NTNU
Norwegian University of Science and Technology
Department of Marine Technology

M.Sc.THESIS

Title:	**Delivered:**
AIS Technology as Support for the Risk Picture in Naval Transport	June 14th, 2011
	Availability: Open
Student: Christian Skollevold (68 41 38)	**Number of pages:** 95

Abstract:

This thesis investigates the feasibility of using AIS technology as a support for determining the risk picture in naval transport. Traffic data is gathered from the AIS interface and compared with accident data from NMD (Norwegian Marine Directorate) to form a statistical foundation for a risk model.

A risk model based on conditional probablities is then developed based on both data from the Norwegian waters as a whole, as well as data from the Bergen seaward approach. The model is then tested on the inner Oslo fjord, providing promising, if not exact, results.

A number of known accidents are also investigated trying to find either common traffic patterns when accidents occur or common traits that "define" an accident. Traffic patterns will help develop a completely dynamic risk model and traits that define accidents will help reveal unreported accidents. Both of these areas are considered to be major benefits of the AIS system, though unfortunately not much work have been published on these topics.

The main outcomes of this project are:
- An overview over published reports and articles regarding AIS and risk analysis
- A working, though not exact, risk model with suggestions for improvements
- An overview over accident traits and suggestions for how to reveal these from larger data sets
- Suggestions for improvements in the online AIS interface

It is concluded that AIS technology greatly improves both the statistical foundation for risk models, as well as the possibility to apply the models to a correct traffic pattern. With some minor improvements in the AIS interface, revealing unreported accidents will also become possible. More work in topics regarding practical use of AIS data is highly recommended.

Keyword:

AIS, ship accident statistics, risk model

Advisor:

Bjørn Egil Asbjørnslett

Address:
NTNU
Department of Marine Technology
N-7491 Trondheim

Location
Marinteknisk Senter
O. Nielsens vei 10

Tel. +47 73 595501
Fax +47 73 595697

NTNU

AIS technology as support for the risk picture in naval transport

Revealing unreported accidents from AIS data, and using traffic and accident data for the Norwegian waters to develop a risk model for a given fairway.

Christian Skollevold, NTNU

Monday, June 13, 2011

Preface

This report was written in spring 2011 and is the result of the undersigned's master thesis at NTNU. The thesis consists of an in-depth look at practical use of traffic data from AIS for risk analysis and revealing unreported accidents in the Norwegian waters.

Despite building on the project work from autumn 2010 (Ombler & Skollevold, 2010), the project had a steep learning curve and consisted initially of literature study of reports with a similar scope. A short summary of the most relevant reports is given as an introduction; several more are referenced in the bibliography. The online AIS interface also yielded some initial hurdles, though these were quickly overcome. Finally, a vast amount of data is given by the AIS and accident database – creating problems with deciding what to analyze and what to discard.

The resulting risk model shows promising, though not exact, results and suggestions for improvements are given. Unfortunately, no straight-forward way of revealing unreported accidents could be found, but suggestions for improvements in the AIS interface that would simplify this process are described.

This project work has, combined with courses in risk analysis, served as a good introduction to how a real life risk analysis is performed.

I would like to thank Håvard Gåseidnes from the Norwegian Maritime Directorate and Tommy Haugsnes the Norwegian Coastal Administration for valuable help and information when asked. I would also like to give a special thanks to my supervisor Bjørn Egil Asbjørnslett for invaluable guidance during the work with this project thesis.

Trondheim, 6/13/11

Christian Skollevold

Summary

The first part of this report contains a break-down of accident and traffic data from the Norwegian waters and this data is then used for a statistical accident model using traffic data from AIS as input. The last part of the report investigates the feasibility of using real-time AIS data to develop a completely dynamic risk model and whether AIS is useful for revealing unreported accidents.

Passenger and cargo vessels were investigated and the following factors were found to increase the likelihood of a vessel being involved in an accident in the Norwegian waters during a one year period (i.e. not per nautical mile of total sailing time):

- Vessels under 100 meters have a higher accident probability
- Norwegian flagged vessels have a higher accident probability
- Vessels older than 20 years have a higher accident probability

External factors were shown to affect accident probability in the following way:

- Accident probability increase in winter
- Wind speed and wave height are not major accident indicators in the Norwegian waters (i.e. they are likely to increase accident probability, but most accidents happen narrow coastal water with fair weather – indicating that fairway complexity is a larger factor)
- Accident probability is higher with low visibility
- Accident probability is higher at late evening, early morning and late afternoon, this is possibly related to shift changes

The proposed risk model divides risk influencing factors into two groups; fairway related factors (fairway complexity, traffic patterns, weather, etc) and traffic related factors (data available from AIS, i.e. the exact number of each vessel type sailing in the fairway). The model is based on the assumption that a vessel with given characteristics (age, size, flag, etc) that have a higher accident probability in one area also will have a higher accident probability in another area.

The traffic factor was calculated using conditional probabilities from vessel traffic from 2010 and accident statistics from 2007 – 2009. The use of data from different years could result in inaccuracies, though the model still gave promising results when testing for the inner Oslo Fjord.

The fairway factor was simply calculated from a similar fairway (the Bergen approach), but comments on how to develop this factor using conditional probabilities are given. When testing for the inner Oslo fjord the following results were found for 2010:

Number of accidents from risk model	2.58
Number of accidents from statistical average	1.83
Correct accident number for 2007-2009	4.67

One feature of this risk model is that not only the expected number of accidents is calculated; the distribution of accidents over vessel types is also given. Despite not giving exact results, the model proved to predict the general trend fairly well – and further work to tune the model is recommended. Comments on the different error sources, and how to overcome them, are given in the report.

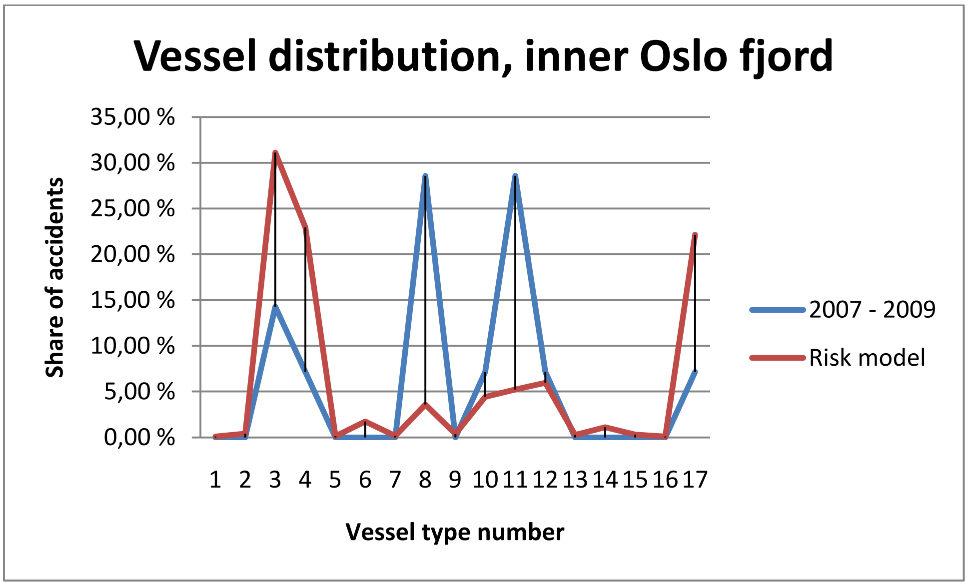


Figure 1 Vessel distribution, inner Oslo fjord

Finally, AIS data from registered accidents were investigated trying to find methods of revealing unreported accidents. The major accident indicator was shown to be drops in speed over ground and it was attempted to develop an algorithm for revealing speed drops from the historical AIS data. The method used proved to give good results for vessels in open sea, but proved not to be feasible in coastal waters. Several recommendations for improvements in the AIS interface that would make the historical data more useful are given, the two main ones being:

- Capability to import .tsv or .csv files and such create filters using data directly from a spreadsheet (this would simplify the process of making advanced filters)
- Setting for the Douglas-Peucker algorithm. As of today more data is used for the graphical display than what is exported as raw data – the ability to export all data points for a limited time period would greatly enhance the usefulness of the historical AIS data

Table of Contents

Tables and Figures

1 Introduction

Accidents happen without warning and in spite of all attempts by regulators to curb the problem. During the work with this project one of the largest oil spills in Norway in the recent years was, the Godafoss accident, happened in a narrow strait in an area widely used for recreation. In this case the captain admitted to having made a navigational error, leaving regulators with the everlasting question; "how can we prevent these situations if all it takes is one man's five minute long dereliction for it to happen?"

On the other hand, it is reasonable to assume that many near-accidents and accidents without visible consequences will go by unreported. A common break-down of near-accidents in the workplace is in three phases:

1. The surprised phase – "wow, that was close!"
2. The "did anyone see it?" phase – "can I get away with this?"
3. The "remove all traces" phase – cleaning up, making sure nothing is left to indicate what happened

There is no reason to think that an OOW who made a course change in the last second would react any different. After all, why face the possible consequences if you don't have to? For regulators this is a problem as less data is reported to help identify factors that may cause an accident in the future.

There is no doubt, however, that the best way to prevent accidents is by understanding them – and to understand them one have to analyze both accidents and near-accidents to find the common denominators. In this project reported accidents have been compared with vessel traffic trying to identify the vessels that are, statistically, most at risk. It has also been attempted to find common accident traits that can be used for revealing unreported accidents.

1.1 Scope and main activities

The scope was defined from a list of seven main areas that was to be investigated. These are given below (in Norwegian). The full problem description is given in the appendixes.

1. *Beskrivelse av AIS og LRIT teknologi for monitorering av skipstrafikk, inkludert de muligheter og begrensninger som ligger i teknologiene.*
2. *Etablere en strukturert oversikt over AIS data for et gitt farledsområde for en gitt tidsperiode.*
3. *Analysere identifiserte skipsulykker i det samme farledsområde og tidsperiode, i forhold til registrert informasjon i skipsulykkesdatabaser, ulykkesrapport og fra AIS data.*
4. *Undersøke sammenhengen mellom ulykker og skipstrafikk for å se om det er noe mønster i trafikken som kan indikere høyere sannsynlighet for ulykker.*
5. *Test av risikomodell basert på AIS data, sammenlignet med faktiske ulykkestall for norske farvann.*
6. *Undersøke sammenhengen mellom vær og vind og erfarte ulykker. Er det spesielle værforhold som går igjen i de forskjellige ulykkene?*
7. *Utarbeide forslag til hvordan korreksjonsfaktorer for underrapportering for relevante skip/ flagg/områder kan utvikles basert på AIS/LRIT informasjon.*

1.2 Structure

To fulfil the given objectives, this thesis will consist of four parts:

1. The first part is an introduction to the technologies and a short summary of previous work with a similar scope as this report.
2. The second part compares accident statistics for the Norwegian waters with data from AIS/weather stations/etc to create a statistical foundation for the risk model.
3. The third part presents the suggested risk model and uses traffic data for the inner Oslo fjord to predict the number of annual accidents.
4. The last part investigates the feasibility to use AIS data for revealing unreported accidents

The individual parts can be read successively or separately and does not expect the reader to have read the previous parts.

1.3 Limitations

Despite having full access to both AIS and accident statistics, some limitations do exist. First, the use of the Douglas-Peucker algorithm (described later) for cleaning the exported traffic data created many problems throughout the project work. Also, when using the vessel break-down chosen for the risk model, accident statistics for entire Norway had to be used to get a plausible distribution of vessels involved in accidents. This leads to the model being based on total annual traffic data for entire Norway – a choice that introduced a large error source to the model. If the project was to be done again, another method of describing vessel traffic would have been chosen. This is commented on in the report.

Finally, a significant amount of time was spent trying to get an overview over similar work in this area and understand how the traffic data can be used to improve risk models. It has been attempted to document these areas as well as making several suggestions for further work for creating a working risk model.

Initially, accident statistics was only available for 1981 – 2009 and statistics for 2010 was found after the work with the risk model had started. As AIS data is only available for two years back in time, the model is based on accident statistics for 2007 – 2009 and traffic data from 2010. It is not clear whether this introduced error sources to the model.

This report, and the bibliography, is hoped to give a good foundation for further work in this area.

2 Background

A short introduction to AIS and LRIT is given below, as well a short summary of previous work in using traffic data as a basis for risk analysis. For more information the reader is referred to other sources (see bibliography).

2.1 Automatic Identification System (AIS)

AIS is an automatic tracking system that broadcasts information about the vessel, most notably its position, speed and course, over the VHF frequency band. This information is broadcasted automatically at fixed intervals and can be picked up by any AIS capable chart plotter (in reality all nearby ships and VTS stations). AIS is a supplement to the marine radar, which is still regarded as the primary method of collision avoidance.

Class A AIS systems generally transmit the following data (Easy AIS):

AIS transceiver sends the following data every 2 to 10 seconds depending on vessels speed while underway, and every 3 minutes while vessel is at anchor. This data includes :

- *MMSI number of vessel - vessel's unique identification*
- *Navigation status - "at anchor", "under way using engine" or "not under command"*
- *Rate of turn - right or left, 0 to 720 degrees per minute*
- *Speed over ground - 0.1 knot resolution from 0 to 102 knots*
- *Position accuracy*
- *Longitude - to 1/10000 minute and Latitude - to 1/10000 minute*
- *Course over ground - relative to true north to 0.1 degree*
- *True Heading - 0 to 359 degrees from eg. gyro compass*
- *Time stamp - UTC time accurate to nearest second when this data was generated*

Not all of above data is displayed (Quantity of shown data is software of the Chartplotter).

- *Typically you can see on the chartplotter following data :*
- *MMSI number of vessel - vessel's unique identification*
- *Speed over ground - 0.1 knot resolution from 0 to 102 knots*
- *Course over ground - relative to true north to 0.1 degree*

In addition, the following data is broadcast every 6 minutes:

- *MMSI number - vessel's unique identification*
- *IMO number*
- *Radio call sign - international radio call sign assigned to vessel*
- *Name - Name of vessel, max 20 characters*
- *Type of ship/cargo*
- *Dimensions of ship - to nearest meter*
- *Location of positioning system's (eg. GPS) antenna onboard the vessel*
- *Draught of ship - 0.1 meter to 25.5 meters*
- *Destination - max 20 characters*
- *ETA (estimated time of arrival) at destination - UTC month/date hour:minute*

SOLAS requires AIS to be fitted on all passenger ships and all international voyaging ships with GT > 300 tons. The cheaper class B transmitters are designed for carriage by sub-SOLAS vessels and broadcast less information at longer intervals. AIS signals can, in many but not all parts of the world, be picked up by satellites, a technology referred to as S-AIS.

The main problems with AIS are that the transmitter can be turned off (if the captain does not want the vessel to be seen by the VTS), that AIS data is freely available online (and used by pirates for identifying vessels) and that human errors in setting up the system on the vessel may result in incorrect data being reported. Despite of these drawbacks, AIS is generally regarded as a positive contribution to ship safety.

2.2 Long Range Identification and Tracking (LRIT)

LRIT could, in many ways, be seen as the successor of AIS though these will two will live side by side for years to come. The two main differences are that LRIT is satellite based (thus available everywhere) and doesn't broadcast data publicly (LRIT data is only available to institutions with a governmental approval and can guarantee confidentiality). Another big difference is that one must only report the vessel position over LRIT four times per day, as opposed to the (almost) continuous broadcasting by AIS. Finally, as LRIT receivers can only be used by governmental approved institutions, this data will not be displayed on other vessel's chart plotters.

LRIT is required for the following ship types who are on international voyage and under a flag that has contracted to the IMO:

- All passenger ships including high-speed craft
- Cargo ships, including high speed craft of 300 gross tonnage and above
- Mobile offshore drilling units

As one can see from the above, most vessels will be equipped with both AIS and LRIT. Work is being done to incorporate LRIT data into already existing AIS systems, and such these two will complement each other. Over time it is reasonable to assume that the wish for privacy (to avoid pirates) will result in LRIT taking over as the main means of reporting position, and AIS only being mandatory when in high traffic areas or approaching port.

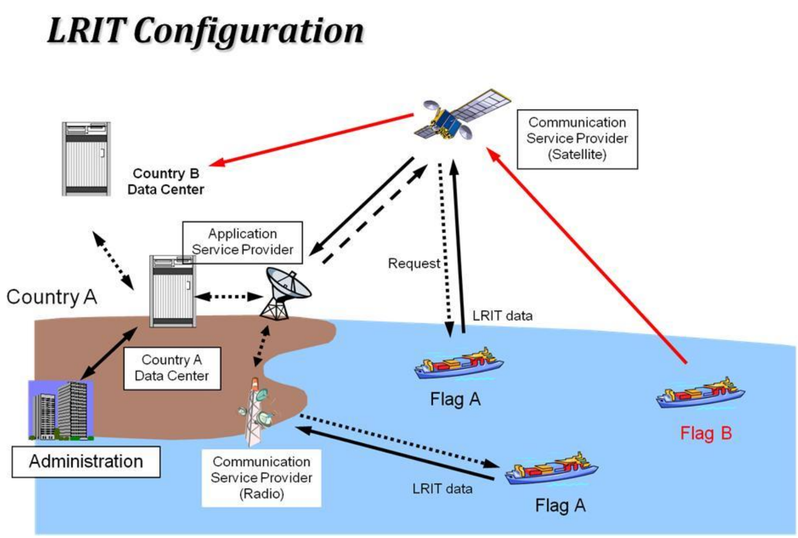
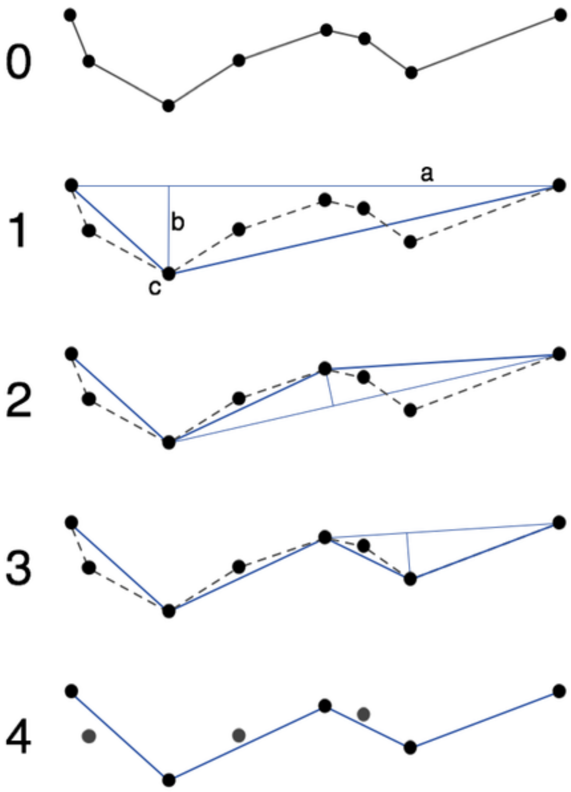


Figure 2 LRIT configuration (ProNav)

2.3 Douglas-Peucker Algorithm

In the help section of the AIS interface it is mentioned that *"to save space and processing time, the "tails" are thinned using the well known "Douglas-Peucker algorithm". With this algorithm "unnecessary" points where the vessel travels along a straight line is removed whereas points where the vessel is turning is preserved."* As much as this improves performance it also reduces number of data points and, possibly, reduces the capability to use AIS for finding unreported accidents. As far as real-time data is concerned, no data simplification is performed.

The algorithm works by setting a minimum distance, ε, that defines the minimum distance from the "new line" that is required for a point to be included. The steps are described below.



0. The original line with all data points is loaded.
1. A line is drawn from the first to the last point, and the point the furthest away from this line is found. If the distance *b* is smaller than the previously defined ε all points are discarded and the line displayed as straight. If not, the point *c* is kept.
2. The point furthest from the new line is identified and the distance is once again compared to the defined ε. If smaller the point is discarded, if larger the point is kept.
3. Step 1 and 2 is repeated as long as points that are further away from the line than ε is found. Note that the line is changing for each iteration, so a point that used to be within this distance can suddenly become significant.
4. Finally, when all points outside of the line are within the distance ε, the line is printed and insignificant points discarded.

Figure 3 Douglas Peucker algorithm (Wikipedia)

An obvious problem with the use of this algorithm is that smaller course deviations will not be displayed. This is, of course, not a problem when looking at a vessel that is mid sea, but for vessels navigating in narrow fairways this could result in loss of important data. Also, changes in speed or sudden, but small, avoiding actions will be omitted from the historical AIS data. It could not be found, however, a detailed description of how the algorithm is being used or what the threshold for omitting a point is.

