expected to increase by 31%. This corresponds to around 200 accidents annually if no preventive measures are implemented.

Concurrently with the traffic increase, growth in other activities along the coast will also affect the traffic situation. Especially the development of new sea-based energy solutions and seafood production will be of great importance. Both aquaculture and wind-energy production are very area demanding, and it is therefore necessary to utilize available areas to enable growth in these industries. Many countries are because of this looking towards solutions such as the utilisation of offshore locations for wind energy production, and installation of aquaculture facilities at more exposed locations.

In the SINTEF report, ”Value creation based on productive oceans 2050” (Olafsen et al., 2012), the potential for sea-based value creation in Norway in 2050 is evaluated. The report points out two main areas that will be highly important besides the oil and gas industry:

1. Further development of the seafood industry’s core areas as we know them today.
2. Development of emerging and new industries.

The core areas of the seafood industry today includes both the fisheries, fish farming of salmon and trout, marine ingredients and fish feed production, as well as the supplier industry and continuous development of marine competence. Farming of new marine species, capture or production of marine micro and macroalgae, and focus on highly productive sea areas, are referred to as the emerging seafood industries. Together, the potential for value creation from these areas is estimated to be around 550 billion NOK in 2050 (Olafsen et al., 2012). The report further states several recommendations on how to achieve a competitive advantage within these industries. The recommendations include among other things to focus on education and to establish superclusters and a common technology strategy. Another recommendation is to focus on good knowledge-based marine and coastal management.

Also, the need for renewable energy sources has resulted in a number of stakeholders wishing to utilise the coast outside Norway for sea-based energy solutions. Especially offshore wind is of great interest, but also solar islands, and wave and tidal devices, might be expected in the future. In 2013, The Norwegian Water Resources and Energy Directorate presented, in cooperation with The Norwegian Coastal Directory, an evaluation of possible development zones for offshore wind parks along the coast of Norway (Langeland and Veim, 2012). Yet, in 2019 there are still no wind parks built. This is mainly due to economical reasons, but, for several of the areas, there are also mentioned challenges related to the interaction with the traffic (Jakobsen et al., 2019). The traffic risk situation is one of the many things that are investigated before a license is granted. In addition to this, it has to be taken into consideration that changes in traffic routes, that are needed to maintain a low risk level, can result in increased transportation costs. It is however granted a license for the construction of a bottom-fixed wind power plant, Havsul, outside the coast of Møre.

In the article ”Forvaltning av Norskehavet”, the Professional forum for Norwegian sea areas (2018) states that a secure and efficient maritime transportation system that takes the environment into account and contributes to continued value creation in the region shall be facilitated. Good marine spatial planning is key to enable sea-based industries to grow side by side. Through analysis of AIS-data from pre- and post-installation of man-made structures, such and fish farms, wind turbines, etc., we can increase our understanding of how traffic patterns changes, and help improve decisions with respect to the choice of location. This is important both from an economical, as well as an environmental and risk perspective. It can provide valuable knowledge to stakeholders and be used as decision support, as well as for risk-reducing purposes. Findings may possibly also be relevant for more dynamic situations where objects appear and disappear more rapidly than semi-permanent installations such as fish- and wind farms.

Detection of repeating patterns in how the traffic changes can give valuable information about the mechanisms of the traffic changes, be useful for the prediction of future traffic patterns, as well as for the matter of assessing the impact such new objects will have on the traffic risk. Through a comparative analysis of the changes in ship traffic after artificial objects are put in place at sea, also an increased understanding of the uncertainties present in the pre-analysis of the development can be obtained.

Some of the questions that can be raised are: How does the traffic lanes shift when a new installation is put into place? How far from an installation can changes be detected? What distance seems to be perceived as safe by the passing vessels? Is the size of the installation of high or low importance with respect to traffic changes? Does the entire traffic lane move, or is it only the vessels closest to the new object that is affected?

1.2 Objectives

For this thesis, the objective is to investigate the navigational effects post installation of man-made structures at sea. The motivation behind this study is to provide increased insight into these resulting effects.

The objective consists of several parts, and the main research questions addressed are as follows:

- How do the maritime vessel traffic change post installation of an artificial object at sea?
- Which effects on navigational risk can be seen subsequently to the installation of a marine-structure?
- Is it possible to detect repeating trends or tendencies in the traffic changes that can help the decision-making process when future structures are to be put in place?

In the attempt of answering these questions, the following research objectives have been addressed through the work:

- Determine feasible objects/cases for investigation
- Extract relevant information from AIS data
- Present visualisations and statistical data for each case
- Explore traffic density and changes based on the processed data
- Evaluate behaviour of different vessel types
- Compare and analyse before/after scenarios

- Compare findings for each case as a search for repeating behaviour
- Use findings from behavioural analysis to assess risk implications

1.3 Scope and Limitations

The main limitation of this study is the AIS data available. The database at hand limits the number of areas/objects feasible for this kind of investigation. The scope of the report will, therefore, be limited to the coast of Norway and to a restricted number of investigated areas. Another limiting factor is the availability of information regarding installation date, period and position for various marine-structures. Additionally, the time it takes to search for and extract relevant information and thereafter analyse large amounts of data limits the scope of the study.

1.4 Structure of the Report

After the introduction, the chapters if the report is structured as follows:

In **Chapter 2** relevant literature on the area is presented to give some insight into previous work on the topic. **Chapter 3** gives an overview of the current situation and expected development in sea-based industries in Norway such as shipping, renewable energy, and aquaculture. In **Chapter 4** the methodology is described. The methodology chapter is divided into two parts. In Part I, the general methodology and approach to achieve the objective of this study is described. Thereafter, in Part II, an introduction to the fundamentals of AIS data and methods for handling AIS-data is presented. In **Chapter 5**, a case study that includes investigation of various locations along the coast of Norway can be found. Lastly, in **Chapters 6-7** the results from the case study, as well as the method of execution, is discussed before concluding remarks are stated, and recommendations for further work suggested. Figure 1.1 on the next page, illustrates the project flow.

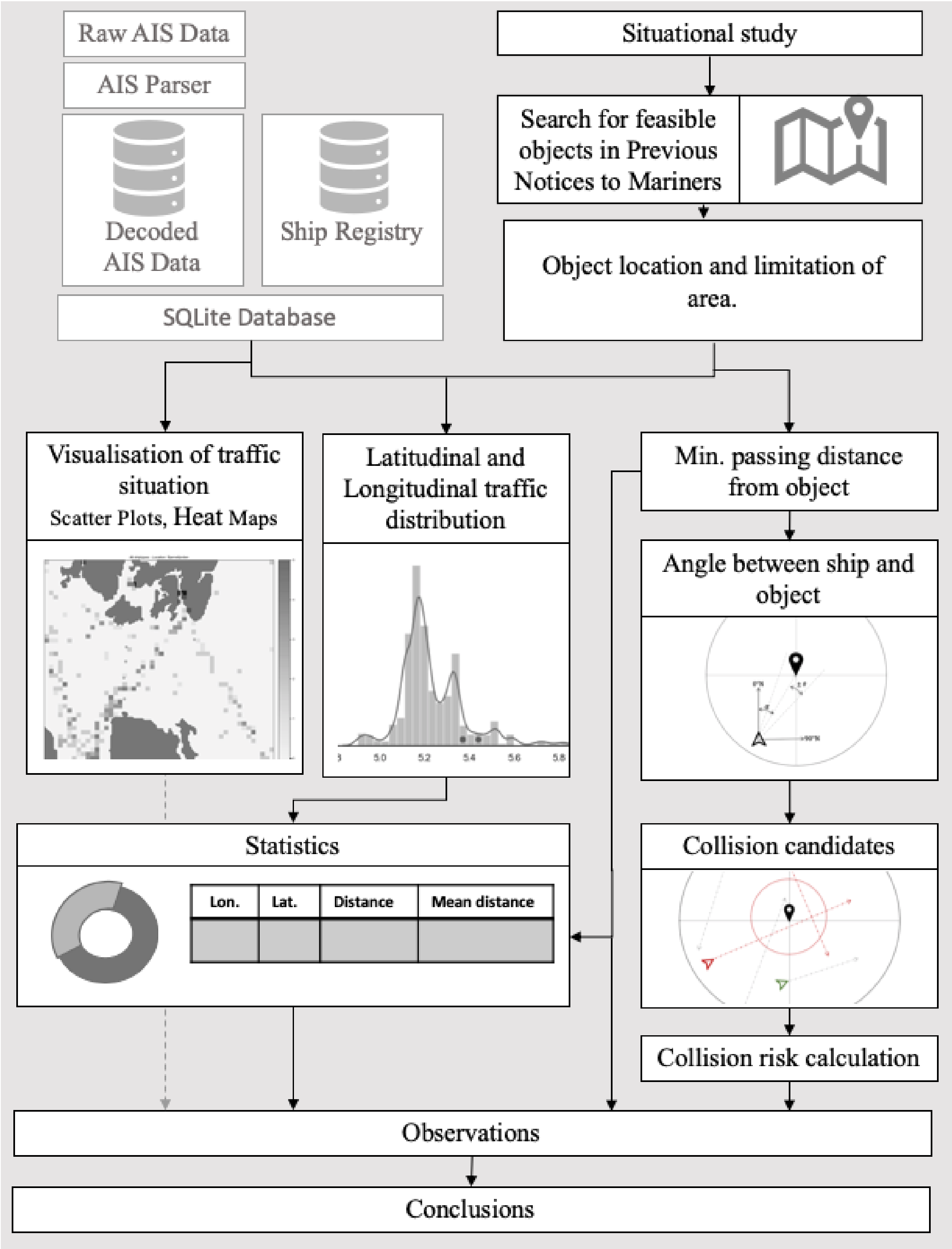


Figure 1.1: Flowchart: Methodology and Project flow.

Chapter 2

Litterature review

There are as mentioned a large interest in the exploitation of AIS data, both for the assessment of navigational risk as well as for industrial and economical purposes. This is reflected in the literature available within the area. Assessment of navigational risk in narrow straits, identification of traffic patterns and estimation of near accidents are just some examples of what AIS data can be used for. Other examples are marine spatial planning, collision avoidance and decision support, emission estimation, ship performance estimation, situational prediction, and anomaly detection.

First, in Section 2.1 below, studies using AIS for safety and collision risk analysis is presented, thereafter some studies addressing handling and analysis of AIS data is presented in Section 2.2. In Section 2.3 literature, where AIS is exploited for economical and industrial purposes, is presented, before statistical analysis of vessel trajectories is addressed in Section 2.4. Additionally, some other methods and approaches for analysis of AIS-data are presented, before at last, in Sections 2.6-2.6.2, literature regarding models for the assessment of maritime traffic risk can be found.

Several of the papers and studies mentioned are related to either petroleum installations, offshore wind farms or ship-to-ship encounters. These are included because there is little literature available investigating the impact of other objects, such as exposed aquaculture facilities, and because they contain information and methods that can be of value for this work.

2.1 AIS-data for navigational safety

2.1.1 Allision risk analysis of offshore petroleum installations

Hassel et al. (2017) present an allision risk analysis for offshore petroleum installations in open waters on the Norwegian Continental Shelf. The study is an empirical study of vessel traffic patterns based on AIS data comparing traffic patterns, before and after seven petroleum installations were put in place. The aim of the assessment was to investigate the accuracy of the allision models used for risk calculations prior to the construction of new petroleum installations. The reason for the interest is that allision risk models, such as COLLIDE (Vinnem, 2014), are highly sensitive to the passing distance and the probability of a vessel being on a collision course. The results from this study show that the current methodology of calculating allision risk with AIS data as leads to overly conservative estimates of allision risk because vessel traffic will adjust their sailing tracks when a new offshore oil and gas installation is commissioned by generally altering course to achieve a passing distance of at least 1 nm.

2.1.2 AIS Data for Intelligent Maritime Navigation

Tu et al. (2016) thoroughly presents the possibilities within AIS and how AIS data can be exploited for safety purposes. Methods for both for anomaly detection, route estimation, and path planning as well as for collision prediction is presented. The use of ship domains is also discussed thoroughly. This is addressed further in section 2.6.

2.1.3 Collision risk analysis - probabilistic approach

Mujeeb-Ahmed et al. (2018) carries out a probabilistic collision-risk analysis of collision between offshore platforms and passing vessels, based on AIS data. First, the statistical distribution of the ship traffic in the study area is described. Thereafter it is considered how this information, based on a probabilistic approach, can be used to effectively estimate collision frequencies and impact energies for different vessel categories.

2.1.4 Ship Escort and Convoy Operations in Ice Conditions

Goerlandt et al. (2017), presents an empirical analysis of ship convoy operations based on AIS data combined with ice hind-cast data. It is, in particular, the ship domain concept that is investigated with a focus on escort and convoy operations. Through analysis of AIS- and ice data, characteristics of convoy operations, particularly convoy distance and speed, are investigated and compared to prevailing ice conditions. The results from the study show that contextualizing AIS data with environmental data can provide insights into the dependency of the environment, ship domains and operational characteristics.

2.1.5 Marine Traffic Patterns and Ship Collision Risk

Silveira et al. (2013) presents a study of marine traffic patterns and ship collision risk off the coast of Portugal based on AIS data. In the study, it is developed programs for decoding, visualisation, and analysis of the AIS data in addition to an algorithm for assessment of the risk profile and the relative importance of routes associated with ports. To assess the risk of ship-ship collisions, collision candidates was estimated based on AIS data. It is in the study suggested calculating collision candidates directly from decoded AIS data, due to the dispersed traffic patterns and a high number of vessel crossings. It is suggested that the approach developed in this study can be used to identify collision candidates in complex traffic patterns, and is not limited to crossings of two waterways characterized in probabilistic terms.

2.1.6 Collision Risk Analysis for Offshore- Structures and Wind Farms

Povel (2006) presents methods and processes developed by Germanischer Lloyd together with results from a sample collision risk analysis. The developed analysis software uses Monte Carlo simulations. Additionally, to evaluate the effect of risk control measures (RCMs), Bayesian nets are used to determine the reduction in the collision probabilities and consequences. As input, ship traffic data, meteorological- and hydrological data for the investigated area are used. Information about optical and technical visibility of the offshore structures or wind farms is also included. The method of Pedersen et al. (1995) and Friis-Hansen (2000) is used to determine collision probability. For drifting collisions, the distributions of wind, current, and waves are in the Monte Carlo simulations generated randomly to make the start conditions equivalent to the real-world distributions of wind, waves, and current. The results from the study showed that the method particularly developed for risk analysis for offshore wind farms also can be used for offshore platforms. It shows that the most important factors for such analysis are the surrounding ship traffic lanes (including the composition of ship types, sizes, loading conditions, and dimensions). Also, equipment on the offshore structures is pointed out as an important factor.

2.1.7 Exceptional Vessel Encounters in Open Waters

Nordkvist (2018) does in his master thesis present an investigation of whether the estimation of rate of turn, before and after the closest point of approach between two encountering vessels, can be used to detect the frequency of exceptional vessel encounters. The approach is a less documented approach for quantification of the presence of risk in an encounter between two vessels. The model developed relies on a ship domain approach. Exceptional encounters are determined based on whether one or both vessels in a ship pair get their ship domain violated, combined with a threshold for rate of turn set to 70 deg/min.

2.2 AIS data handling and analysis

2.2.1 Exploration of Methods for Analysing AIS Data

Næss et al. (2017) investigates through their project thesis quantitative methods for analysing AIS data with the purpose of exploring methods that can be used for further investigation of AIS data. Different methods within geo-fencing, network generation and clustering is addressed, some of which is further explored through a case study where a model based on the work of Leonhardsen (2017) is used.

2.2.2 Context-Enhanced Vessel Prediction

Pallotta et al. (2014) presents a method for predicting motion patterns through parametrized stochastic modelling enhanced by historical traffic patterns. The study illustrates the potential exploitation of the traffic routes derived via the TREAD model (See Section 2.3.4). In the paper, it is stated that the experimental results obtained using a real-world data set, in support of the second NEREIDS (New Service Capabilities for Integrated and Advanced Maritime Surveillance) data campaign, have demonstrated the goodness of fit of the Ornstein-Uhlenbeck model for the uncertainty of vessel position predictions. The model was validated to estimate the position of vessels several hours ahead with an uncertainty of a few kilometres over a route on the order of hundreds of kilometres.

2.3 AIS-data for economical and industrial purposes

2.3.1 Marine AIS to better inform industries, developments, and planning

Shelmerdine (2015) presents a study of the area around Shetland performed to investigate how increased understanding of marine AIS can be used to better inform industries, developments, and planning. The work demonstrates ways of processing, analyzing and visualizing AIS data, resulting in an outline of the potential of AIS as a tool for a wide range of industries. In addition to the AIS data, a vessel database of all the vessels in the area was created in order to capture all vessel types accurately. Although creating a vessel database is time-consuming, it was in this study evaluated as necessary due to variations in the reliability of fields related to vessel category and dimensions. The database was in the study also used as a way to quality control the vessel information. AIS data was used to create a point shape-file in the ArcGIS map tool where the data was analysed. It is suggested that AIS as a tool has a large potential for a wide range of industries and users of the marine environment. Analysis of data is recommended as a guide for future use of the marine environment, taking into consideration shipping and navigational safety in development planning and marine spatial plans. In addition, it is suggested that AIS can be helpful for local marine industries, in risk mapping, and for investigation temporal variations of vessel activity.

2.3.2 Global Ship Traffic Through the Singapore Strait

Smestad (2015) presents in his master thesis an investigation of the quality and utility of AIS data, where he uses heuristics to, based on Satellite AIS (S-AIS) data, determine specific ship types in the Singapore Strait. This is done to enable analysis of AIS data without access to commercial ship databases. S-AIS data is also used to track vessels back to their origin. Errors related to S-AIS data is thoroughly described. His work has been an important contributor and basis for both the work of Leonhardsen (2017), Næss et al. (2017) and Axelsen (2018).

2.3.3 AIS for marine spatial planning

Fiorini et al. (2016) presents a complete pipeline for visualization of ship routes from raw AIS data through the use of open-source software only. This is done to meet the need for careful strategies for data visualization that is necessary to be able to exploit AIS data for Marine Spatial Planning (MSP).

2.3.4 Vessel Pattern Knowledge Discovery from AIS Data

Pallotta et al. (2013) proposes a method called TREAD (Traffic Route Extraction and Anomaly) to be used for anomaly detection and route prediction. The TREAD methodology automatically learns a statistical model for maritime traffic from AIS data in an unsupervised way. This means without assuming any prior knowledge on the monitored scene. In this work, vessels are considered as a collective entity, meaning it is the traffic patterns formed by the vessels in the area of interest that is analysed. To include successive data points, the model uses a point-based traffic representation and integrates time information into knowledge exploitation. This is done to get a reliable representation of the traffic without increasing the complexity of the model.

2.3.5 Estimation of Fuel Savings

Leonhardsen (2017) presents in his master thesis a study where the fuel savings that can be achieved by re-configurable bulbous bows are estimated. Especially the lessons with respect to the challenges of processing AIS data and how to handle or overcome these have been useful in this study.

2.4 Statistical analysis of vessel trajectories

Fiorini et al. (2016) divides the methods used to deal with maritime data into two main categories: grid-based approaches and a vectorial representation of traffic. These are described respectively in Section 2.4.1 and 2.4.2.

2.4.1 Grid-based approach

The grid-based approaches are feasible for analysis of limited geographical data. In these approaches, the area of interest is divided into cells creating a spatial grid. The cells are thereafter characterized by the motion properties of the crossing vessels (Fiorini et al., 2016).

Shelmerdine (2015) uses this approach in the study of how to use marine AIS to better inform industries, developments, and planning. Information from AIS data was here used to create a point shapefile in the ArcGIS map tool. Route information was extracted from ship type codes, and poly-lines used to create ship-specific routes. The Create Fishnet function in ArcGIS is used to create density maps. An initial grid is created at two resolutions, $1km^2$ and $0.25km^2$, and a join is created between the grid and the point shapefile. To account for time spent while not producing a data point, and to compensate for overestimation of density from vessels at anchor, a second set of grids at the same resolution is created based on a join with the vessel track data. In addition, the Natural Neighbour function in ArcGIS is used to interpolate between the point data for vessel speed, length, draught, and tonnage.

Silveira et al. (2013) also use a grid-based approach in their study. To visualize the data, a program is developed to create an initially zero-value matrix consisting of elements which correspond to a given position in the area evaluated, each pixel equivalent to 0,001 degrees of latitude. Pixels with positions corresponding to that element is then incremented. The resulting bitmap images and decoded messages are then used for traffic statistics and characterization of traffic lanes of TSSs (Traffic Separation Schemes).

Pallotta et al. (2013) states that although a grid-based approach is effective for small area surveillance, there are some limitations. The main limitation of the approach is the increased computational burden that comes as a result of increasing the scale. Also, the need to select optimal cell size prior to the analysis should be mentioned. The approach can lead to complex algorithms to be able to perform anomaly detection in areas with complex traffic, such as intersecting sea lanes.

2.4.2 Vectorial representation

An alternative to the grid-based approach is the vectorial representation of traffic. Here, vessel trajectories are modeled as straight paths connecting a set of waypoints (Pallotta et al., 2013). This representation is in other words more feasible for larger scale problems and investigation of larger geographical areas as it allows for a reduced amount of data points and thus a more compact representation of the vessel motions. Pallotta et al. (2013) highlights that when using this method on areas with complex routing systems, it can be necessary to introduce intermediate nodes in addition to the set of waypoints to capture the characteristics of the routes more accurately. These turning points can be difficult to detect in unregulated areas with complex vessel behavior that is hard to categorize. This issue is addressed in their paper. I contrast to other vectorial representations, the route objects here include directional changes without explicitly having to derive turning points. This is achieved by identifying the vessel trajectories based on a preliminary clustering of waypoints. This way, the traffic is still represented in a vectorial way, but the routes are instead formed by the flow of vectors from vessels with paths connecting the derived waypoints, including both stationary areas and entry/exit points.

2.5 Other methods and approaches for analysis of AIS-data

2.5.1 Geo-fence approach

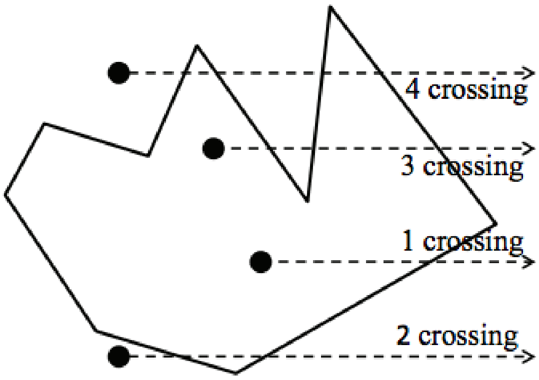


Figure 2.1: Illustration: Ray Casting Algorithm (Yan et al., 2012)

2.5.2 Ramer-Douglas-Peucker (RDP) algorithm

The Ramer-Douglas-Peucker algorithm is a method for reducing unnecessary data points based on a predefined minimum distance ε, which thereby helps space and processing time. Skollevold (2011). The algorithm goes through step 1-4, as illustrated in Figure 2.2. At step 0 the original line containing all data points can be seen. Step 1 of the algorithm is to draw a line from the first to the last point of the line (a). Thereafter the point furthest away from this line is found (b). If the value of ε is smaller than the distance b, point c is included. However, if ε is larger than the distance b, all points are discarded and the line is displayed as a straight line between the two points furthest apart. At step 2 the point furthest away from the new line is again found and compared to ε. The same rules apply for step 2 as for step 1. At step 3, step 1 and 2 are repeated until there are no more points that are further away than ε from the new line. The last step is then to print the new line where all insignificant points in discarded. A disadvantage with this algorithm is that if smaller course changes are of importance for the study, this algorithm might not be feasible as these will not be displayed. Alternatively a small value for ε can be used.

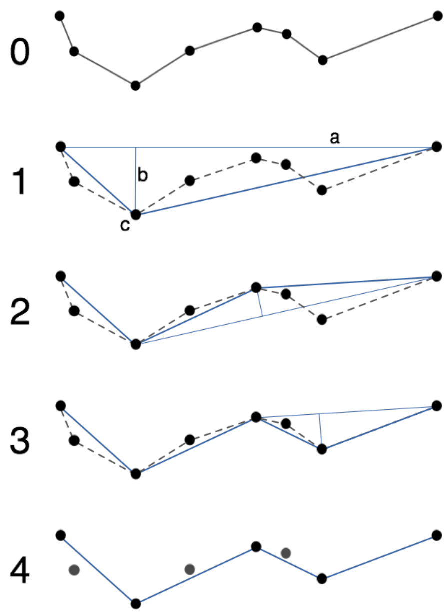


Figure 2.2: Illustration of the Ramer-Douglas-Peuker algorithm. [Source: Wikipedia Commons, CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/)].

2.5.3 Networks

A good way to get an overview of traffic patterns, or to investigate large geographical areas is to generate port-to-port networks based on voyage destination, given that this information is included in the AIS messages. Another networking method is the breakpoint detection method which is used to reduce the number of points need to describe a route through detection of variations in COG. However, these methods might not be especially feasible in cases where it is important to capture more exact changes in traffic routes. The reason for this is that these methods might present a too general traffic picture, where data points that will be important for the investigation of traffic changes around objects, such as exposed fish farms, are excluded.

2.6 Maritime Risk Assessment Models

2.6.1 Collision candidates and collision probability

Determination of the number of possible ship accidents N_a, i.e. the number of groundings and/or collisions if no evasive maneuvers are made, is the main principle behind commonly used risk models such as IWRAP (IALA, 2017b) and COLLIDE (Vinnem, 2014).

When analysing the risk for vessels colliding with offshore structures or wind farms Povel (2006) distinguishes between two different scenarios: powered vessel collisions and drifting vessel collisions, illustrated in Figure 2.3. The powered collision category is again divided into two categories:

- Category I: Ships following the ordinary and direct route. Due to the inaccuracy of navigation and/or meteorological and hydrological input, the vessels on a route exhibit a lateral distribution.
- Category II: Ships which fail to change course at a waypoint.

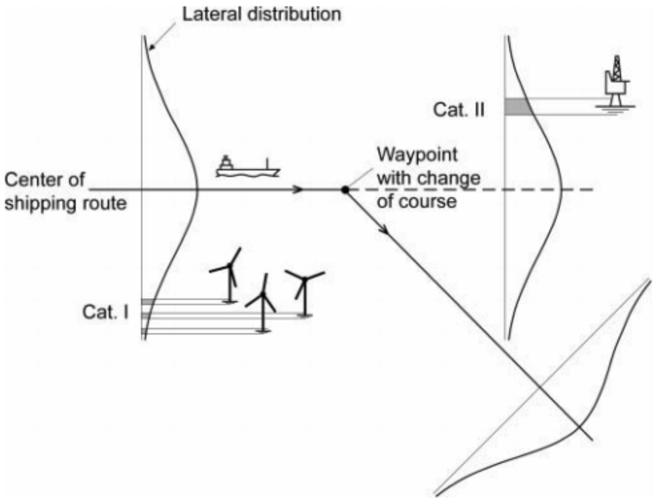


Figure 2.3: Collision category I and II for offshore structures (Povel, 2006)

To determine collision probability, the method of Pedersen et al. (1995) and Friis-Hansen (2000) can be used. It is assumed that two conditions have to be fulfilled for a collision between a powered ship and an obstacle to occur. The first condition to be fulfilled is that the vessel is on collision course, heading towards the obstacle, while the second condition is that the watch-keeper does not undertake any correction of the course. The majority of these grounding candidates will be able to take necessary actions to avoid hitting the obstacle. However, a fraction, represented by the causation probability P_c will not manage to avoid the obstacle (Friis-Hansen, 2008). The collision frequency is then obtained by multiplying the number of geometric collision candidates, N_a, with the causation probability of failing to avoid collision in an accident scenario, P_c (Pedersen et al., 1995), as in Equation 2.1.

$$N_{collisions} = N_a \cdot P_c \tag{2.1}$$

The equation is based on the pioneering work of Fujii et al. (1970), Fujiii (1974), and Macduff (1974). Later Pedersen et al. (1995) adopted the equation, and substituted the ship density from Fujiii (1974) with traffic flow. The causation probability, P_c depends on the navigators, the manoeuvrability of the vessels, the equipment, and more (Pedersen, 2010). It can either be estimated on the basis of traffic observations, by counting of accidents and estimating the geometric probability P_i for a specific fairway, or it can be found through fault tree analysis (FTA) Kristiansen (2005).

The methodology of the IALA Waterway Risk Assessment Program (IWRAP Mk II) is inspired by Fujii and MacDuff from the 1970s in addition to the tool developed by the Canadian Coast Guard called "Minimum Safe Design" (IALA, 2009). It is a risk assessment tool developed at the Technical University of Denmark, which purpose is to provide authorities with a standardized quantitative method for evaluation of the probability of groundings/collisions with fixed objects in a given waterway (IALA, 2009).

In Figure 2.4, the navigation route, and the two collision categories are again illustrated. In the shipping lane, the vessels are distributed over a transverse section of the waterway with a probability density function $f_i(z)$, where z is the transverse coordinate and the index i refers to the ship (Pedersen et al., 1995). The number of grounding candidates can be calculated as an integral over the width of the obstacle as illustrated by the hatched area on the figure.

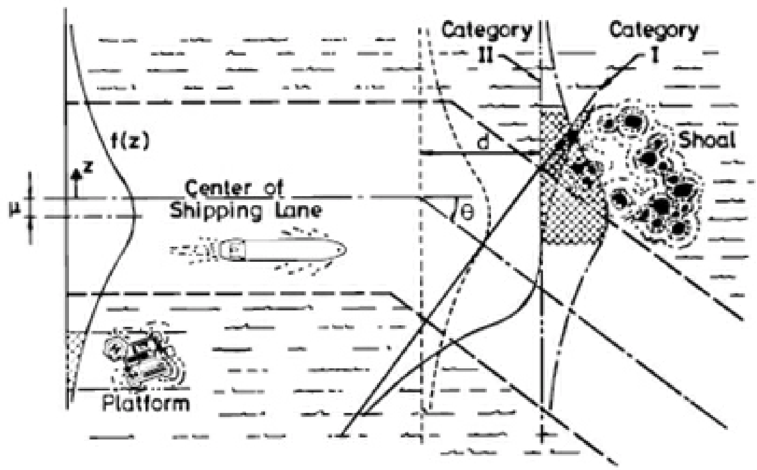


Figure 2.4: Model for predicting the expected number of grounding events or collisions with fixed objects on a given ship route (Pedersen et al., 1995).

For category I and II, the expected number of collisions, N_I and N_{II}, with a stationary object can be calculated by respectively Equations 2.2 and 2.3:

$$N_I = \sum_{Shipclass,i} P_{c,i} Q_i \int_{z_{min}}^{z_{max}} f_i(z) dz \tag{2.2}$$

$$N_{II} = \sum_{Shipclass,i} P_{c,i} Q_i e^{-d/a_i} \int_{z_{min}}^{z_{max}} f_i(z) dz \tag{2.3}$$

Here, Q_i is the number of ships passing a rout cross-section, in class i, while z_{min} and z_{max} are the transverse coordinates for the obstacle. The average distance between position checks by the navigator is represented by a_i, and e^{-d/a_i} is the probability of the navigator not checking position between the fairway bend and the obstacle, assuming that a_i can be described as a Poisson process (Simonsen, 1997).

For this model, it is typical to assume that the lateral traffic distribution is Gaussian, with given standard deviations for different contexts. However, if the Gaussian distribution does not fit the actual vessel distribution, the course distribution can be obtained from AIS data through passage line analysis Chang et al. (2014).

2.6.2 Ship-to-ship collisions

To assess the risk of ship-ship collisions, Silveira et al. (2013) estimates collision candidates based on AIS data. An approach for calculation of collision candidates, N_A, directly from decoded AIS data is suggested. The reason for this is that, according to the model by Pedersen et al. (1995), the number of collision candidates (N_A) has to be calculated in a specific crossing of two waterways characterized in probabilistic terms. In the case of Silveira et al. (2013), the number of crossings was high and traffic patterns sometimes too dispersed to identify a specific crossing. The method suggested, therefore, uses position, course and speed from AIS data to estimate future positions of ships and the distance between them. This estimation was then compared by with the collision diameter defined by Pedersen et al. (1995). Two ships were considered collision candidates if the estimated distance between the ships was less than the collision diameter for the same ships.

Figure 2.5 illustrates the risk area of ship-ship collisions in two overlapping waterways. Here, i and j represent the number of different ship classes, while f(z) represents the vessel distribution of vessels in the waterways (Pedersen, 2010).

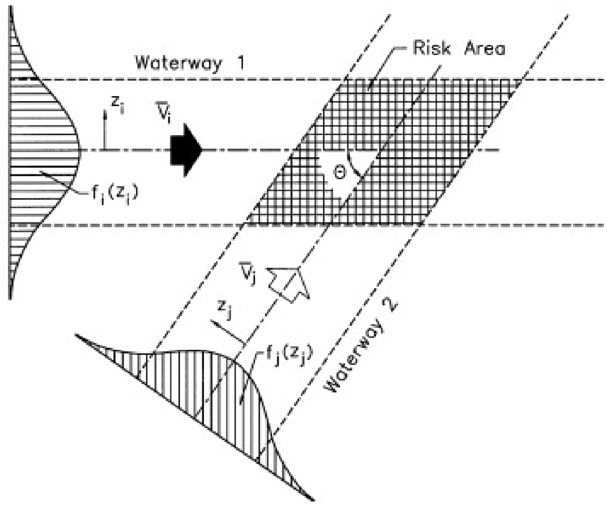


Figure 2.5: Risk area for ship-ship collision in the crossing between two waterways (Pedersen, 2010).

Tu et al. (2016) mention five concepts which play an important role when assessing collision risk, and states that collision risk assessment is performed either by detecting possible violations of these domains or by defining a risk index based on ship domain, distance to the closest point of approach and time to closest point of approach. The five concepts are listed below:

- Ship Domain (SD): The surrounding effective water area in which the navigator of a ship wants to keep clear of other ships.
- Own ship (OS): A ship we directly control.
- Distance at the Closest Point of Approach (DCPA): the smallest distance between domains of own ship and target ship during the process of approach.
- Time to the Closest Point of Approach (TCPA): The time costed to reach DCPA point at current manoeuvring state.

The ship domain is by Goodwin (1975) defined as ”the effective area around a ship which a navigator would like to keep free with respect to other ships and stationary obstacles.” Tu et al. (2016) distinguishes between simple ship domains, such as the elliptical ship domains of Fujii and Coldwell, and Goodwin’s circular ship domain, and compound ship domains such as the quaternion ship domain identified by Wang (2010). Fujiii (1974) was the first to propose the ship domain, illustrated in Figure 2.6. Goodwin’s circular ship domain was first proposed as a domain emphasizing the front right area of the ship because accordion to the COLREGs from 1972 own ship is directly responsible for the risks between own ship and any target in this area (Tu et al., 2016). To avoid the disadvantage of having a discontinuous boundary, a circular domain with off-centring was introduced. See Figure 2.7.

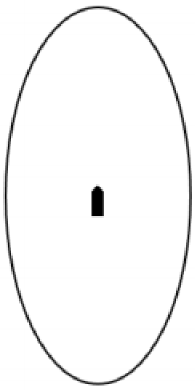


Figure 2.6: Simple ship- domain (Fujiii, 1974).

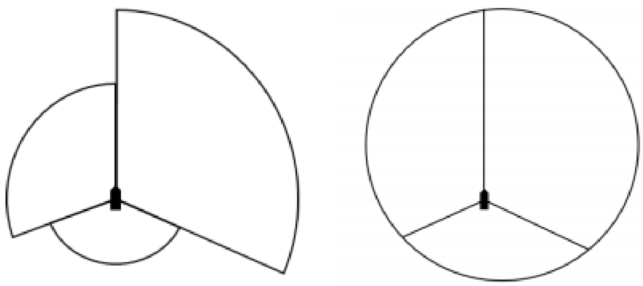


Figure 2.7: Compound ship domain (Goodwin, 1975).

The shape and size of different ship domains are decided based on the case of use and several different input variables. These factors are identified by (Szlapczynski and Szlapczynska, 2017) through a review of the most used ship domains: ship length, own ship speed, the manoeuvrability of own ship, length of the target, speed of the target.

Chapter 3

Situation: Development and exploitation of Norwegian costal waters

In this chapter, the traffic situation in Norwegian coastal waters is described. Focus is put on the shipping traffic today and development expected in the following decades, as well as on the development plans for offshore wind and exposed aquaculture. Additional man-made obstacles at sea, such as weather buoys, tidal devices, and other renewable energy devices, are also included. Thereafter, in section 3.6, the potential for accidents along the coast of Norway is addressed. In the two last sections, rules and regulations relevant for the before-mentioned development are briefly touched upon, before the problems addressed in this study is more closely described.

3.1 Marine traffic along the coast of Norway

As the ship traffic outside Norway varies between the different coastal regions, it is not possible to give an exact description of the maritime traffic situation that applies to the various areas. However, in Figure 3.1 the inner and outer main fairway, as well as the fairway used by passing traffic, is illustrated.

In the report by DNV GL Maritime mentioned in the introduction, the expected changes in the shipping traffic for the different regions in Norway are described (Lasselle et al., 2018). The predicted development is shown in Figures 3.2. From 2013 to 2040 it is predicted a total increase of 41% in the marine traffic. In most ship-categories growth, measured in terms of sailed distance, is expected. Especially the increase in traffic from general cargo ships and product tankers is significant, but also traffic from gas carriers, as well as from reefer vessels and cruise ships, is expected to grow greatly. It is, on the other hand, predicted decreased activity from vessel categories related to the oil industry.

Figure 3.1: Fairways (Illustration: DNV (2004))

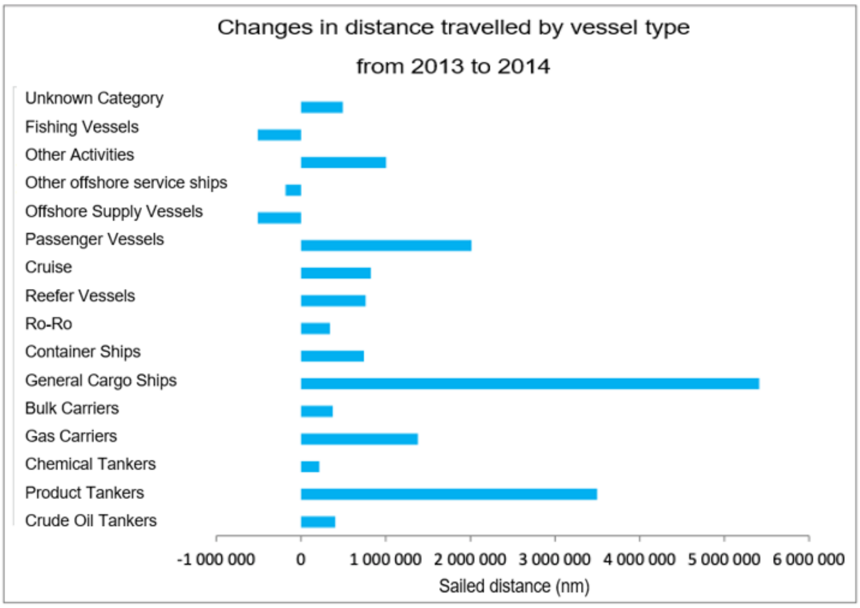


Figure 3.2: Expected change in distance travelled 2013-2040, by vessel type. (Lasselle et al., 2018)

3.2 Exposed fish farming

As mentioned in the introduction, there is a common view that the Norwegian seafood industry will play an important international role in the years towards 2050 (St, 2013). The potential for value creation based on ocean production is estimated by SINTEF to be around 550 billion NOK in 2050, which corresponds to a six-fold of the level in 2012. This estimated marine turnover is based on how global trends such as the increased demand for food in general, and for seafood in particular, will help drive a great increase in the value creation in Norwegian marine sector (Olafsen et al., 2012). The expected development is illustrated in Figure 3.3. The visions for the aquaculture industry are particularly large and assume a five-fold increase in salmon farming by 2050 (St, 2013).

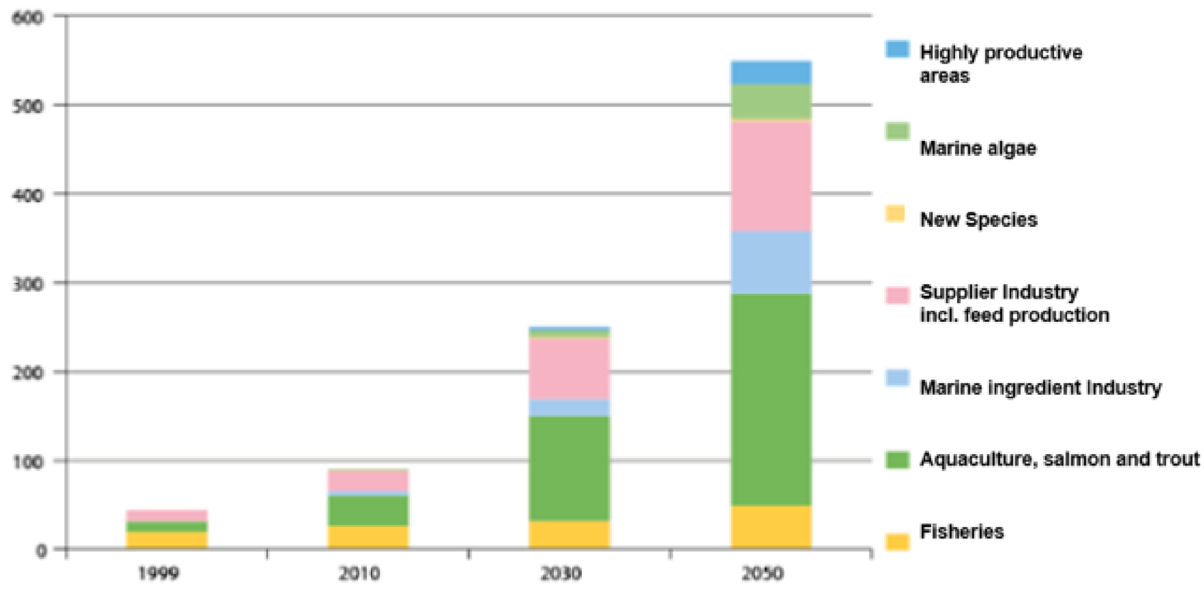


Figure 3.3: Potential For Marine Value Creation (St, 2013)

However, the industry is facing several challenges to achieve this goal. The sheltered locations in the Norwegian fjords are already overexploited, forcing the industry to find new solutions for how to increase production while at the same time having to minimize the environmental impact and maximise the fish welfare and quality. As a result, are fish farming companies looking towards more and more exposed areas for production, with fewer but larger and more innovative facilities. This development is to a large degree initiated by the Norwegian Government. Development licenses are granted to facilitate innovative solutions involving significant investments that can help solve one or more of the environmental and area challenges that the aquaculture is facing (Norwegian Directorate of Fisheries, 2018). There are today granted 68 licenses divided between 11 different companies. This amounts to a total of 50 770 tons of fish (Norwegian Directorate of Fisheries, 2019). Although several concepts are under construction, Ocean Farm 1 is at this point the only fish farm commissioned that is built for exposed locations. Areas for production are determined according to the new ”traffic light” system implemented in 2017 to ensure predictable growth and protection of the environment (Regjeringen, 2017). 17 production zones along the Norwegian coast are given a green, yellow or red colour dependent on whether production is allowed in the area or not. The areas are illustrated in Figure 3.4. Increased production will be offered in the ”green” areas, as well as in areas that satisfy the conditions for exemption (Regjeringen, 2017).

There are several well-known factors that determines which locations are suitable for fish farming with respect to external factors. This includes the ship traffic in the area, interaction with the nearby ecosystems and species, sea-floor conditions, interaction with other industries such as fisheries, etc. For the fish farm owners, factors such as current, sea temperature and waves, are obviously also very important. Proximity to shore is another factor, as this determines how far both the fish and fish feed have to be transported, and how maintenance is to be performed. In some cases, the choice of location can lead to a conflict in interest between aquaculture companies and other users of the sea areas. Especially when fish farming sites are moved further out from sheltered areas, it will to a larger degree than before interfere with the ship traffic.

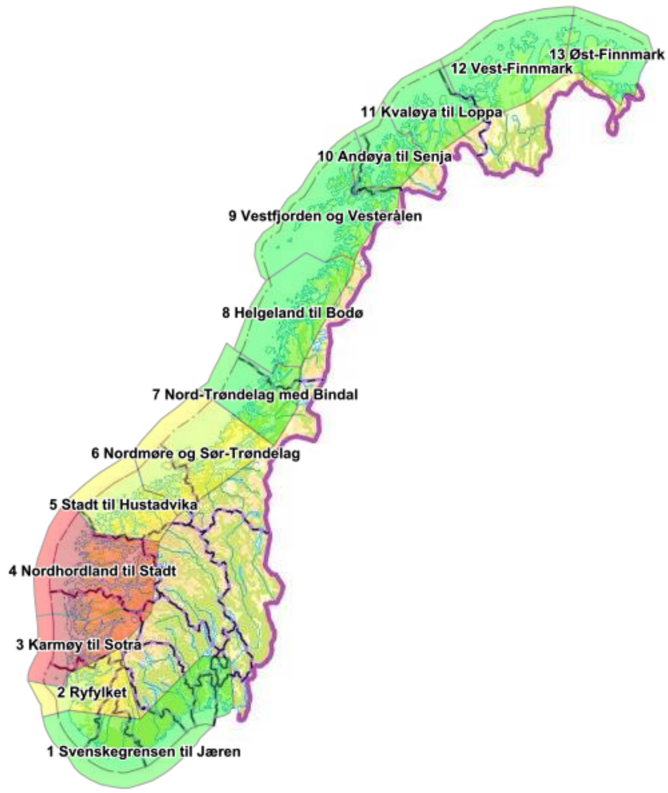


Figure 3.4: Traffic light system (Regjeringen, 2017)

3.3 Offshore wind

Recently, there has been a large increase in the construction of offshore wind power in Europe, and the cost for bottom-fixed projects has dropped. In Norway, most of the sea areas are deeper than 50-60 meters, which is the depth currently considered feasible for bottom-fixed turbines. Deeper waters and more difficult topographical bottom conditions mean that the cost level in Europe is not transferable to Norway (Jakobsen et al., 2019). When it comes to floating offshore wind, the cost is at a significantly higher level than for bottom-fixed technology. However, it is reason to expect that technology development in a more long-term perspective will drive down costs for floating offshore wind as well (Jakobsen et al., 2019), and due to high offshore competence and good wind resources, the interest in offshore wind is large also Norway.

Investigation of possible areas for wind farms at sea has been performed for several locations along the coast. In Figure 3.5 below, these areas are illustrated. The areas are divided into three categories green (A), yellow (B) and red (C), respectively representing which areas that should be first prioritised. Until now, only one large project has been granted a license. This is the Havsul project of 350 MW, outside Møre, which is developed by Havgul. In addition, 6 offshore areas of 3-10 MW have been granted a license for testing of renewable energy at sea. Only Statoil's Hywind is built. For the development of offshore wind, good wind resources and bottom conditions for mooring are important, but also considerations with respect to bird populations and shipping traffic have to be taken. The introduction of renewable energy installations can induce additional hazards to the navigation of ships, especially in already crowded waterways.

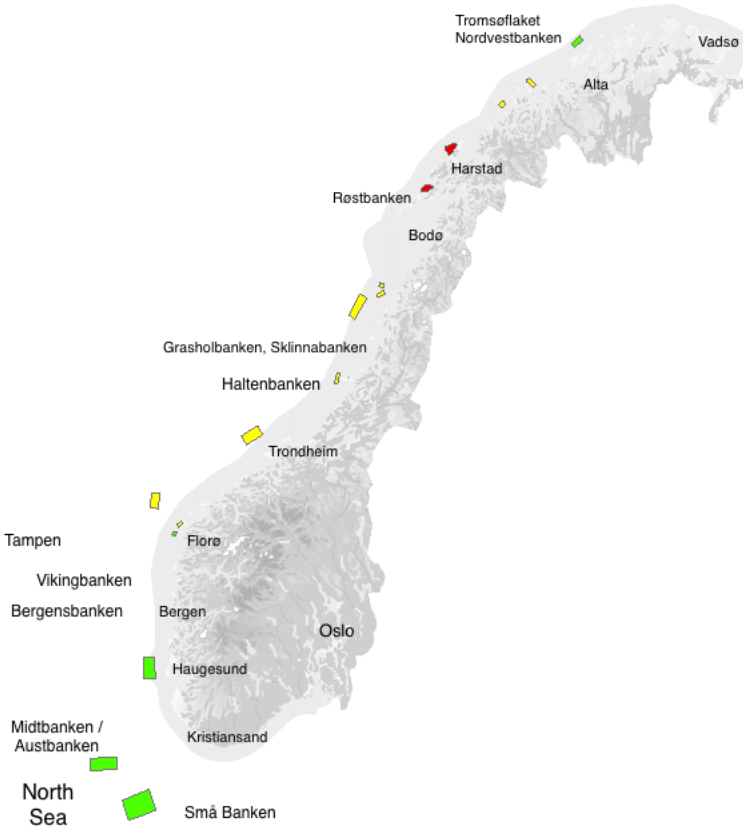


Figure 3.5: Research areas for offshore wind. Source: Norgeskart

To understand the potential impacts to navigation from the construction, operation and decommissioning of a wind farm, a number of means is typically utilised in the Navigational Risk Assessment (NRA) (Rawson and Rogers, 2015). For the Norwegian coast, an NRA is conducted taking into account traffic density, ship type, meteorological conditions, proximity to shore, and the number of wind turbines. The results from this NRA is presented in Appendix A.1. What should be noted from this NRA is that several of the areas in development category A, has "High" or "Medium" score on the total evaluation of the probability of an accident. However, the areas with a "High" score has got at the most 4,4 points on a scale from 1-12. This score indicates that development will impose small changes for existing traffic compared to the current structure of the fairway. A score below 4.0 indicates that development will barely be noticeable for existing traffic and that there is no need for the additional marking of changes in the fairway (Berg et al., 2019). None of the suggested areas are in other words found to be in direct conflict with the existing traffic routes. However, if wind parks are built in Stadthavet and Sørlige Nordsjø, the traffic will have to cross the TSS, especially in the construction phase

Berg et al. (2019). This increase in traffic activity and crossings of the TSSS can again change the risk level in the area.