2.4 Previous studies on grounding/collision avoidance using AIS data

Some work has already been done in this area and the most relevant published papers are summarized below to provide some background. The papers given below are not directly referenced in the text, though they provided valuable information for my own work.

2.4.1 Traditional Formulas

Traditionally, the probability of grounding or collision has been calculated by estimating the number of *accident candidates* (vessels that are on a grounding/collision course where an accident will happen if no actions are carried out) and then multiplied this with a *causation probability* (the fraction of accident candidates that will result in an accident). This gives the following formula for accident frequency:

$$N_{accident} = P_{causation} N_{accident\ candidates}$$

The number of accident candidates is often estimated by assuming that vessels are normal distributed over the breadth of the fairway, though some work has been put into obtaining an actual distribution from AIS data (Kujala, Hänninen, Arola, & Ylitalo, 2008). The causation probability can be found by either using accident data (*scenario approach)* or by developing a FTA/BBN for the involved vessels (*synthesis approach*). Some variations of this method exist, mostly regarding estimating number of accident candidates. These approached was studied in detail in the pre-work (Ombler & Skollevold, 2010), and are not described further.

The problem with these methods is that they answer the question *"What is the probability of an accident occurring over a given time-frame, given that the vessel traffic remains unchanged?"*. A more interesting question (for VTS and OOW) would be *"What is the probability right now of an accident being about to happen, and which vessels are most at risk?"*. This kind of model can only be developed using real-time AIS data.

2.4.2 Study on collision avoidance in busy waterways using AIS data

In this paper the authors attempt to develop a dynamic risk model (a risk model that, as opposed to statistical models, changes with time and traffic patterns) for vessel collisions. The paper starts by defining two important concepts in regards to collision (and also grounding), both being similar to the ones used for traditional risk analysis.

- Encounter: The event when two vessels are close enough for the situation to be considered an undesirable event, regardless of whether it results in an accident or not. Traditionally an encounter is determined by applying the concept of ship domain in relation to ship traffic distribution. In other words, an encounter occurs every time a vessel enters a safety domain defined around another vessel. The number of encounters in a cross-traffic waterway can be estimated by predicting the ship traffic distribution (Pedersen P. T., 2002).

- Probability: Since not all encounters will lead to an accident, it is necessary to calculate the probability of an accident given an encounter. This can be found from statistics or through simulations.

The authors suggest using a statistical risk model (SAMSON – Safety Assessment Model for Shipping and Offshore in the North Sea) (Maritime Research Insitute Netherlands) for the probability, combined with multipliers from the AIS data to achieve a dynamic risk model. The suggested multipliers are (as these are generally considered as the three key parameters of collision avoidance):

- CPA – Closest Point of Approach, defined as *the closest distance two vessels will come to each other based on their current course and speed.*

- TCPA – Time to Closest Point of Approach, defined as *time until the closest point of approach for two vessels.*

- Encounter Angle, course difference divided into three groups (0-60^o, 60-150^o and 150-180^o) to differentiate between overtaking, crossing and head-on. Statistically, crossing is more dangerous than head-on which, in turn, is more dangerous than overtaking.

The drawback of this method is that encounters have to be identified manually before the risk calculation can be performed, and the author only calculates the risk for 20 encounters in a limited area. This makes it hard to confirm the validity of the model, as the total number of encounters in the area over a longer time-frame is not known. It is, however, likely that the model would be useful for a VTS as high-risk vessels are identified.

2.4.3 Analysis of the marine traffic safety in the Gulf of Finland

In this paper, a different approach is chosen. The AIS data is merely used for finding the ship traffic distribution in the waterway, the risk is then calculated using Pedersen's model (Pedersen P. T., 2002). The authors do stress that the paper "can be considered as a good start to more profound analysis of accident risks in the area" and only general ideas regarding subdivision of ships, accidents, etc was used.

2.4.4 Probability modeling of vessel collisions

This paper picks up the thread from the one above and presents a geometrical model that uses a molecular collision model. In short the ship domain is now dependent on vessel size, type and speed with causation probabilities still being used for calculating the number of accidents.

2.4.5 Statistical Analysis of Motion Patterns in AIS Data: Anomaly Detection and Motion Prediction

This paper presents a statistical analysis of vessel motion patterns based on AIS data. Motion patterns are extracted from the historical AIS data (which basically gives which fairway vessel of a certain size/type will choose and at what speed it will sail) and using this data one can detect anomalies. These vessels should trigger an alarm at the VTS as it could be an early sign of the vessel being an accident candidate.

Using the historical data one can also predict the motion of other vessels and such provide valuable input to the officer on watch.

3 Traffic and Accident statistics for the Norwegian waters

As a basis for the risk model both accident and traffic statistics for the Norwegian waters were developed. It was also attempted to develop similar statistics for a smaller area or a fairway, though large variations in the accident statistics for different areas indicate that the data set is not large enough for one fairway to be representative. This would have to be solved by finding a high enough number of fairways to get an accident picture similar to that of Norway as a whole.

As an initial test of the feasibility of using AIS and accident data as a basis for risk analysis it was decided to base the analysis on data for the Norwegian waters as a whole. The drawbacks of using this method is commented on under the risk model discussion.

3.1 Accident statistics

The public Norwegian Marine Directory (NMD) database contains all registered accidents (both vessels in Norwegian waters and Norwegian vessels abroad) from 1981 through 2009. To gain an overview of accident types and the involved vessels, accident statistics for the Norwegian water for 2007 through 2009 were developed. By comparing these statistics to standard vessel traffic statistics, one can determine which vessels are most likely to be involved in an accident. This is comparable to work done by DNV (Eide, et al.), though the DNV project only looked into oil tankers (in fairly great detail) and also included consequences. The approach used in the following is thus both simpler and broader, making it more feasible for getting a general idea of the risk level for either an area or a certain vessel. By also including weather and waters in the analysis the risk becomes somewhat dynamic (a completely dynamic risk model would have to include all factors, including other vessels in the fairway at the moment of the analysis).

	2007		2008		2009		Total	
January	13	7,1 %	21	9,3 %	19	7,0 %	53	7,8 %
February	12	6,6 %	15	6,7 %	28	10,3 %	55	8,1 %
March	9	4,9 %	16	7,1 %	32	11,7 %	57	8,4 %
April	7	3,8 %	21	9,3 %	18	6,6 %	46	6,8 %
May	18	9,9 %	17	7,6 %	13	4,8 %	48	7,1 %
June	18	9,9 %	11	4,9 %	16	5,9 %	45	6,6 %
July	8	4,4 %	19	8,4 %	33	12,1 %	60	8,8 %
August	20	11,0 %	17	7,6 %	28	10,3 %	65	9,6 %
September	15	8,2 %	17	7,6 %	21	7,7 %	53	7,8 %
October	20	11,0 %	23	10,2 %	22	8,1 %	65	9,6 %
November	30	16,5 %	20	8,9 %	27	9,9 %	77	11,3 %
December	12	6,6 %	28	12,4 %	16	5,9 %	56	8,2 %
Total	**182**	**100,0 %**	**225**	**100,0 %**	**273**	**100,0 %**	**680**	**100,0 %**

Table 1 Accidents by Month

The total number of accidents for the Norwegian waters is given above. It should be noted that the total number of accidents is rising steadily despite a change in the NMD regulations before 2009 that raised the bar for reporting. The numbers for 2009 should thus have been lower than the preceding years.

By breaking the accidents into months and vessel type, a quite clear trend can be seen with passenger vessels peaking at summer and cargo vessels peaking at fall/winter. This is could be related to traffic as passenger traffic is higher in summer (thus more accidents) and cargo traffic fairly evenly distributed (thus more accidents when the weather is bad).

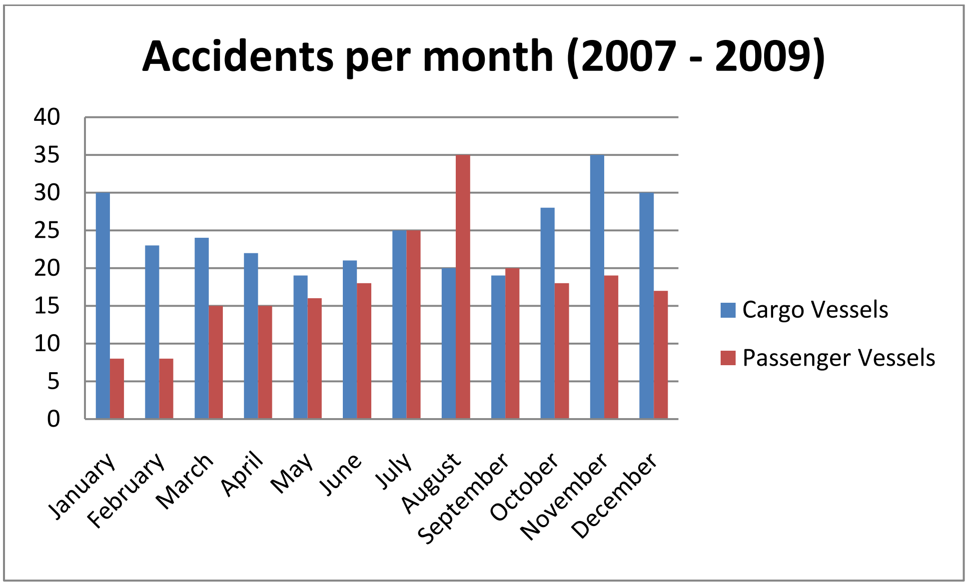


Figure 4 Accidents per Month

Breaking accidents into type also gives a reasonable result. Most passenger vessels in Norway are ferries sailing the same fairway every trip, thus the likelihood of grounding accidents are lower than that of a cargo vessel sailing a fairway for the first time. Contact damage is higher for passenger vessels due to the higher number of port calls, while the collision rate is quite similar for both vessel types. The category "other" contains capsizing, leaks, environmental damage, etc – these were not investigated as they are not relevant to AIS data.

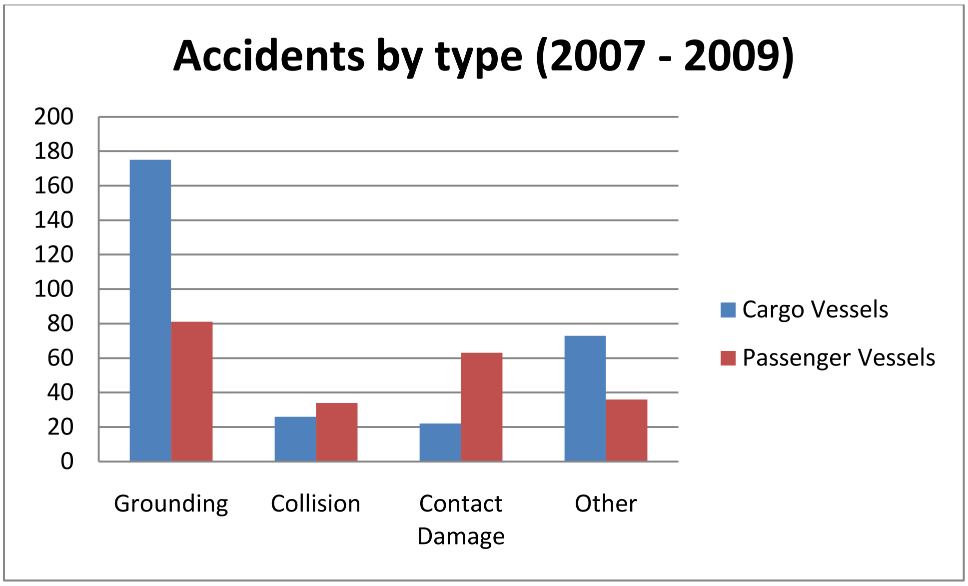


Figure 5 Accidents by Type

3.2 Traffic statistics

At first a break-down of all vessels involved in accidents was made, showing that cargo and passenger vessels are most common. Almost a quarter of the vessels involved in an accident were fishing vessels, though it was decided to only use cargo and passenger vessels in the subsequent analysis. The vessel break-down is given below.

Fartøystype	Vessel type	Number	Percentage
Lasteskip	Cargo vessel	296	43,5 %
Passasjerskip	Passenger vessel	214	31,5 %
Fiskefartøy	Fishing vessel	151	22,2 %
Fritidsfartøy	Leisure vessel	9	1,3 %
Flyttbar innretning	Moveable installation	8	1,2 %
Ukjent	Unknown	2	0,3 %
Total		680	100,0 %

Table 2 Accidents by Vessel Type

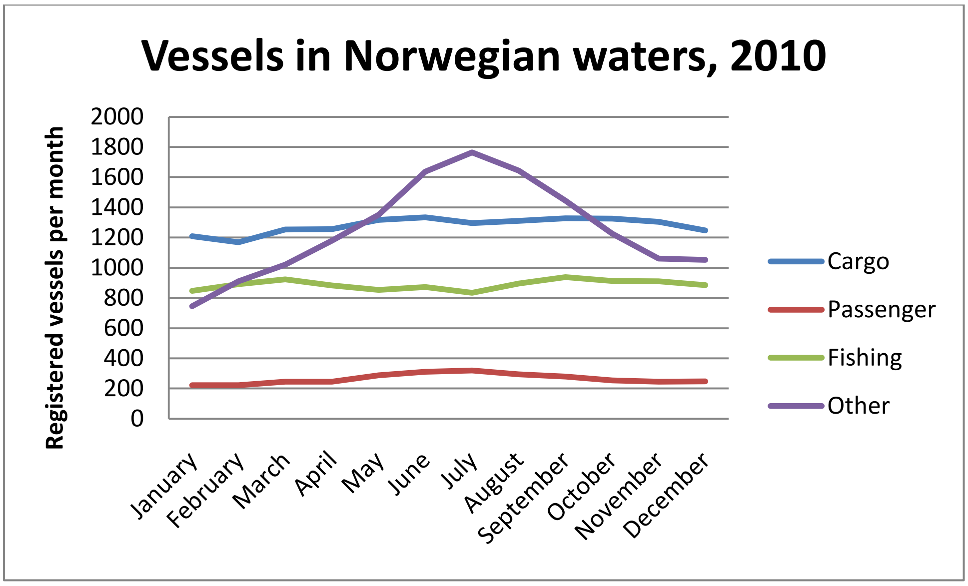


Figure 6 Vessels in Norwegian Waters

Using AIS data from 2010 the number of vessels registered in Norwegian waters per month was recorded. These numbers does not take into account the actual time spent in Norway, thus both a vessel that has all port calls in Norway and a vessel that only has one port call in Norway will count as "one" in the above graph. This does, however, show the distribution of the different vessels and the seasonal variations. Also, only vessels that had a registered IMO number are included.

It should also be noted that total number suggested by the above graph will be exaggerated as a vessel that sails in Norway all year will be counted twelve times (once per month).

A drawback of using AIS data is that all vessel data is manually entered by the vessel management (as opposed to the accident data where the data is entered by NMD). It is reasonable to assume that the vessels that have a given vessel category are correct, the uncertainty comes from the category labeled "other". This includes "blanks" (vessels with no data entered), but also a number of other named categories. By investigating these further it seems like smaller vessels that are passenger vessels by NMD standard (fishing boats from a resort, sea rafting boats, etc) are often registered as a "pleasure craft" in the AIS data. It is easy to see why the vessel owner would choose this category (as a twenty foot RIB doesn't "feel" like a passenger vessel), but it does create an inconsistency between the two databases used. This also helps explaining why the "other" category peaks mid-summer while the passenger vessel category is relatively unchanged, as most vessels in the passenger vessel category would be ferries (that would also be traveling in winter, though some of them with less port calls) and the increase would be foreign cruise ships. The increase in smaller passenger vessels, however, would be part of the reason for the peak in "other" category.

Finally, the total number of accidents per 100 vessels was calculated showing a high peak for passenger vessels in summer and a, at first sight, relatively flat graph for cargo vessels. It should be noted that these are accident numbers for three years and traffic data for one year (i.e., the number of annual accidents per year would be a third of what the graph suggests).

The reason for the peak in passenger vessel accidents is explained above. Part of the reason is that some of the accidents where the vessel was registered as a "passenger" vessel are registered as "other" in the traffic data and part of the reason is that many ferries increase number of port calls but not the number of actual ferries. This means that the "distance traveled" will increase more than number of vessels, resulting in a higher probability of an accident per vessel. It does, however, not necessarily indicate an increased accident risk per voyage or sea mile traveled.

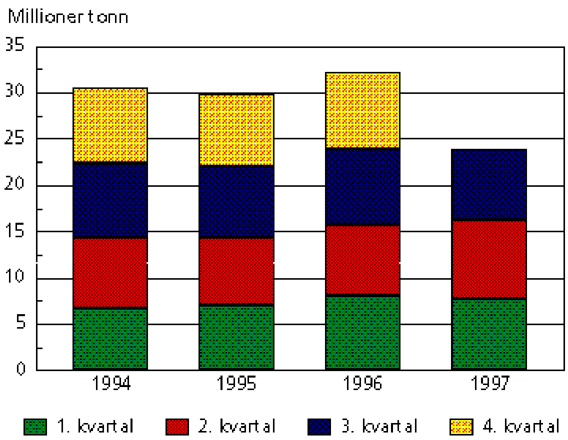


Figure 7 Cargo traffic by quarter, 1994 - 97

The data for cargo ships, however, is more interesting as the seasonal variations in both traffic and accidents are smaller and number of port calls per vessel is assumed to be fairly stable (as the above figure indicates). The lowest month, May, shows 1.44 accidents per 100 vessels while the highest month, November, shows 2.68 accidents – an 87.3% increase month over month. This indicates the assumption that the accident risk is higher in fall/winter than in spring/summer is correct.

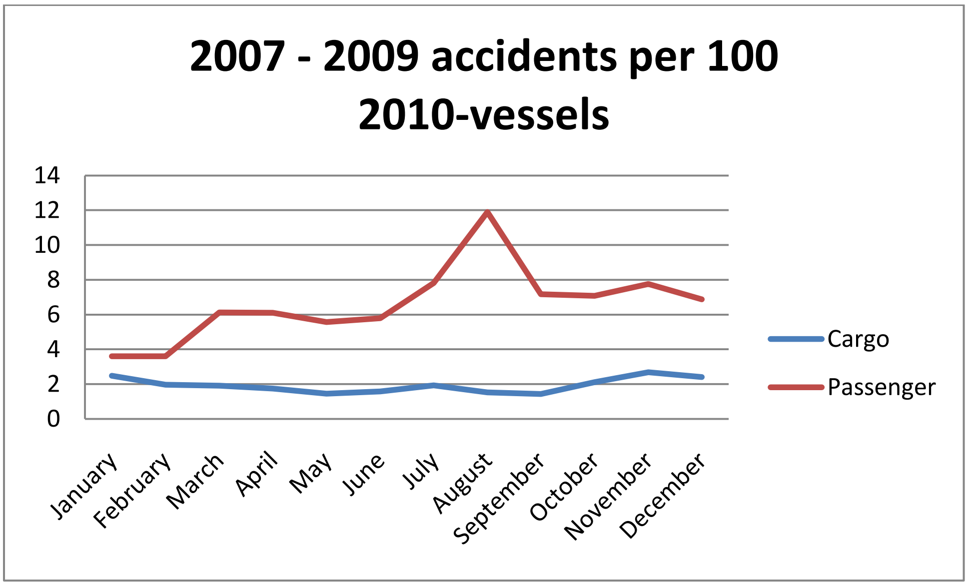


Figure 8 Monthly Accidents per 100 Vessels

The average statistical accident probability per monthly vessel in registered in Norwegian water was calculated as:

$$P(Accident) = \frac{Annual\ Accidents}{Total\ Vessels\ Registered} = \frac{680/3}{44203} = 5.13\ \times\ 10^{-3}$$

Again, this probability does not differ between vessels or time spent in Norwegian waters and can such not be used for calculating risk for a specific ship. It can, however, be used for estimating the expected number of accidents for an area with a traffic picture similar to that of Norway as a whole. Another requirement is that, to account for seasonal variations, monthly vessel traffic for one year have to be used – a per month calculation would not give correct results.

No attempts were made to plot traffic data based on port calls or total travel time as this information is not given by the AIS. This would, however, give interesting data on the seasonal variations of accident risk, but was deemed to be outside the scope of this project. It was considered to use the number of entries per vessel as an indicator of total travel time in Norway, but this was deemed to not give correct results (as the variation between number of entries for vessels in similar trade varies significantly). When (Kujala, Hänninen, Arola, & Ylitalo, 2008) developed similar data for the Gulf of Finland it was chosen to use number of arrivals (vessels crossing a pass line) as opposed to number of vessels, a method that would give a more dynamic risk model. This method would not, however, be feasible for a larger area as it would not include traffic that did not cross the pass line.