3.4 Met-ocean buoys and renewable energy installations

Also, solar islands, and wave- and tidal devices can be expected to be seen at sea in the future. The technology is still immature, and since it is not planned any development of this kind of installations in Norway in the near future, it is chosen not to elaborate any further on these objects. Meteorological masts and weather buoys are, on the other hand, objects we from time to time can find along the Norwegian coast. The purpose of these can either be to give ships direct updates on the weather conditions, or they can be put out for site-surveys prior to installation of any of the before-mentioned objects. Along the coast especially wave and current measurement buoys are typical The buoys can also be data collectors for subsea survey-installations. In Figure 3.6 below, two typical met-ocean buoys are illustrated. These buoys are normally painted yellow to be easily visible for passing traffic, is a couple of meters high and up to about 5 meters in diameter. This means that these objects are way smaller than any wind turbine or aquaculture facility. However, the buoys are often put out for surveys in areas where development is evaluated. Therefore, different kinds of met-ocean buoys are seen as objects that are relevant to investigate as well, despite the large size difference compared to the other man-made structures presented.

Figure 3.6: Met-ocean buoys

3.5 Marking and safety zones

With respect to new installations at sea, it is regulated how different structures should be marked in order to make the objects visible for ships and avoid accidents.

Both Offshore oil and gas installations, as well as aquaculture facilities, meteorological masts tidal/wave generator fields and offshore wind farms are should according to IALA - Marking of man-made offshore structures be equipped with fog signal, radar beacon and AIS AtoN. In addition, either white or yellow lights are recommended depending on the type of structure. It is also recommended for the base structures of offshore wind turbines to be painted yellow all around from the level of HAT (Highest Astronomical Tide) up to 15 metres IALA (2013).

With respect to safety zones, it is for petroleum installations today a safety zone of 500 meters. Safety zones are also important for conflict between ship traffic and wind parks, in addition to factors such as location, layout, geographical conditions, regulations Berg et al. (2019). In the Netherlands, vessels are prohibited to enter the wind park area, while in Great Britain restrictions based on risk evaluations are given. I Germany it is differentiated between vessel sizes Berg et al. (2019). Apart from the collision between vessels and substructures, higher ships, typically above 20-25 m, are also prone to be hit by the turbine blades. For the single wind turbine, Hywind demo, outside Karmøy, a caution area is set to 50 meters. Tracking of traffic pre- and post-installation have shown that the area has got a lot of traffic and that the ships passing keeps a distance greater than 50 meters.

3.6 Accident and risk potential

The expected changes in traffic risk that follow the predicted increase in ship traffic in Norway is also estimated in the previously mentioned report by Lasselle et al. (2018). The number of annual ship accidents is predicted to increase for all regions except Jan Mayen. Western Norway is predicted to be the region with the largest number of ship accidents, both with and without the implementation of new risk-reducing measures, but also for Mid-Norway and Nordland the numbers are high. With regard to vessel type, passenger ships are the ones most exposed to accidents, followed by fishing vessels and general cargo ships. Although these vessel categories propose a lower environmental risk than for example gas- and oil tankers, more human lives are at risk if accidents occur (Lasselle et al., 2018).

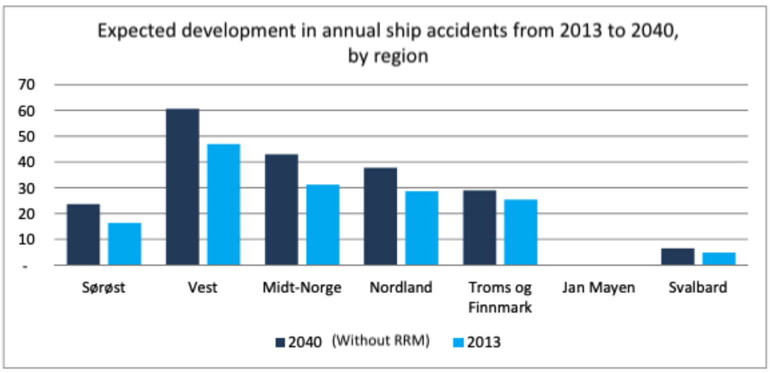


Figure 3.7: Expected no. of ship accidents by region, 2013-2040 (Lasselle et al., 2018)

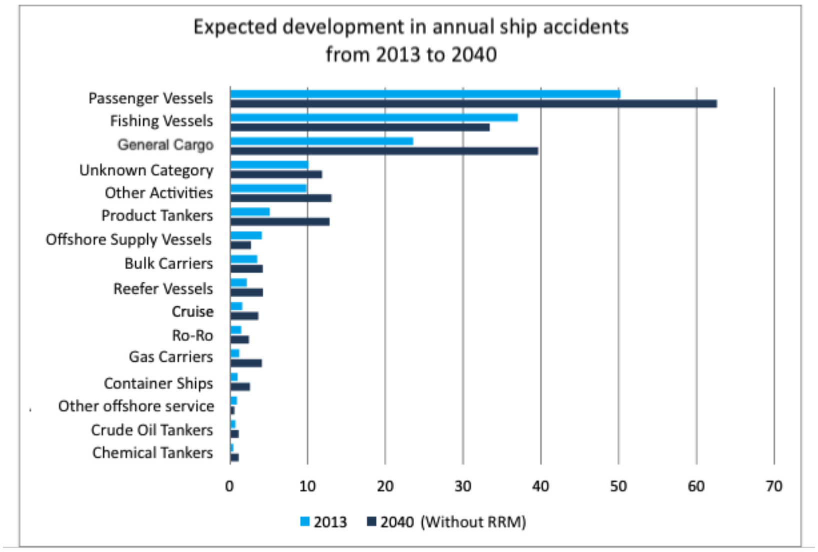


Figure 3.8: Expected no. of ship accidents by ship type, 2013-2040 (Lasselle et al., 2018)

Further, the introduction of renewable energy installations can induce additional hazards to the navigation of ships, especially in already crowded waterways (Rawson and Rogers, 2015). The same applies to both fish farms and other floating objects at sea. Between 2017 and 2018, 114 cases where vessels have lost propulsion somewhere along the Norwegian coast are registered (Aftenposten, 2019). If this happens close to shore or close to any man-made structure located at sea, the consequences can be large.

In 2012, an impact assessment was performed by The Norwegian Water Resources and Energy Directorate (Jakobsen et al., 2019). If we take a closer look at some of these study areas listed in Appendix A.1, we can see that there are recorded vessel traffic passing through all of the areas. Directions with respect to safety distances to fairways, routes, TSS and marking of offshore facilities are given IALA (2017a), however, this does not exclude all interaction between vessel traffic and the installations. As can be seen in Figures 3.9 to 3.12, some of the study areas for offshore wind in Norway are located relatively close to traffic lanes and will therefore to some extent interfere with the vessel traffic. A collision with a wind turbine can result in harm both to the vessel, the crew or passengers, and to the environment if a collision results in pollution. For aquaculture, the environmental risk related to escape of fish is particularly critical, but as the installations now are growing in size, the harm an impact can cause to a ship and its passenger is also very large. Therefore also aquaculture facilities will be deployed of safety distance from fairways, routes, and TSS.

Although these considerations are taken, there are still uncertainties related to the exact development of the ship traffic can have a large influence on the development, especially if a traffic increasing industry is established after an NRA is performed (Berg et al., 2019).

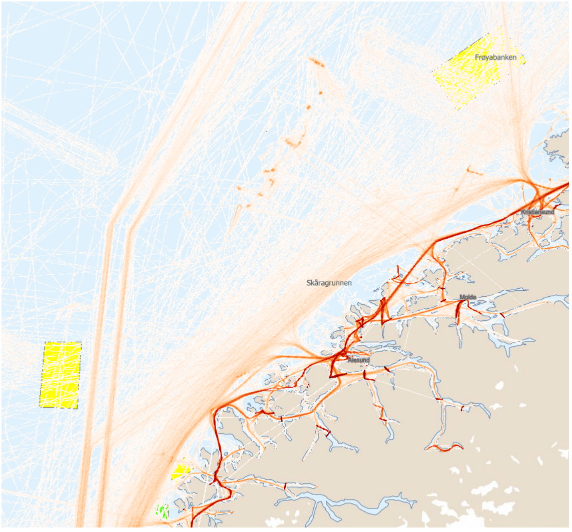


Figure 3.9: Research areas, Frøyagrunnene, Oldervegger, Stadthavet and Frøyabanken

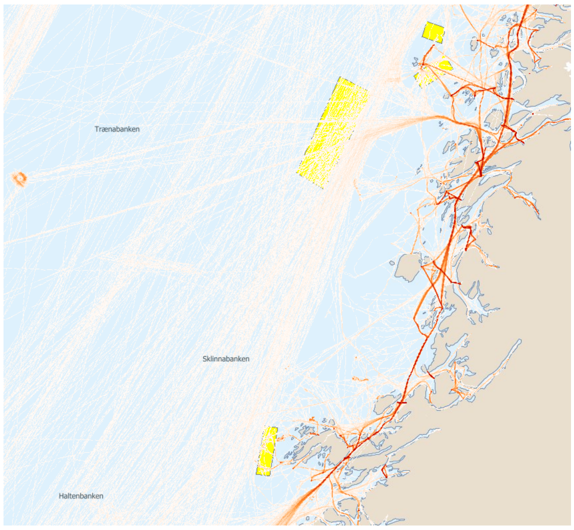


Figure 3.10: Research areas, Nordland

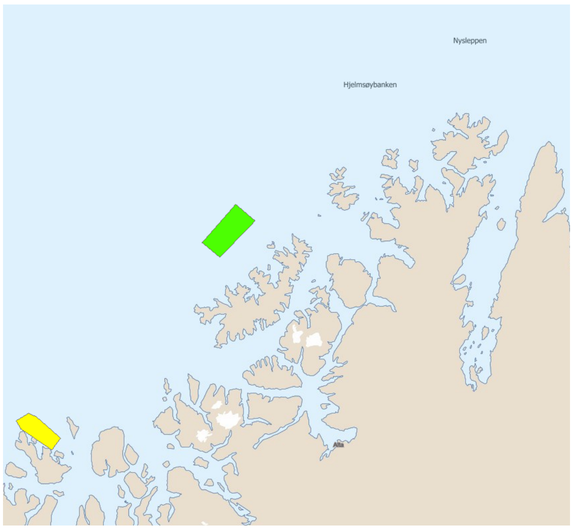


Figure 3.11: Research area, Troms/Finnmark

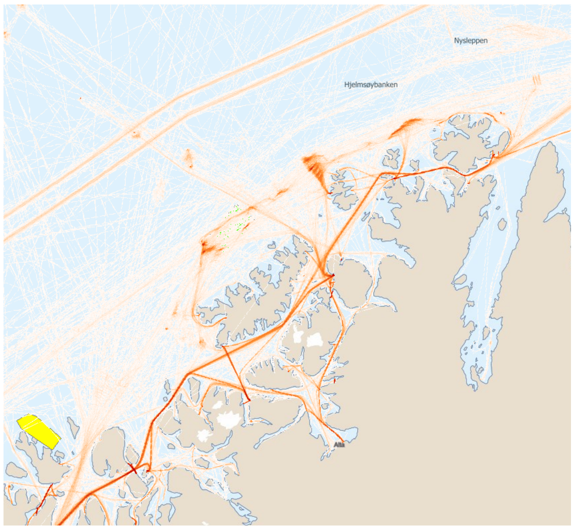


Figure 3.12: Traffic density, Troms/Finnmark).

3.7 Investigation of post-installation effects

Altogether it is clear that the coastal zone around Norway is under great pressure. Several different industries and stakeholders are interested in exploiting the coastal areas, and this might happen at the cost of the maritime traffic safety. In the worst case, it can bring harm to the environment and human lives. However, this development is highly important for us to be able to meet the increasing demand for food and renewable energy. Therefore, studies of traffic changes imposed by man-made structures are essential to increase the understanding of post-installation navigational risk and to make better-informed decisions.

Although NRAs are conducted prior to the development of offshore wind farms, there is according to Rawson and Rogers (2015) little understanding as to whether the modeling accurately reflects the post-constructed navigation risks. They state that the work associated with the establishment of new wind farms are generally predictive and that there are few retrospective case studies which contrast the initial and resulting traffic profile. They further state that it has rarely been conducted retrospective analysis comparing predictions against reality to enable better predictions for future projects. Minor discrepancies between modeled and actual traffic routes can, according to Rawson and Rogers (2015), have a significant impact on the results of a risk analysis. To make sure risk evaluations are made based on reliable predictions, and avoid that stakeholders are making decisions based on too little information, they emphasise the importance of case studies not only for the initial traffic situation but also for the resulting situation. It is perceived that this problem is highly relevant to other offshore structures as well. This is, combined with the high interest in the exploitation of Norwegian sea areas, the reason why this study is conducted. The methodology used in the study is described in the next chapter.

Chapter 4

Methodology

The methodology chapter is divided into two parts. In Part I, Section 4.1, the methodological approach is presented. In Part II, Section 4.2, some general information about AIS data, as well as the data foundation for this work, can be found. As mentioned in the introduction is this study focused on the coast of Norway.

4.1 Part I - Methodological approach

4.1.1 Objects/areas for case study

After the situational study performed to get an overview of the current situation and expected development along the Norwegian coast, the next step is to determine objects/areas feasible for investigation. Due to the fact that most of the development related to exposed aquaculture and offshore wind in Norway still is at an early stage, and few objects yet are installed, alternative objects had to be chosen to be able to perform this study. The choice of objects was for this study also highly restricted by the AIS dataset available. For the results to hopefully be applicable also for objects such as exposed fish farms and wind-turbines interacting with the traffic, some requirements are set for the areas that are chosen for investigation:

1. Located at the coast of Norway
2. Equipped with Radar reflector/beacon or AIS AtoN
3. Known date/period for installation
4. Availible AIS data for the area before an after object is put in place

This set of criteria includes not only larger structures but also objects such as meteorological buoys and masts, as feasible objects. The reason why the object should be equipped with AIS

AtoN is that this is recommended for most structures relevant for such a study, like as aquaculture facilities, renewable energy installations, and met-ocean buoys. A date for installation is not always easy to find, and to detect objects that are put into place sometime in between the start and end time of the AIS-data at hand can be challenging. In this study, the search is done manually by going through maps and public data online. The database at hand contains a dataset covering Norway in the time between 12.07.2010-31.12.15. More detailed info about the database, the data handling and AIS in general can be found in Part II of this chapter.

By going through previous Notices to Mariners (Kartverket) from 2011 to mid-2015, most objects put into place or removed during this time period was evaluated, and a selection of feasible objects found. In Table 4.1 on the next page, this selection is presented together with some additional information about the position, installation date, and object type etc. Map tools such as Marinetraffic, Barentswatch or similar are useful to visualise positions. Additionally, if an object is still present today, it can give information about whether it is equipped with an AIS-transponder or not based on AIS position updates. It should be noted that going through Notices to Mariners is time-consuming. Each year 24 notices are published. Therefore, it is recommended to find a more effective way to determine objects for the analysis would. Alternatively, ensure that more information about commissioning dates, and/or that a larger AIS-dataset is available. Figure 4.1 illustrates the positions of the objects.

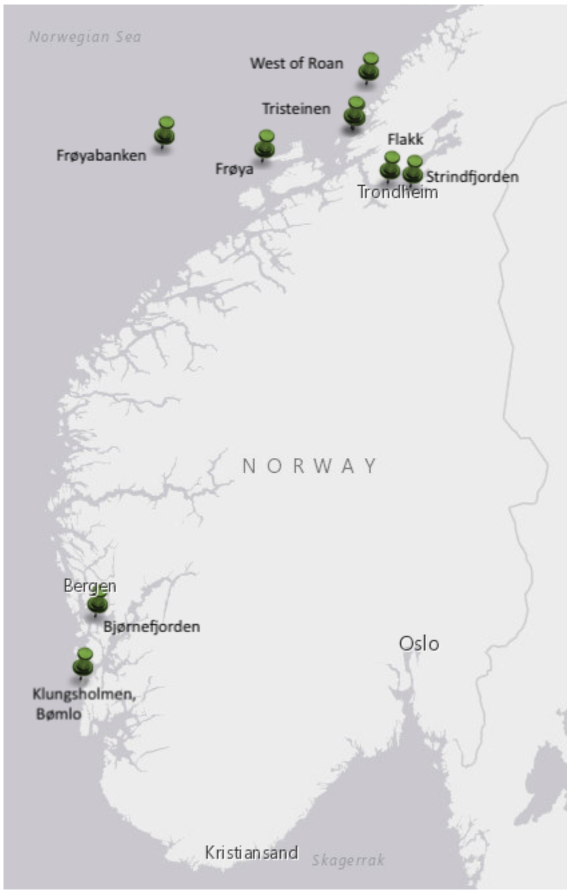


Figure 4.1: Areas for investigation marked

4.1.2 Case study

AIS data for a given time period is analysed to represent the pre- and post construction scenarios for six different cases. The time period for each case is chosen dependent on commissioning date, and, if only present for a period of time, decommissioning date. The time intervals are as far as possible chosen for the same period during different years to avoid seasonal changes in traffic. However, in some cases, the dataset did not allow this. Further, it was in some cases found necessary to look at the time period directly before installation, and after decommissioning, in order to capture immediate changes and in an attempt to avoid looking at traffic changes caused by external reasons. To limit the area around the object, a maximum distance of 4nm is set. In some cases, the area is smaller if already naturally restricted by land, shoals, etc. This distance is chosen based on the findings in the allision risk study by Hassel et al. (2017), where the results from the study shows that outside a 4 nm distance the traffic remains unchanged.

4.1.3 Preliminary Analysis

For each of the cases in the case study, a preliminary analysis is performed to get an overview of the area with respect to factors such as vessel size, number of messages, number of unique vessels and average speed. All of this is not presented in the case study, as it is done mainly to get an overview of each area.

4.1.4 Visualisation of traffic distribution and density

By use of scatter- and heat plots, the situations are visualised to and get an impression of vessel distribution and traffic density. Plotting the AIS-records this way can also give some indications of what changes to expect. By distinguishing between vessel types in the scatter plots, they also give an indication of the vessels types in the area. For these plots, data for a relatively large geographical area is presented. This is done to include some of the topography and the traffic lanes in the vicinity of the object, and thereby help understand the situation in the area better. In the case study, only the heat maps are presented. The distribution of the closest passing vessel types are instead presented as sector diagrams. In Appendix G.2, Figure G.2, the Python code used for the heat maps can be found.

4.1.5 Latitudinal and longitudinal traffic distribution

Latitudinal and longitudinal traffic distribution is thereafter presented in histograms for both pre- and post-installation scenarios. The areas included in the histograms are limited to smaller areas of about 4.4nm x 4.8nm for most cases. This corresponds to 0.08 degrees between max and min latitude, and 0.16 degrees between min and max longitude. Here, 0.1-degree longitude is taken as 5053,799 meters, while 0.1-degree latitude is 11 131,949 meters. The object(s) is located approximately in the centre of the areas. If found necessary, for example, if the area contains more than one object, the areas increased/reduced some. This size is set to include the traffic relatively close to the object, and avoid that traffic further away is assessed. The results from the Allision Risk study by Hassel et al. (2017) showing that accumulated traffic effects can be seen up to 4 nautical miles away from an object, is also taken into account. To discard vessels drifting/at anchorage or directly operating on the object, vessels with speed below 1kn is not included. The Kernel Density Estimation (KDE) estimates the probability density function of a random variable. For th distribution histograms, the KDE-curve is included to help visualise the ”shape” of the vessel distribution. In Appendix G.2, Figures G.4-G.3, the Python code for the distribution histograms can be found. Additionally in Figure G.5, the code for the statistical description of the vessel distribution is presented.

Table 4.1: Details, areas for investigation

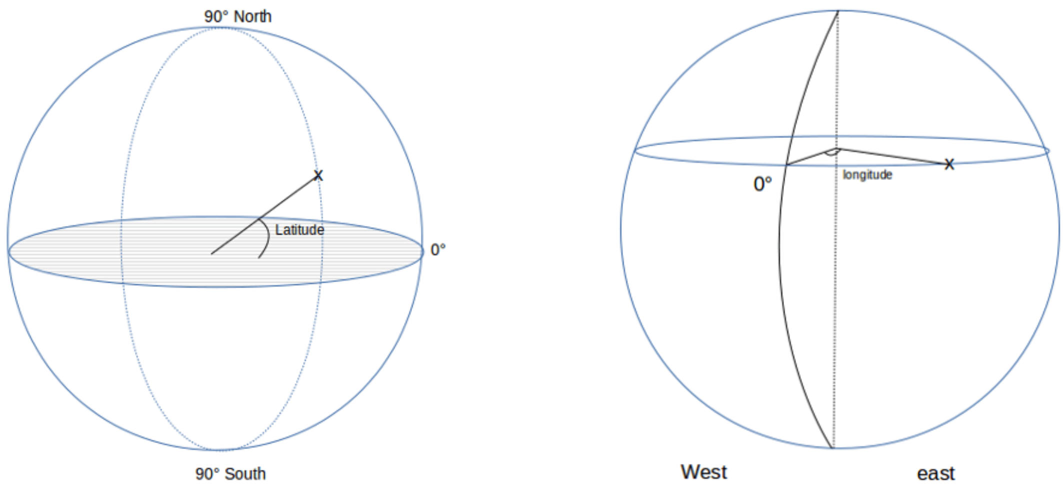
Object	Area	Date	Position	Comment
Reserach buoy	Frøya, Trøndelag	Fr: 1/11-10 To: -	N: 63.65167° E: 08.15500°	Geophysical Institute, UIB
Buoys for seaweed experiment	Frøyabanken, Norwegian Sea	Fr: 7/4-12 To: 7/12-12	N: 63.73333° E: 007.4500° N: 63.73750° E: 07.44883°	Seaweed Energy Solution AS
Current meas. buoys	Tristein, Trøndelag	Fr: 15/02-13 To: 30/4-13	N: 63.89917° E: 09.62717° N: 63.87650° E: 09.64417°	SINTEF
Aquaculture facility	Klungsholmen, Bømlo, Hordaland	Fr: 15/3-13 To: Present	N: 59.59673° E: 05.16152°	Mørenor Karmsund AS
Communication buoy for subsea measuring rig	West of Roan, Trøndelag	Fr: 10/12-14 To: 10/04-15	N: 64.19650° E: 09.88083°	SINTEF
Data collection buoys (ODAS)	Bjørnefjorden, Hordaland	Fr: Jan-15 To: Present	N: 60.09276° E: 5.368302° N: 60.10336° E: 5.367898° N: 60.11163° E: 5.369642° N: 60.11897° E:5.37003° N: 60.12289° E:5.438622°	Norwegian Public Roads Administration
Buoy	Trondheimsfjorden, Flakk, Trøndelag	N: 19.06/12 E: 03.07/12	N: 63.48333° E: 10.23333°	OCEANOR AS
Buoy	Strindfjorden, Trøndelag	Fr: 15.03/13 To: 01.04/13	N: 63.48400° E: 10.57483°	SINTEF

4.1.6 Minimum passing distance from object

In order to say something about the vessel behaviour and risk situation before and after an object is put into place, the shortest distances between an AIS-record and the position of the objects are found. When working with GPS coordinates, geodesic distances gives a more precise result than Euclidean distances since the spherical curve of the earth is taken into consideration. Therefore, the Haversine formula, which gives the great circle distance between two points, is used to calculate the distance between passing vessels and objects (Sinnott, 1984). The distance, d, is defined as:

$$d = 2Rarcsin(\sqrt{sin^2(\frac{\varphi_2 - \varphi_1}{2}) + cos(\varphi_2)sin^2(\frac{\lambda_2 - \lambda_1}{2})}), \tag{4.1}$$

where R corresponds to the Earths mean radius (6372800m), while φ_i and λ_i represents respectively the latitudinal and longitudinal position of the vessel and object, in radians. The Python code used for the calculations can be found in Appendix G.3.