A more detailed study was performed by identifying all RIFs given by both the NMD accident database and from AIS/maps/weather stations and creating a qualitative break-down of what makes a vessel likely to be involved in an accident for both cargo and passenger vessels. A simplified influence diagram is given below, as well as a break down for each vessel type, and each RIF is analyzed in detail in the following chapters.

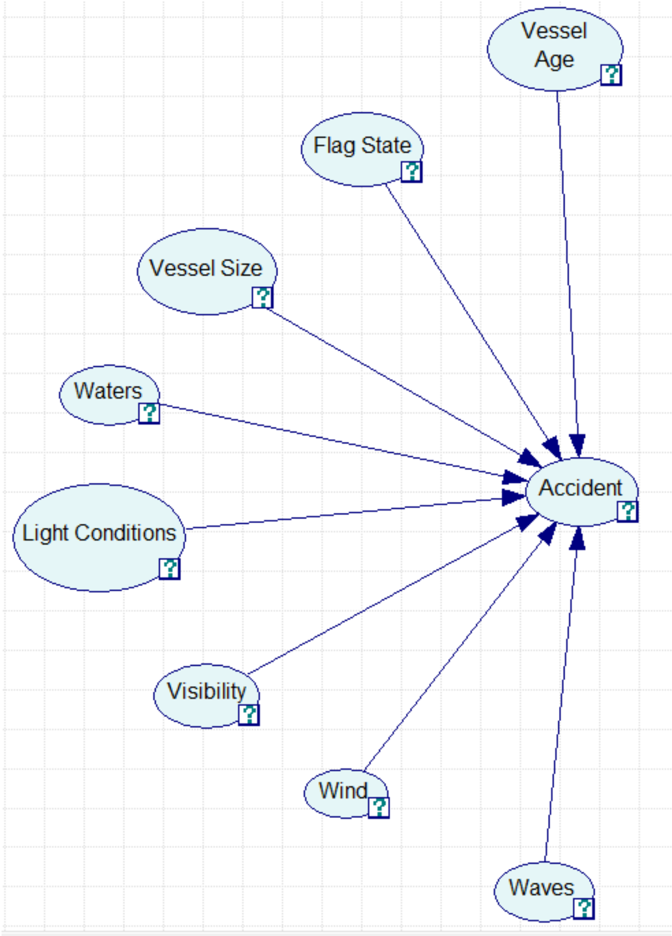


Figure 9 Factors That Influence Accident Probability

This influence diagram differs from most influence diagrams due to the fact that all RIFs influence accident probability directly. Most influence diagrams (and BBNs) would have the RIFs influence the *risk of an incident* which, in turn, influences risk of an accident. This approach was not chosen as estimating the risk of an accident given an incident has occurred is hard due to lack of data and would generally require a synthetic approach. Instead, the above set-up would allow for data available from AIS/weather stations/etc to be entered directly and would give the probability for a certain vessel to be involved in an accident.

A qualitative breakdown of the NMD database, showing the most common characteristics for both cargo and passenger vessels, is given below. Each of these rows are then analyzed in detail in the subsequent chapters.

3.2.1.1 Accident characteristics - Cargo Vessels

296 of the 680 registered accidents involved a cargo vessel. The characteristics of a cargo vessel accident are given below:

Light	Grounding	61% more accidents when dark
	Collision	No trend found
Visibility	Most accidents with "good visibility" (more than 5 nautical miles)	
Wind strength	Most at low winds for both accident types	
Wave height	Most at low wave heights for both accident types	
Waters	Most in "narrow coastal water" for both accident types	
Size	Vessels under 100 meters are overrepresented	
Flag	Roughly 40% of accidents with ship under foreign flag for both accident types	
Age	Highest number for vessels built in the 70s for both accident types	

Table 3 Characteristics of an Accident, Cargo Vessels

In short, most accidents happen in fair weather and the grounding risk seems to be higher when dark. Almost half of accidents involved a vessel under foreign flag and the highest numbers are for vessels from the 70s.

3.2.1.2 Accident characteristics - Passenger Vessels

384 of the 680 registered accidents involved a passenger vessel. The characteristics of a passenger vessel accident are given below.

Light	Grounding	126% more when light
	Collision	450% more when light
Visibility	Most accidents with "good visibility" (more than 5 nautical miles)	
Wind strength	Most at low winds for both accident types	
Wave height	Most at low wave heights for both accident types	
Waters	Most in "narrow coastal water" for both accident types, as well as many groundings in "harbor area"	
Size	Vessels under 100 meters are overrepresented	
Flag	5% of all accidents with vessel under foreign flag	
Age	Highest grounding number for vessels from the 70s, for collisions it's the same number for the 70s and the 90s	

Table 4 Characteristics of an Accident, Passenger Vessels

The characteristics for passenger vessels are similar to those of cargo vessels, with the exception that the grounding numbers are highest when it's light. Also a majority of vessels involved in an accident sail under a Norwegian flag.

4 AIS and accident data comparison

AIS and accident data was compared to give a basis for the risk model. As commented on earlier, it was first attempted to develop these statistics for a given fairway and such also include other vessels in the fairway at the time of the accident. This proved hard as none of the fairways investigated have had enough accidents for the accident distribution (over vessel types) to be statistically correct. The most accident prone fairway in Norway is the Bergen approach with an annual accident rate of 6.67 - a far too low number for giving a correct distribution.

Instead it was decided to find a “base probability” for accidents (similar to SAMSON by (Maritime Research Insitute Netherlands)) based on the vessel in question and use multipliers for the fairway to get a dynamic risk picture. The resulting model is not completely dynamic, however, as vessels only contribute to the total risk in terms of their own base probability – not on the basis of the combination of vessels in the fairway at a given moment. This is described further in chapter 5.2.

4.1 Vessel size

Generally, gross tonnage is used to describe ship size but this information is not provided by the AIS. Instead ship length was used and the vessels involved in accidents were grouped into categories of 50 meters. As can be seen from the table below, more than 80% of the vessels involved in accidents are less than 100 meters long.

The two columns to the right show the total number of vessels registered by summing over all months (in other words, a ferry which is in Norway year round will be counted twelve times). This results in the vessel count being off and the percentage share being quite close to reality. By comparing these numbers it can be seen that vessels under 100 meters are overrepresented in the accident database, the inflection point is in the region of 100 – 150 meters and the higher categories being underrepresented. Also, the “unknown” category is overrepresented in the AIS data, a result that makes sense as it is more likely that an accident report will be filled out to satisfaction than the AIS transponder.

The fact that larger vessels are less likely to be involved in an accident also seems reasonable, as the risk will be more obvious to the OOW and such reduce the probability of a human error. Also, these vessels will generally hire more experienced crew, get more attention during inspections and from the pilot and could have more advanced navigational equipment. In short, the elevated consequences and perceived risk is likely to reduce the actual probability of an accident to occur. It is, however, also likely that larger vessels spend less time in Norwegian waters and this would also affect these results.

Length	Accidents	Percentage share	Total registered	Percentage share
Under 50	319	46,9 %	15755	35,6 %
50-100	247	36,3 %	13183	29,8 %
100-150	64	9,4 %	4587	10,4 %
150-200	11	1,6 %	2116	4,8 %
Over 200	9	1,3 %	2030	4,6 %
Unknown	30	4,4 %	6532	14,8 %
Total	**680**	**100,0 %**	**44203**	**100,0 %**

Table 5 Accidents and Vessel Length

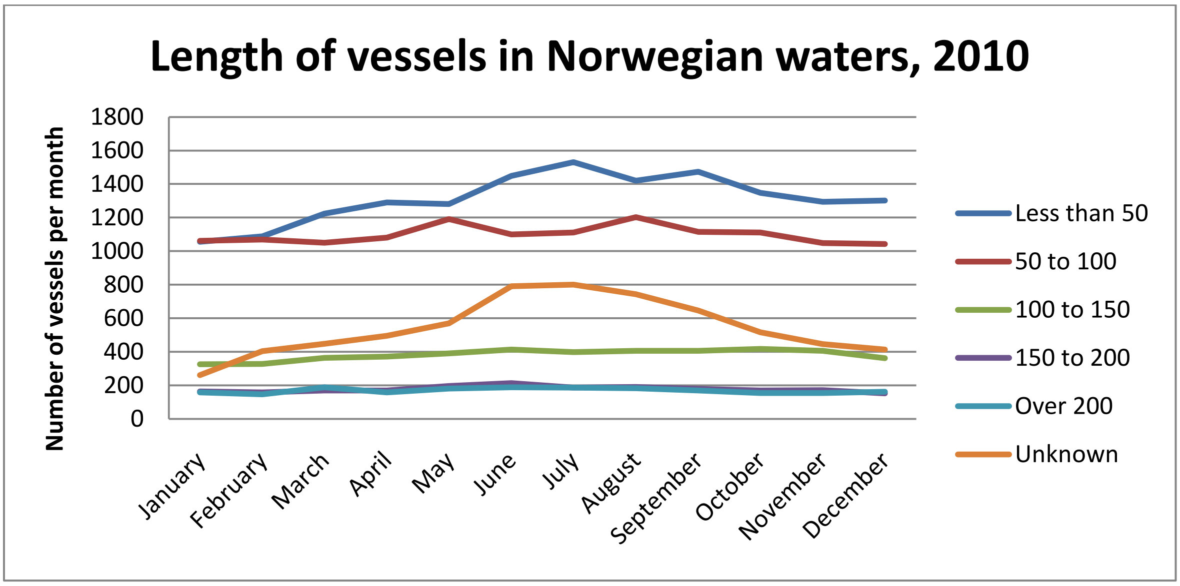


Figure 10 Length of Vessels in Norwegian Waters

This result is in compliance with a comment made by NMD in the annual report for 2003, namely that smaller cargo vessels (with one cargo hold and one hatch) are involved in a disproportional high number of accidents over the past twenty years (in this case from 83 – 03). Reasons for this are suggested to be low freeboards and insufficient reserve buoyancy, as well as the fact that the coastal fleet at the time was old with low earnings. The fact that smaller vessels are still overrepresented suggests that this might not have changed over the past years.

4.2 Vessel Flag

It is widely accepted amongst many vessel owners to choose a “flag of convenience”, meaning that the vessel is registered in a state with sub-standard inspections and regulations, making day-to-day operations cheaper. This could also make the owner harder to identify and is such a common point of criticism in shipping. Still, flags of convenience are widely used by both companies and private owners, with the drilling rig Deepwater Horizon (flagged under Marshall Islands) as a recent example. Despite the criticism, though, it is yet to be proved that vessels under these flags actually have a higher accident rate (ie, it has been suggested that certain owners are a greater indicator of a sub-standard vessel than the flag it is sailing under – owners that tend to register their vessels under these flags) (Winchester, 2002). It is beyond discussion, however, that not all flag states have ratified all international conventions and it is such reasonable to assume that a vessel from a certain flag may not be accepted under a different flag.

According to the Paris MoU regulations, 25% of all foreign vessels have to be controlled by the port state. Norway comply with these regulations (in 2007 25.8% of all foreign vessels were controlled) and in 2007 2.5% percent of the vessels controlled were retained for not complying with Norwegian standards. In the same time-frame 3.1% of Norwegian vessels controlled by a foreign port state were retained, indicating that Norwegian flagged vessels do not necessarily hold a higher standard than foreign flagged vessels.

It has not been attempted to identify which flag states are most accident prone in the Norwegian waters, though the difference between Norwegian flagged and foreign flagged vessels was investigated. Again, this is done by total number of vessels registered in Norwegian waters per month and not by mileage.

4.2.1 Cargo vessels

The total number of Norwegian flagged cargo vessels in Norwegian waters is stable year round while foreign flagged vessels show an increase during the summer months. The fact that foreign flagged vessels are higher year round, however, indicates that the use of a flag of convenience is common also amongst “Norwegian” vessels (as it is reasonable to assume that not all of these are from foreign trade). No exact numbers for foreign flagged cargo vessels in coasting trade in Norway could be found, though it has been noted that this number has been increasing over the past years. SSB notes, however, that 65% percent of all gods loaded/unloaded in Norway are sailing to or from a foreign port.

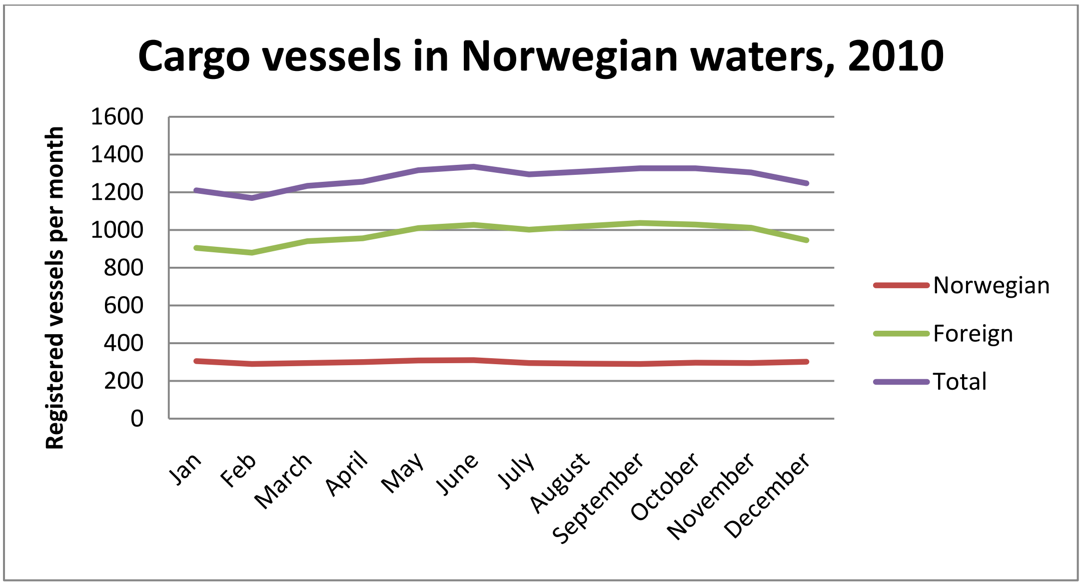


Figure 11 Cargo Vessels in Norwegian Waters

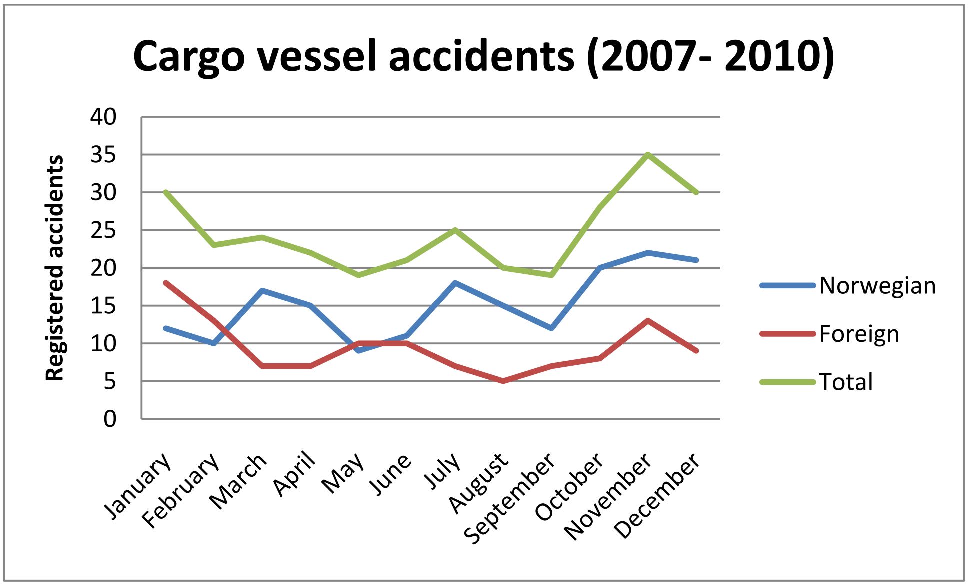


Figure 12 Cargo vessel accidents by flag

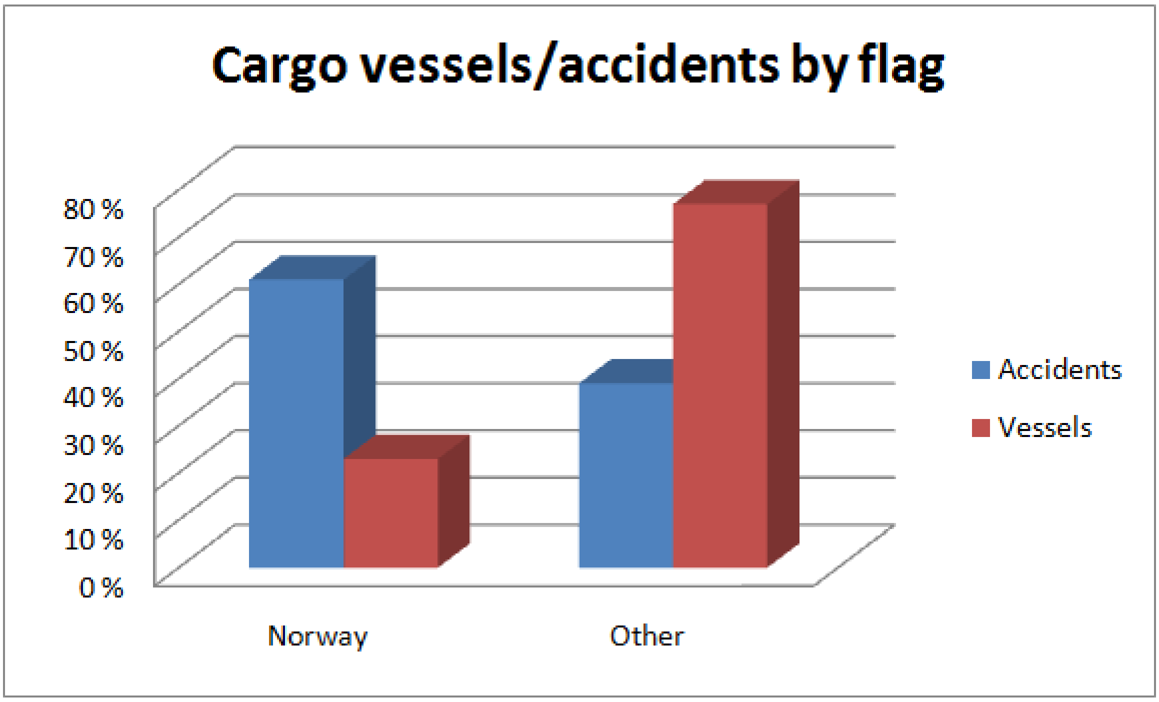


Figure 13 Cargo Vessels, Accidents and Flag

By comparing vessel accidents with number of vessels under each flag, it is apparent that Norwegian flagged vessels are overrepresented in the accident statistics. Part of the reason could, as mentioned above, be due to Norwegian vessels having a higher mileage within Norway.

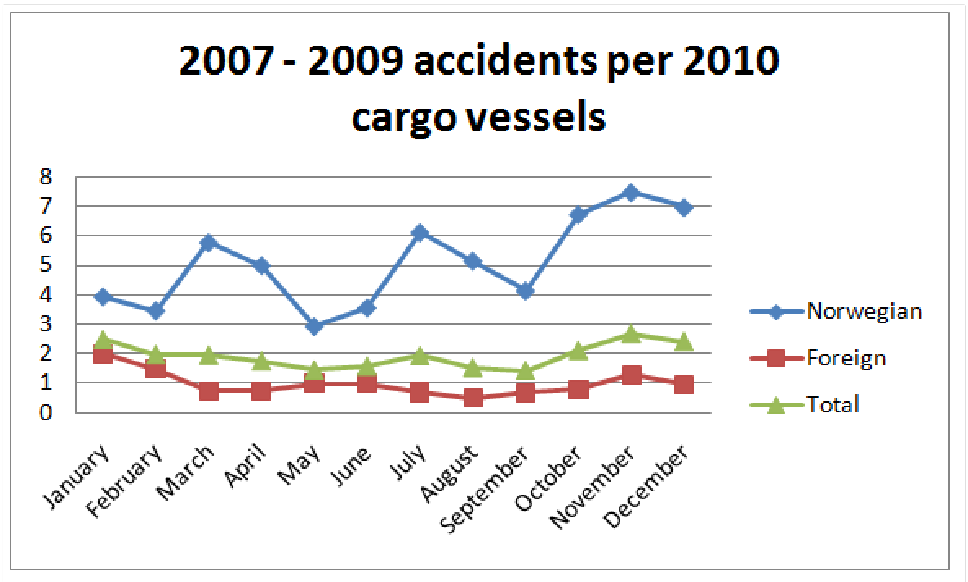


Figure 14 Accidents per cargo vessel

4.2.2 Passenger vessels

For passenger vessels the picture is clearer, as the number of Norwegian flagged vessels is stable and the foreign flagged vessels increases over summer. Comparing with the accident distribution it can be seen that number/accidents for foreign flagged vessels show similar distributions while Norwegian flagged vessels have a higher accident number for the same number of vessels.