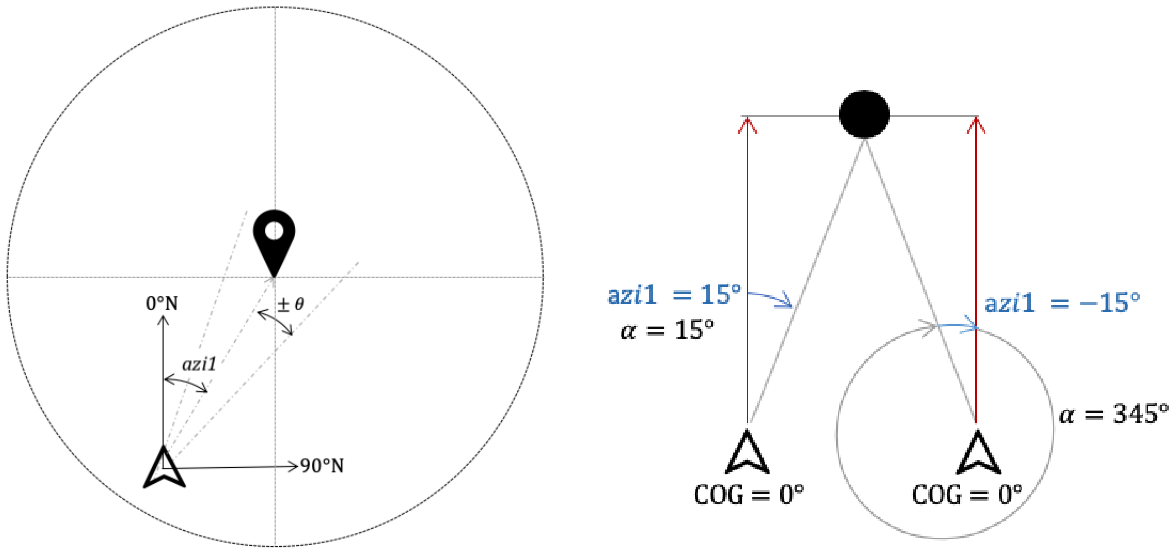
4.1.7 Bearing angle between ship and object

Course over ground, COG, is in this study defined as critical if a vessel has got a course straight towards the object, ± 15°. The Geographiclib package in Python is used to calculate $azi1$, which is the absolute clockwise angle from ship centre to centre the object from 0° north (Nordkvist, 2018). The exception is when the object is located west of the ship. Then, the angle is negative and calculated anti-clockwise. See Equation 4.2. Geographiclib can be used to solve distances on an ellipsoid and is compatible with the WGS48 reference coordinate system used by the Global Positioning System (GPS).

$$azi1 = \begin{cases} Geodesic.WGS84.Inverse(lat_1, lon_1, lat_2, lon_2) & if \quad lon_2 \geq lon_1 \\ 360 + Geodesic.WGS84.Inverse(lat_1, lon_1, lat_2, lon_2) & if \quad lon_2 < lon_1 \end{cases} \tag{4.2}$$

Here lat_1, lon_1, lat_2 and lon_2 is the latitude and longitude and of respectively the vessel and the object. The angle, α, is defined in Equation 4.3, is the clockwise angle from ship heading (COG) to centre of object (Nordkvist, 2018). Figure 4.2 illustrates the angles, and in Appendix G.1, the Python code used for the calculations can be found.

$$\begin{cases} \alpha = 360 - (COG - azi1) & if \quad azi1 \leq COG \\ \alpha = azi1 - COG & if \quad azi1 > COG \end{cases} \tag{4.3}$$



(a) (b)

Figure 4.2: Angles: azi1, α.

4.1.8 Collision candidates

Since the objects investigated are located at places with too dispersed traffic for a fairway to be defined, the number of possible collision candidates are taken as vessels within a given distance from the object with a course towards the object, instead of traffic flow heading in one direction as defined by Pedersen et al. (1995).

Critical COG is used to determine if a vessel is a collision candidate. The vessels marked red in Figure 4.3 are considered as collision candidates. These vessels are both within a 2nm radius and have got an α-angle in the interval 0°-15° or 345°-360°. The vessels marked green is not considered as collision candidates. These are either outside 2nm radius, or have an α-angle 15°-345°, or both.

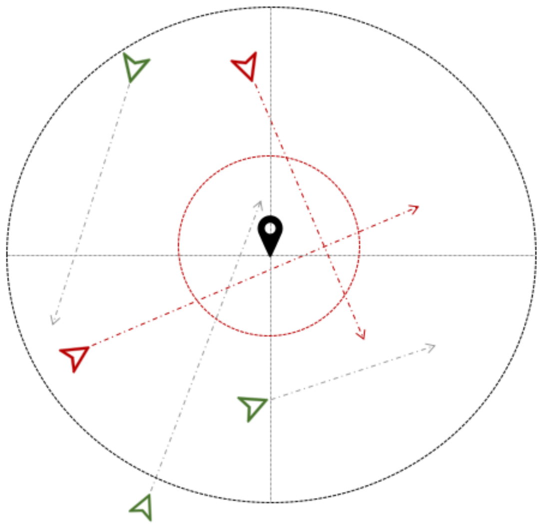
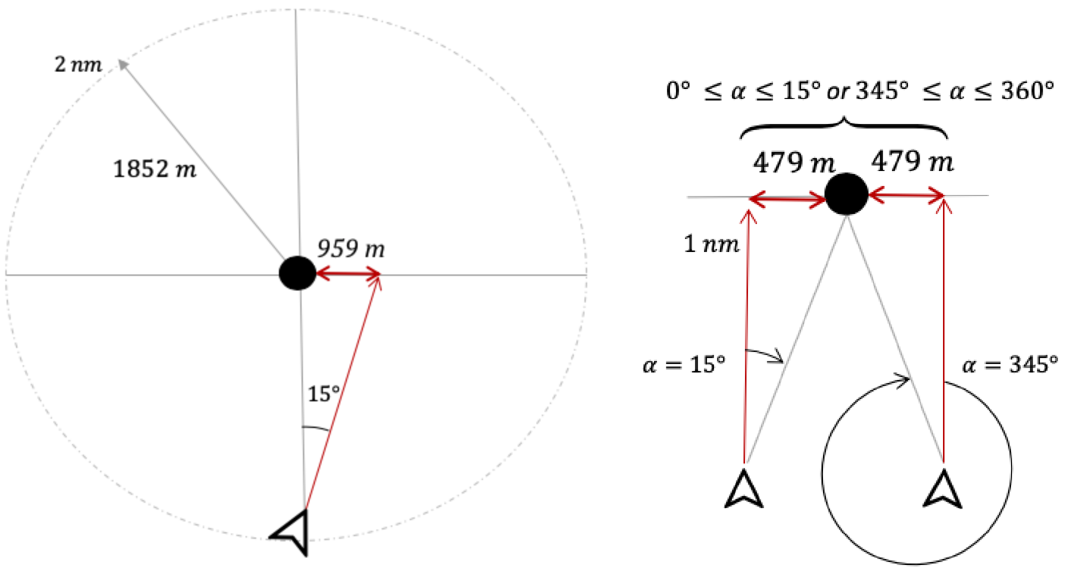


Figure 4.3: Possible collision candidates marked with red.

The reason why a maximum distance of 2nm and a maximum angle of 15° between vessel COG and object is set to define collision candidates, is that this at most results in a passing distance of 959 meters if no course alternations are made. For a distance of 1nm, the maximum passing distance with a heading 15 degrees to the side of the object, gives a passing distance of 479 m. See Figure 4.4. A distance of 2nm and with an unchanged heading of 8 degrees to the side of the object also results in a passing distance of about 500m. Especially for larger objects, a distance of 500 meters is typical for what is recommended or mandatory not to violate for passing vessels. Additionally, since it is chosen to present other statistical traffic data for vessels within a distance of 2nm, this was evaluated as an appropriate limit.



(a) (b)

Figure 4.4: Passing distance between vessel and object.

4.1.9 Evaluation of collision risk

Based on the previous steps, the findings are used to evaluate changes in risk based on the risk models presented in the literature chapter. The mechanisms of collision is used to address and evaluate the changes with respect to potential for increased collision probability both between a ship and the object, and between two ships. The findings are in this case not used to calculate the expected number of collisions per year, as this is considered less relevant for the buoys investigated. However, this could easily be achieved by taking the traffic density at the position of the objects multiplied with a causation probability from literature.

4.2 Part II - AIS data

In this part, more detailed information about AIS data in general and how the AIS data is handled in this study is presented.

4.2.1 Introduction to AIS Data

AIS was introduced by the International Maritime Organisation, IMO, in the early 2000's to improve maritime safety (IALA, 2018). It is a ship to ship and ship to shore communication system, using four worldwide channels in the VHF maritime mobile band. In addition to data exchange between nearby vessels and AIS base stations, information can be exchanged with satellites. This is known as S-AIS. The land-based stations have receivers able to collect messages within a range of 15-20 nautical miles around it for antennas placed 15 meters above sea level, and dependent of the altitude of the base station as well as the elevation and type of antenna AIS can be received within a range of 40-60 nautical miles (Traffic, 2018). AIS data from vessels outside this range will have to be collected by satellites as S-AIS.

AIS provides an effective means to transfer digital data, including both an automatic exchange of shipboard information from vessel sensors (dynamic data), as well as manually entered static and voyage related data (IALA, 2011). The dynamic data includes information which dynamically changes such as vessel speed and heading, while draught, vessel type, and estimated time of arrival are examples of static and voyage related data.

In addition to the originally-intended purpose of providing vessel position and related information to aid in collision avoidance, support VTS operations and contribute to the safety of navigation, AIS is being used for a number of other applications, including for example vessel tracking, search and rescue, port state control and vessel traffic services (IALA, 2018).

According to the IMO RESOLUTION MSC.74(69) Annex 3 (1998), the AIS should improve the safety of navigation by assisting in the efficient navigation of ships, protection of the environment, and operation of Vessel Traffic Services (VTS), by satisfying the following functional requirements:

1. in a ship-to-ship mode for collision avoidance;
2. as a means for littoral States to obtain information about a ship and its cargo;
3. and as a VTS tool, i.e. ship-to-shore (traffic management).

Guidelines for Use of AIS Data

According to the revised Chapter V of SOLAS 1974, Section 19, paragraph 2.4, AIS is mandatory for all ships in international traffic above 300 GT, for cargo ships not in international voyage above 500 GT and for all passenger ships independent of size (IMO, 2018). In addition, it was from 31st of May 2014 required by European Union for all fishing vessels above 15 meters, sailing in water under the jurisdiction of the EU-Member States, to be fitted with AIS equipment (EU, 2016).

AIS Reporting Frequency

The intervals for AIS-transmission is dependent on the information category and whether the shipborne mobile equipment is class A or B. The AIS-messages can be divided into the two categories: dynamic information, and static and voyage related information. Static and voyage related information is transmitted every 6 minutes, when data has been amended, or on request. Dynamic information is transmitted dependent on speed and course alteration. It is updated at least every 3 minutes, but can be updated as often as every 2 seconds in cases of change in course and vessel speed above 14 knots (ITU, 2014). See Appendix C.

4.2.2 Message types and content

The International Telecommunication Union (ITU, 2014) defines 27 different message types, of which some are more common than others. Message types 1-5 is the most common ones.

Of these, messages 1, 2, and 3 are position reports. Message type 1 and 2 contain scheduled/assigned position report. Since the information in these two messages is the same, Leonhardsen (2017) recommends for these two messages to be merged into one category when handling the data to simplify the work. Message type 3 contains to a large degree the same information as message type 1 and 2. Message 4 contains information related to base station report; Position, UTC, date and current slot number of base station. Message 5 contains ship static and voyage related data, more specifically scheduled static and voyage related vessel data report. In Appendix **??** details of the static, dynamic and voyage related AIS information is presented. Key information included in message type 1 and 5 is presented in respectively Tables 4.2 and 4.3 below.

Table 4.2: Message type 1 - Key information (USCG, 018a)

Information	**Description**
Unixtime	Timestamp: number of seconds elapsed since 1. January 1970
Navigational status	”Under way”, ”at anchor”, etc.
Rate of turn	Right or left (0-720 degrees per minute)
Position	Coordinates: longitude and latitude
Speed	Speed over ground (SOG) in knots
Course	Course over ground (COG)
MMSI	Maritime Mobile Service Identity (Vessel ID)

Table 4.3: Message type 5 - Key information (USCG, 018b)

Information	**Description**
Unixtime	Timestamp: number of seconds elapsed since 1. January 1970
Vessel spesification	Length and beam in meters
Draught	Maximum present static draught
Origin	Origin of voyage
Destination	Destination of voyage
ETA	Estimated time of arrival for voyage, measured in unixtime
MMSI	Vessel ID: Maritime Mobile Service Identity
IMO number	International Maritime Organization number
Ship type	Ship type: category

Taking, for instance, the AIS ”Type of Ship” parameter, the information is listed as a two-digit numeric code, where the ship type is represented by the first digit and the second digit tells whether the ship is carrying dangerous goods, harmful substances or marine pollutants. In Table 4.4 below, the significance of the first digit, as described by the United States Coast Guard encoding guide for AIS data (USCG, 2012), is presented.

Table 4.4: Ship type - 1st digit representation (USCG, 2012)

First digit	Information: ship type
1	Reserved for future use
2	Wing-in-Ground (WIG) craft
3	Other vessels
4	High-speed craft (HSC) or passenger ferries
5	Special craft
6	Passenger ships (other than HSC and passenger ferries)
7	Cargo ships (or integrated tug barge (TB) vessels)
8	Tankers (or integrated tug thank barge vessels)
9	Other types of ships

The navigational status is also represented numerically. In Table 4.5 below, the significance of number 0-8 is explained.

Table 4.5: Navigational status (USCG, 018a)

Number	Navigational status
0	Under way using engine
1	At anchor
2	Not under command
3	Restricted maneuverability
4	Constrained by draught
5	Moored
6	Aground
7	Engaged in fishing
8	Under way sailing

4.2.3 Decoding/Decryption of AIS-Data

Handling and decoding of raw AIS data have to be done before any analysis of the data can be performed. The AIS-dataset used for this study is a decoded AIS data provided by Bjørnar B.

Smestad, and is more closely described later in this chapter. If extraction and decoding of raw AIS data is of interest, both Smestad (2015) and Leonhardsen (2017) did in their master thesis' extract AIS data to an SQLite database by utilizing a Python script by Smestad (2015) and an open source aisparser provided by Lane.

4.2.4 Data Quality

There are several factors affecting the quality of AIS data. Erroneous data can be related to human errors, AIS-equipment, the decoding, the satellite coverage, etc. Smestad (2015) presents some examples of typical errors in the AIS-data and how to handle these. For IMO numbers, a check-sum verification can be used, assuming that all ships not required to have an IMO number will report a blank and not an erroneous number. To verify the MMSI numbers, he suggests matching the MMSI numbers with the ships IMO number. If the time period of the data for analysis is small enough to assume that the number of ships that have changed owner during that period can be neglected, there should only be one IMO number for each MMSI number. Thus, if an MMSI number belongs to more than one IMO number it is not valid. These two methods can however only be used for the static messages as the dynamic messages do not contain the IMO number. Positional messages with over/under respectively +90 and -90 degrees latitude or +180 deg and -180 longitude should be deleted from the database or excluded by constraints.

Erroneous ship dimensions can be detected for instance through a comparison between ship type and vessel length/breadth or by looking for improbable large dimensions. If such deviations are found, Smestad (2015) suggests that they can either be corrected manually or excluded from the database. Nordkvist (2018) emphasizes the importance of correct ship dimensions and SOG for the determination of the ship domain size. He suggests that a simple and robust way of handling missing SOG values is to replace the empty value with 5.001 since the SOG has a diminishing effect on the ship domain size. The three decimals are used to easier identify where artificial values for SOG is used.

4.2.5 AIS-Data filtering

AIS data should be filtered to reduce the amount of information for vessel types that are not relevant to the study area. Leonhardsen (2017) did in his thesis extract cargo ships from the database based on the 2-digit number in message type 5, specifying ship type. As the first digit represents ship type and the second refers to the cargo on board, vessels with a value between 70 and 79 in the ship type field was extracted, where 7 represent cargo ships. However, since the cargo-ship category includes several vessel types such as bulk carriers, cargo barges and container ships, heuristics can be used to filter out one or more of the subtypes. To achieve this, Leonhardsen (2017) adopted some heuristics from Smestad (2015). The heuristics utilize known features for certain vessel types to filter out vessel types that are not desired or relevant for the analysis. The remaining vessels in the data set will thus have certain specified features, and therefore to a large degree be of a certain type.

4.2.6 Dimension Reduction

To reduce the number of data points and save processing time, extraction of the variables that is essential for the analysis that is to be performed is beneficial. Vessel features are typically numerical such as length, breadth, SOG, COG, IMO number, and so on. As explained in the next subsection, the database used in this study is small. However, if a larger database was used, selection of the features of interest is essential in order to reduce size and thus processing time.

4.2.7 Database

The AIS database used is as mentioned provided and decoded by Bjørnar B. Smested. It is transferred to an SQLite database and contains features of relevance from MessageType1 and MessageType5e. In addition, it contains a ship registry table with only one record per ship. It holds IMO number, MMSI, ship types and dimensions found in MessageType1, as well as max and minimum draught. It should, however, be noted that these data are manual input and may, therefore, contain errors. The queries for making this table is done in the SQLite terminal. Also, an index on unixtime is made in the database, to make it easier to find the corresponding data between specific dates, as queries for data between time intervals will be given quite often. The most important

As can be seen from the Table 4.6 this AIS database is unfortunately very small with respect to time period, as it contains data only for Norwegian waters between June 2010 and December 2015. This restricts the scope of the study significantly, as it limits the number of feasible objects for investigation a lot. Structures that would be interesting to assess, such as Hywind Demo and Ocean Farm 1 are in other words excluded.

Table 4.6: AIS-database

AIS database	
Name	AISNOR.db
Size	8 GB
Area	Norway
First Date	2010-07-12T16:30:13Z
Last date	2015-12-31T23:27:23Z
Number of Records	62608147

It should also be noted that the use of AIS data alone to conduct this study limits the applicability of the results. Smaller vessels, such as recreational craft and small fishing vessels, are not mandated to carry AIS, leaving these categories outside the study. For these vessel types to be included, a radar survey or visual inspections would be necessary. Despite a relatively small area and time interval, the database does contain all types of data necessary for this kind of study. The most important features in this case are:

- Unixtime
- MMSI number
- Ship type
- Vessel name
- Longitudinal position
- Latitudinal position
- COG
- SOG

4.2.8 Data Analysis

For the purpose of extracting relevant information and analysing the AIS data, some Python scripts are made. A large part of the work with this study has been to learn Python in order to make these codes and analyse the data. A description of the codes can be found in Table 4.7 below.

Table 4.7: Description of the Python codes used for analysis of AIS data

Name	**Description**
Main_AIS.py	The analyses of interest are run from this script. The script also contains the definition of all areas and positions for all objects. This way the different codes in Analysis_AIS.py can be run for various time periods, ship types, areas, and area size.
Analysis_AIS.py	Extraction of AIS from databases and plotting of data from the database is done in this script. This includes both statistical analyses as well as data visualisation. Run from Analysis.py. It contains the codes for: - Heat maps - Distribution histograms . - Distribution statistics - Minimum distance to object - Critical heading / collision candidates
haversine.py	Calculates the distance between two points on a sphere.
bearing.py	Geodesic.WGS84 for calculation of $azi1$ and α.

Chapter 5

Case Study

In this chapter, the cases investigated are presented. AIS data for a given time period is analysed to represent the pre- and post construction scenarios for six different cases. From going through previous Notices to Mariners (Kartverket) eight possibly feasible objects were identified. Of these, the following six were chosen: Frøya, Frøyabanken, Tristeinen, West of Roan, Bjørnefjorden, and Flakk/Trondheimsfjorden. See Figure 5.1 below.

The time period for each case is chosen based on commissioning date, and, if only present for a period of time, decommissioning date. The time intervals are as far as possible chosen for the same period during different years to avoid seasonal changes in traffic. However, in some cases, the dataset did not allow this. In Table 5.1, the dates representing the different periods is presented. For the cases, results from period (1), pre-installation, and period (2), post-installation, are presented.

It is chosen to carry out the discussion of the results where they are presented. However, in Chapter 6, the overall results from the case study, as well as a discussion of the methodology, can be found.

Figure 5.1: Areas for case study marked

Table 5.1: Dates for pre- and post installation scenarios by case/area.

Location	Dates for period 1, 2 and 3 by Case/Area			Time period
	Pre Installation (1)	Before installation (2)	Post installation (3)	
Frøya	01.11.2011-01.02.2012	12.07.2010 - 12.10.2010	01.11.2010 - 01.02.2011	3 months
Frøyabanken, Buoy 1, 2	07.04.2011-07.12.2011	01.08.11-01.04.2012	07.04.2012-07.12.2012	8 months
Bjørnefjorden, Buoy 1, 4, 5	09.03.2014-09.09.14	01.09.14-01.03.15	09.03.2015-09.09.15	6 months
Tristeinen, Buoy 1, 2	15.02.12-30.04.2012	15.11.12-30.01.13	15.02.13-30.04.2013	2,5 months
West off Roan	10.12.2013-10.04.2014	01.08.2014-01.12.14	10.12.2014-10.04.2015	4 months
Flakk, Trondheimsfjorden	19.06.2011-03.07.2011	15.05.12-31.05.2012	19.06.2012-03.07.2012	15 days

In the first part of the case study, the traffic density and distribution is visualised through scatter plots and heat maps. This is done to increase the understanding of the traffic in the area in combination with the topography around the investigated objects.

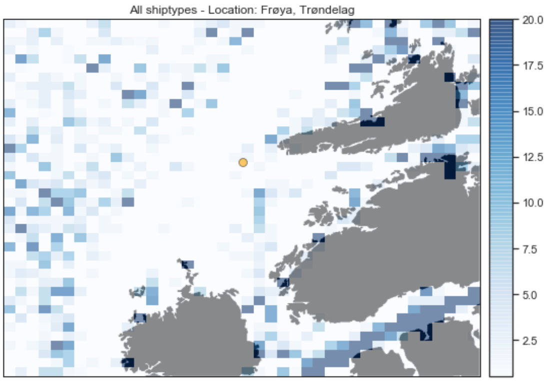
Thereafter, histograms representing the distribution of the latitudinal and longitudinal ship traffic is presented for each case. As mentioned in the methodology, the initial size of the areas for these plots was set to cover about 2 nautical miles from the object in each direction. In some cases, this size is adjusted, either due to more than one object, or due to the topography in the area. The object(s) are marked with red dots on the histograms. In cases where several objects are present, the histograms do in some cases only show one dot although there is more than one object. If so, this is because the objects have approximately the same latitudinal or longitudinal coordinate. Due to compliant mooring for several of the buoys, the buoys have been able to move some. This means that the positions used for the buoys can have differed some compared to the position taken from previous Notices to Mariners. In Sections 5.1-5.6 the pre- and post installation scenarios for each area is assessed one by one, while in Section 5.7 statistical results for all the areas are presented. In Section 5.8 the implications with respect to collision risk is commented.

5.1 Research buoy, Frøya Trøndelag

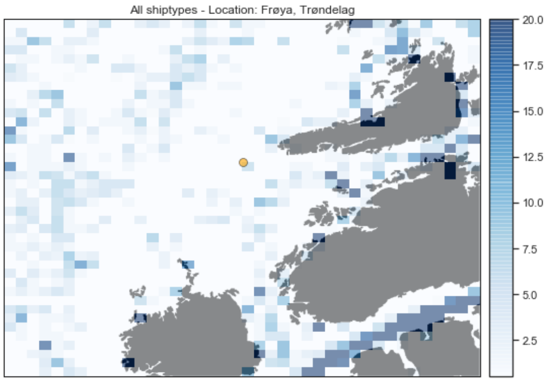
Between 01.11.2010 and 01.02.2011, a yellow, disc-shaped research buoy was located outside Frøya 3 nautical miles west of Sletringen. This period represents the post installation scenario. The buoy was set out by the Geophysical Institute in Bergen, and had a 5 meters tall signal mast with a flashing lantern. Fishing was to be avoided within a 600 meters distance from the buoy due to possible harm to subsea instruments or the mooring system. The pre-installation scenario is here the same period as when the buoy was present installed, only one year later instead of earlier as it is for the other cases: 01.11.2011-01.02.12.For simplicity, the period when the buoys were present will still be referred to as ”post-installation” and the period for comparison as ”pre-installation. The reason for this is that the dataset does not go back far enough to include the same period one year before installation. Also, in comparison with a period directly before installation may lead to seasonal variations. The area included for the distribution histograms is about 5.45 x 6.01 nm, with the buoy in the centre.

The traffic in the area is mainly dominated by Other vessels and Cargo ships. In Figure 5.2 the heat maps pre- and post installation of the research buoy is presented, and in Figure 5.3. As one can see from the distribution histograms in Figure 5.3, the results differ some from what would normally be expected. Especially with respect to the latitudinal distribution it seems to have become more uniform after the buoy was installed. However, the area exact at the buoy location is avoided both in the post and pre scenarios. It seems like the vessel density on each side of the object did increase. For latitudinal positions, this is around 66.620 and 63.700 degrees, and for longitudinal positions around 08.06 and 08.20/08.25 degrees. However, from Table 5.2, it can be seen that post-installation there is only one vessel within 2nm of the buoy. Considering the distance and speed of this vessels,it is likely that this vessel had something to do with the buoy.