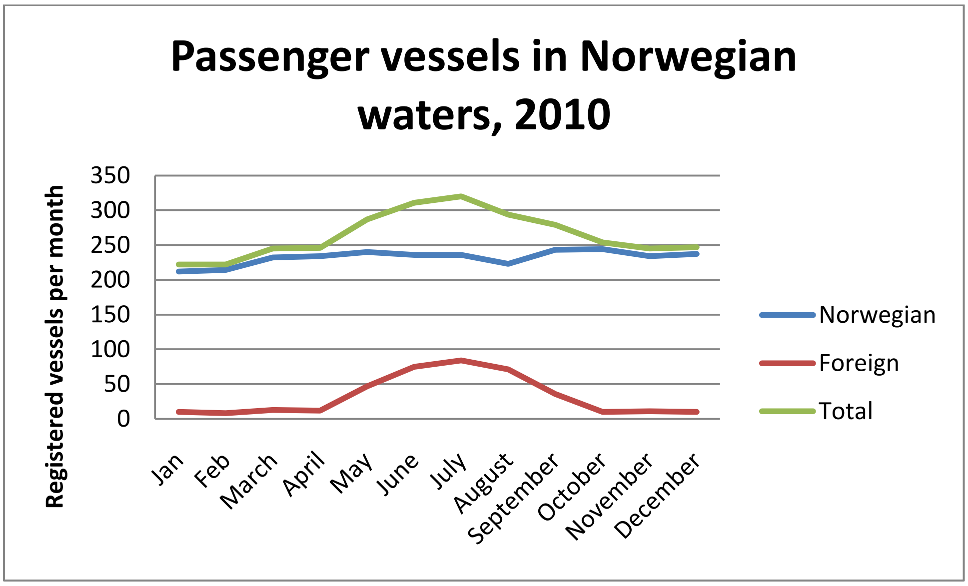


Figure 15 Passenger Vessels in Norwegian Waters

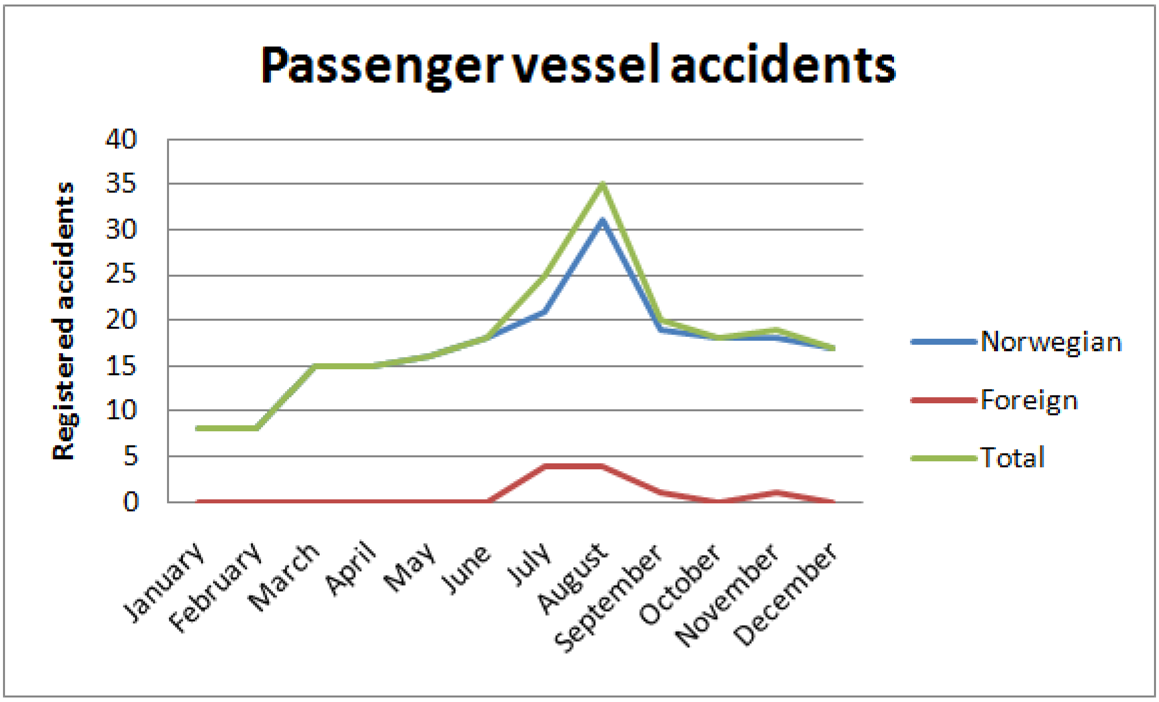


Figure 16 Passenger Vessel Accidents

Again, as mentioned earlier the increase in accidents for the same number of vessels could be due to both incorrectly filled out AIS data and an increased number of port calls over summer.

By comparing statistics for the whole year no clear trend can be found. This could indicate that Norwegian flagged vessels are safer (as the accident peak in summer, with increased mileage, is neutralized by low accident numbers in winter). It also be due to what was discussed earlier, namely that some of the accidents registered with NMD are by vessels that are not registered as a passenger vessel in the AIS data.

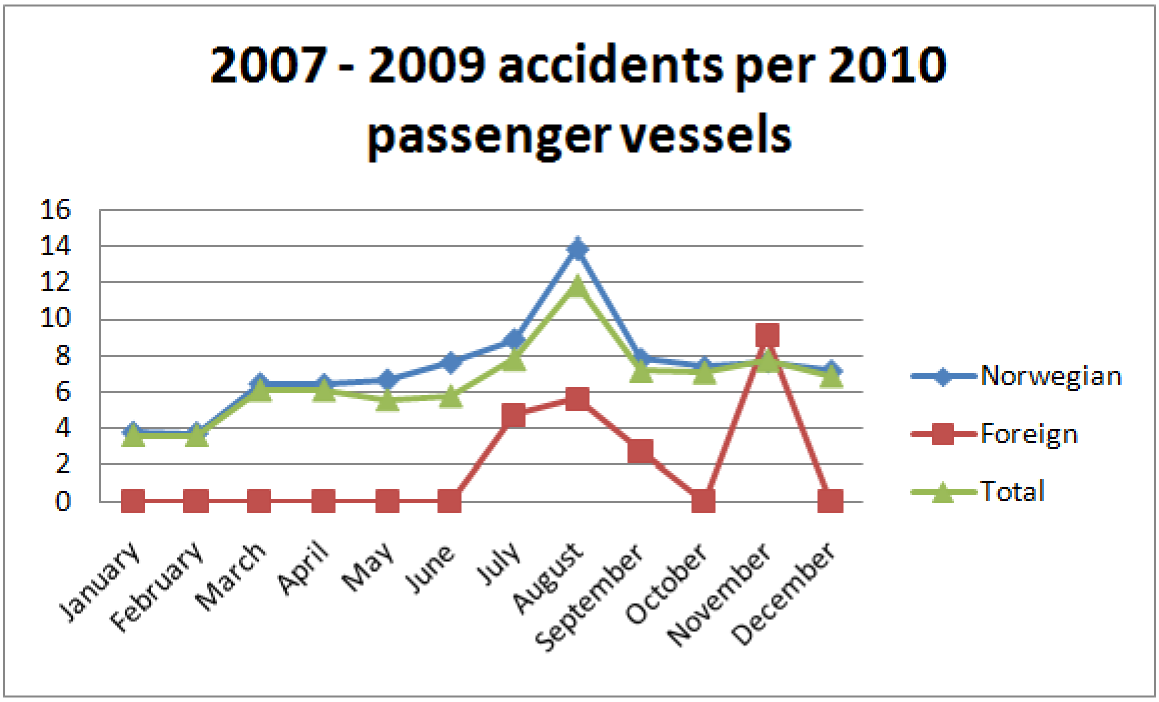


Figure 17 Accidents per passenger vessel

Still, foreign flagged vessels are somewhat underrepresented in the accident database.

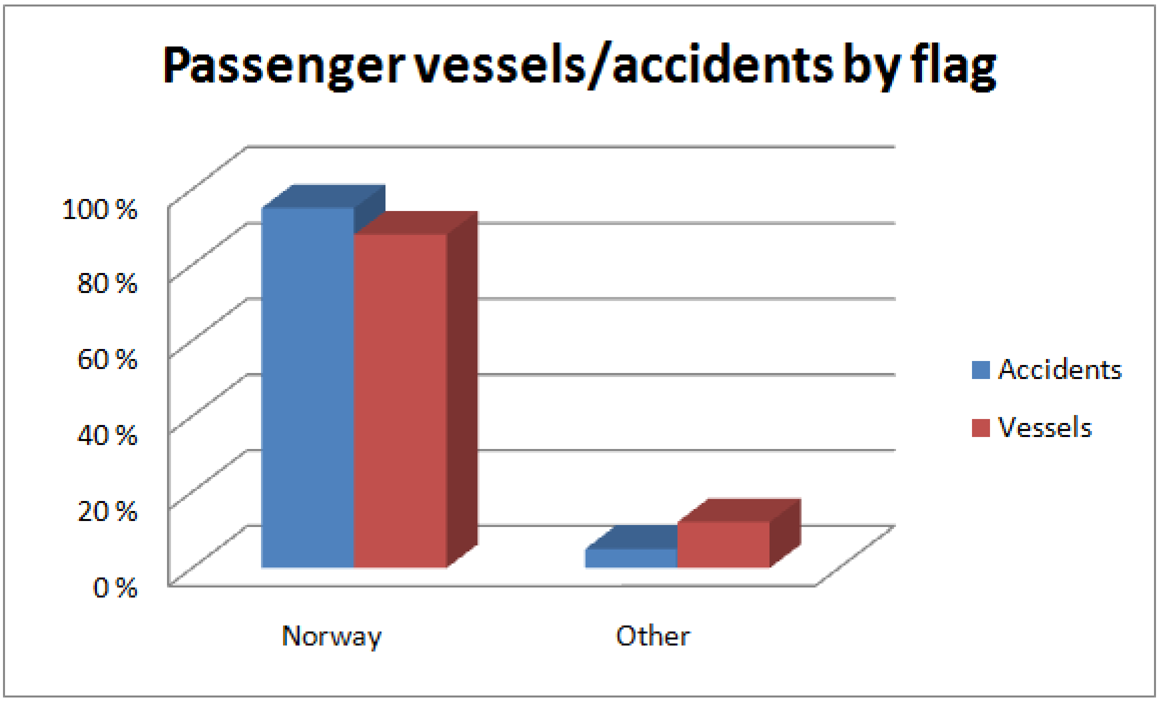


Figure 18 Passenger Vessels, Accidents and Flag

4.3 Wind speed and wave height

NVE has developed a “wind map” for Norway to determine locations for placing out wind mills. Unsurprisingly, the windiest area on the Norwegian coast is by Stadt with wind speeds as shown on the map below. This map also shows a common trend along the Norwegian coast, namely that a lot of sheltered water exists. As found from the accident data above, most accidents in Norway happen in "narrow coastal waters" where the wind speed is generally quite low. This then explains why a majority of accidents in Norway happen in fair weather (low wind speed and wave height), as the areas prone to accidents are also very sheltered.

A similar result was found has been reported (Toffoli, Lefevre, Monbaliu, Savina, & Bitner-Gregersen, 2003), however, indicating that weather may not be a major factor when determining accident probability. It is also noted (Talley, 1999) that "*Although adverse weather and visibility conditions are likely to increase the risk of a tanker accident, their impact on vessel damage severity is unclear*".

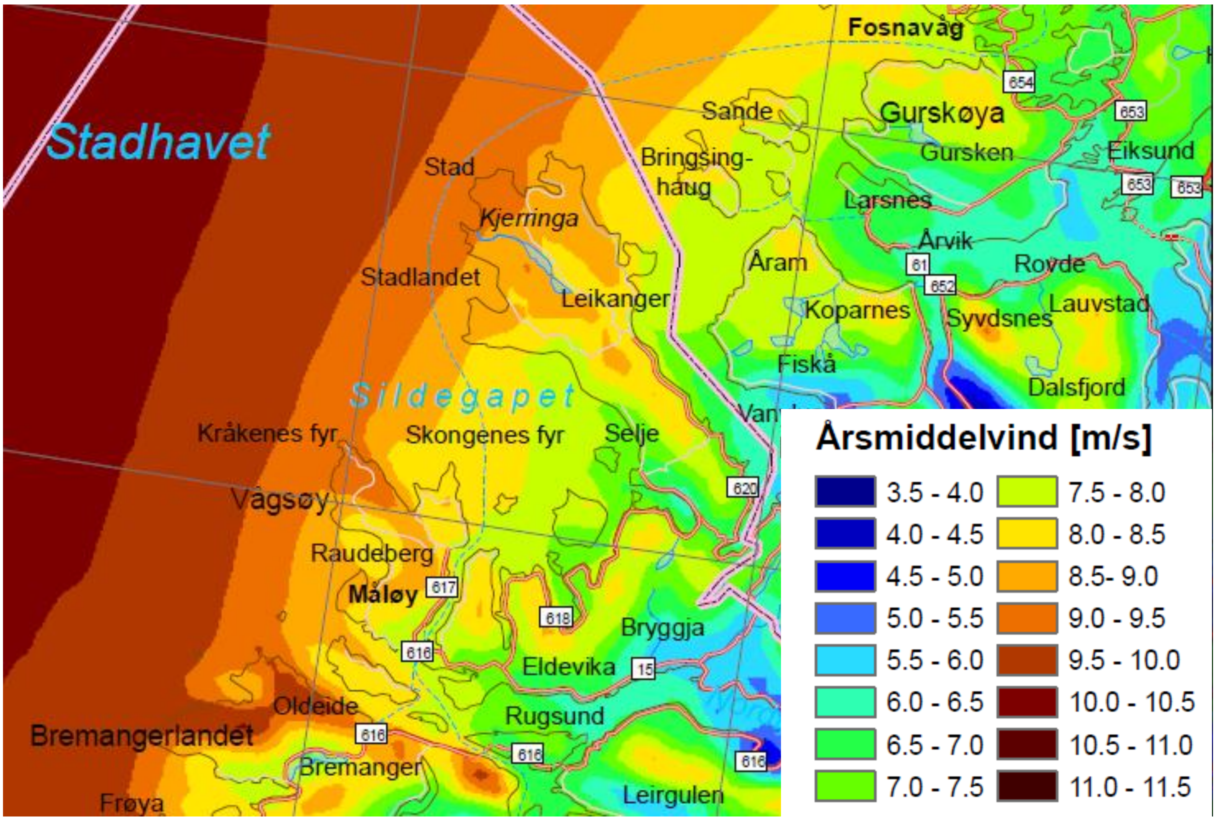


Figure 19 Annual Median Wind, Stadt

The wind speeds in the map are at 50 meters above sea level (as they were measured thinking of wind mills), and the annual average wind speed at sea level can be calculated using the wind profile power law as given below:

$$\frac{u}{u_r} = \left(\frac{z}{z_r}\right)^{\alpha}, \text{ with z = 5 meters and } \alpha = 1/7$$

Due to the high number of hills/mountains on the Norwegian coast, the actual wind speed will most likely be significantly lower than what is predicted from this formula.

The exact values for the wind speed were not calculated as no data exist for where vessels spend most of their time. A reasonable assumption would be that coastal ferries and smaller vessels tend to stay in areas with "up to yellow" (in the above map) wind speeds, while fishing vessels and cargo ships will spend most of their time in the higher wind speed areas. It would, however, require a huge effort to make a good estimation of the exact percentage share of time spent in each wind speed/wave height – especially as the route choices will, to some degree, depend on the weather.

4.4 Light and Visibility

As mentioned before, most accidents happen in good visibility. This was also reported by NMD in a report that looked into all reported groundings in 1999. Only a small improvement can be seen, as 57.5 % of all groundings in 1999 happened in good visibility and 50 % of the groundings for the years 2007-2009. Finding a good explanation for this is harder, though the NMD report indicates that the most likely reason is the OOW being more relaxed (and prone to mistakes) when the visibility is good. Still, it was decided to investigate the weather statistics for the Norwegian coast more closely.

Weather statistics for Norway is available for free from eKlima and data from Utsira fyr and Lista fyr was obtained. The daily bulletin contains weather data from morning, mid-day and evening, giving a total of 2190 data points for both stations for 2010. Due to the high number of registrations the percentage share of reported data can be assumed equal to the percentage of time with this weather. Also, data from these two points were assumed to give a representative picture for Norway as a whole. The table below shows reported visibility for 2010 and ship accidents from 2007 – 2009 (only 450 of the accidents had the visibility given).

Visibility	Accidents	Percentage	No Reportings	Percentage
Under 0.25 nm	9	2,00 %	6	0,27 %
0.25 - 0.5 nm	5	1,11 %	7	0,32 %
0.5 - 2 nm	22	4,89 %	102	4,66 %
2,1 - 5 nm	60	13,33 %	163	7,44 %
Over 5 nm	354	78,67 %	1912	87,31 %
Total	**450**	**100,00 %**	**2190**	**100,00 %**

Table 6 Visibility - Accidents and Reported Visibility

From this table another obvious reason for accidents happening when the visibility is good can be seen, simply the fact that the visibility is good almost 90 % of the time (meaning most sailing will, in fact, be with good visibility). If the visibility didn’t affect accident risk at all, then the percentage share of accidents with a certain visibility should be equal to the percentage share of that visibility. This is not the case in the above table. The accident rate is disproportionately high in almost all the lower categories and 9.7 % lower in the highest category. This result indicates that the NMD argument that officers are “too relaxed” in good visibility is not correct, as the accident rate is lower when the visibility is good.

For passenger vessels, most accidents happen when it’s light while grounding numbers for cargo vessels are highest when it’s dark. Having a higher risk when it’s dark is in compliance with a study from Germany (German Accident Investigation Board), where it was seen in correlation with time of day. This report concluded that the accident rate was higher in the dark because accident rates were higher at night – and the OOW would be tired and prone to human errors. In short, they concluded that the darkness itself was not the reason for the higher accident rate.

For Norwegian waters it is a little bit different as the passenger vessel accident rate is higher when it’s light. This implies that other factors can relevant, such the time of year most accidents happen. Passenger traffic, and accidents, peak in summer when the days are long while cargo traffic, being relatively stable year round, peak in late fall/winter when days are short. This could indicate two things:

- A higher accident rate when it's dark is merely a consequence of a higher accident probability at night. A large share of Norwegian passenger vessels (namely coastal ro/ro passenger ferries) does not sail at night and this makes it reasonable that the accident rate for passenger vessels is higher when it's light. Cargo vessels on the other hand, would not have a significant traffic drop at night and the increased accident probability would explain the increased accident rate.
- A higher accident rate when it's dark is merely a consequence of a higher accident probability in winter/fall. Passenger vessel traffic is lower at this time of year, which compensates for the increased accident probability, while cargo traffic is stable and accidents increase. As days are shorter in winter, more of the accidents would be in the dark.

By printing the time of day accidents happen in Norwegian waters there is no very clear trend of accidents happening at night. Passenger vessels have, as expected most accidents during the day while cargo peak at 00 :00– 01:00 and decrease during the night. There is a clear peak for both vessel types, however, between 7:00 and 8:00 in the morning. Note that the below graph is not continuous and accidents registered at, for instance, 7:00 means all accidents between 7:00 and 8:00.

The peaks for cargo can be seen in relation with the beginning and end of an eight hour night shift, while the two peaks for passenger vessels could be in relation with an eight hour day shift.