Other than that, one can see from the vessel type diagrams, in Figure 5.7 and 5.8, that the percentage of cargo vessels decreased after the buoy was put in place. The main part of the 20 closest records went from Cargo vessels 80% to 55%. Note that not all of these are from within 2nm. This can either be a random change or indicate that the cargo vessels have made some route alterations. The increased percentage in other vessel types pre-installation might be due to the before-mentioned vessel within 2nm.



(a) Heat map pre-installation.

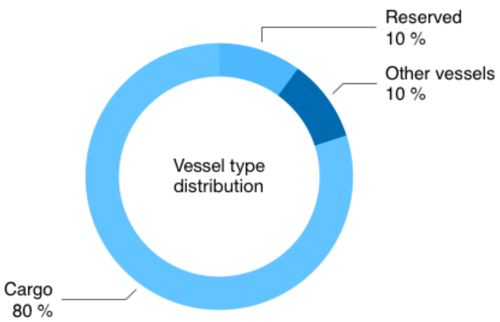


(b) Heat map post-installation.

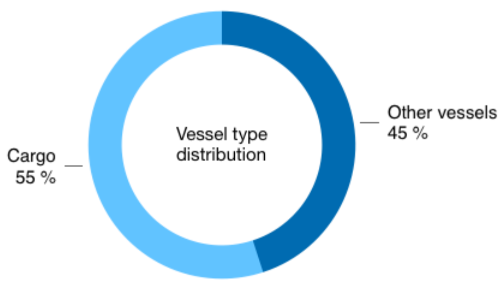
Figure 5.2: Frøya. Traffic density illustrated by heat maps.

Table 5.2: Frøya. Data for traffic within 2 nm distance of object.

Frøya, Buoy	**Pre**	**Post**
Number of AIS records within 2 nm.	12	6
Number of vessels within 2 nm.	5	1
Min. passing distance [nm]	0,6170	0,2896
Speed at min. passing distance [kn]	9,20	2,90
Mean distance for 20 closest messages. [kn]	0,9626	0,5983
Mean speed for 20 closest messages. [kn]	9,02	2,21
Records representing collision candidates	2	0

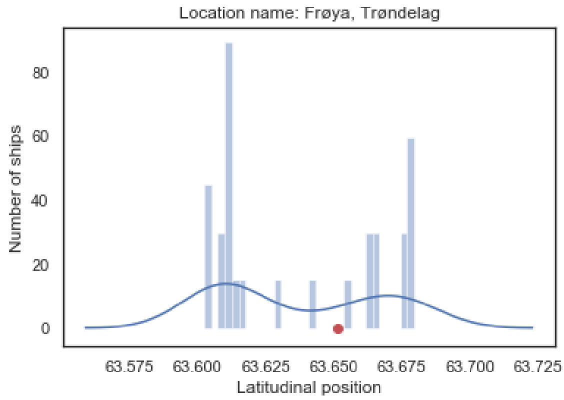


(a) Pre installation.

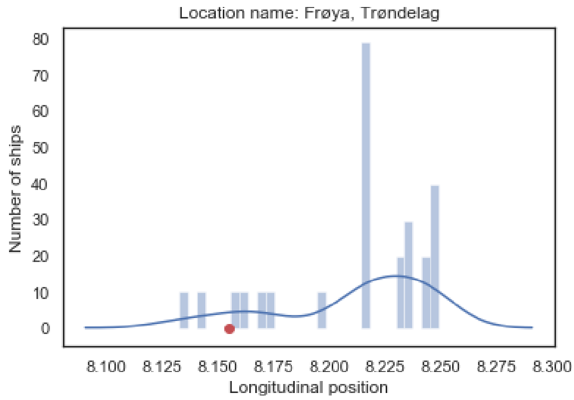


(b) Post-installation.

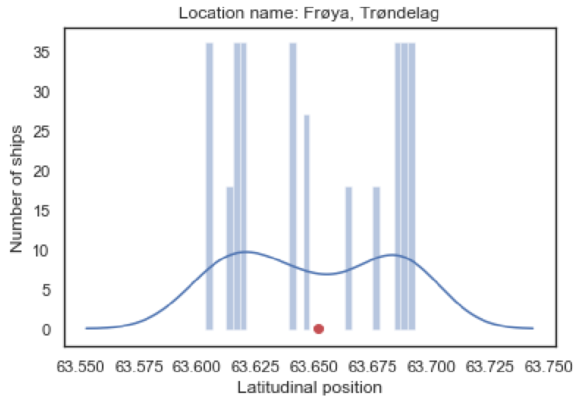
Figure 5.4: Frøya. Vessel type distribution of 20 closest passing vessels.



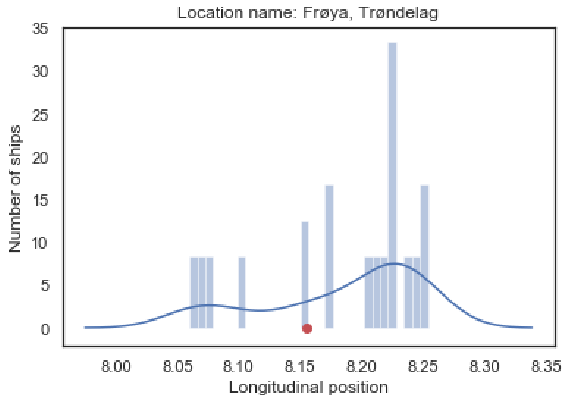
(a) Latitudinal distribution pre-installation.



(b) Longitudinal distribution pre-installation.



(c) Latitudinal distribution post-installation.



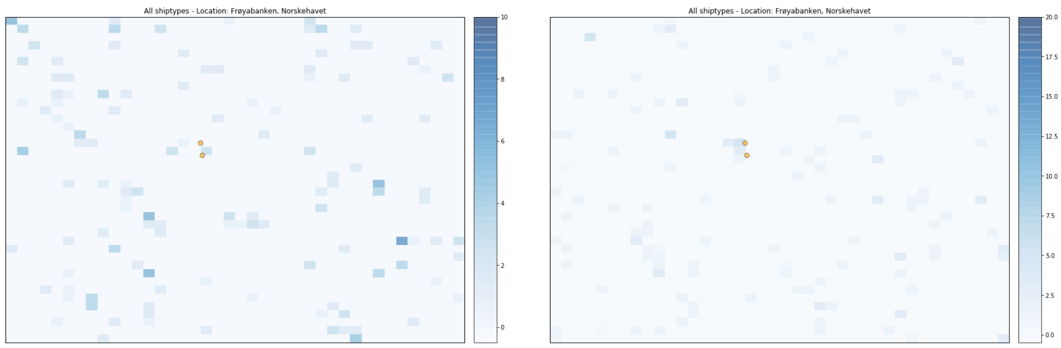
(d) Longitudinal distribution post-installation.

Figure 5.3: Traffic distribution pre- and post-installation of a research buoy at Frøya.

5.2 Seaweed experiment buoys, Frøyabanken

In the context of a ”seaweed experiment” by Seaweed Energy Solution AS, two yellow buoys were set out at Frøyabanken for about 8 months, between 07.04.12-07.12.12. The buoys were equipped with radar-reflector and lights. The pre-scenario for this location is the same time period one year in advance: 07.04.11-07.12.11. The area for the traffic distribution histograms is taken as 4.4 nm x 5.07 nm, in respectively longitudinal and latitudinal direction, with the buoys in the centre.

From the heat maps in Figure 5.5 one can clearly see that there is some activity in the area, and that also very close to the location of the buoys some AIS-messages is received both before they were installed and after installation. Here, as for the buoys at outside Frøya, the distribution is not changing as expected. With respect to the latitudinal and longitudinal distribution, Figure 5.6 seems to show an increase in the number of AIS-messages received around the position of the buoys. Based on the record and vessel count presented in Table 5.3 the number of messages within 2nm is however relatively constant. Also, it can be seen that the closest message was recorded at a shorter distance for from buoy 1 at in post-scenario, while for buoy 2 the minimum distance increased. Further, the average distance for the 20 messages closest to the location did decrease both for buoy 1 and 2. Compared to the buoy outside Frøya, a higher number of vessels within 2nm was recorded. The reason for this can be that the buoys, in this case, were located at more open waters with normally higher traffic. For the post scenario are the number of records putting a vessel the category ”collision candidate” as high as respectively 15 and 17 out of 53 for buoy 1 and 2, compared to 0 candidates pre installation. Further, one can again suspect a tendency of cargo vessels making route alternations based on the decreased share of cargo vessels post installation, while the share of other vessels did increase also here.



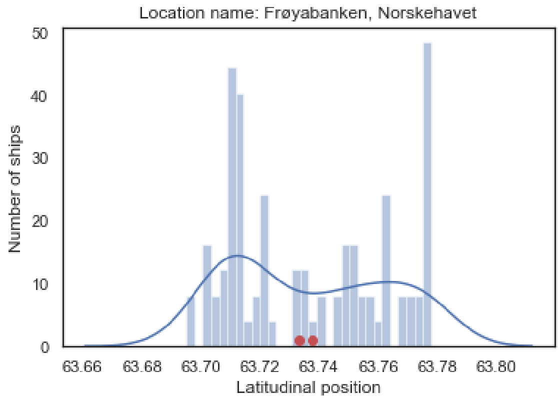
(a) Heat map pre-installation.

(b) Heat map post-installation

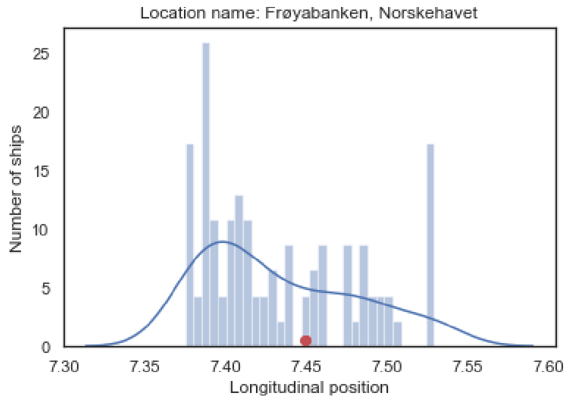
Figure 5.5: Frøyabanken. Traffic density illustrated by heat maps.

Table 5.3: Frøyabanken. Data for traffic within 2 nm distance of object.

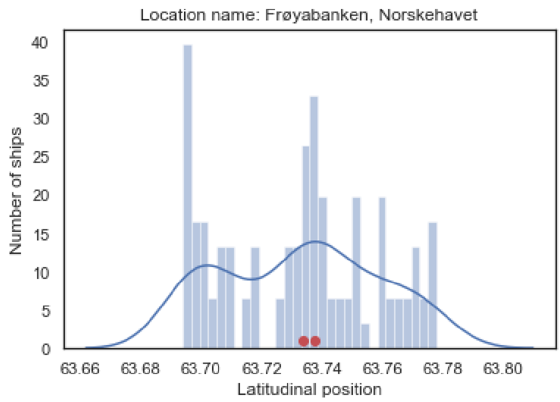
Frøyabanken, Buoy	**1**		**2**	
Pre/Post Installation	Pre	Post	Pre	Post
Number of AIS records within 2 nm.	53	47	53	47
Number of vessels within 2 nm.	17	15	18	16
Min. passing distance [nm]	0,1837	0,1546	0,0480	0,1655
Mean distance for 20 closest messages. [kn]	0,9912	0,5377	0,9838	0,4990
Mean speed for 20 closest messages. [kn]	10,70	8,37	10,97	8,76
Records representing collision candidates	0	15	0	17



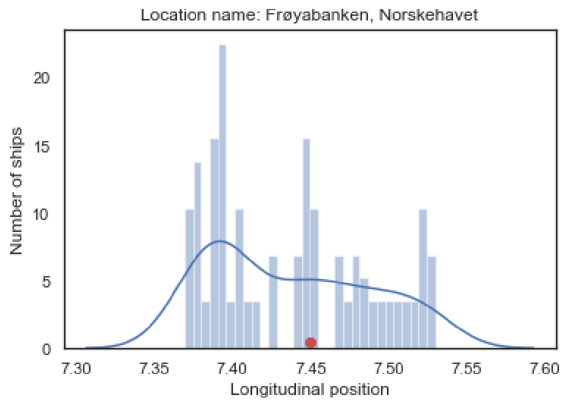
(a) Latitudinal distr. pre-installation.



(b) Longitudinal distr. pre-installation.

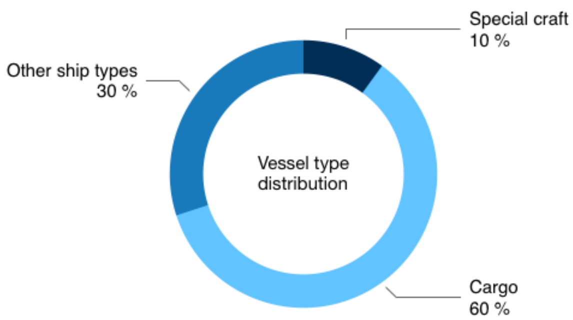


(c) Latitudinal distr. post-installation.

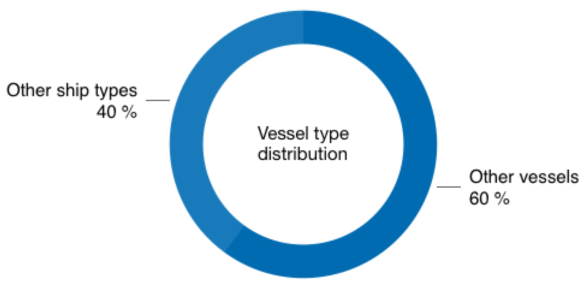


(d) Longitudinal distr. post-installation.

Figure 5.6: Traffic distribution pre- and post-installation of two experiment-buoys at Frøyabanken.

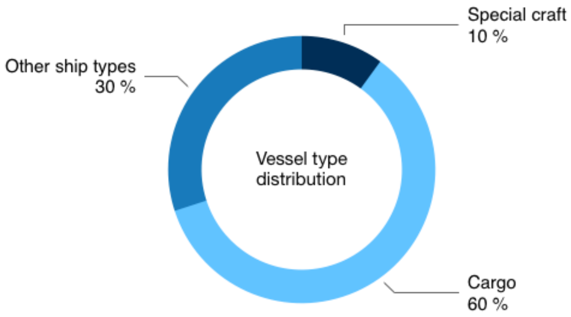


(a) Pre installation, Buoy 1.

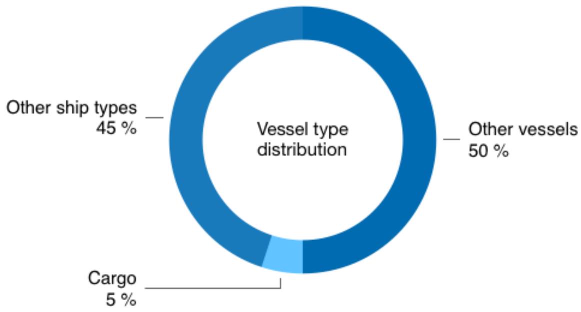


(b) Post-installation, Buoy 1.

Figure 5.7: Frøyabanken Buoy 1. Vessel type distribution of 20 closest passing vessels.



(a) Pre installation, Buoy 2.



(b) Post-installation, Buoy 2.

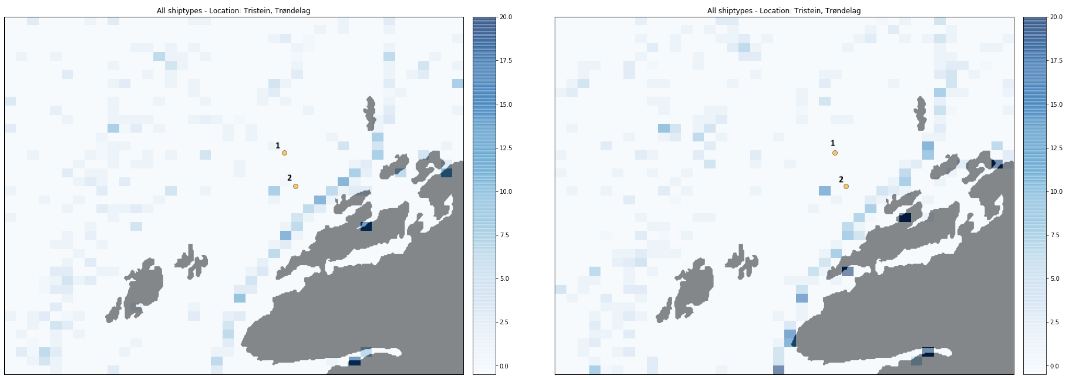
Figure 5.8: Frøyabanken, Buoy 2. Vessel type distribution of 20 closest passing vessels.

5.3 Current measuring buoys, Tristeinen

For 2.5 months, between 15.02.13 and 30.04.13, SINTEF conducted current measurements at five positions in the area around Tristeinen, Gjæsingen, and Valsøya in Trøndelag. For two of these positions, the installations had surface buoys with a pole and light. The two buoys are marked with orange dots on the heat maps in Figure 5.9, and have got a distance of about 2500 meters in between them. The buoys were described as compliantly moored, and thus some movement in the surface was to be expected. Vessels were told to keep at least 100 meters distance when passing the buoys. The post-installation scenario for this case is the same period one year prior to the installation. The area for the traffic distribution histograms is limited to 4.36 nm x 5.81 nm, in respectively longitudinal and latitudinal direction, with the buoys in the centre.

When looking at the post-installation scenario for the latitudinal distribution, in Figure 5.10, it seems like more of the traffic have shifted to the south side of the buoys. The highest peak indicates that more vessels than before chooses to pass at exactly this latitude. Also, the number of messages between the two buoys is reduced with respect to latitudinal distribution. For the longitudinal distribution, one can clearly see that the vessels keep clear of the buoys post installation. In addition, one can see that there is an increased number of messages both in between the buoys as well as on both sides, indicating that the traffic density in the area around increased some after the buoys were put in place. What seems like a route alternation in the histograms is further substantiated by the increase in both minimum registered distance and mean distance for the 20 closest messages, as can be seen in Table 5.4. From the table, one can also see that there is a significant difference between the number of messages registered within 2 nm miles of buoy 1 and 2. The reason for this is most likely that buoy 2 is located closer to the fairway. The total number of unique vessels within the 2 nm radius is also significantly higher, with 33 vessels versus 5 vessels pre-installation. The number of messages registered pre and post installation is relatively constant, with a slight decrease post-installation for both buoys.

For the 20 closest records pre-installation, the vessel types represented were other ship types, cargo ships, tankers, and other vessels. Post-installation no tankers were represented in these 20 records. In contrast to the previous cases, did the share of cargo vessel this time increase post installation for buoy 1, while for buoy 2 it decreased as for the previous cases. The share of other vessels did, as seen before, increase for buoy 1 and decrease for buoy 2. When looking at the share of tankers the number also here decreases for one buoy and increases for the other. The changes for the two buoys are in other words quite contradictory. This indicates that most of the tankers passes on the fairway between buoy 2 and land. This also applies for the number of records representing collision candidates where an increase can be seen for buoy 1, while for buoy 2 the number decreases post installation.

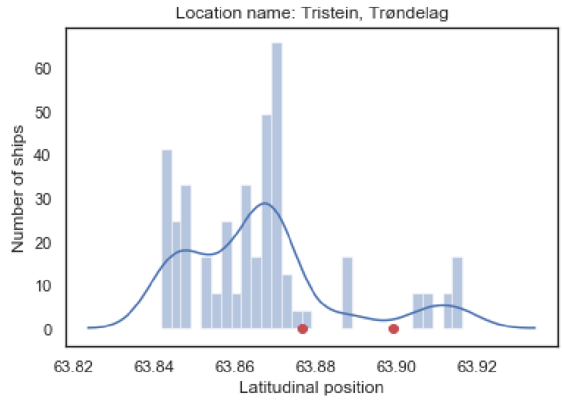


(a) Heat map pre-installation. (b) Heat map post-installation.

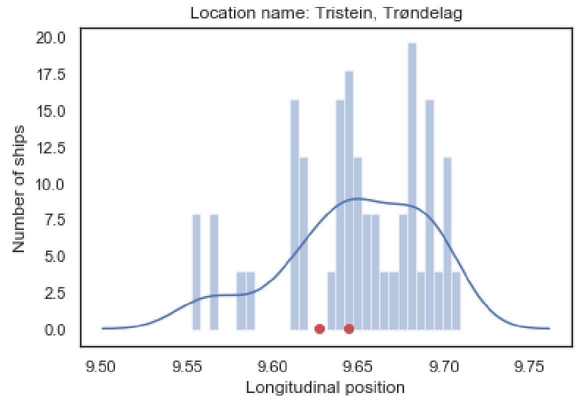
Figure 5.9: Tristeinen. Traffic density illustrated by heat maps.

Table 5.4: Tristeinen. Data for traffic within 2 nm distance of object.

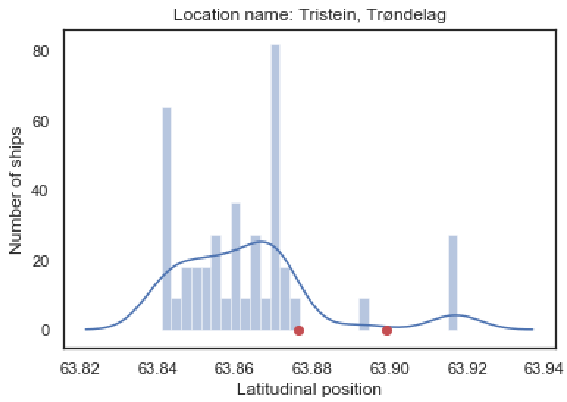
Tristeinen, Buoy	**1**		**2**	
Pre/Post Installation	Pre	Post	Pre	Post
Number of AIS records within 2 nm.	18	14	67	50
Number of vessels within 2 nm.	5	4	33	21
Min. passing distance [nm]	0,4617	1,0433	0,1361	1,1831
Speed at min. passing distance [kn]	6,60	10,50	6,40	6,40
Mean distance for 20 closest messages. [kn]	1,9605	2,1105	1,1227	1,2837
Mean speed for 20 closest messages. [kn]	7,53	10,87	8,82	11,07
Records representing collision candidates	0	4	26	16



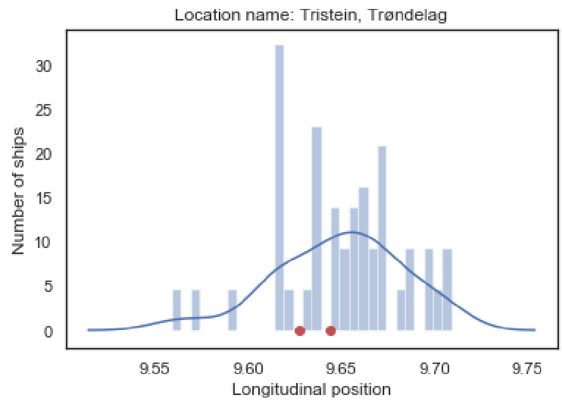
(a) Latitudinal distribution pre-installation.



(b) Longitudinal distribution pre-installation.

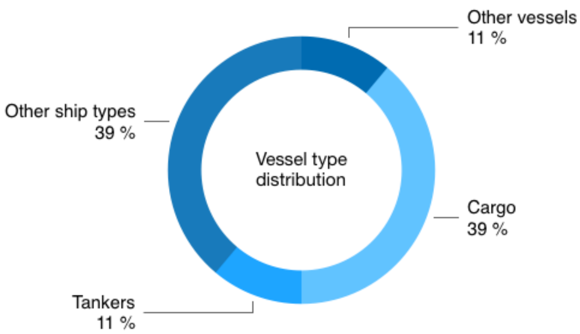


(c) Latitudinal distribution post-installation.

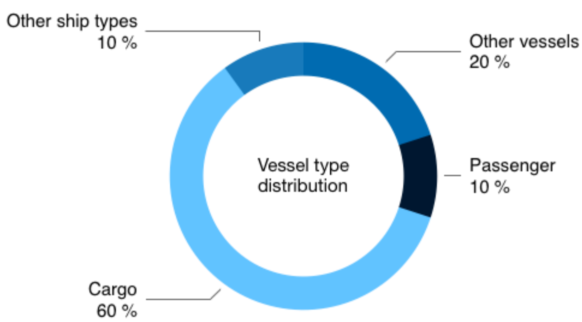


(d) Longitudinal distribution post-installation.

Figure 5.10: Traffic distribution pre- and post-installation of two current measuring buoys at Tristeinen.