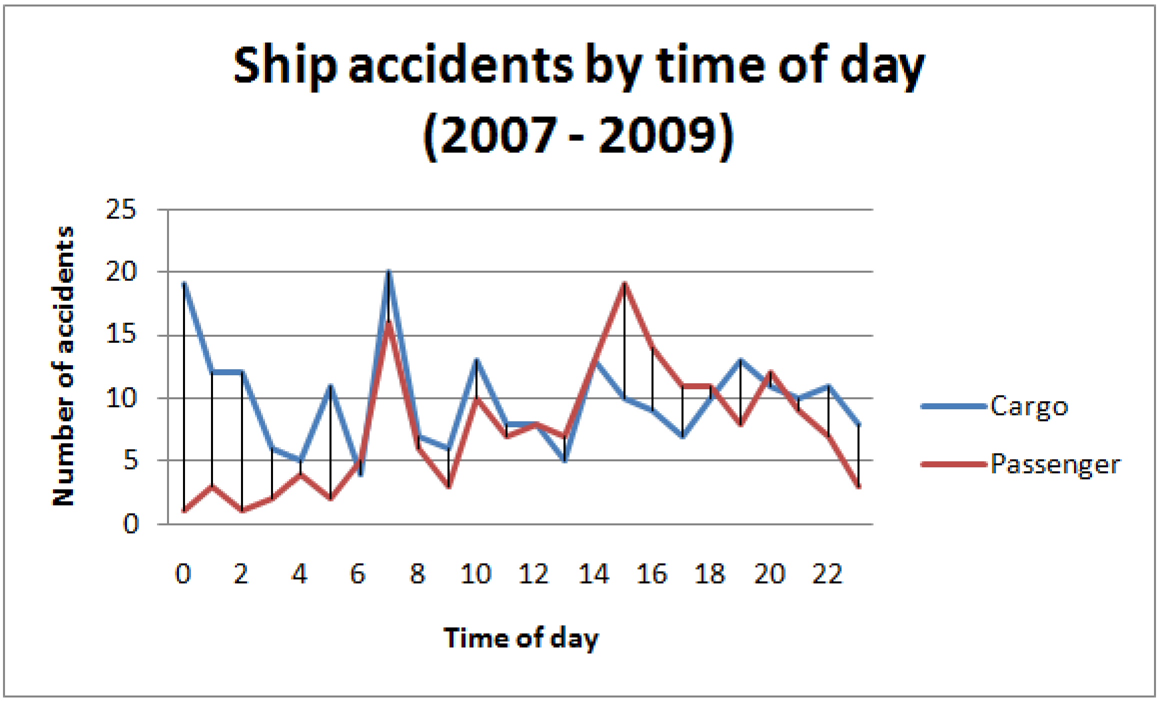


Figure 20 Ship accidents by time of day

Based on the above results (accidents over time of year and time of day), no evidence was found to imply that darkness increase accident rates. It does, however, seem to be a correlation between working hours (and most importantly shift changes) and accidents. Still, a more detailed study would be required to confirm this correlation.

4.5 Ship Age

Finding the age of all vessels in Norwegian waters is hard as this data is not given by the AIS. One would therefore have to look up each vessel in a ship database, a job that would be too comprehensive. Instead it was assumed that the age of the Norwegian fleet (from NIS and NOS, including foreign owners) would give a good indication of the age of vessels in Norwegian waters.

The age of the Norwegian fleet (per December 21st 2009, as given by (SSB)) is given below.

Tanker includes gas, chemicals and oil tankers, while dry-cargo includes passenger ships and ferries, dry bulk, supply vessels, etc.

	Tanker		Dry-cargo ship		Total	
Unknown	20	7,1 %	36	3,1 %	56	3,9 %
0 to 4 (2006 - 2009)	62	22,0 %	202	17,4 %	264	18,3 %
5 to 9 (2001 - 2005)	38	13,5 %	126	10,8 %	164	11,4 %
10 to 14 (1996 - 2000)	47	16,7 %	119	10,2 %	166	11,5 %
15 to 19 (1991 - 1995)	42	14,9 %	76	6,5 %	118	8,2 %
20 to 24 (1985 - 1990)	21	7,4 %	80	6,9 %	101	7,0 %
25 to 29 (1981 - 1985)	19	6,7 %	83	7,1 %	102	7,1 %
Over 30 (Before 1980)	33	11,7 %	440	37,9 %	473	32,8 %
Total	282	100,0 %	1162	100,0 %	1444	100,0 %

Table 7 Age of the Norwegian Fleet (SSB)

To check the validity of using this data, the age of the Norwegian fleet (measured in dwt) was compared to the world fleet and a group of open registry countries consisting of Bahamas, Bermuda, Cyprus, Liberia, Malta, Panama and Vanuatu. The percentage share of dwt in each age category is given below, showing a similar distribution for all three categories. This distribution is also interesting due to the fact that the open registry countries have the newest fleet, by dwt, indicating that open registry may not mean sub-standard. Due to the similarities in the distributions, the age distribution for Norwegian flagged vessels was deemed representative for vessels in Norwegian waters.

	0 to 4	5 to 9	10 to 14	15 to 19	Over 20	Total
World	25,1 %	21,0 %	16,7 %	10,9 %	26,2 %	99,9 %
Open	27,6 %	21,3 %	16,7 %	10,5 %	24,0 %	100,1 %
Norway	27,0 %	16,2 %	21,1 %	9,0 %	26,7 %	100,0 %

Table 8 Age of Norwegian Fleet Comparison (UNCTAD, 2007) (SSB)

The age of vessels involved in accidents were found from the accident database and is given below. As stated earlier, vessels from the 70’s are overrepresented in the accident statistics.

Year of construction	Number	Percentage
Before 1950	20	3,2 %
1950 - 59	30	4,8 %
1960 - 69	58	9,4 %
1970 - 79	164	26,5 %
1980 - 89	118	19,0 %
1990 - 99	110	17,7 %
2000 - 09	120	19,4 %
2010 - Present	0	0,0 %

Table 9 Age of Vessels in NMD Accident Database

To give a better picture of the relation between these two databases, the results are displayed graphically (shown below). It should be noted that the categories are not perfectly comparable, as they use different age grouping (i.e., accidents are grouped from 80 – 89 while age is grouped from 81 -90).

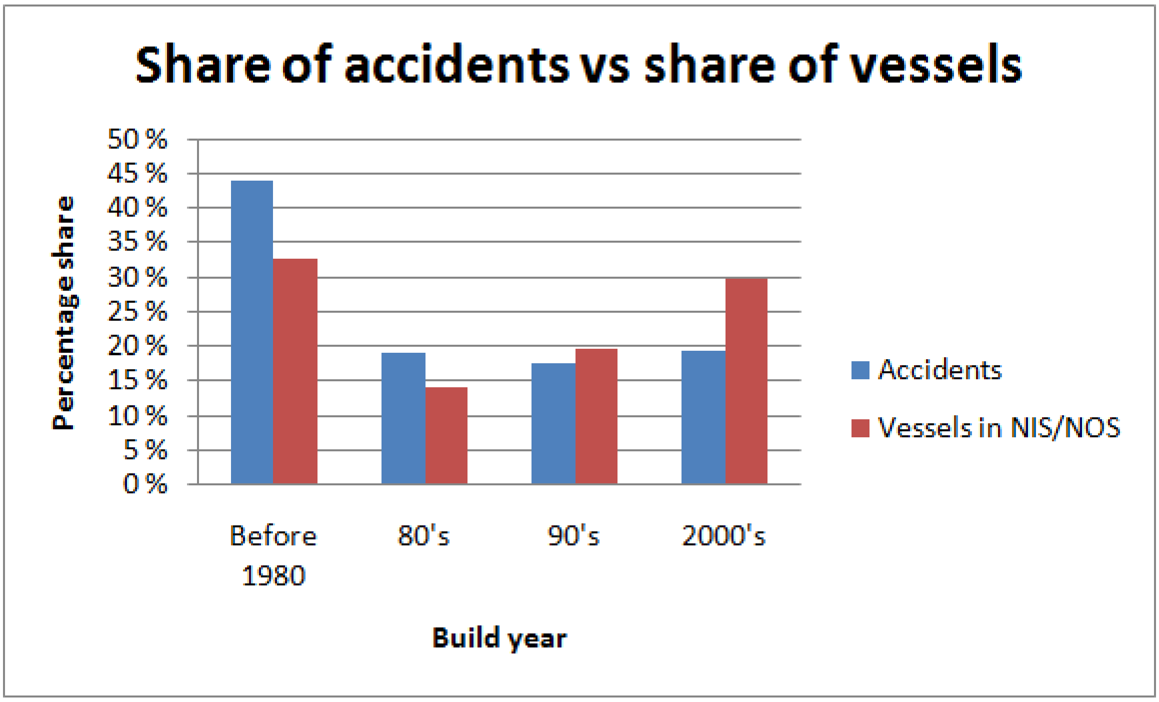


Figure 21 Age - Accidents vs Vessels

From the figure above it is apparent that the accident rate is increasing with vessel age, with the inflection point being around 1990 (twenty years old). Interestingly, the picture is almost symmetrical. The share of vessels in the accident database built before 1980 is 33.8% higher than the corresponding share in NIS/NOS, while the share of vessels built after 2000 is 34.7% higher than the number of newer vessels in the NMD database.

4.6 Discussion and conclusions

Above the various factors that are likely to influence the accident probability were investigated separately and it was attempted to see each factor in relation with other factors.

It has hard to draw clear conclusions, but some trends can be seen:

Accident probability seems to increase in winter. The increase in accidents per vessel for passenger vessels is assumed to be due to an increased mileage during summer (and, to some extent, errors in the reported AIS data), while the increase for cargo vessels is assumed to show the true trend for vessels in Norwegian waters. It should be noted, however, that this is based on the assumption that cargo traffic is stable year round.

Vessels under 100 meters seem to be more at risk. These vessels are overrepresented in the accident database compared to the traffic data from AIS and it is such likely to assume that they pose a greater risk than larger vessels.

Norwegian flagged vessels have a higher probability of being involved in an accident in Norwegian waters, especially for cargo vessels. This could be due to a higher mileage within Norway and further work would have to be done to determine if these vessels also have a higher accident probability per nautical mile traveled.

Wind speed and wave height are not major accident indicators. This result does not indicate that they do not influence accident probability at all (they most likely do), only that the waters and fairway are greater contributors to the accident risk. In short it seems like a vessel sailing in fair weather in narrow coastal water have a higher accident probability than a vessel sailing in rough weather on the open sea. An inflection point most likely exist (at some point the weather is so adverse that the risk increase greatly), though it is not clear how to find this point. Research has been done in this area, though no clear conclusions have been drawn.

Good visibility decrease accident probability and accident probability is higher at certain times of the day. It seems clear that visibility and accident probability are in inverse ratio with an inflection point around 0.5 – 2 nm visibility. There is also a significant increase in the accident rate in late evening, early morning and in the afternoon, implying that shift changes could affect the accident risk.

Vessels older than 20 years seem to have a higher accident probability. Vessels older than 20 years are overrepresented in the accident database, and this trend increase for older vessels.

5 Risk model

The above chapters, and RIFs, can be divided into two groups – RIFs concerning vessels and traffic and RIFs concerning the fairway. By reorganizing the influence diagram presented earlier, a model for calculating fairway risk was developed. In this model the accident probability is directly influenced by three factors; one concerning the traffic ("type" of traffic), one concerning the fairway (weather, waters, complexity of crossing fairways, etc), and the actual traffic numbers. In short, an average risk per vessel in the given area is calculated and multiplied with the actual number of vessels.

Human error is not included in the discussion earlier as it can be considered as a "result of other factors", i.e. sub standard vessel is assumed to be more prone to human error than a vessel with good routines. By calculating the accident probability for a certain type of vessel the HEP (human error probability) will be included, just not mentioned directly. This decision was made based on experiences from the pre-work (Ombler & Skollevold, 2010) where estimating the HEP proved to contain a lot of "guessing".

The "traffic type" factors are all given by the AIS and were calculated using Bayes' rule. "Fairway type" factors are based on data available from other sources, though these were proved hard to estimate due to the basic probabilities not being readily available (i.e., the probability of a cargo vessel being Norwegian can be found, but what is the probability of a cargo vessel currently sailing in rough sea?). Further work could be done in this area, but was deemed outside the scope of this project.

Instead, the total number of accidents and number of vessels were used to calculate the statistical average accident probability for vessels in Norwegian waters. The fairway factor itself was instead set equal to "1" for Norway as a whole, in effect setting the accident rate for the Norwegian waters as a reference value. A value for this factor was then estimated by using the accident rate from the Bergen seaward approach.

It should be noted that this model gives the annual risk and "time of year" is thus not relevant.

The traffic factor is denoted $P(A)_{traffic}$ and the fairway factor $P(A)_{fairway}$. The argument is that these two factors are independent, resulting in:

- A fairway factor found for one area (in this case for the Norwegian waters) can be used in risk calculations for an area with similar characteristics (based on the factors shown in the model below). Conditional probabilities regarding the fairway are assumed to be correct everywhere.
- The conditional probabilities used for calculating the traffic factor are representative everywhere (for all fairway factors), and are *not* tied to a certain fairway/traffic picture/etc.
- Risk will varied based on changes in traffic or changes in fairway, but the *contribution* to the total accident probability from either factor will not vary based on changes in the other.

A result of this is that the vessels that are most accident prone in one area are assumed to be the most accident prone also in another area, i.e. the *distribution* of vessel types involved in accidents will be the same for all areas with the same traffic picture. What will influence the accident rate is the traffic distribution and the fairway characteristics.

The influence diagram is given below.

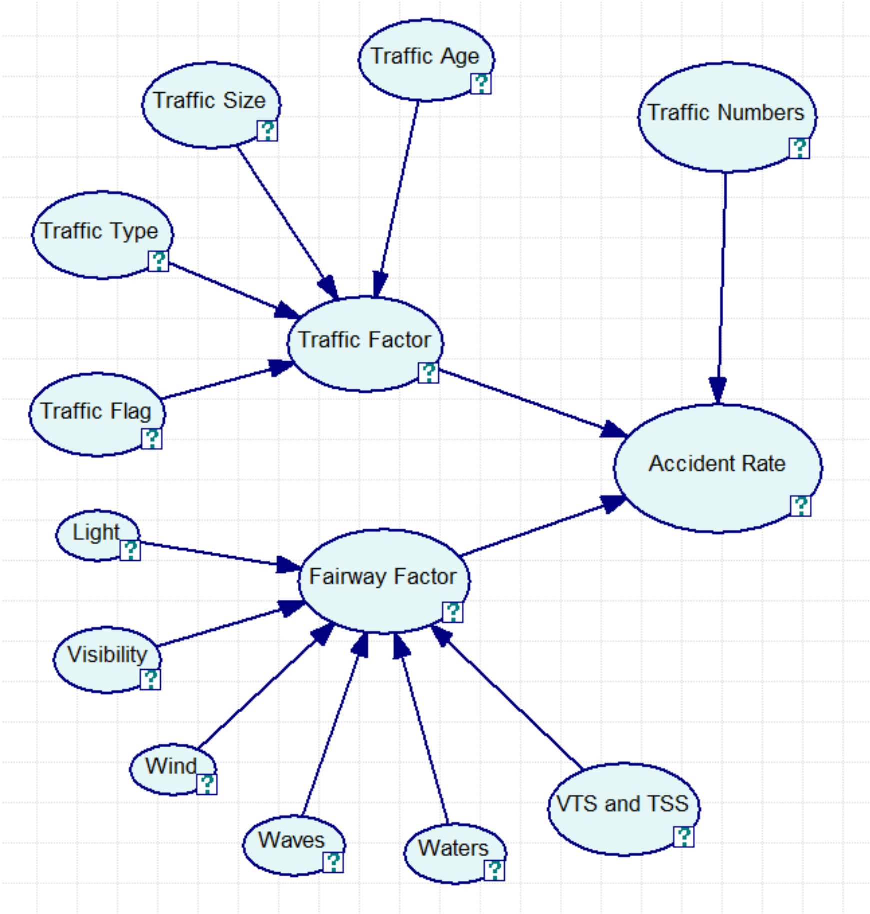


Figure 22 Risk model

The traffic factor will thus be a conditional probability of accident given a set of traffic characteristics and the fairway factor a conditional probability of accident given a set of fairway characteristics. They have to, however, be combined before finding the total accident probability are thus not *accident probabilities* per se.

The development of the traffic factor is shown below. As argued earlier, the conditional probabilities that are used for finding traffic factor are assumed to be valid in all fairways.

5.1 Risk model development

The individual risk for a vessel was calculated using Bayes' theorem, which is defined as:

$$P(A|B) = \frac{P(B|A) \times P(A)}{P(B)}$$

A total of 7935 unique vessels were registered in Norway in 2010. These were categorized as shown below.

	Vessels	Share	Accidents	Share
Vessel type				
Cargo	3854	54 %	296	43.5 %
Passenger	382	5.4 %	214	31.5 %
Vessel flag				
Norwegian	2836	39.8 %	548	80.1 %
Foreign	5024	70.5 %	130	19.1 %
Vessel age				
Under 20 yrs	n/a	49.4 %	272	43.9 %
Over 20 yrs	n/a	46.9 %	248	56.1 %
Vessel length				
Under 100 m	4398	61.7 %	566	83.2 %
Over 100 m	2729	38.3 %	84	12.3 %

Table 10 Share of vessels vs share of accidents

The above table gives the conditional probability of a vessel having certain characteristics given an accident has happened (i.e. $P(cargo\ vessel|accident\ has\ happened) = 0.435$) and the probability of a vessel having that characteristics in the first place ($P(cargo) = 0.54$). This would be equal to the vessel type's share in the accident database and its share in the total traffic data.

The annual probability of an accident for any vessel is calculated as:

$$P(Annual\ Accident\ for\ one\ Vessel) = \frac{Accidents}{Vessels} = \frac{680/3}{7935} = 2.86 \times 10^{-2}$$

This is the average annual accident probability for all vessels – in other words the probability that a randomly selected vessel currently in Norway will have an accident in Norwegian waters at some point during the next twelve months. Also, this is based on number of *unique* vessels registered over a twelve month period (2010), and does such not account for time spent in Norwegian waters.

Using the above values, and Bayes' theorem, the conditional probability of an accident occurring to a given vessel was calculated. These probabilities are given below:

Situation	Conditional probability
$\boldsymbol{P(Accident|Cargo\ Vessel)}$	2.3×10^{-3}
$\boldsymbol{P(Accident|Passenger\ Vessel)}$	0.167
$\boldsymbol{P(Accident|Norwegian\ Flag)}$	5.75×10^{-2}
$\boldsymbol{P(Accident|Foreign\ Flag)}$	7.75×10^{-3}
$\boldsymbol{P(Accident|Less\ than\ 20\ years\ old)}$	2.54×10^{-2}
$\boldsymbol{P(Accident|More\ than\ 20\ years\ oldl)}$	3.34×10^{-2}
$\boldsymbol{P(Accident|Less\ than\ 100\ meters)}$	3.86×10^{-2}
$\boldsymbol{P(Accident|More\ than\ 100\ meters)}$	9.19×10^{-3}

Table 11 Conditional probabilities

The above table gives the conditional probability of a vessel with set characteristics to be involved in an accident, though any vessel will have four of these characteristics – meaning there will be a total of 16 different "vessel types" with different accident probabilities. Appendix A shows the full event tree for the conditional probability $(vessel\ characteristics|accident\ has\ occured)$. Using Bayes' rule as above, but for all of these probabilities, the table below was developed. These probabilities are the same as the above table, but this time for all 16 vessel types (plus a category "other"). Based on the assumption stated above – that the traffic contribution to accident probability is independent of fairway – these were said to be valid for all fairways. This gives the Venn diagram shown below.

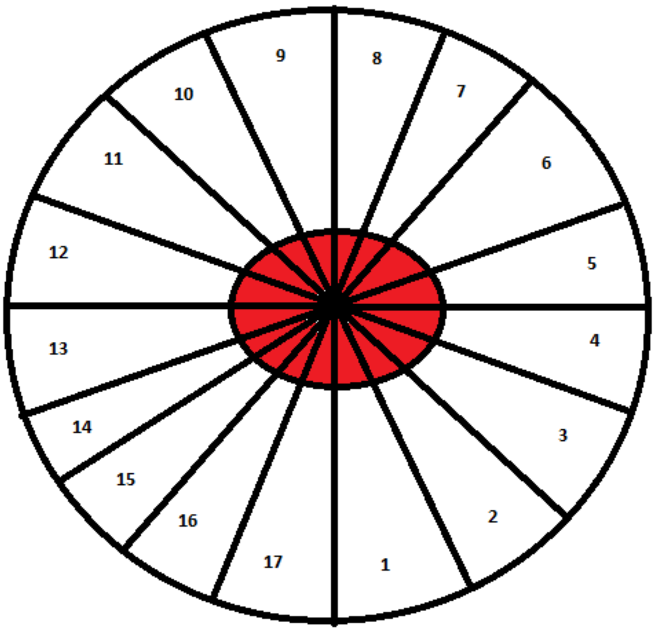


Figure 23 Venn diagram

The seventeen "slices" all represent a vessel category while the red section represents the accident probability. In short, all vessels have a probability of being involved in an accident and a vessel has to be involved for an accident to occur. Also, all vessels have to be in one and only one of the vessel categories.

The diagram could be extended to account for different accidents or the fact that two vessels can be involved in the same accident (collisions), though this is not necessary to find the accident rate. The different outcomes are not drawn to scale.

Now the total accident risk becomes:

$$\sum_{i=1}^{17} P(A \cap B_i) = \sum_{i=1}^{17} P(A) \times P(B_i|A) = \sum_{i=1}^{17} P(B_i) \times P(A|B_i)$$

From the Venn diagram it is apparent that the sum on the intersections, $(A \cap B_i)$, is equal to the total accident probability, P(A). So the accident probability for a fairway or an area, P(A), is given as

$$P(A) = \sum_{i=1}^{17} P(B_i) \times P(A|B_i)$$

The conditional probability is calculated using Bayes' rule as stated above and, as mentioned earlier, both conditional probabilities are said to be equivalent to that of Norway as a whole regardless of the fairway chosen. What can be altered is the probability of a vessel to have a certain characteristics – in effect the percentage share of vessels with this characteristic.

The table below shows the accident probability for the Norwegian waters. A small rounding error has occurred as the total accident probability is calculated as 2.854×10^{-2}, not 2.86×10^{-2}.

#	Probability	#	Probability	#	Probability	#	Probability
$P(B_1)$	1,86 %	$P(B_1\|A)$	0,3 %	$P(A\|B_1)$	0,46 %	$P(A \cap B_1)$	8.58×10^{-5}
$P(B_2)$	1,95 %	$P(B_2\|A)$	1,5 %	$P(A\|B_2)$	2,20 %	$P(A \cap B_2)$	4.29×10^{-4}
$P(B_3)$	0,72 %	$P(B_3\|A)$	13,2 %	$P(A\|B_3)$	52,43 %	$P(A \cap B_3)$	3.78×10^{-3}
$P(B_4)$	0,75 %	$P(B_4\|A)$	10,0 %	$P(A\|B_4)$	38,13 %	$P(A \cap B_4)$	2.86×10^{-3}
$P(B_5)$	13,53 %	$P(B_5\|A)$	0,3 %	$P(A\|B_5)$	0,06 %	$P(A \cap B_5)$	8.58×10^{-5}
$P(B_6)$	14,25 %	$P(B_6\|A)$	3,7 %	$P(A\|B_6)$	0,74 %	$P(A \cap B_6)$	1.06×10^{-3}
$P(B_7)$	5,83 %	$P(B_7\|A)$	0,1 %	$P(A\|B_7)$	0,05 %	$P(A \cap B_7)$	2.86×10^{-5}
$P(B_8)$	6,14 %	$P(B_8\|A)$	2,2 %	$P(A\|B_8)$	1,02 %	$P(A \cap B_8)$	6.29×10^{-4}
$P(B_9)$	0,21 %	$P(B_9\|A)$	0,3 %	$P(A\|B_9)$	4,09 %	$P(A \cap B_9)$	8.58×10^{-5}
$P(B_{10})$	0,22 %	$P(B_{10}\|A)$	3,8 %	$P(A\|B_{10})$	49,40 %	$P(A \cap B_{10})$	1.09×10^{-3}
$P(B_{11})$	1,25 %	$P(B_{11}\|A)$	11,8 %	$P(A\|B_{11})$	27,00 %	$P(A \cap B_{11})$	3.38×10^{-3}
$P(B_{12})$	1,32 %	$P(B_{12}\|A)$	13,5 %	$P(A\|B_{12})$	29,25 %	$P(A \cap B_{12})$	3.86×10^{-3}
$P(B_{13})$	0,49 %	$P(B_{13}\|A)$	0,1 %	$P(A\|B_{13})$	0,58 %	$P(A \cap B_{13})$	2.86×10^{-5}
$P(B_{14})$	0,52 %	$P(B_{14}\|A)$	0,4 %	$P(A\|B_{14})$	2,20 %	$P(A \cap B_{14})$	1.14×10^{-4}
$P(B_{15})$	0,12 %	$P(B_{15}\|A)$	0,4 %	$P(A\|B_{15})$	9,53 %	$P(A \cap B_{15})$	1.14×10^{-4}
$P(B_{16})$	0,12 %	$P(B_{16}\|A)$	0,1 %	$P(A\|B_{16})$	2,38 %	$P(A \cap B_{16})$	2.86×10^{-5}
$P(B_{17})$	50,72%	$P(B_{17}\|A)$	38,09 %	$P(A\|B_{17})$	2,15 %	$P(A \cap B_{17})$	1.09×10^{-2}
						P(A)	$\mathbf{2.854 \times 10^{-2}}$

Table 12 Conditional probabilities, Norway

Definitions for each vessel type can be found in appendix A, but some of these vessels stand out with a very high/low accident probability $P(A|B_i)$:

- B_3: Norwegian flagged cargo vessel, under 100 meters and more than 20 years old
- B_5: Foreign flagged cargo vessel, more than 100 meters and more than 20 years old
- B_7: Foreign flagged cargo vessel, less than 100 meters and less than 20 years old
- B_{10}: Norwegian flagged passenger vessel, more than 100 meters and less than 20 years old
- B_{17}: Other vessels (highest contribution to total accident probability)

Again, this is the probability that the selected vessel will be involved in an accident in the Norwegian waters at some point during the next twelve months. As discussed earlier, this does not account for time spent in Norwegian waters. The fact that Norwegian vessels most likely spend more time in Norwegian waters (though no data to support this argument this have been found) could be the reason why Norwegian vessels seem to be more accident prone.

Still, it is assumed that the distribution of time spent in Norwegian waters per vessel type would be equal to the corresponding distribution in a specific fairway – thus making these probabilities applicable for calculating the overall annual risk for a fairway. The model should also be able to predict the number of accidents that is to be expected from the different vessel types, making preventive actions easier to target.

Setting the fairway factor for the Norwegian waters equal to 1, the expected number of annual accidents in the Norwegian waters is:

$$\begin{aligned} Number\ of\ accidents &= traffic\ factor \times fairway\ factor \times number\ of\ vessels \\ &= P(A)_{traffic} \times 1 \times 7935 = 226.15 \end{aligned}$$

As this is merely a matter of "calculating back to the starting point", it is very close to the actual accident number (680 accidents over three years).

Next the seaward approach to Bergen was used to find a value for the fairway factor and this factor was then used to calculate the risk for the inner parts of the Oslo fjord.

5.1.1 Bergen seaward approach

The busiest port in Norway is the port of Bergen (SSB) and the fairway leading in to Bergen is the geographical area with the sixth highest number of accidents in the NMD database. The top 8 are given below, with "Selbjørnsfj. - Korsfj. ,Bjørnafjorden – Bergen" being the Bergen approach.

Geographical Area	No. Accidents
Nordsjøen med tilliggende kyster av England	660
Østersjøen, Skagerak, Kattegat, Øresund	422
Østersjøen, Skagerak, Kattegat, Øresund	422
Jærens rev - Sletta	341
Østkyst N Amerika til Panama, Karibiske hav	244
Selbjørnsfj. - Korsfj. ,Bjørnafjorden - Bergen	244
Vestfinmarkfjordene	202
Hovedleia Hammerfest - Vardø	201

Table 13 Most accident prone areas

Using the AIS data a total of 1634 vessels were registered and they were categorized as above (event tree in appendix C). The same approach as above was used, giving the following probabilities. Note that both conditional probabilities are kept equal to that of Norway as a whole.

#	Probability	#	Probability	#	Probability	#	Probability
$P(B_1)$	0,66 %	**$P(B_1\|A)$**	0,3 %	**$P(A\|B_1)$**	0,46 %	**$P(A\cap B_1)$**	3.04×10^{-5}
$P(B_2)$	0,70 %	**$P(B_2\|A)$**	1,5 %	**$P(A\|B_2)$**	2,20 %	**$P(A\cap B_2)$**	1.54×10^{-4}
$P(B_3)$	4,68 %	**$P(B_3\|A)$**	13,2 %	**$P(A\|B_3)$**	52,43 %	**$P(A\cap B_3)$**	2.55×10^{-2}
$P(B_4)$	4,93 %	**$P(B_4\|A)$**	10,0 %	**$P(A\|B_4)$**	38,13 %	**$P(A\cap B_4)$**	1.88×10^{-2}
$P(B_5)$	4,22 %	**$P(B_5\|A)$**	0,3 %	**$P(A\|B_5)$**	0,06 %	**$P(A\cap B_5)$**	2.53×10^{-5}
$P(B_6)$	4,44 %	**$P(B_6\|A)$**	3,7 %	**$P(A\|B_6)$**	0,74 %	**$P(A\cap B_6)$**	3.29×10^{-4}
$P(B_7)$	7,69 %	**$P(B_7\|A)$**	0,1 %	**$P(A\|B_7)$**	0,05 %	**$P(A\cap B_7)$**	3.85×10^{-5}
$P(B_8)$	8,10 %	**$P(B_8\|A)$**	2,2 %	**$P(A\|B_8)$**	1,02 %	**$P(A\cap B_8)$**	8.26×10^{-4}
$P(B_9)$	0,43 %	**$P(B_9\|A)$**	0,3 %	**$P(A\|B_9)$**	4,09 %	**$P(A\cap B_9)$**	1.76×10^{-4}
$P(B_{10})$	0,45 %	**$P(B_{10}\|A)$**	3,8 %	**$P(A\|B_{10})$**	49,40 %	**$P(A\cap B_{10})$**	2.22×10^{-3}
$P(B_{11})$	1,35 %	**$P(B_{11}\|A)$**	11,8 %	**$P(A\|B_{11})$**	27,00 %	**$P(A\cap B_{11})$**	3.65×10^{-3}
$P(B_{12})$	1,42 %	**$P(B_{12}\|A)$**	13,5 %	**$P(A\|B_{12})$**	29,25 %	**$P(A\cap B_{12})$**	4.15×10^{-3}
$P(B_{13})$	1,38 %	**$P(B_{13}\|A)$**	0,1 %	**$P(A\|B_{13})$**	0,58 %	**$P(A\cap B_{13})$**	8.00×10^{-5}
$P(B_{14})$	1,45 %	**$P(B_{14}\|A)$**	0,4 %	**$P(A\|B_{14})$**	2,20 %	**$P(A\cap B_{14})$**	3.19×10^{-4}
$P(B_{15})$	0,23 %	**$P(B_{15}\|A)$**	0,4 %	**$P(A\|B_{15})$**	9,53 %	**$P(A\cap B_{15})$**	2.19×10^{-4}
$P(B_{16})$	0,24 %	**$P(B_{16}\|A)$**	0,1 %	**$P(A\|B_{16})$**	2,38 %	**$P(A\cap B_{16})$**	5.17×10^{-5}
$P(B_{17})$	57,63 %	**$P(B_{17}\|A)$**	38,09 %	**$P(A\|B_{17})$**	2,15 %	**$P(A\cap B_{17})$**	1.24×10^{-2}
						$P(A)$	$\mathbf{6.89 \times 10^{-2}}$

Table 14 Conditional probabilities, Bergen

$$Number\ of\ accidents = traffic\ factor \times fairway\ factor \times number\ of\ vessels$$
$$= P(A)_{traffic} \times P(A)_{fairway} \times 1634 = 6.67$$

By inserting the traffic factor found above, 6.89×10^{-2}, the only unknown is the fairway factor. Using Excel's goal seek function, the required fairway factor, $P(A)_{fairway}$, was found to be 0.0592.

5.1.2 Inner Oslo fjord

The inner Oslo fjord area is similar to the Bergen approach in regards to many of the factors used to describe the fairway factor, and was used as a test to see if the above method would give the correct result. In the NMD database there is 14 accidents (over three years) registered and the AIS data had 1083 vessels registered. The event tree is given in appendix D and the traffic factor was calculated as above (appendix E). Below is a map over the area defined as inner Oslo fjord.

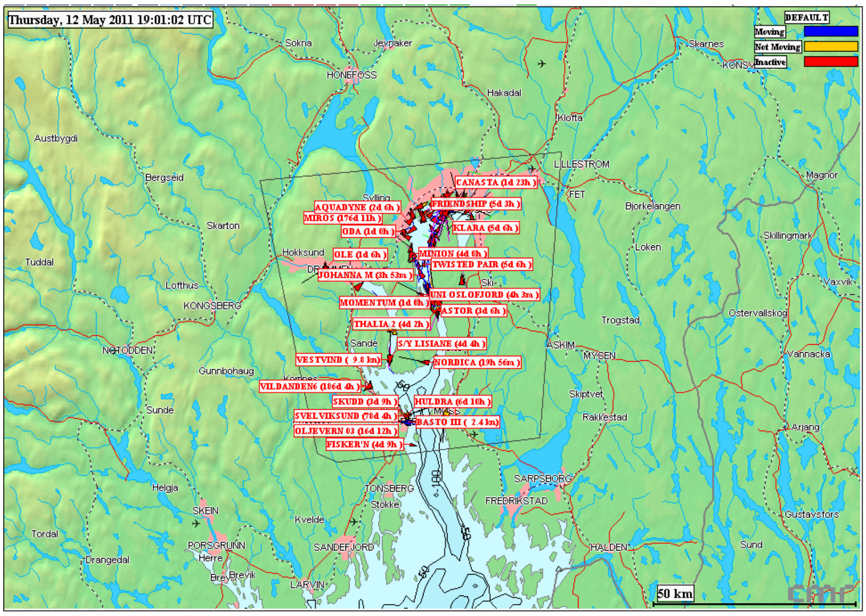


Figure 24 Inner Oslo fjord

The resulting traffic factor for the inner Oslo fjord was calculated as

$$P(A)_{traffic} = 4.02 \times 10^{-2}$$

By using the fairway factor calculated from Bergen and the total vessel count, the calculated annual accidents in the inner Oslo fjord becomes

$$\begin{gathered} Number\ of\ accidents = P(A)_{traffic} \times P(A)_{fairway} \times number\ of\ vessels \\ = 4.02 \times 10^{-2} \times 5.92 \times 10^{-2} \times 1083 = 2.58 \end{gathered}$$

Compared with the actual average for 2007 – 2009, $\frac{14}{3} = 4.67$, the calculated number is 45 % lower. There could be several reasons for this; these are discussed in the next chapter.

By printing the distribution over vessels involved in accidents (shown below), several similarities between the results from the risk model and the real life results can be seen. The risk model over predicts the number of accidents from Norwegian cargo vessels under 100 meters (B_3 and B_4) and the category consisting of other vessels (B_{17}). On the contrary, the number of accidents for foreign cargo vessels under 100 meters and Norwegian passenger vessels under 100 meters (B_8 and B_{11}) are underestimated.

The result is, however, uplifting as the general trend is similar for both distributions.

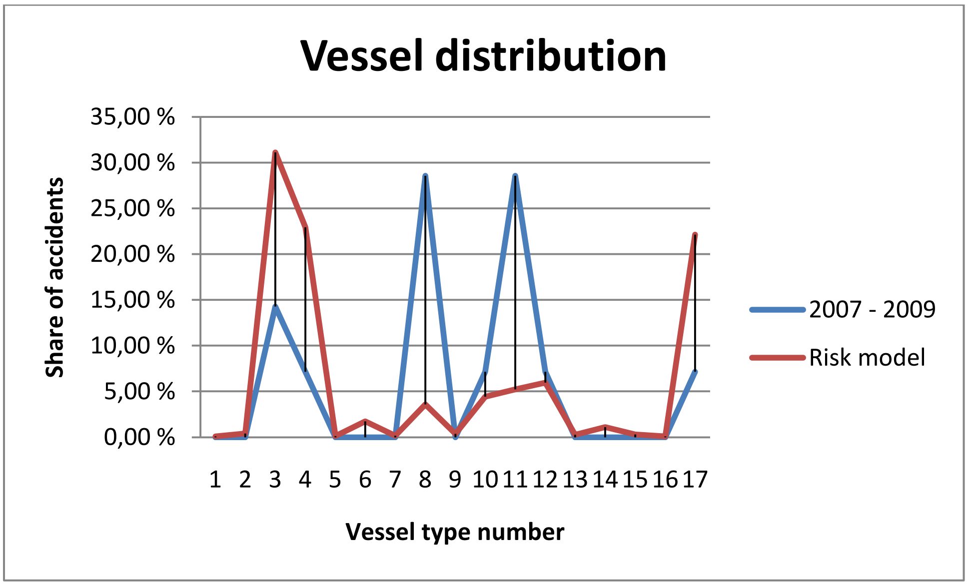


Figure 25 Vessel distribution

Finally, the average accident rate per vessel in the inner Oslo fjord was compared to that of Norway as a whole.

Average accident rate per vessel for the Norwegian waters (calculated):

$$P(Annual\ Accident\ for\ one\ Vessel) = \frac{Accidents}{Vessels} = \frac{680/3}{7935} = 2.86 \times 10^{-2}$$

Average accident rate per vessel for the inner Oslo fjord waters (calculated):

$$P(Annual\ Accident\ for\ one\ Vessel) = \frac{Accidents}{Vessels} = \frac{14/3}{1083} = 4.31 \times 10^{-3}$$

There is a major difference between the accident rate for Norwegian waters and that for the inner Oslo fjord; this is most likely due to each of the registered vessels spending a larger share of total sailing time in the Norwegian waters than in the inner Oslo fjord. Again, this does necessarily mean that the accident rate per nautical mile is higher in the Oslo fjord.

Average accident rate per vessel for the inner Oslo fjord waters (from risk model):

$$P(Annual\ Accident\ for\ one\ Vessel) = P(A)_{traffic} \times P(A)_{fairway} = 4.02 \times 10^{-2} \times 5.92 \times 10^{-2} = 2.38 \times 10^{-3}$$

This is an important result as it shows that the model gives a far better result than simply using the average accident rate for entire Norway. If the accident rate had been calculated using the Norwegian average the rate would have been estimated as (without the fairway factor):

$$Number\ of\ accidents = 2.86 \times 10^{-2} \times 1083 = 30.97$$

To really compare the model with the accident rate from the Norwegian average, the accident number can be multiplied with the same fairway factor as the one used in the risk model. This should scale for travel time and fairway characteristics in the same manner as in the model. The new accident rate then becomes:

$$Number\ of\ accidents = 2.86 \times 10^{-2} \times 5.92 \times 10^{-2} \times 1083 = 1.83$$

The model predicts:

$$Number\ of\ accidents = 2.38 \times 10^{-3} \times 1083 = 2.58$$

And the correct accident rate is:

$$Number\ of\ accidents = \frac{14}{3} = 4.67$$

5.2 Discussion

As shown above, the model underestimated the total accident number for the inner Oslo fjord by 45% and did not calculate the accident distribution correctly (though the general trend was fairly close to reality). The model did, however, predict the accident rate better than what was predicted by simply using the Norwegian average – indicating that the assumption that a vessel that is more accident prone in one fairway will also be more accident prone in another is correct (if not perfect in its current form).

There could be several reasons for the divagation, these are commented on below.

5.2.1 Traffic factor and accident vessel distribution

First, the fact that the distribution is different reveals that the assumption of simply using the same conditional probability everywhere is not correct in its current form. It should be noted, however, that the model overestimates small Norwegian cargo vessels (a vessel category where all vessels are likely to spend the whole year in Norwegian waters) and underestimates foreign cargo vessels (where the vessels possibly spend less time in Norwegian waters). It is not given, though, that the share of time in Norwegian waters is equal to the share of time spent in the inner Oslo fjord, as a Norwegian vessel could be sailing in liner traffic between Oslo and Bergen while a foreign vessel could sail in liner between Oslo and Esbjerg. This will give the Norwegian vessel a higher conditional accident probability (from the Norwegian waters), though it will not spend more time in the inner Oslo fjord. It is assumed that the model would give better results if a similar approach as above was used with calculations per time or per nautical mile in Norwegian waters.

The other category that is highly underestimated is Norwegian passenger vessels under 100 meters – this is harder to explain. It could mean that the initial assumption is not correct, though it could also mean that an even more precise characteristic of the vessels involved is required. Most passenger vessels in Norway are in the category 5C2 (Ro/ro – passenger ferry), though only one of the six passenger vessel accidents in the Oslo fjord involved one of these. Still, the AIS simply gives "passenger vessel" as a category, a more precise definition is not readily available. Using more categories for vessel length could be a possible work-around, though this has not been investigated further.

The category "other" is highly overestimated in the model, though this category consisted of approximately 50% of all vessels registered in the Norwegian waters in 2010. It is likely that large variations within this category exist (i.e. the share of fishing vessels is most likely smaller for the inner

Oslo fjord than for Norway as a whole), making it hard to make a conclusion. Making another break-down with more vessel categories could remove this problem.

Finally, in this model each vessel only contribute to the accident probability in terms of the vessels own base probability, not based on the combination of vessels in the fairway at the given moment. It could be argued that an "unsafe" vessel will also increase the accident probability of surrounding vessels, and such increase the conditional accident probability of all surrounding vessels.

The smaller deviations could be due to the dataset of 14 accidents not being large enough.