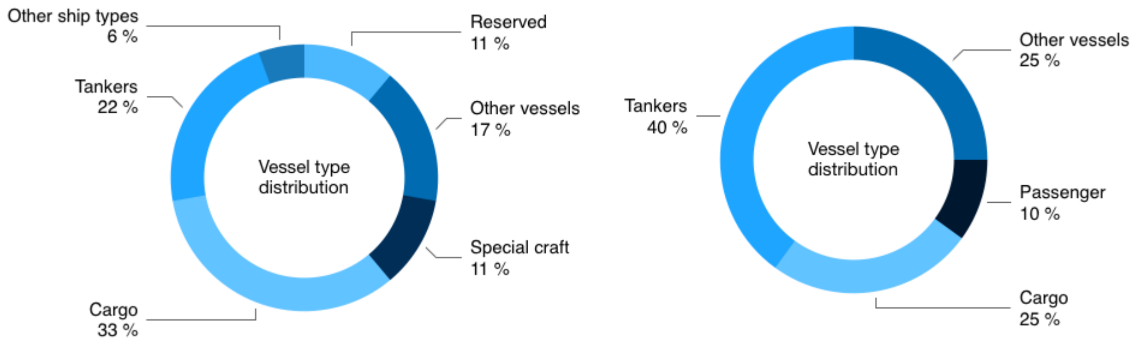


(a) Pre installation, Buoy 1.



(b) Post-installation, Buoy 1.

Figure 5.11: Tristeinen Buoy 1. Vessel type distribution of 20 closest passing vessels.



(a) Pre installation, Buoy 2. (b) Post-installation, Buoy 2.

Figure 5.12: Tristeinen Buoy 2. Vessel type distribution of 20 closest passing vessels.

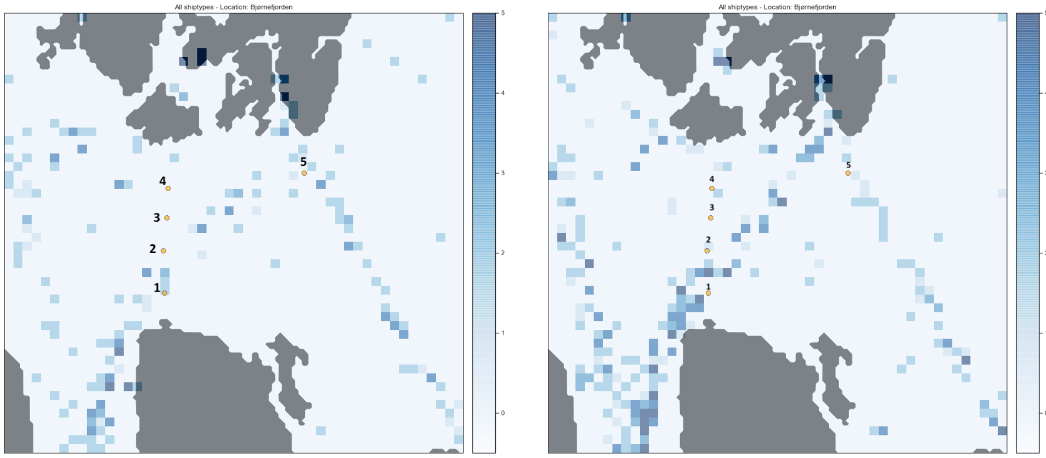
5.4 Data collection buoys, Bjørnefjorden

For the purpose of collecting wave and current data for the ”Ferjefri-E39” project, the Norwegian Public Roads Administration put out five yellow oceanographic data collection buoys in Bjørnefjorden, between Reksteren N and Røtinga. They were put in place in January 2015 and are still present today. It should be noted that the positions used for the buoys are for this case taken from MarineTraffic. The pre- and post scenarios for this case are represented by a 6 month period between 9th of March and 9th of September, respectively in 2014 and 2015. Each buoy has got a weight of 2,6 tons and reaches 5 meters above the sea surface. All buoys are equipped with lantern and AIS-transponders and are easy to see due to the bright yellow color Tysnesbladet (2015). The area for the traffic distribution histograms is for this case limited to an area of 6,29 nm x 61,62 nm, in respectively the longitudinal and latitudinal direction. This size is chosen to include all buoys, in in addition to at least a distance of about 2nm around each buoy. In Table 5.5 and Figure 5.15 only buoy 1, 4, and 5 is presented.

From Figure 5.15, which illustrates the distribution of vessel types represented by the 20 records closest to buoy 1, 4, and 5, one can see that a lot of the traffic in the area are from passenger vessels. For buoy 4, which is the one closest to the north side of the fjord, cargo-, reserved- and other vessels are also represented in the 20 records received closest to the buoy. For buoy 1 and 5, all 20 messages are represented by passenger vessels. Also, from the heat maps in Figure 5.13, the ferry routes across the fjord, Halhjem-Sandvikvåg, and Halhjem-Våge, can be easily identified. One can also see an increase in the traffic density from 2014(a) to 2015(b), and that a large part of the traffic passes between buoy 1 and 2. As can be seen in Table 5.5, the number of records within a 2nm radius of buoy 1 and 4 did approximately double from 2014 to 2015. Only for buoy 5, the number of records decreased some. However, only for buoy 1 did also the number of unique vessels increase. This indicates that a lot of the same travels the same route.

With respect to distance from the object did the minimum passing distance increase for all three buoys. However, did the mean distance increase both for buoy 1 and 4. For this case, the mean speed for the 20 closest records is notably higher than for the other cases. This may be because the ferries and passenger vessels have a schedule that must be followed, and that they are familiar with the route.

For the latitudinal distribution, Figure 5.14 (a) and (c), one can clearly see that the number of AIS-messages have increased for the positions between the buoys, while a decrease can be seen at the buoy positions. Especially the increase between buoy 1 and 2 is significant. One can also see that the two peaks for the latitudinal distribution shifted towards north, indicating that more of the traffic did choose a route between the north side of the fjord and buoy 4 after the installation. For the longitudinal distribution, the changes are not as significant. However, the traffic on the south side of the buoys seems to be more evenly distributed for the post-installation scenario, except from the one peak at 5.34° E.

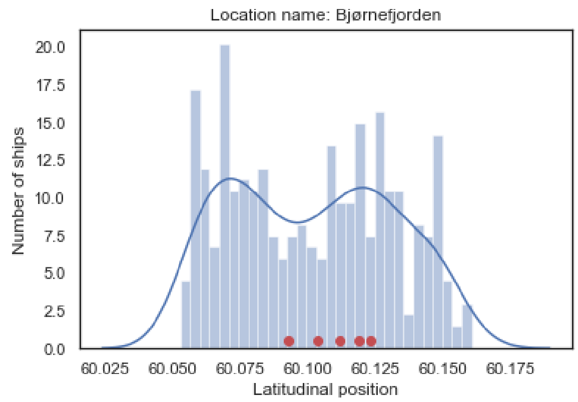


(a) Heat map pre-installation.   (b) Heat map post-installation.

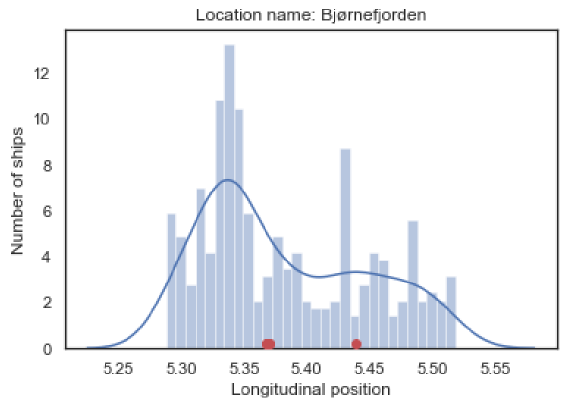
Figure 5.13: Bjørnefjorden. Traffic density illustrated by heat maps.

Table 5.5: Bjørnefjorden. Data for traffic within 2 nm distance of object.

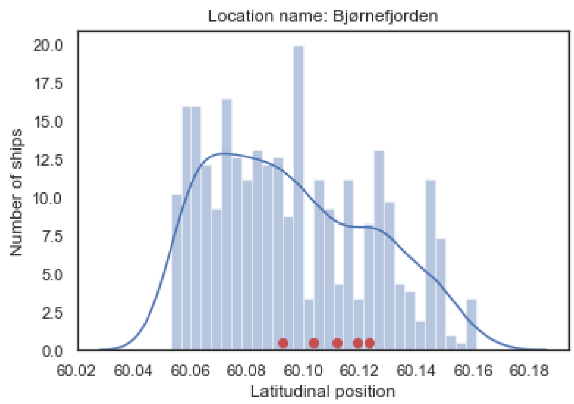
Bjørnefjorden Buoy	**1**		**4**		**5**	
Pre/Post Installation	Pre	Post	Pre	Post	Pre	Post
Number of AIS records within 2 nm.	111	227	86	161	87	109
Number of vessels within 2 nm.	17	35	16	15	11	10
Min. passing distance [nm]	0,0480	0,1655	0,3639	0,1671	0,1391	0,1749
Speed at min. passing distance [kn]	16,2	20,0	9,20	12,40	12,1	13,2
Mean distance for 20 closest messages. [kn]	0,3737	0,2427	0,7300	0,6313	0,3542	0,4815
Mean speed for 20 closest messages. [kn]	17,60	18,83	14,94	15,87	15,22	15,18
Records representing collision candidates	30	19	25	46	19	17



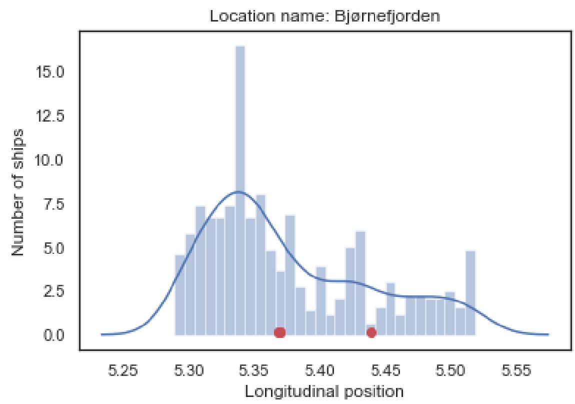
(a) Latitudinal distribution pre-installation. The buoys are counted from 1 to 5 starting from the left.



(b) Longitudinal distribution pre-installation.

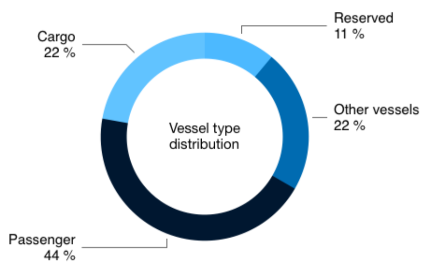


(c) Longitudinal distribution post-installation.

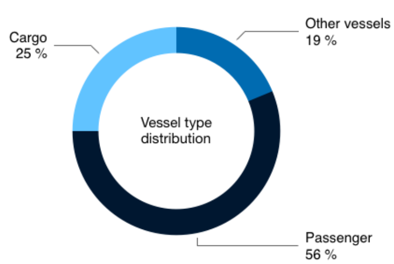


(d) Longitudinal distribution post-installation.

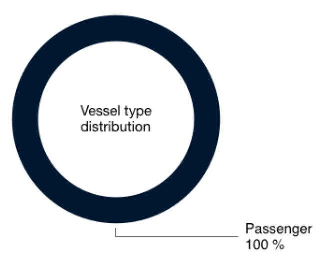
Figure 5.14: Illustrations of how the traffic density and distribution pre- and post-installation of five buoys in Bjørnefjorden.



(a) Pre installation, Buoy 4.



(b) Post-installation, Buoy 4.



(c) Pre and Post installation, Buoy 1 and 5.

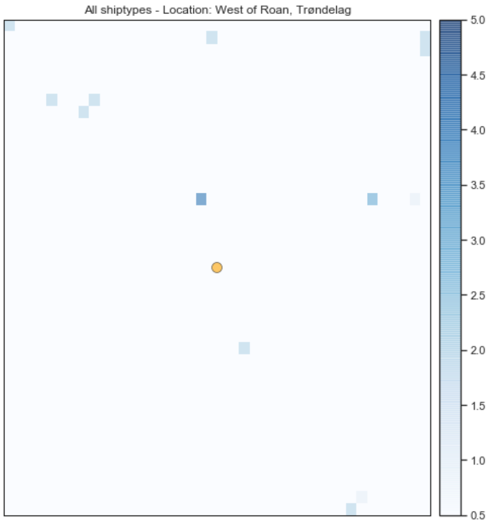
Figure 5.15: Bjørnefjorden. Vessel type distribution of 20 closest passing vessels.

5.5 Communication buoy, West of Roan

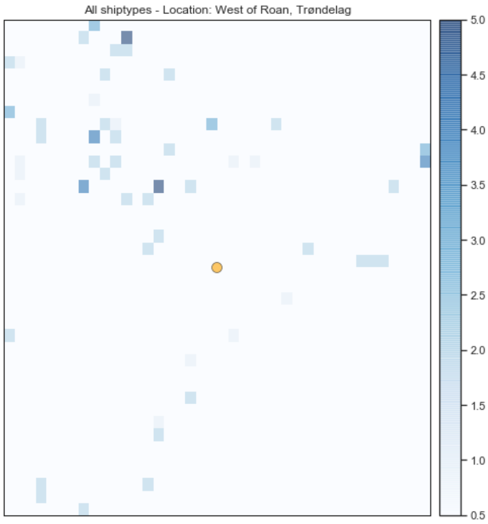
A communication buoy for a subsea current measurement rig was located about 10 nautical miles off the Coast of Roan in the period 10.12.2014-10.04.2015. This period of four months represents the post-installation scenario for this case, while the same period in 2013 represents the pre-installation scenario. Passing vessels were asked to keep a distance of at least 100 m. The area for the traffic distribution histograms in Figure 5.17 are for this case limited to an area of 4,36 nm x 4,81 nm, in respectively the longitudinal and latitudinal direction.

From the distribution diagrams in Figure 5.16 it seems like there is a large difference in traffic density between the pre- and post installation scenario. This is confirmed by the count of AIS-records presented in Table 5.6. The reason for this is hard to say. From the table, it can also be seen that the minimum registered passing distance and the mean distance for the 20 closest received messages did increase post installation. This indicates that some course alternations might have been done, especially since the traffic density in the area did increase for the same period. With respect to the distribution of vessel types, are the nearest passing vessels represented by cargo- and other vessels. As for buoy 1 at Tristeinen, the share of cargo vessels did also for this case increase post installation, in contrast to many of the other cases. The share of other vessel types did decrease correspondingly. Of the 54 records within 2nm, 11 represented possible collision candidates.

From the distribution histograms, some clear changes in the traffic can be seen. For the latitudinal distribution, most of the traffic was registered at some longitudes pre-installation. The majority of the traffic is located north of the object for both scenarios, but for the post-scenario, the traffic seems to be distributed a bit more evenly. Especially when looking at the peak at 120 and the two smaller peaks on the north side pre-installation. This also applies to the longitudinal distribution. Here, one can also see that the majority of the traffic did shift towards the west side of the buoy post installation.



(a) Heat map pre-installation.

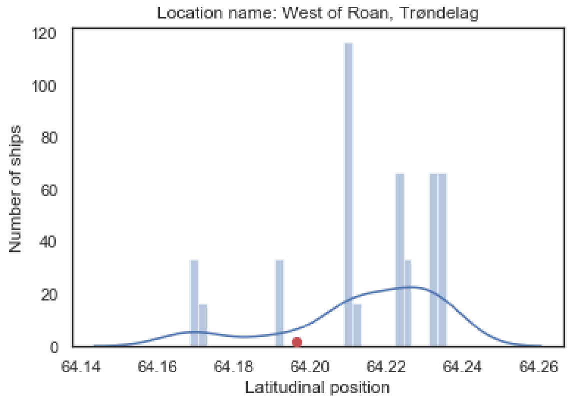


(b) Heat map post-installation.

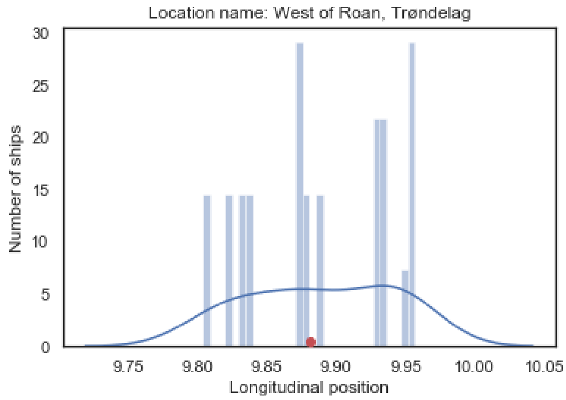
Figure 5.16: Roan. Traffic density illustrated by heat maps.

Table 5.6: Roan. Data for traffic within 2 nm distance of object. *Based on the 7 vessels within 2 nm. for the pre-scenario.

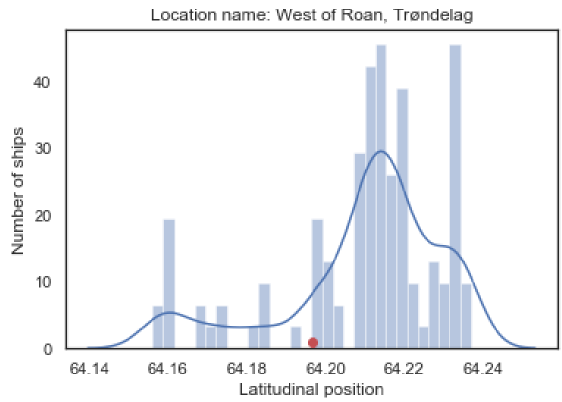
	Pre Installation	**Post Installation**
Number of AIS records within 2 nm.	7	54
Number of vessels within 2 nm.	3	14
Min. passing distance [nm]	0,3853	0,6585
Speed at min. passing distance [kn]	10,5	14,1
Mean distance for 20 closest messages. [kn]	1,387*	0,997
Mean speed for 20 closest messages. [kn]	9,84*	8,86
Records representing collision candidates	0	11



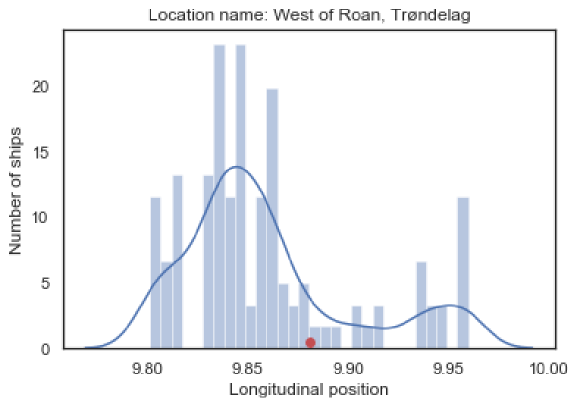
(a) Latitudinal distribution pre-installation.



(b) Longitudinal distribution pre-installation.

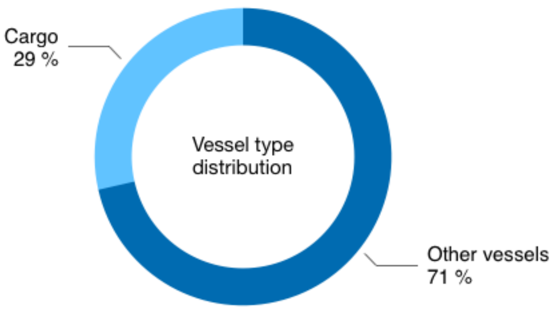


(c) Latitudinal distribution post-installation.

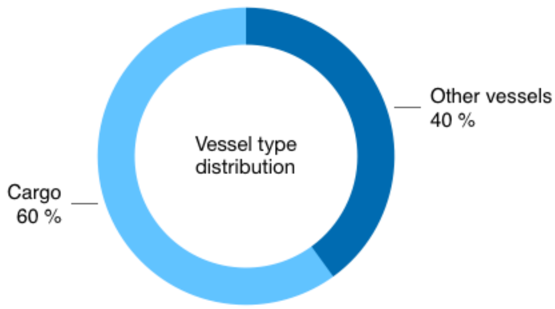


(d) Longitudinal distribution post-installation.

Figure 5.17: Illustrations of how the traffic density and distribution pre- and post-installation of a buoy west of Roan.



(a) Pre installation.



(b) Post installation.

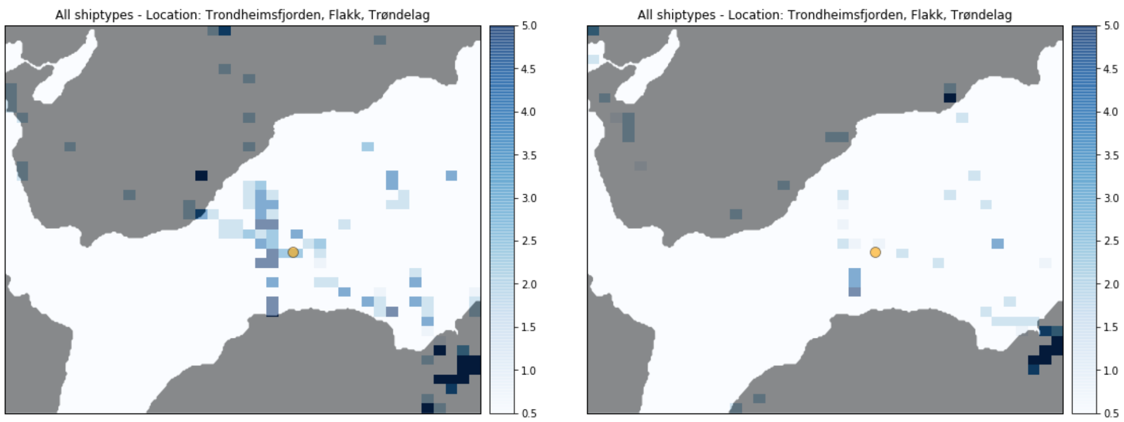
Figure 5.18: Roan. Vessel type distribution of 20 closest passing vessels.

5.6 Buoy, Flakk - Trondheimsfjorden

An oceanographic measuring buoy was temporarily set out in Trondheimsfjorden near Flakk by Fugro OCEANOR. The buoy was present for two weeks around 19.06.12-03.07.12. The pre-installation case is represented by the same time period one year in advance. The buoy is not described any further in the Previous Notices to Mariners but was most likely a typical oceanographic buoy of the type that can be found on Fugro's webpage.

As can be seen from the heat maps in Figure 5.19, the buoy was located relatively close to the ferry route Flakk-Rørvik. Other than passenger vessels, Figure 5.21 shows that the 20 records closest to the location also was represented by cargo-, high-speed and other vessels. Post-installation on the other hand, almost all of the records were from passenger vessels, with only 10% cargo vessels. The number of vessels within 2 nm did, as can be seen in Table 5.7, decrease from 125 to 25 after installation. Further did both minimum passing distance and mean distance for the 20 closest recorded messages increase. The number of records representing collision candidates did on the other hand not decrease. The reason for this is most likely the ferry route. By looking into the vessels belonging to the records, it can be found that most of these are from the ferry "Korsfjord" going from Flakk to Rørvik.

When looking at the latitudinal traffic distribution in Figure 5.20 a large increase at about 63.45°N can be seen. For the rest of the area, the traffic is relatively similar to the post-installation scenario. However, also an increase exactly north of the buoy and a peak even a little further north can be seen for the post-installation scenario. With respect to longitudinal distribution, the cases do not differ much. Only a little less even distribution of the traffic, and a peak at 10.31^{circle} E can be seen for the post-installation scenario.



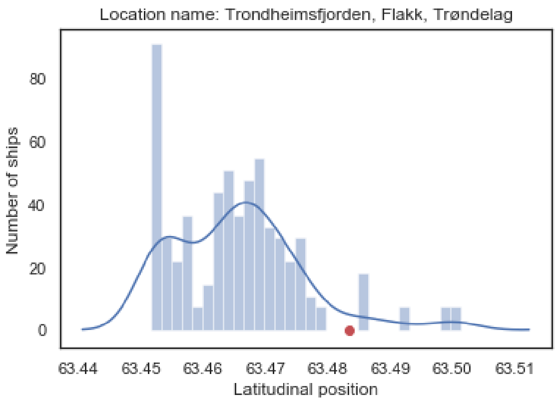
(a) Heat map pre-installation.

(b) Heat map post-installation.

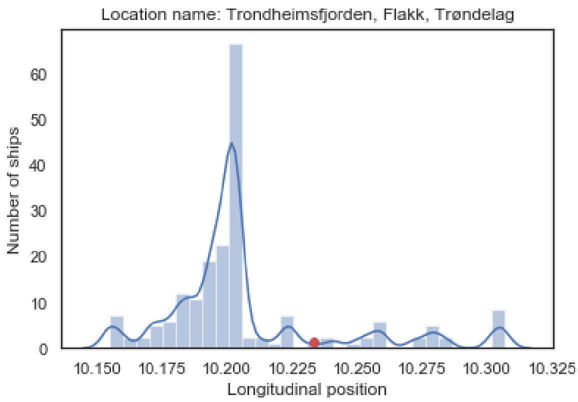
Figure 5.19: Flakk. Traffic density illustrated by heat maps.

Table 5.7: Flakk. Data for traffic within 2 nm distance of object.