5.2.2 Fairway factor

The fairway factor will only affect the total accident number, not the distribution of accident vessels. The calculated total accident number for the Oslo fjord was 45 % too low, meaning the number would have been correct if a fairway factor that was 86 % larger had been used. This is a rather large difference and hard to comment on as the fairway factor used was simply found from the Bergen sail in. Simply assuming that these two would be equal is most likely not correct as this method of estimating the fairway factor is based on the assumption that "if six percent of all vessel accidents happened in this area, another six percent will happen in this similar area". This is most likely a too gross simplification.

It could, however, be put more work into developing this factor using a similar procedure to that of the traffic factor. Using weather statistics as a basis, conditional probabilities for wind, waves, visibility and light could be developed. For the fairway complexity a similar system to that used for terrain in avalanche risk analysis could be used, a suggestion for this is given below.

Description	Class	Area Criteria
Simple	1	Exposure to open water with few or no barriers/reeves. No crossing fairways and many options to avoid collisions.
Challenging	2	Some or no exposure to islands, barriers and/or reeves. Few or no crossing fairways, options to avoid collisions are reduced and route choices have to be made and communicated.
Complex	3	Exposure to multiple crossing fairways and/or maneuvering highly restricted by islands/barriers/reeves. Options to avoid collisions highly reduced and route choices have to be made and communicated.

Table 15 Suggested fairway complexity break-down

There is, of course, already a waters ("farvann") categorization in the NMD database, and this could also be used for the complexity categorization as it does to some extent take crossing fairways into account. Based on personal experiences (from judging avalanche terrain), however, it is hard use more than three categories as it could (or would) result in different people judging the same terrain to be in different categories.

5.2.3 Traffic factor vs fairway factor – weighting

In the above model the traffic factor and the fairway factor were weighted equal, this most likely not correct. Unfortunately, not much research has been put into this – making it hard to come up with a better suggestion for the ratio.

Evidence does, however, suggest that the vessel in question is a greater contributor to risk than weather and fairway. For instance, an often quoted number is that 80 % of all ship accidents are related to a human error and 25 % of the world's most substandard ships are involved in 50 % of all major accidents (Soma, 2005). Both of these results imply that the vessel is the main reason for an accident, not its surroundings.

As no detailed study has been performed on the weighting of these factors, a 1:1 ratio was chosen (both being weighted equal).

5.2.4 Recommendations

Recommendations based on the above discussion are given below

- Base the conditional probabilities on time or distance instead of the vessel being present. This is most likely the major reason for the accident distribution being inaccurate and would have to be improved for the model to be correct.
- Have more than 17 vessel categories; put more effort into finding more exact inflection points for the accident rates. The vessel category "other" is too large and the inflection points were not investigated in close enough detail (e.g. the inflection point for "vessel size" might be at 90 meters, not 100).
- Put more effort into quantifying the fairway factor "from the bottom up", as opposed to calculating it from a similar area. The fairway factor can be estimated by the use of condition probabilities similar to the traffic factor, and this would have to make the model applicable for all fairways.
- Find a better ratio between the fairway and the traffic factor – a 1:1 scale is most likely not correct.

The model should, without much improvement, be able to give good results when simulating the impact from traffic changes (e.g. when building a new quay) as one can determine the fairway factor from the area that is to be analyzed. It also proves helpful to determine which vessels are most likely to be involved in accidents (the conditional probability of an accident, given a certain vessel) and can such help in making targeted preventive measures.

By working on the areas commented on above it should also be possible to use the model for risk analysis of a fairway without a known accident rate.

5.2.5 A suggestion for model extension

By using conditional probabilities found similar to above and combining them with more detailed traffic data for only one fairway crossing, a risk model could be developed. This idea arose late in the project work and thus only the main steps required are outlined. The model was not created and is such to be regarded as a suggestion for further work.

Based on the work by (Kujala, Hänninen, Arola, & Ylitalo, 2008) it was decided to find traffic statistics for only one fairway crossing and the Halhjem approach (just south of Bergen) was chosen. Two major ferry routes have port calls in this harbor and there is a significant amount of crossing traffic. The resulting east – west and north – south map plots are given below and a tails process for each of these was run for one year.

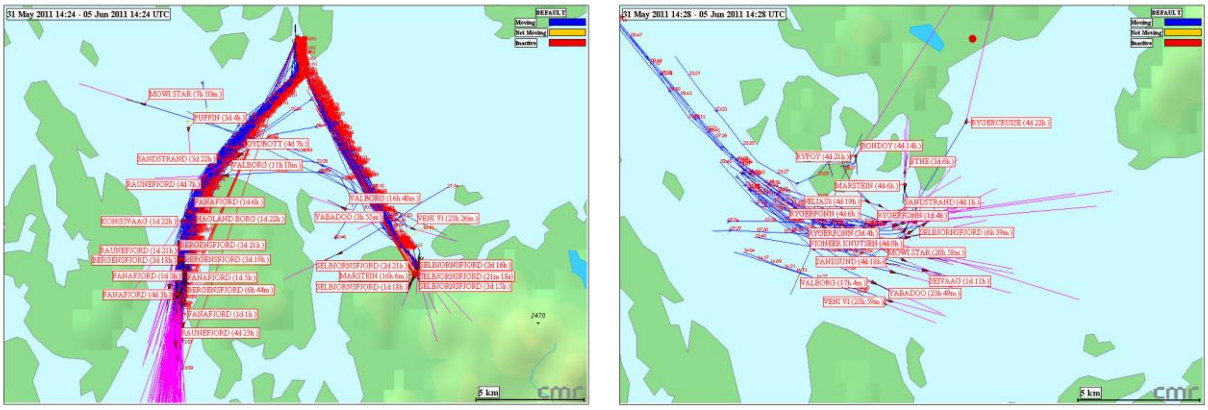


Figure 26 Tails process

Running this tails process over one year gave 1434 vessels registered traveling east – west (or west – east) and 14448 vessels traveling in the north – south direction. By sorting these vessel passings by time of day and month of the year, and using the EasyFitXL software (Mathwave), the expected distribution of vessels in the fairway at a given moment was found. The distributions are given in the appendixes. An obvious weakness in the data exists, as the distribution for monthly vessels going north – south has an empty bar midsummer. This could be due to the fact that the trial version of EasyFitXL only accepts data sets of up to 5000 entries, so this set was trimmed by using only every third value from the original set of almost 15000 entries.

These distributions do not take head-on encounters into consideration (i.e., vessels are assumed to sail only one way in the fairway), though this could easily be accounted for by sorting the vessels after registered heading when crossing the pass line. As the data was given as binned variables (time is a continuous variable, but was grouped into whole hours for this analysis), the chi-square test was used for ranking the distributions. The rankings are given in the appendixes.

The distributions could then be used as input for a model that simulates the number of vessels in the fairway and the number of encounters could then be estimated using Pedersen's model (Pedersen P. T., 2002). Finally, by removing the *causation probability* (which is hard to estimate) from the traditional formula and instead use the *conditional accident probability for a certain vessel type* (which can be determined from traffic and accident statistics), the expected number of accidents could be determined as follows:

$$N_{accidents} = P(A)_{traffic} \times N_{accident\ candidates} \times P(A)_{fairway}$$

The fairway factor would in this case be determined for only one fairway crossing, not a larger area as above. This formula is in many ways similar to the one proposed by (Moua, Tak, & Ligteringen, 2010) where the collision risk per vessel is calculated by:

$$R_{colli} = R_{basic} \times F_{tcpa} \times F_{cpa} \times F_{angle}$$

R_{basic} in the above formula is equivalent to the conditional probabilities used for defining $P(A)_{traffic}$ and the three factors describe the traffic pattern in a similar manner to the description from $P(A)_{fairway}$. The difference is, however, that the formula for R_{colli} only finds the collision risk for two given vessels at a certain time. The formula for $N_{accidents}$ on the other hand, can be used for calculating the expected number of accidents based on a larger data set.

Again, this model was not developed and thus not tested. Based on experiences from the statistical model, and from reading a number of reports regarding risk analysis, however, this model is expected to give good results.

6 Common traffic traits for 2010 accidents

It is reasonable to assume that certain traffic traits could indicate a higher accident risk (e.g. a high number of old vessels in the fairway at a given moment) and such traits were attempted to be found from by investigating accidents from 2010. During this work another suggestion for an extension to the AIS interface was found, namely a filter that registers the vessels in a fairway every time it changes (i.e. a polyline filter that instead of registering vessels at given time intervals registers vessels as a vessel leaves or enters the defined area). This would help answering the question *what is the normal traffic picture in this area?*, and such simplify the process of indentifying factors that are different when accidents happen.

As no such filter exists as of today the registered accidents had to be checked individually without a good way of comparing with the normal traffic picture.

Especially two factors were assumed to be important:

- Vessels in the fairway at the time of the accident
- Time from vessel lost its course until the accident had happened (TCPA)

6.1 Accident data

For this study the 2010 accident database was used. This database contains a total of 332 accidents and is extended compared to the one used for the risk model earlier. The most important extension is that it now lists direct and indirect causes for the accidents (based on accident surveys), making it easier to find relevant accidents. At first 10 accidents that had other vessels listed as a direct cause where found, and it was attempted to find some common traffic patterns for these accidents. The accidents studied are given in appendix L.

To find the TCPA when vessel lost its course it was decided to use accidents where the OOW had fallen asleep on the bridge. A total of 9 accidents had this given as a cause.

6.2 AIS study

The accidents were investigated by running a tails process over two hours around the time of the accident, and the registered accident position was then found on the map. The vessels in the fairway were then found either by a visual inspection or by the use of the *circle* or *pass line* filters in the AIS interface. The results are all given in appendix L.

Unfortunately, there is a significant lack of data in the accidents investigated. Only two of the accidents with other vessels listed as a direct accident cause could be found and only one of the vessels with the OOW falling asleep was found. This does, of course, make it impossible to come up with a conclusion regarding traffic characteristics during these accidents.

This was considered a small part of this project and no further work was done to improve these results.

7 Revealing old, unreported accidents

One interesting aspect of utilizing AIS data is for revealing accidents that never was reported, as it is reasonable to assume that a number of close-call incidents and accidents that allows the ship to continue sailing will go by unreported. AIS data for known accidents in the five main categories was extracted from the AIS database and it was attempted to find common traits that can be identified in a larger data set by means of functions already present in the AIS interface or MS Excel. Suggestions for extensions in the AIS interface that would improve "surveillance" of the ship traffic were also proposed.

The five main accident categories, with suggestions for how to reveal unreported accidents, are given below.

7.1 Groundings

Groundings could be identified by two factors available in the AIS data; either by a sudden and unexpected drop in speed over ground or by the vessel being in an area with too shallow water for her to sail. Both of these methods have pros and cons and were both investigated. In short, using vessel speed will reveal accidents even in an area without any registered barriers/reeves, but will not reveal any near accidents as the vessel would not actually hit the ground (and not have a SOG drop). On the contrary, by counting over areas where the vessel "should not sail" a vessel will be registered even when she does not experience a speed drop. The drawback of this method is, however, that only marked areas will be included in the analysis.

Both methods are described in the following.

7.1.1 Counting over known barrier/reef

This can once again be done in two ways; one could either use charts and mark all areas with too shallow water for the ship to sail, or one could instead use already registered accidents and mark all ships that sail within a certain radius of these as accident candidates. With future improvements in AIS technology it is reasonable to assume that depth will be part of the charts used and combined with vessel draught (which is already reported by the AIS) the first approach will be the most feasible. As of today, though, this would require huge amounts of manual labor and the second approach was chosen for this study.

First all reported groundings from January 1st, 2007 to December 15th 2009 were extracted from the NMD database. Out of these there were 291 accidents that had the exact position registered and these were converted from decimal degrees (given from NMD) to degrees, minutes and seconds (the output given in the AIS data). The first five accidents are provided below as an example to show the conversion. The constraint chosen for this process was "circle", that is a circle with center as given from the two left columns and radius as in the right is drawn and all vessels that have passed through are registered. The input for each constraint would be on the form:

(5.584666667, 59.71716667,200).

Geographical Area	Dec. Latitude	Dec. longitude	Latitude	Longitude	Radius
Hardangerfjorden	59.71716667	5.584666667	59°43'02"	5°35'05"	200
Kristiansand - Lindesnes	58.025	7.335	58°01'30"	7°20'06"	200
Sognefjorden	61.03883333	4.7875	61°02'20"	4°47'15"	200
Korsfjorden - Holmengrå	60.75033333	4.705833333	60°45'01"	4°42'21"	200
Trondheimsfjorden	63.53333333	9.818	63°32'00"	9°49'05"	200

Table 16 Groundings table, example

The above table could easily have been exported as a .tsv file ("tabulator separated values", the same form as data exported from the AIS interface), though importing capabilities does unfortunately not exist in today's interface. This is something that is hopefully being considered for implementation, as creating filters from a table would simplify the process of creating advanced filters considerably. Creating all 291 constraints by hand was deemed unnecessary, and instead a couple of accidents were chosen to investigate the concept. These are given below.

7.1.1.1 Godafoss accident

Godafoss is a 165 meter cargo vessel flagged under Antigua and Barbuda that grounded by Hvaler outside of Oslo on February 17th, 2011. The below map shows the vessel path as it grounded as well as its path going north through the strait the day before. From the picture it is clear that the vessel got off course around 19:51 on the evening of the accident and grounded only minutes later. The captain was alone on the bridge at the time of the accident and has admitted that he made a navigational error.

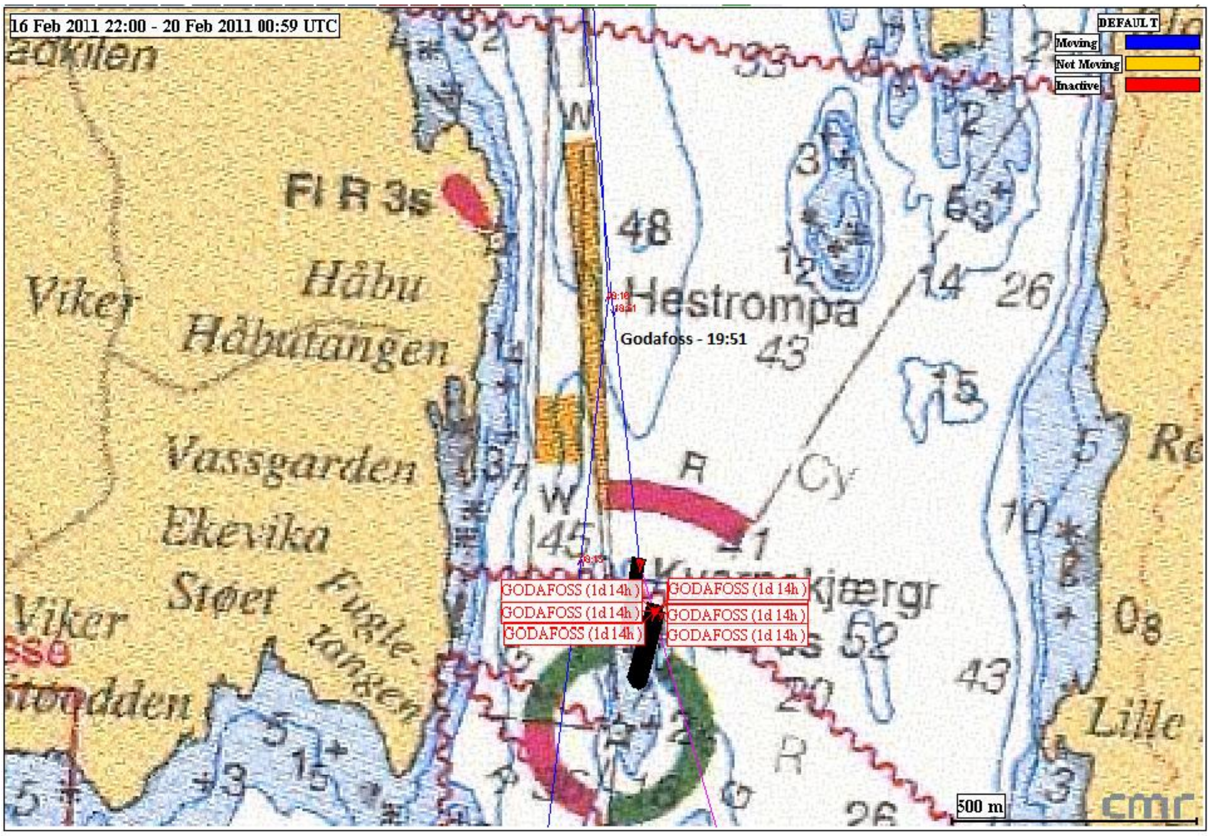


Figure 27 Godafoss accident

The exported data is given below (with times in UTC = Norwegian time -1 hour) and shows one reporting only minutes before the grounding. The next reporting, however, is 17 hours later and this is the first sign that the accident had happened (as long periods without position updates are common in the exported data). The main indicators of the accident are the drop in SOG and the fact that several of the reported positions are similar. Had the vessel continued sailing before the next retained data point (due to favorable tidal water or similar) no obvious signs of the vessel suddenly coming to a stop would have remained. Based on these results it was decided to count over the accident site itself and manually check the registered vessels.

latitude	longitude	time stamp	sog	cog	heading	nav status	Tail speed
N 59−10.98'	E 010−57.12'	2011-02-17T18:08:51Z	7.8	162	163	under way, using engine	5.40
N 59−02.46'	E 010−58.36'	2011-02-17T18:52:18Z	9.6	160	186	under way, using engine	12.20
N 59−02.41'	E 010−58.40'	2011-02-18T12:23:56Z	.0	341	192	not under command	.00
N 59−02.41'	E 010−58.40'	2011-02-18T13:36:24Z	.0	327	191	not under command	.00
N 59−02.41'	E 010−58.39'	2011-02-18T13:54:15Z	.0	278	192	not under command	.00
N 59−02.41'	E 010−58.40'	2011-02-18T14:24:35Z	.0	243	193	not under command	.00
N 59−02.41'	E 010−58.40'	2011-02-18T14:54:26Z	.0	267	191	not under command	.00
N 59−02.41'	E 010−58.39'	2011-02-18T17:52:45Z	.0	270	191	not under command	.00
N 59−02.41'	E 010−58.40'	2011-02-18T20:46:55Z	.0	326	191	aground	.00
N 59−02.41'	E 010−58.39'	2011-02-18T21:09:25Z	.0	298	191	aground	.00

Table 17 Godafoss, data export

The method was tested by running a tails process over the Godafoss grounding site to see if other vessels are registered in close vicinity. The circle used was described using the following coordinates (the Godafoss grounding site as center of the circle and a 200 meter radius):

10.9733477,59.0401421,200

The process was run over a year with a time step of 1 hour giving the following results:

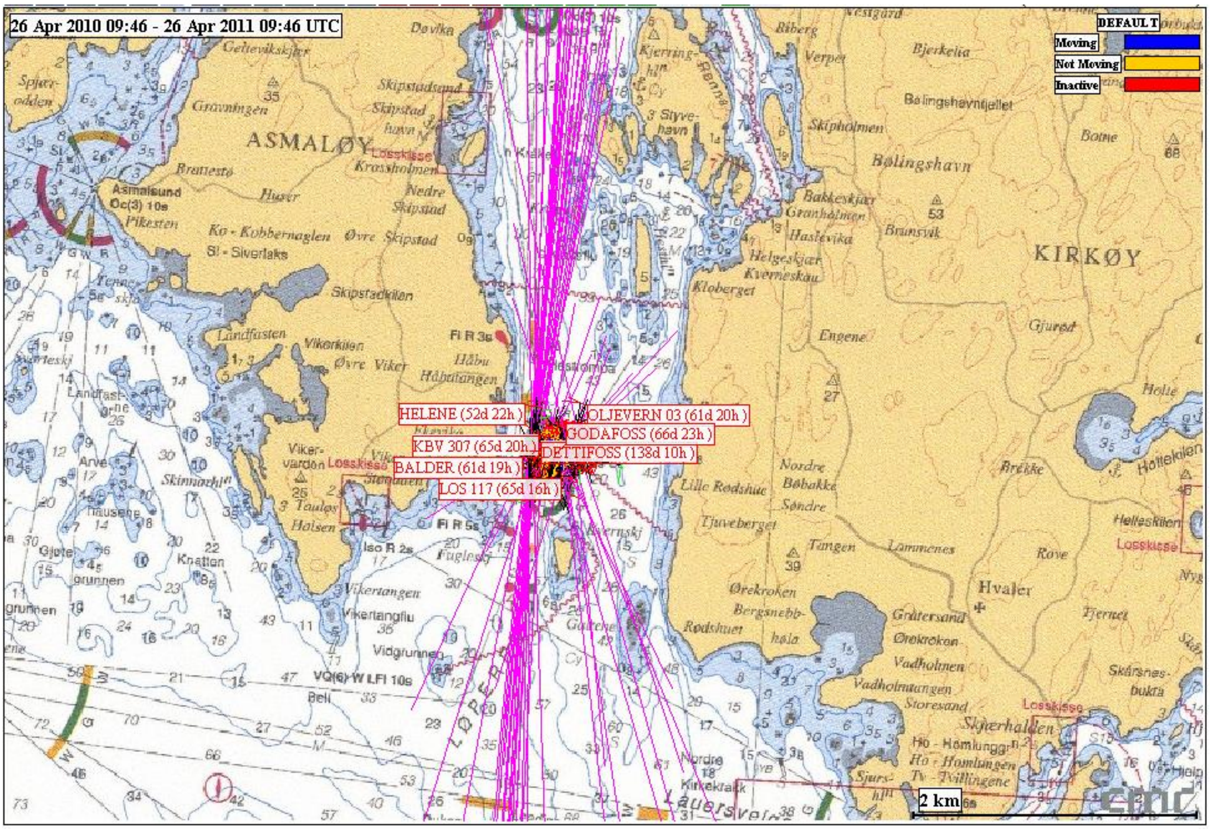


Figure 28 Godafoss accident, one year tails process

r = 200				r = 150			
Country	**#**	**Ship type**	**#**	**Country**	**#**	**Ship type**	**#**
Norway	18	**Cargo ship**	32	**Antigua & Barbuda**	1	**Cargo ship**	3
Malta	6	**Tanker**	11	**Bahamas**	2	**Law enforcement vessel**	4
Faroe Islands	5	**Law enforcement vessel**	6	**Norway**	11	**Other**	2
Sweden	5	**Tug boat**	4	**Sweden**	2	**Pilot vessel**	2
Antigua and Barbuda	4	**Other**	3			**SAR vessel**	1
Bahamas	3	**Pilot vessel**	2			**Tug boat**	4
Cyprus	3	**SAR vessel**	2				
Netherlands	3						
Barbados	2						
Denmark	2						
Germany	2						
Gibraltar	2						
Liberia	1						
Panama	1						
Russia	1						
South Korea	1						
Togolese	1						

Table 18 Data export, Godafoss accident

From the above table there is a clear difference between a radius of 200 meters and one of 150 meters. Also, the numbers include vessels that participated in the rescue operation. At the 150 meter radius, only two vessels are registered a different time than the rescue operation, these are registered as a SAR vessel and a pilot vessel.