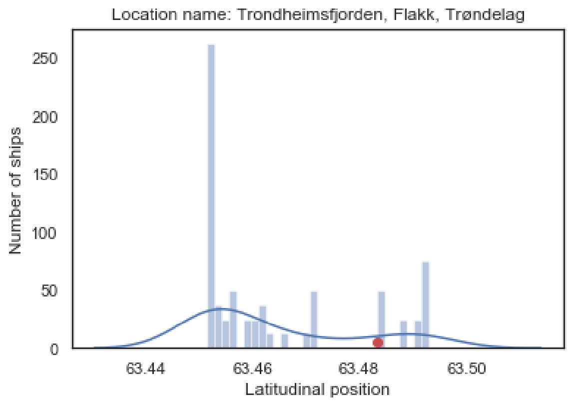
	Pre Installation	**Post Installation**
Number of AIS records within 2 nm.	125	25
Number of vessels within 2 nm.	11	6
Min. passing distance [nm]	0,3853	0,6585
Speed at min. passing distance [kn]	13,9	14,2
Mean distance for 20 closest messages. [kn]	1,1000	1,5802
Mean speed for 20 closest messages. [kn]	15,36	13,86
Records representing collision candidates	15	17



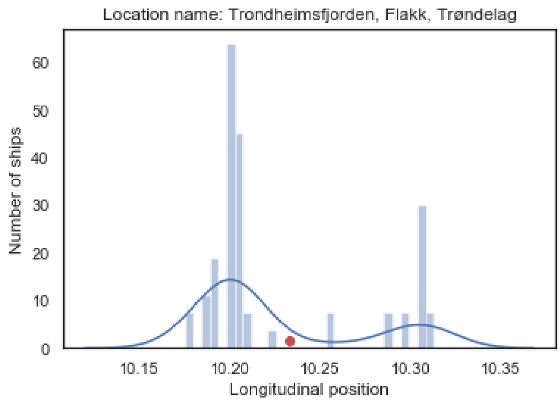
(a) Latitudinal distribution pre-installation.



(b) Longitudinal distribution pre-installation.

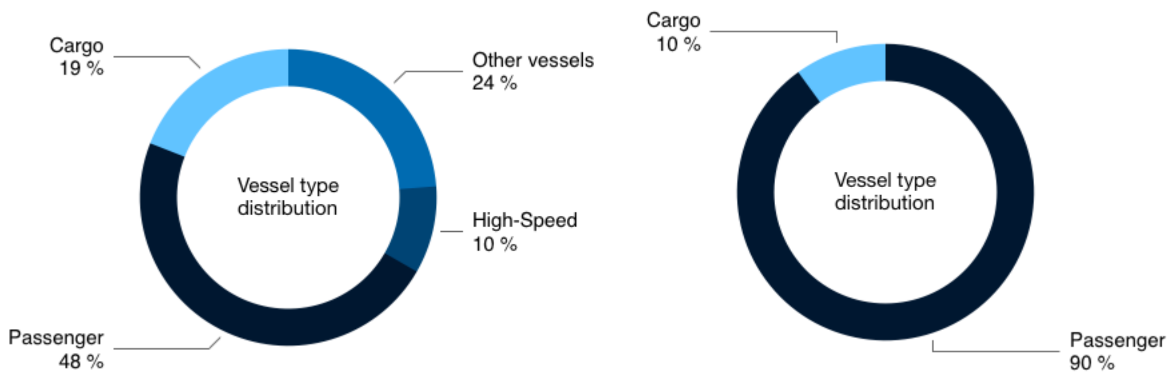


(c) Longitudinal distribution post-installation.



(d) Longitudinal distribution post-installation.

Figure 5.20: Illustrations of how the traffic density and distribution pre- and post-installation of a buoy west of Flakk.



(a) Pre installation. (b) Post-installation.

Figure 5.21: Flakk, Trondheimsfjorden. Vessel type distribution of 20 closest passing vessels.

5.7 Statistics, all cases

In this section, some statistics for all cases combined are presented to easier be able to compare and look for similarities between the cases.

In Table 5.8, the data presented separately for each case is here gathered in one table. The difference and percentage difference in the minimum registered distance are also added to the table. As one can see, the cases vary quite a bit with respect to changes in minimum distance. For four of ten objects, the minimum distance decreased after the object was put in place, while for six of ten it increased. Further did the number of records within 2 nm decrease for all cases except for the buoys in Bjørnefjorden and the one outside Roan. Despite the increase in the number of records, only buoy 1 in Bjørnefjorden and the one outside Roan did show an increased number of unique vessels within 2 nm distance post installation.

Table 5.8: Records within 2 nm of object pre- and post installation (SOG $\geqslant$ 1.0 kn)

Area	Pre installation			Post installation			Diff.	
	# Records	# Vessels	Min dist [nm]	# Records	# Vessels	Min. Dist [nm]	Min dist	% Diff
Frøya	12	5	0,6170	6	1	0,2896	-0,33	-53 %
Føyabanken, B1	53	17	0,1837	47	15	0,1546	-0,03	-16 %
Frøyabanken, B2	53	18	0,2449	47	16	0,1194	-0,13	-51 %
Bjørnefjorden, B1	111	17	0,0480	227	35	0,1655	0,12	244 %
Bjørnefjorden, B4	86	16	0,3639	161	15	0,1671	-0,20	-54 %
Børnefjorden, B5	87	11	0,1391	109	10	0,1749	0,04	26 %
Tristeinen, B1	18	5	0,4617	14	4	1,0433	0,58	126 %
Tristeinen B2	67	33	0,1361	50	21	1,1831	1,05	769 %
West of Roan	7	3	0,3853	55	14	0,6585	0,27	71 %
Flakk	125	11	1,0120	25	6	1,2790	0,27	26 %

Since only looking at the minimum recorded distance is not representative for all of the surrounding traffic, the mean distance and the corresponding change between pre- and post installation is also taken for the 20 closest recorded messages. This is presented in Table 5.9. When looking at the 20 closest recorded messages from vessels with SOG $\geqslant$ 1.0 kn, even more of the cases show a decreased minimum passing distance post installation. At most, mean passing distance did decrease with more than 800 meters. This is the case for the buoys at Frøyabanken. The reason for this change is hard to say. Also for the buoys outside Frøya and Roan, a relatively large decrease in the mean distance is seen. However, for the cases where a increase is registered, the increase are of the same scale. Overall the change for the 20 closest messages varies here between $\pm 15 - 50\%$.

Table 5.9: Mean passing distance for the 20 closest recorded messages (SOG $\geqslant$ 1.0 kn)

Area	Mean passing distance		Diff		
	Pre installation	Post installation	[nm]	[m]	%
Frøya	0,9626	0,5983	-0,3643	-674,62	-38 %
Frøyabanken B1	0,9912	0,5377	-0,4535	-839,83	-46 %
Frøyabanken B2	0,9838	0,4990	-0,4848	-897,78	-49 %
Bjørnefjorden B1	0,3737	0,2427	-0,1310	-242,65	-35 %
Bjørnefjorden B4	0,7300	0,6313	-0,0987	-182,80	-14 %
Bjørnefjorden B5	0,3542	0,4815	0,1273	235,77	36 %
Tristeinen B1	1,6905	2,1105	0,4200	777,85	25 %
Tristeinen B2	1,1227	1,2837	0,1610	298,25	14 %
West of Roan	1,3869	0,9765	-0,4104	-760,05	-30 %
Flakk	1,1001	1,5802	0,4802	889,25	44 %

The 20 closest recorded messages give quite ambiguous indications with respect to change in passing distance. Therefore, the mean and standard deviation is also taken for all the vessels within the same area as the distribution histograms are made for. This is presented in Table 5.10. The coordinates for each area can be found in Appendix F.

As one can see for the area as a whole, do the mean passing distance decrease for fewer cases than when only the minimum passing distance or the 20 closest records are considered. Additionally, the percentile change and the change in meters for each case is much smaller regardless of whether there is an increase or decrease in distance. The change in mean distance is now in the range of $\pm\ 0 - 13\%$, with the largest difference equal to -469 meters. It should also be noted that the areas with the largest and smallest decrease are not the same as when only considering the 20 closest records. An example is the buoys at Frøyabanken, where a decrease in passing distance of above 40% and more than 800 meters was calculated. When including all records for the entire area, the change was calculated to be only -16 meters, corresponding to approximately 0%. This indicates that it is not only changes near the object that increases or decreases the mean distance the traffic keeps to the object. However, the changes can also be caused by external factors, besides the object itself, but at least one can see that even a relatively small buoy might affect more than the closest passing vessels.

Buoy 1 in Bjørnefjorden and the one West of Roan, still shows a relatively large decrease in the mean distance, and the same applies to Flakk, when compared to several of the other cases. Another similarity that is that both for the 20 closest records and for the entire area, there are the same cases that shows an increase or decrease in distance to object. The only exception is buoy 4 in Bjørnefjorden where it changes from a decrease in distance to an increase when the entire area is included.

Table 5.10: Distance to object pre- and post installation (SOG $\geqslant$ 1.0 kn)

Area	Pre installation [nm]		Post installation[nm]		Diff				
	Mean	Std	Mean	Std	Mean	Std	Mean	Std	[m]
Frøya	2,5146	0,9048	2,5017	1,0009	-0,01287	0,0961	-1 %	11 %	-24
Føyabanken, Buoy 1	1,9357	0,7506	1,9269	0,8513	-0,00880	0,1007	0 %	13 %	-16
Frøyabanken, Buoy 2	1,9375	0,7072	1,9288	0,8917	-0,00865	0,1845	0 %	26 %	-16
Bjørnefjorden, Buoy 1	2,4084	1,0945	2,1587	1,6322	-0,24965	0,5377	-10 %	49 %	- 462
Bjørnefjorden, Buoy 4	2,6976	1,1404	2,6409	1,1948	-0,05674	0,0544	-2 %	5 %	105
Børnefjorden Buoy 5	3,0934	1,5084	3,3003	1,3947	0,20690	-0,1137	7 %	-8 %	383
Tristeinen, Buoy 1	2,5928	0,6318	2,6874	0,5703	0,09456	-0,0615	4 %	-10 %	175
Tristeinen Buoy 2	1,6768	0,5492	1,6947	0,4580	0,01791	-0,0912	1 %	-17 %	33
West of Roan	2,1159	0,7073	1,8627	0,6084	-0,25323	-0,0990	-12 %	-14 %	-469
Flakk	1,6106	0,3797	1,8168	0,2705	0,20619	-0,1092	13 %	-29 %	382

It was also considered as interesting to look into the changes in latitude and longitude between pre and post-installation. The numbers in Table 5.11 are based on all messages within the defined areas, same as for the table above. Also here, the changes are quite varying with respect to distance. For most of the cases, there are no particular connection between the change in longitude and latitude, for some cases, the shift is largest in the latitudinal direction and for other cases, it is largest in the longitudinal direction. The significant shift in mean latitude that can be seen for Tristeinen is most likely caused by other factors than the installation of the buoy.

Table 5.11: Change in mean latitude and longitude for each case

Area	Mean Latitude		Mean Longitude		Diff [deg]				Diff [m]	
	Pre	Post	Pre	Post	Lat	Dir	Lon	Dir	Lon	Lat
Frøya	63,636955	63,649447	8,212067	8,18395	0,012492	North	0,028117	West	1390,6	1421,0
Frøyabanken	63,736386	63,732243	7,433588	7,436892	0,004143	South	0,003304	East	461,2	167,0
Bjørnefjorden	60,101599	60,095588	5,381768	5,375628	0,006011	South	0,00614	West	669,1	310,3
Tristeinen	64,209571	63,86225	9,653651	9,648443	0,347321	South	0,005208	West	38663,6	263,2
Roan,	64,214123	64,209571	9,8883	9,859052	0,004552	South	0,029248	West	506,7	1478,1
Flakk,	63,465451	63,464459	10,20713	10,226726	0,000992	South	0,019596	East	110,43	990,3

5.8 Evaluation of changes in risk

With respect to changes in risk, one can see that the closest passing distance recorded post installation is 0,1194nm. This corresponds to 221 meters. The lowest mean passing distance for 20 closest messages is recorded for buoy 1 in Bjørnefjorden, with a passing distance of 449 meters. For many of the other cases, both the minimum and mean passing distance is much larger. This points towards that the traffic still keeps a safe distance after installation of new objects. Even when if it is a smaller object such was met-ocean buoys.

A shift in the traffic can be seen for several of the cases, resulting in accumulated effects leading to increased traffic density for parts of the area or fairway. Thus, despite that the traffic seems to avoid the object, the ship-ship collision risk may increase. An example of this is the increased number of vessels registered between the latitudinal positions of the buoys in Bjørnefjorden. When the vessels choose a path between the buoys and land, the results are in addition a more narrow fairway, which again can increase the vessel density and thus the expected number of encounters. This also limits the ability if perform evasive manoeuvrers if found necessary.

When analysing speed, there are not observed any particular reduction in speed closer to the object, and vice versa not observed any tendency of increased speed at a larger distance. For vessels passing very close, the speed is however low. For most cases, the mean speed for the 20 closest recorded messages did decrease. The only exception is for the buoys at Tristeinen, and Bjørnefjorden. In Bjørnefjorden the main share of the passing traffic is passenger vessels/ferries, while at Tristeinen the 20 closest records are from cargo ships, other vessels/ship types and passenger vessels. This may be an interesting observation, as passenger ships are described as the category most exposed to accidents, followed by fishing vessels and general cargo ships by (Lasselle et al., 2018). Tankers, on the other hand, did in most cases show a tendency of increasing the distance from the object something that is positive with respect to the risk of colliding with the obstacle, although the ship-ship collision risk still applies.

Chapter 6

Discussion

6.1 Evaluation of Methodology

Taking into account the methodology, there are most definitely some areas for improvement. First of all, one should be aware of that finding the date of installation for different objects can be challenging. A different solution to this problem than going through the previous notices to mariners is therefore recommended. Additionally, for this approach, an AIS database covering a larger timespan would be beneficial. This would help ease the work with identification of feasible objects as well as increase their relevance.

Further, an even deeper look into some of the cases would be interesting. Especially if the relevance of the objects was a little stronger in relation to the problem description. The time periods for analysis of the cases is also an interesting matter of discussion. Due to relatively short installation periods and dispersed traffic in many of the areas, it was chosen to investigate the entire period the objects were present. For some of these cases, the time period was as short as only 2-4 weeks. An alternative approach could have been to investigate fewer cases more toughly, focusing on several periods of time both the years pre- and post installation. This would obviously require that the AIS-dataset is large enough. This also could have helped analyse the cases where the results shows a large difference in the traffic amount, that cannot be explained by the objects alone, and therefore makes the results hard to interpret.

For example this applies to the case for the buoy outside Roan, where the year pre installation showed a very small amount of traffic, while the year post installation not was a part of the dataset. By looking into the same period one year after installation as well, it could have helped say something more certain about the post-installation changes. Due to limited time, the relevance of the objects and the inconsistencies in the results, even deeper analysis was not conducted for the cases presented in the case study.

6.2 Discussion of results

The results from the six cases do as mentioned show rather ambiguous results. Especially with respect to the increase/decrease in mean distance to the objects. They do in other words not show clear trends of how far away from the object the traffic passes, or how much the traffic will change. The results do however point towards some intervals for minimum recorded distance for vessels with SOG above 1 kn. For Frøya, Frøyabanken, and Bjørnefjorden the interval for minimum passing distance is between 0,12 - 0,28 nm, which corresponds to 222-518 meters. For Tristeinen, Roan, and Flakk the interval is in between 0,66-1,28 nm which corresponds to 1222 - 2370 meters. This indicates that the traffic keeps a reasonable distance to even small objects such as oceanographic buoys, although a reduction in mean distance is registered for several of the cases.

One can also see that the implications of installing a new object at sea not only applies to vessels passing very close to the object, but also has significance for vessels further away. This can be due to accumulated effects as seen also in other studies such as the allision risk study by Hassel et al. (2017). When an object is put into place, the traffic as a whole show in most of the cases a route shift of between 0,001-0,01 degrees, which corresponds to approximately 260-1500 meters. By studying both the closest received AIS messages, as well as all of the records from the areas, the mean distance to the buoys decreases for fewer cases when the area as a whole is considered. However, it is hard to say what the large decrease in mean distance found when analysing only the 20 closest records means.

The largest changes are seen for the vessels closest to the object. It is not unexpected that the vessels the furthest away from the objects don't seem to change course post installation. The distance is most likely evaluated as more than sufficient, and thus, no actions are taken. The combination of these two outcomes, on the other hand, result in more vessels using the same part of the fairway. One can for many of the cases see some kind of ”compression” of the traffic at some latitudes and longitudes post installation. This also substantiates the findings indicating that a higher percentile change in passing distance is calculated for the vessels closest to the object compared to when all vessels in the area are included. As long as this happens sufficiently far away from the structure, it will not increase the risk of colliding with the new object. However, from a traffic risk perspective, these accumulated effects can be just as important as the impacts more close to the object. An increase in traffic density and flow in an area can result in an increased probability of ship-ship collisions in that part of the fairway. Further it can result in that, vessels passing between the object and land experiences restricted possibilities to perform evasive manoeuvrers, in addition to a more ”compact” fairway in general. Both of which, may increase risk. For other cases, where the impact seems to be small, it may be explained by the location of the buoys. These cases provides less information about the resulting effects of new objects, but can on the other hand demonstrate the importance of marine spatial planning.

With respect to vessel types, do the share of tankers decrease post installation for most cases where tankers are represented in the 20 closest records. Other vessel types, on the other hand, is the category that in most cases show an increase. For cargo vessels, the results are varying. For some cases, a reduction is seen, for others cases an increase. For the cases with a large share of passenger vessels, the buoys is located in fjords. For these cases, the share of the other vessel types decreases while passenger vessels have increased. This can most likely be explained by the buoys being located very close to the ferry routes. It may, but does not necessarily mean that passenger vessels in other areas would keep a shorter distance to the object. An additional hazard that can be introduced is intersecting traffic caused by increased activity from the new installation. This is not investigated in this study as the objects in the case study did not generate new traffic of any kind. It is however a highly relevant topic to include for further studies.

6.3 Uncertainty

One should keep in mind that some of these changes also can be caused by external stimuli. The year-to-year changes can be caused by other factors in addition to the installation of new objects, such as: establishment of new industries in the area, new intersections or fairways as a result of this, and route changes due to other objects. Another important result from the case study, is that the way the areas around the objects are limited, has a large impact on the results. This is something one should be aware of when performing this kind of studies. If not taken into consideration, it can lead to misleading results.

The relevance of the study with respect to the applicability of the results for larger marine structures is uncertain. Due to the small size of the buoys, the results might not be used to say something about what passing distance that seems to be perceived as safe for larger structures. Additionally, the size and type of objects result in locations that may differ some in topography and traffic amount compared to where larger structures usually would be put in place. Finally, it should be added that also the surface motions of the buoys contributes with some uncertainty to the results. The distances calculated are not necessarily correct, as some the buoys were able to move some at the surface.

Chapter 7

Conclusion

7.1 Concluding Remarks

The objective of this thesis is to investigate the navigational effects post installation of man-made structures at sea, in an attempt to provide increased insight into the resulting effects. This is done by conducting a case study of six locations along the coast of Norway, where one or more oceanographic buoys were installed for a period of time. Information from AIS data has been attained and analysed through codes/programs developed for visualisation and statistical analyses. The data is used to visualise and present statistics for the traffic density, the longitudinal and latitudinal traffic distribution, vessel speed and type, as well as the distance and angle between vessels and the investigated objects, for both pre- and post installation scenarios.

Unfortunately, due to a small dataset, different types of oceanographic/met-ocean buys are the only type of objects assessed in this study. Thus, both the size of the objects, as well as the surrounding areas and the traffic situations, differs quite a bit from marine structures and where larger these normally would be put in place. The results from the case study are quite ambiguous. This may point towards that each case is unique to situation, and that the resulting effects depend on the situation, traffic type, and density, topography and other navigational obstacles or constraints present. However, the results do point towards some post-installation tendencies, though with some uncertainty involved. From an overall perspective, it seems like one can distinguish between two scenarios: the implications/changes close to the object, and the accumulated effects that occur somewhat further away from the object.

Despite that some of the cases show a reduction in the distance to the objects post installation, the results indicate that a reasonable distance is kept for all cases. Further, are route alternations post installation identified for several of the cases. The changes seem to be largest for the vessels closest to the object, even if the results are not entirely consistent. Such ”circumnavigation” by the closest vessels can result in greater traffic density in the areas around the object, and consequently, increase the risk of ship-ship collisions. Additionally, this increased traffic density for some parts of the fairway can lead to conflict with other interests. For the cases where the traffic, on the contrary, showed a decreased mean passing distance, some of these had a more logical explanation to this. For example that the buoys were located close to a ferry route.

For cases where the impact seems to be small, the results may be explained by the location of the buoys. These cases provide less information about the resulting effects of new objects, but can, on the other hand, demonstrate the importance of marine spatial planning.

To answer the last question asked in the objectives: *Is it possible to detect repeating trends or tendencies in the traffic changes that can help in the decision-making process when future structures are to be put in place?* The answer to this is that the results from this study show indications of repeating patterns in vessel behaviour post installation. However, the results are still too varying to conclude with exact tendencies that can be taken further before more cases are investigated. The results may also point towards that a certain degree of similarity between the cases is needed for the results to be applicable also for other areas with similar features.

Altogether, this study points towards that the most significant implications of the buoys are the accumulated traffic effects in the areas around the objects. The study demonstrates that AIS data can provide useful information for studies of marine traffic. It also demonstrates that comparative analysis of AIS data can provide valuable information and increase the insight into traffic changes post installation of man-made structures.

7.2 Recommendations for Further Work

For further work, it is suggested to find and investigate cases with more similarities. Preferably also with larger structures in areas more similar to the ones where for example exposed fish farms will be located if the data available allows for this. Also, investigation of changes in traffic for areas with higher traffic density, closer to more defined fairways, areas also outside Norway should be considered. By investigating several cases with similar features, one might be able to detect behaviour that with high certainty will be repeated for areas with comparable features. Further, such findings can be tested with respect to the prediction of post-installation changes for other similar areas. If mechanisms that correspond to several cases are identified, this can possibly be used as a basis for automatically predicting changes in traffic patterns and to assess more dynamical situations.

Based on the statement by Rawson and Rogers (2015): *Accurate traffic flow prediction is a vital input into risk modeling; with sensitive models even minor discrepancies can result in significant differences in the results of the analysis*, it would be interesting to compare the risk assessments performed prior to installation of one of the new exposed fish farms with the actual situation post installation, when they are put in place. An evaluation of whether artificial objects such as wave buoys are representative for larger structures such as exposed fish farms, and secondly investigation of the correlation between size and degree of change is highly interesting. In this context, also the proximity to the object and degree of change is relevant.

Increased vessel activity near the new installation can introduce new traffic situations and intersections that again can increase the risk of ship-ship collision. This is also a post-installation effect that can be investigated further. In this context, also, investigation of the effect of buoys put in place to mitigate the collision risk between vessels and larger structures can be interesting. Especially with the accumulated effects in mind. Do the buoys actually mitigate risk, or is the risk only transferred from collision risk between vessels and the marine installation to the risk of collisions between vessels. For assessment of drifting collisions, weather statistics can be interesting to include in the analysis. For this, critical current and wind directions leading a drifting vessel from the fairway towards have to be identified.

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Appendix A

Offshore wind, research areas

OMRÅDE	TRAFIKKMENGDE	SKIPSTYPE	METEOROLOGISKE FORHOLD	NÆRHET TIL LAND	ANTALL VIND-TURBINER	SAMLET VURDERING - SANNSYNLIGHET FOR UHELLSHENDELSE
Sørlige Nordsjø II	Svært høy trafikk, nær hovedfarled	Mange oljetankere	Over gjennomsnittlig vindstyrke og bølgehøyde	Lang avstand til land (149 km)	125	Høyest (4,3)
Sørlige Nordsjø I	Lav trafikk	En del oljetankere	Over gjennomsnittlig vindstyrke og bølgehøyde	Lang avstand til land (140 km)	150	Middels (3,0)
Utsira nord	Svært høy trafikk, nær hovedfarled	Høyt antall oljetankere	Over gjennomsnittlig vindstyrke og bølgehøyde	Middels avstand til land (22 km)	100	Høyest (4,4)
Frøyagrunnene	Moderat trafikk	Få oljetankere	Over gjennomsnittlig vindstyrke og bølgehøyde	Svært kort avstand til land (9 km)	15	Høyere (3,1)
Olderveggen	Høy trafikk	Få oljetankere	Over gjennomsnittlig vindstyrke og bølgehøyde	Svært kort avstand til land (2 km)	20	Høyere (3,5)
Stadthavet	Lav trafikk, nær hovedfarled	En del oljetankere	Høy andel sterk vind og høye bølger	Over 40 km fra land (58 km)	100	Høyere (3,1)
Frøyabanken	Høy trafikk	En del oljetankere	Gjennomsnittlig vindstyrke og bølgehøyde	Middels avstand til land (34 km)	100	Høyere (3,6)
Nordøyan - Ytre Vikna	Lav trafikk	Svært få oljetankere	Gjennomsnittlig vindstyrke og bølgehøyde	5–15 km fra land (12 km)	20	Middels (2,3)
Træna Vest	Høy trafikk	Få oljetankere	Gjennomsnittlig vindstyrke og bølgehøyde	Over 40 km fra land (45 km)	100	Høyere (3,5)
Trænafjorden - Selvær	Høy trafikk	Få oljetankere	Under gjennomsnittlig vind-styrke og bølgehøyde	20 – 40 km fra land	20	Middels (2,9)
Gimsøy nord	Moderat trafikk	En del oljetankere	Lav gjennomsnittlig vindstyrke og bølgehøyde	Mindre enn 5 km fra land	20	Middels (2,6)
Nordmela	Moderat trafikk	En del oljetankere	Lav gjennomsnittlig vindstyrke og bølgehøyde	Mindre enn 5 km fra land	20	Middels (2,6)
Auvær	Lite trafikk, ikke lokalisert nær hovedfarleder.	Ikke lokalisert nær risikotrafikk, hovedsakelig fiskefartøy, ingen oljetankere.	Som de fleste andre områdene	5–15 km fra land	20	Lavere (1,7)
Vannøya nordøst	Lite trafikk, ikke lokalisert nær hovedfarleder.	Ikke lokalisert nær risikotrafikk, hovedsakelig fiskefartøy, ingen oljetankere.	Ligger noe skjermet	Mindre enn 5 km fra land	20	Lavere (1,3)
Sandskallen - Sørøya nord	Noe trafikk, men ikke nær hovedfarled	Lokalisert nær risikotrafikk, men få oljetankere.	Som de fleste andre områdene	5–15 km fra land	20	Middels (2,5)

Figure A.1: Research areas, traffic (Jakobsen et al., 2019)

Appendix B

Offshore wind development categories, Norway

Table B.1: Offshore wind development categories, Norway

Offshore wind development categories, Norway (NVE)		
Category A	**Category B**	**Category C**
Areas that are well-technically and economically feasible have relatively few conflicts of interest and can be linked to networks without major challenges by 2025. NVE believes that these can be opened without any significant challenges.	Areas that have challenges related to either technical aspects and / or existing land interests or natural environment. The challenges are assumed to be solved by future technology development, network measures and / or mitigating measures. NVE believes that these areas can be opened when the technology is mature enough, when the net measures have been carried out, and / or if the objections of interest can be resolved.	Areas that have many and / or large area conflicts that cannot easily be resolved by mitigating or consequential reducing measures. NVE believes that the area conflicts are still not so large that an opening of the areas is not possible, but recommends that these are not given priority in favor of areas in categories A and B.

Appendix C

AIS - General reporting inverval, class A.

Table C.1: General reporting interval, class A shipborne equipment (ITU, 2014)

Type of ship	General reporting interval
Ship at anchor or moored and not moving faster than 3 knots	3 min
Ship at anchor or moored and moving faster than 3 knots	10 s
Ship 0-14 knots	10 s
Ship 0-14 knots and changing course	$3\,\frac{1}{3}$ s
Ship 14-23 knots	6 s
Ship 14-23 knots and changing course	2 s
Ship >23 knots	2s
Ship >23 knots and changing course	2s

Appendix D

AIS message types.

According to ITU (2014) the 4 levels of message priority are described as follows:
- Priority 1 (highest priority): Critical link management messages including position report messages in order to ensure the viability of the link.
- Priority 2 (highest service priority): Safety related messages. These messages should be transmitted with a minimum of delay.
- Priority 3: Assignment, interrogation and responses to interrogation messages.
- Priority 4 (lowest priority): All other messages.

Message ID	Name	Description	Priority	Access scheme	Communi-cation state	M/B
1	Position report	Scheduled position report; (Class A shipborne mobile equipment)	1	SOTDMA, RATDMA, ITDMA(1)	SOTDMA	M
2	Position report	Assigned scheduled position report; (Class A shipborne mobile equipment)	1	SOTDMA(9)	SOTDMA	M
3	Position report	Special position report, response to interrogation; (Class A shipborne mobile equipment)	1	RATDMA(1)	ITDMA	M
4	Base station report	Position, UTC, date and current slot number of base station	1	FATDMA(3), (7), RATDMA(2)	SOTDMA	B
5	Static and voyage related data	Scheduled static and voyage related vessel data report; (Class A shipborne mobile equipment)	4(5)	RATDMA, ITDMA(11)	N/A	M
6	Binary addressed message	Binary data for addressed communication	4	RATDMA(10), FATDMA, ITDMA(2)	N/A	M/B
7	Binary acknowledge-ment	Acknowledgement of received addressed binary data	1	RATDMA, FATDMA, ITDMA(2)	N/A	M/B
8	Binary broadcast message	Binary data for broadcast communication	4	RATDMA(10), FATDMA, ITDMA(2)	N/A	M/B
9	Standard SAR aircraft position report	Position report for airborne stations involved in SAR operations, only	1	SOTDMA, RATDMA, ITDMA(1)	SOTDMA ITDMA	M
10	UTC/date inquiry	Request UTC and date	3	RATDMA, FATDMA, ITDMA(2)	N/A	M/B
11	UTC/date response	Current UTC and date if available	3	RATDMA, ITDMA(2)	SOTDMA	M
12	Addressed safety related message	Safety related data for addressed communication	2	RATDMA(10), FATDMA, ITDMA(2)	N/A	M/B
13	Safety related acknowledge-ment	Acknowledgement of received addressed safety related message	1	RATDMA, FATDMA, ITDMA(2)	N/A	M/B
14	Safety related broadcast message	Safety related data for broadcast communication	2	RATDMA(10), FATDMA, ITDMA(2)	N/A	M/B
15	Interrogation	Request for a specific message type (can result in multiple responses from one or several stations)(4)	3	RATDMA, FATDMA, ITDMA(2)	N/A	M/B
16	Assignment mode command	Assignment of a specific report behaviour by competent authority using a Base station	1	RATDMA, FATDMA(2)	N/A	B

Figure D.1: Message types 1-16 (ITU, 2014)

Message ID	Name	Description	Priority	Access scheme	Communi-cation state	M/B
17	DGNSS broadcast binary message	DGNSS corrections provided by a base station	2	FATDMA(3), RATDMA(2)	N/A	B
18	Standard Class B equipment position report	Standard position report for Class B shipborne mobile equipment to be used instead of Messages 1, 2, 3(8)	1	SOTDMA, ITDMA(1), CSTDMA	SOTDMA, ITDMA	M
19	Extended Class B equipment position report	No longer required; Extended position report for Class B shipborne mobile equipment; contains additional static information(8)	1	ITDMA	N/A	M
20	Data link management message	Reserve slots for Base station(s)	1	FATDMA(3), RATDMA	N/A	B
21	Aids-to-navigation report	Position and status report for aids-to-navigation	1	FATDMA(3), RATDMA(2)	N/A	M/B
22	Channel management(6)	Management of channels and transceiver modes by a Base station	1	FATDMA(3), RATDMA(2)	N/A	B
23	Group assignment command	Assignment of a specific report behaviour by competent authority using a Base station to a specific group of mobiles	1	FATDMA, RATDMA	N/A	B
24	Static data report	Additional data assigned to an MMSI Part A: Name Part B: Static Data	4	RATDMA, ITDMA, CSTDMA, FATDMA	N/A	M/B
25	Single slot binary message	Short unscheduled binary data transmission (Broadcast or addressed)	4	RATDMA, ITDMA, CSTDMA, FATDMA	N/A	M/B
26	Multiple slot binary message with Communi-cations State	Scheduled binary data transmission (Broadcast or addressed)	4	SOTDMA, RATDMA, ITDMA FATDMA	SOTDMA, ITDMA	M/B
27	Position report for long-range applications	Class A and Class B “SO” shipborne mobile equipment outside base station coverage	1	MSSA	N/A	M

Figure D.2: Message types 17-27 (ITU, 2014)

Appendix E

AIS data content

Table E.1: Detail of static information (IMO, 2015)

Information item	**Information generation, type and quality of information**
Static	
MMSI	Set on installation Note that this might need amending if the ship changes ownership
Call, sign and name	Set on installation Note that this might need amending if the ship changes ownership
IMO Number	Set on installation
Length and beam	Set on installation of if changed
Type of ship	Select from pre-installed list
Location of electronic position fixing system (EPFS) antenna	Set on installation or may be changed for bi-directional vessels or those fitted with multiple antennas

Table E.2: Detail of dynamic information (IMO, 2015)

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 approximately 10m
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 may not be availible.
Speed over ground (SOG)	Automatically updated from the position sensor connected to AIS. This information might not be available.
Heading	Automatically updated form 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 maneuver (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 where changed.
Rate of turn (ROT)	Automatically updated from the ship's ROT sensor or derived from the gyro. This information might not be available.

Table E.3: Detail of voyage-related information (IMO, 2015)

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 draft 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	To be manually entered at the start of the voyage, at the discretion of the master, and updated when required.

Appendix F

Areas for case study

Table F.1: Areas for traffic distribution histograms

Areas for traffic distribution histograms:	
Location Name = Frøya, Trøndelag (5.45 x 6.01 nm)	minlon = 08.0550
	minlat =63.601667
	maxlon =08.2550
	maxlat =63.701667
Location Name = Frøyabanken, Norskehavet (4.4 x 5.07 nm)	minlon = 07.368833
	minlat =63.69333
	maxlon = 07.5300
	maxlat = 63.77775
Location Name = Bjørnefjorden (6.29 x 6 nm)	minlon = 05.2879
	minlat = 60.05276
	maxlon = 05.51862
	maxlat = 60.16289
Location Name = Tristein, Trøndelag (4.36 x 4.81 nm)	minlon = 09.8010
	minlat = 64.1560
	maxlon = 09.9610
	maxlat = 64.2370
Location Name = ”West of Roan, Trøndelag (4.36 x 4.81 nm)	minlon = 09.801
	minlat = 64.1560
	maxlon = 09.9610
	maxlat = 64.2370
Location Name = ”Trondheimsfjorden, Flakk, Trøndelag (4.36 x 4.81 nm)	minlon = 10.1533
	minlat = 63.4433
	maxlon = 10.3133
	maxlat = 63.5233

Appendix G

Python Code

G.1 Main_AIS.py

```
#!/usr/bin/env python3
# -*- coding: utf-8 -*-

"""
Filename: Main_AIS.py
Created on Wed Apr 10 12:50:11 2019

@author: AmalieBu

Made as a part of the work with my Master thesis,
at NTNU, Dep. of Marine Technology, 2019
"""

import Analysis_AIS as AIS
import time
import datetime

#Add more databases if necessary, #out the ones not in use
databasepath = ('/Users/AmalieBu/Documents/NTNU/4Semester/Master/Python/AIS_InitialAnalysis/AISNOR.db')

#All methods are run from this script: 1 = Run, 0 = Don´t Run

TimeCheck = 0             # Displays First date, Last date and Number of records in database.
DataLook = 0              # Displays number of ships of each shiptype in database
DataLook2 = 0             # Displays number of unique vessels for given area and time period
VesselPlot = 0            # Visualisation of vessel traffic
VesselPlotAll = 0         # Visualisation of traffic, all vessel types with different colours
HeatMapAll = 0            # Heat plot, displays vessel density, all vessels types
VesselHistLon = 0         # Histogram lon distribution, by vessel type
VesselHistLonAll = 0      # Histogram lon distribution, all vessel types
VesselHistLat = 0         # Histogram lat distribution, by vessel type
VesselHistLatAll = 0      # Histogram lat distribution, all vessel types
Statistics = 0            # Describes positional data for timeperiod and area
MinDistObject = 1         # Min distance to object
CriticalCOG = 0           # Collision candidates based on 2nm distance and COG towards object

##################################
# Geographical area for analysis #      1: Norway, 3: Frøya, 4: Frøyabanken, 6: Bjørnefjorden,
##################################      7: Tristeinen, 8: Klungholmen, 9: Roan, 10 Flakk
Loc = 10

##################################
# Choose time window of interest #
##################################
starttime1 = '19/06/2012'            #first date of AISNOR.db 12/07/2010
endtime1 = '03/07/2012'              #last date  of AISNOR.db 31/12/2015
print(starttime1)
print(endtime1)
#print('Buoy 4')
##################################
# Choose shiptype(s) of interest #
##################################
#shiptype = [10,30,40,50,60,70,80,90]               #Choose one shiptype or more shiptypes,
shiptype = [10, 20, 30, 40, 50, 60, 70, 80, 90]     #Or choose all shiptypes
```

Figure G.1

G.2 Analysis_AIS.py

```
####################################################
#        Heat Map    - Vessel DISTRIBUTION         #
####################################################
def HeatMapAll(databasepath,minlon,minlat,maxlon,maxlat,lat0,lon0,lat1,starttime,\
               endtime,Loc_Name,shiptype,shiptypename,lonp,latp,HeatMapAll):

    inputquery = "SELECT unixtime, latitude, longitude, cast(ship_type/10 as int)*10 \
    AS shiptype FROM MessageType1 LEFT JOIN ShipRegistry ON MessageType1.userid = ShipRegistry.mmsi \
    WHERE longitude >= {minlon} AND latitude >= {minlat} \
    AND longitude <= {maxlon} AND latitude <= {maxlat} \
    AND unixtime >= {starttime} AND unixtime <= {endtime}".format(minlon = minlon,\
    minlat = minlat, maxlon = maxlon, maxlat = maxlat, starttime = starttime, endtime = endtime)

    con = lite.connect(databasepath)
    with con:
        ais_dataframe = pd.read_sql_query(inputquery, con)
    con.close()

    fig,ax=plt.subplots(figsize=(9,9))
    m = Basemap(llcrnrlon=minlon, llcrnrlat=minlat, urcrnrlon=maxlon, urcrnrlat=maxlat,\
                rsphere=(6378137.00,6356752.3142), resolution = 'f', projection = 'merc', \
                lat_0 = lat0, lon_0 = lon0, lat_ts = lat1)
    m.drawmapboundary(fill_color='white')
    m.fillcontinents(color='black', lake_color='white')
    x, y = m(ais_dataframe['longitude'].values, ais_dataframe['latitude'].values)
    xmin = minlon
    xmax = maxlon
    ymin = minlat
    ymax = maxlat
    heatmap, xedges, yedges = np.histogram2d(x, y, bins=(40,40))
    extent = [xmin,xmax,ymin,ymax]
    m.imshow(heatmap.T, extent=extent, origin='lower', alpha=0.55, cmap=cm.Blues, zorder=1, vmin=0.5, vmax=10)
    m.colorbar()

    x1,y1 = m(lonp,latp)
    m.plot(x1,y1,linestyle='none', marker="o", markersize=10, alpha=0.6, c="orange",\
           markeredgecolor="black", markeredgewidth=0.7)

    plt.title('All shiptypes - Location: %s' %(Loc_Name))
    plt.show()
    #plt.savefig('filename.png')
```

Figure G.2: Analysis_AIS.py

```
############################################################
#   HISTOGRAM All TYPES - Longitudinal DISTRIBUTION #
############################################################
def VesselHistLonAll(databasepath,minlon,minlat,maxlon,maxlat,lat0,lon0,lat1,lonp,\
                     starttime,endtime,Loc_Name,VesselHistLonAll):

    sns.set(style="white", color_codes=True)
    sns.despine(left=True)
    inputquery = "SELECT unixtime, latitude, longitude, cast(ship_type/10 as int)*10 \
    AS shiptype FROM MessageType1 LEFT JOIN ShipRegistry ON MessageType1.userid = ShipRegistry.mmsi \
    WHERE longitude >= {minlon} AND latitude >= {minlat} \
    AND longitude <= {maxlon} AND latitude <= {maxlat} \
    AND unixtime >= {starttime} AND unixtime <= {endtime}".format(minlon = minlon,\
    minlat = minlat, maxlon = maxlon, maxlat = maxlat, starttime = starttime, endtime = endtime)

    con = lite.connect(databasepath)
    with con:
        ais_dataframe = pd.read_sql_query(inputquery, con)
    con.close()

    y = np.ones(len(lonp))
    ax = sns.distplot(ais_dataframe['longitude'], bins=30, kde=True)
    ax.scatter(lonp,y*0.1, color='r',zorder=10)
    ax.set(ylabel="Number of ships", xlabel="Longitudinal position")
    plt.title('Location name: %s' %(Loc_Name))
```

Figure G.3: Histogram, longitudinal

```
############################################################
#   HISTOGRAM All TYPES  - Latitudinal DISTRIBUTION   #
############################################################
def VesselHistLatAll(databasepath,minlon,minlat,maxlon,maxlat,lat0,lon0,lat1,latp,\
                     starttime,endtime,Loc_Name,VesselHistLatAll):

    sns.set(style="white", color_codes=True)
    sns.despine(left=True)
    inputquery = "SELECT unixtime, latitude, longitude, cast(ship_type/10 as int)*10 \
    AS shiptype FROM MessageType1 LEFT JOIN ShipRegistry ON MessageType1.userid = ShipRegistry.mmsi \
    WHERE longitude >= {minlon} AND latitude >= {minlat} \
    AND longitude <= {maxlon} AND latitude <= {maxlat} \
    AND unixtime >= {starttime} AND unixtime <= {endtime}".format(minlon = minlon,\
    minlat = minlat, maxlon = maxlon, maxlat = maxlat, starttime = starttime, endtime = endtime)

    con = lite.connect(databasepath)
    with con:
        ais_dataframe = pd.read_sql_query(inputquery, con)
    con.close()
    y = np.ones(len(latp))
    ax = sns.distplot(ais_dataframe['latitude'], bins=30, kde=True)
    ax.scatter(latp,y*0.2, color='r',zorder=10)
    ax.set(ylabel="Number of ships", xlabel="Latitudinal position")
    plt.title('Location name: %s' %(Loc_Name))
```

Figure G.4: Histogram, latitudinal

```
#############################
#       Statistics          #
#############################
def Statistics(databasepath,minlon,minlat,maxlon,maxlat,lat0,lon0,lat1,\
                     starttime,endtime,shiptype,shiptypename,Loc_Name,Statistics):

    inputquery = "SELECT unixtime, latitude, longitude FROM MessageType1 \
    WHERE longitude >= {minlon} AND latitude >= {minlat} \
    AND longitude <= {maxlon} AND latitude <= {maxlat} \
    AND unixtime >= {starttime} AND unixtime <= {endtime}".format(minlon = minlon,\
    minlat = minlat, maxlon = maxlon, maxlat = maxlat, starttime = starttime, endtime = endtime)

    con = lite.connect(databasepath)
    with con:
        ais_dataframe = pd.read_sql_query(inputquery, con)
    con.close()

    print(ais_dataframe['latitude'].describe())
    print(ais_dataframe['longitude'].describe())
```

Figure G.5: Statistics

```
##################################
#       Distance to object       #
##################################

def MinDistObject(databasepath,minlon,minlat,maxlon,maxlat,lat0,lon0,lat1,\
                    starttime,endtime,shiptype,shiptypename,Loc_Name,lonp,latp,\
                    MinDistObject):

    inputquery = "SELECT unixtime, latitude, longitude, cog, sog, mmsi, name, cast(ship_type/10 as int)*10 \
    AS shiptype FROM MessageType1 \
    LEFT JOIN ShipRegistry ON MessageType1.userid = ShipRegistry.mmsi \
    WHERE longitude >= {minlon} AND latitude >= {minlat} \
    AND longitude <= {maxlon} AND latitude <= {maxlat} \
    AND unixtime >= {starttime} AND unixtime <= {endtime} \
    AND sog >= 1.0".format(minlon = minlon, minlat = minlat,\
    maxlon = maxlon, maxlat = maxlat, starttime = starttime, endtime = endtime)

    con = lite.connect(databasepath)
    with con:
        ais_dataframe = pd.read_sql_query(inputquery, con)
    con.close()

    lat_vessel, lon_vessel = (ais_dataframe['latitude'].values,\
                              ais_dataframe['longitude'].values)
    lat_obj, lon_obj = (latp,lonp)
    distance = haversine.distance(lat_vessel, lon_vessel, lat_obj, lon_obj)
    distance_nm = distance/1852.0
    A = np.zeros((len(distance),2))
    A[:,0] = distance
    A[:,1] = distance_nm
    A = np.concatenate((ais_dataframe,A),axis=1)
    A = A[A[:,8].argsort()]           # Sort by distance
    df = pd.DataFrame(data=A, columns = ['unixtime','latitude','longitude','cog',\
                                         'sog','mmsi','name','shiptype','dist [m]','dist [nm]'])

    print(df.iloc[0:50,[1,2,3,7,9]])
    print(df.iloc[0:5,[4,5,6,7,9]])
    print(df.mean(axis = 0))
    print(df.std(axis = 0))
```

Figure G.6: Distances

```
######################################
#       Critical heading             #
######################################

def CriticalCOG(databasepath,minlon,minlat,maxlon,maxlat,starttime,endtime,latp,lonp):

    inputquery = "SELECT latitude, longitude, cog, cast(ship_type/10 as int)*10 \
    AS shiptype FROM MessageType1 \
    LEFT JOIN ShipRegistry ON MessageType1.userid = ShipRegistry.mmsi \
    WHERE longitude >= {minlon} AND latitude >= {minlat} \
    AND longitude <= {maxlon} AND latitude <= {maxlat} \
    AND unixtime >= {starttime} AND unixtime <= {endtime} \
    AND sog >= 1.0".format(minlon = minlon, minlat = minlat,\
    maxlon = maxlon, maxlat = maxlat, starttime = starttime, endtime = endtime)

    con = lite.connect(databasepath)
    with con:
        ais_dataframe = pd.read_sql_query(inputquery, con)
    con.close()

    lat_vessel, lon_vessel = (ais_dataframe['latitude'].values,\
                              ais_dataframe['longitude'].values)
    lat_obj, lon_obj = (latp,lonp)
    distance = haversine.distance(lat_vessel, lon_vessel, lat_obj, lon_obj)
    distance_nm = distance/1852.0
    A = np.zeros((len(distance),6))
    A[:,0] = distance_nm
    A[:,1:-1] = ais_dataframe
    A = A[A[:,0].argsort()]

    n = 25 #Number of vessels within 20 nm
    lat_0 = A[0:n,1]
    lon_0 = A[0:n,2]
    cog_0 = A[0:n,3]/10
    lat_2, lon_2 = (latp,lonp)

    count = 0
    for i in range(0,n):
        angle = bearing.alpha(lat_0[i],lon_0[i],lat_2[0],lon_2[0],cog_0[0])*10
        print(angle)
        if 0 <= angle <= 15 or 345 <= angle <= 360:
            count += 1
            print('collision candidate')
        else:
            print('ok')
    print( 'The number of collision candidates is: %s of %s vessels within 2.0 nm' %(count, n))
```

Figure G.7: Heading relative to object

G.3 haversine.py

```
#!/usr/bin/env python3
# -*- coding: utf-8 -*-
"""
Filename: haversine.py
Created on Sun May 19 10:42:21 2019

@author: AmalieBu

Made as a part of the work with my Master thesis,
at NTNU, Dep. of Marine Technology, 2019
"""

import numpy as np

#Haversine formula (vector implementation):
def distance(lat_vessel,lon_vessel, lat_obj, lon_obj):

    #R = 6373.0      # approximate radius of earth in km
    R = 6372800.0     # approximate radius of earth in m

    lat_vessel = lat_vessel*np.pi/180.0
    lon_vessel = np.deg2rad(lon_vessel)
    lat_obj = np.deg2rad(lat_obj)
    lon_obj = np.deg2rad(lon_obj)

    distance = np.sin((lat_obj - lat_vessel)/2)**2 + np.cos(lat_vessel)*np.cos(lat_obj)\
               * np.sin((lon_obj - lon_vessel)/2)**2

    return 2 * R * np.arcsin(np.sqrt(distance))
```

Figure G.8: Distance to object

G.4 bearing.py

```
#!/usr/bin/env python3
# -*- coding: utf-8 -*-
"""
Filename: bearing.py
Created on Sun May 19 17:36:38 2019

@author: AmalieBu

Made as a part of the work with my Master thesis,
at NTNU, Dep. of Marine Technology, 2019
"""

import numpy as np
from geographiclib.geodesic import Geodesic


def alpha(lat_0,lon_0,lat_2,lon_2,cog_0):

    azi1 = Geodesic.WGS84.Inverse(lat_0, lon_0, lat_2, lon_2)['azi1']
    if type(cog_0) == str:
        if azi1 < 0:
            return np.radians(360 + azi1)
        else:
            return np.radians(azi1)
    else:
        if azi1 < 0:
            azi1 = 360 + azi1
        if cog_0 >= azi1:
            return np.radians(360 - (cog_0 - azi1))
        else:
            return np.radians(azi1 - cog_0)
```

Figure G.9: Calculation of bearing angle

Calculation of bearing angle based on the method used by Nordkvist (2018).