For the 200 meter radius things are different, as a total of 43 vessels are registered at a different time than the rescue operation. 39 of these vessels are registered as tanker or cargo vessels, and two of these vessels have a higher “maximum actual draught” than Godafoss. One of these was a Godafoss sister ship, the cargo ship “Dettifoss” with a flag from Antigua and Barbuda and this ship is studied below. It should be noted that Dettifoss was also involved in the rescue operation after the accident, this is not the pass-through that is studied below.

The Godafoss accident happened in a fairway that is only about 650 meters wide in total, meaning a vessel that chooses a course off to the side could easily be within 200 meters of the accident site. By printing a snapshot of Dettifoss pass through (shown below), it can be seen that other vessels where approaching as well. At the instant shown Dettifoss is at its closest to the Godafoss accident site (marked on the map), and safely within the fairway on a safe course (this is apparent when comparing with the Godafoss map given above). Consequently, despite being close to a grounding site this is not a near-accident.

This reveals a major point with this method of revealing unreported near groundings; one cannot simply state that an incident has occurred simply because of a vessel being within a certain distance of a known barrier or reef. A detailed algorithm could be developed (that takes into account the vessel cog and the direction from the vessel to the grounding point), but a visual check is also efficient. Using a visual check will also reveal if the vessel had a sudden stop that could imply grounding.

Using these experiences it was decided to start with a filter which each constraint (circle) having a radius of 200 meters, and reduce until the total number of vessel reached an amount feasible for visual checks. This could leave out some incidents (vessel that changed course at the last second), though this is not assumed to be a likely situation.

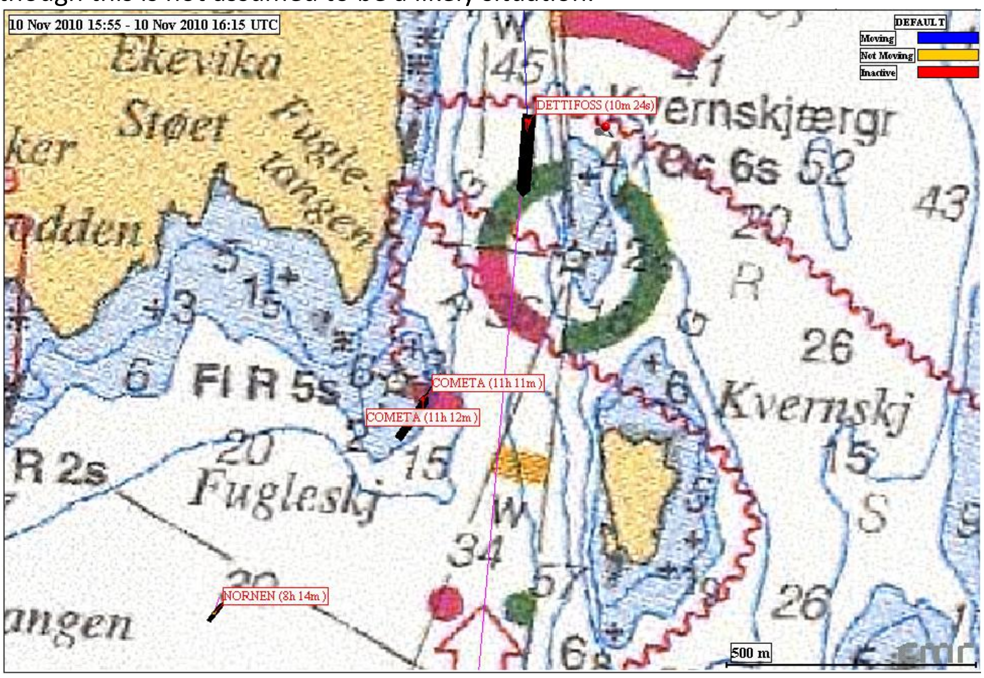


Figure 29 Dettifoss

7.1.1.2 The Bergen Seaward Approach

To test the method used above with a larger data set, the approach to Bergen was chosen and all groundings from 2007 – 2009 (a total of 12) were used as constraints for a 365 day tail process. The number of vessels registered for different radiuses are given below.

Radius	Number of vessels
200	282
100	111
75	70
50	41

At first a 365 day tail process for all the 41 vessels (using a “name” filter) that had been within the 50 meter radius was performed and the results investigated. This revealed another element of the implementation of the Douglas Peucker Algortihm, namely that a larger time-span results in more reportings being omitted. As a result of this, none of the vessels that had been counted in the 50 meter radius had a reported position in this area, and the process had to be re-done over smaller time-intervals around the registered times. Below is the resulting map from a one-month tails process with three of the grounding sites clearly visible. Once again the grounding sites are in narrow sections of a fairway and several vessels are therefore in close vicinity of the former accident site.

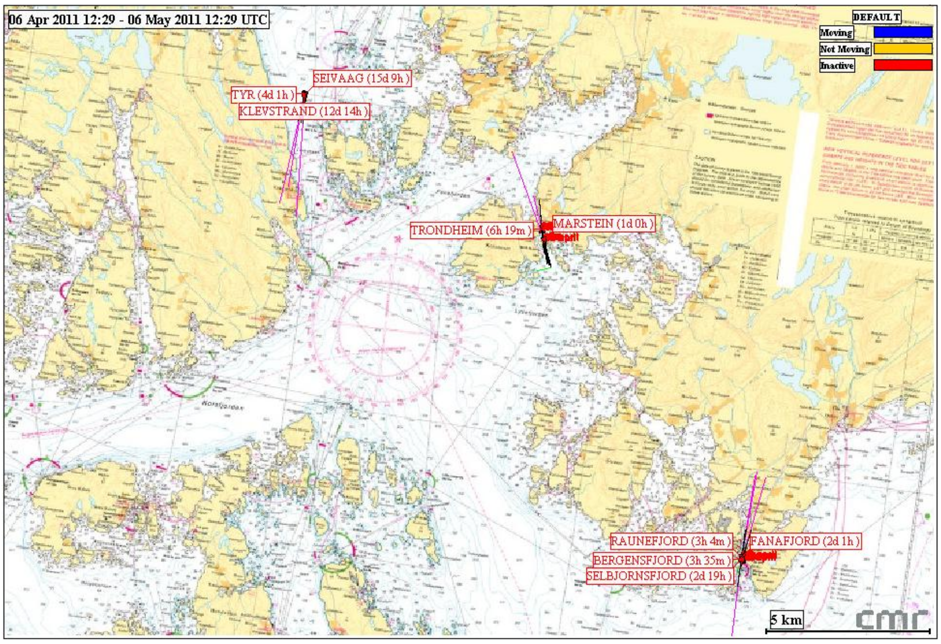


Figure 30 Bergen seaward approach

One of the vessels, the passenger vessel Selbjornsfjord, was chosen and the entry from the 50 meter radius spreadsheet is given below.

SELBJORNSFJORD	N 60°08.51'	E 005°25.60'	2011-01-08T19:59:32Z

The filter used for the tails process was then altered to use a 500 meter radius around the grounding site and a process was run over the evening of January 8th. The resulting map and data export are both given below, once again showing the difference in data used for constructing the visual tail and the data that is actually exported. The star in the map is the vessel position at 19:59, at which point she was within 50 meters of the grounding site. The vessel does, however, seem to navigate safely and there is no evidence that a near accident has occurred.

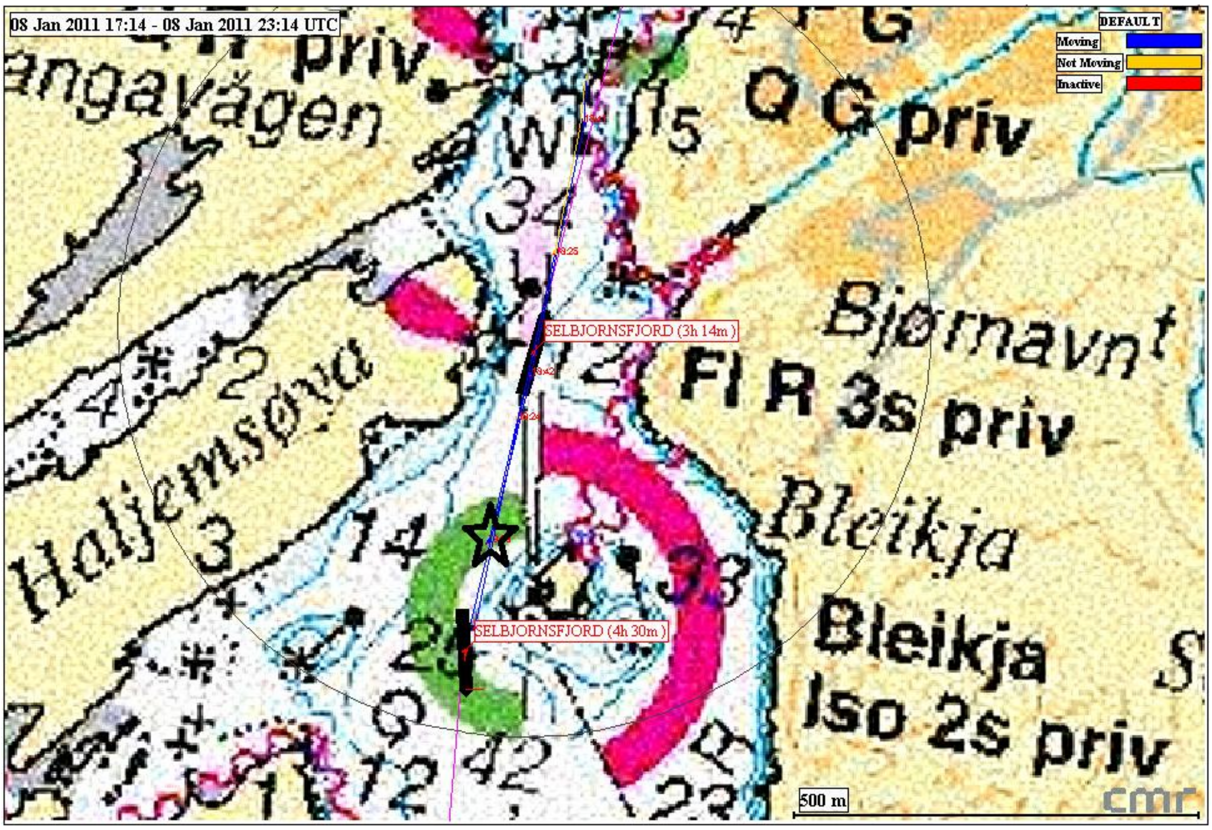


Figure 31 Selbjørnsfjord

ship name	latitude	longitude	time stamp	sog	cog
SELBJORNSFJORD	N 60−08.30'	E 005−25.56'	2011-01-08T18:43:55Z	11.1	176
SELBJORNSFJORD	N 60−08.51'	E 005−25.60'	2011-01-08T19:59:32Z	6.9	006

Table 19 Data export, Selbjørnsfjord

Based on the experiences described above it was decided that the method could be useful for screening out vessels that are more likely to have been involved in a grounding, but it could not be used alone as too many vessels are registered. Checking each vessel occurring within the chosen radius could be done manually (giving good results, but requiring a large amount of effort) or possibly by checking if the reported speed is higher than the calculated average speed (which would indicate that the vessels was delayed). The method described below cold be used for this purpose.

7.1.2 Looking at AIS data for sudden stops

As shown above, finding sudden stops from the AIS data is hard due to the use of the Douglas-Peucker algorithm as one cannot simply look simply look at the reported SOG for drops. Instead it was decided to calculate the average speed between two reportings and compare this with the average of the last two reported SOG's (at the beginning and the end of the time interval over which average speed is calculated). By doing this for a number of vessels (where there are no signs of an accident) one can define a threshold for the normal variation between calculated and reported speed over ground.

The concept was first developed for a vessel sailing in open waters and then tested at a vessel in coastal waters.

To calculate the distance between two the different points it was decided to use arc length (that is, the calculated distance also includes the curvature of the earth). This is not necessary when calculating short distances, but makes a rather big difference when the distance is large. First the positions given by the AIS had to be rewritten from the given form:

N 60°15.02'

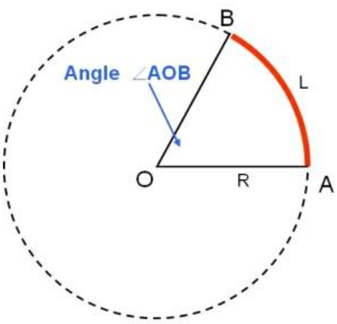
This positions is written in degrees and minutes (not seconds), and the final ".02" denote "two hundredths of a minute", not "two seconds". To calculate the distance using Excel the above position would have to be in decimal degrees on the form "60.25033", a conversion that was done in four steps:

1. Rewrite the original formatting to "60,1502" using "find and replace" and RIGHT.
2. Isolate only the decimals using the formula "60,1502 – ROUNDDOWN(60,1502;0)
3. Convert from minutes to decimals using $\frac{0,1502}{60} \times 100 \ = 0,25033$
4. Combine to a decimal degree position using ROUNDDOWN(60,1502;0) + 0,25033 = 60,25033

The decimal position gives the angle from the center of the earth to a point on the surface (on the figure below A would be equator, 0 degrees, and the point B would be described be the angle between A and B ≈ 60 degrees north). The north/south position is named latitude and the east/west position longitude. An Excel formula by (BlueMM) was found and is given below:

=ACOS(COS(RADIANS(90-Lat1)) *COS(RADIANS(90-Lat2)) +SIN(RADIANS(90-Lat1))
*SIN(RADIANS(90-Lat2)) *COS(RADIANS(Long1-Long2))) * 3440,065

The final number, 3440.065, is the median radius of the earth in nautical miles. As the earth radius is not uniform, this formula will have an error. The radius in Norwegian waters is, however, similar to the median value (as the radius is largest by equator and smallest at the poles).



7.1.2.1 Open sea example - Ahtela

Ahtela is a 6700 dwt Finnish cargo vessel and AIS data for April 1st to April 15th was found. At this time the vessel was sailing in liner trade between Esbjerg and Egersund and had a total of 201 AIS reportings exported. This vessel was chosen to test the method with a vessel sailing on a, presumably, rather straight course with only minor speed changes. The map below shows that the vessel had two port calls in Egersund during the first two weeks of April.

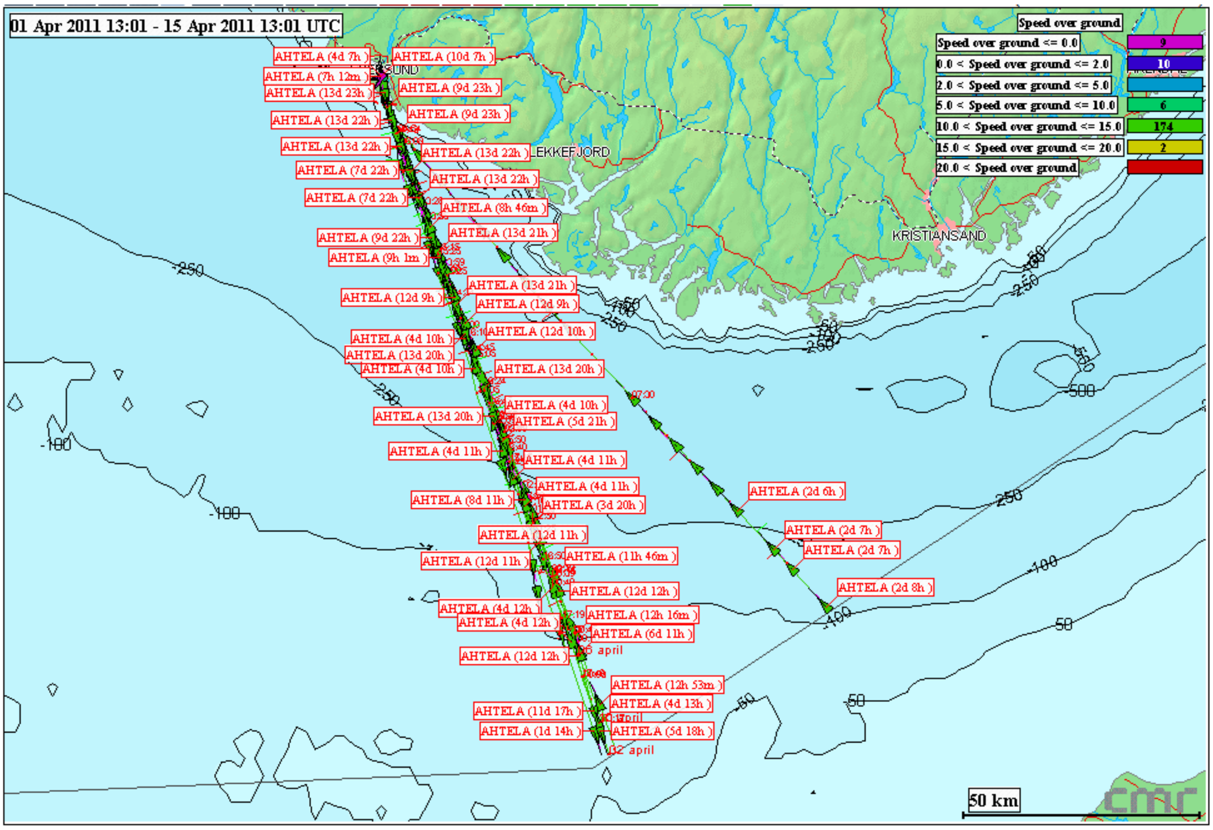


Figure 32 Ahtela

Below is the first part of the table with AIS data, not showing the “helper columns” described above. The exported data for Ahtela is surprisingly good, as several position reports are only 15 minutes apart. In the excerpt shown below only two of the reportings are more than one hour after the last – and both of these show a calculated speed similar to the one reported by the AIS. The almost 30 hour period without reportings is time spent outside of Norwegian waters and should be omitted. It can be seen that the final column, variation, is less than ± 0.5 knots in all cases, suggesting that this method with a threshold of 0.5 knots could be used for revealing unreported groundings.

Lat	Long	Distance	Timestamp	Time difference	Average speed	SOG	Variation
58,4093	5,9967		01.04.2011 13:53			11,6	
58,3578	6,0223	3,1959	01.04.2011 14:09	0:15:59	12,0	12,8	0,2
58,3085	6,0542	3,1273	01.04.2011 14:24	0:14:41	12,8	13,1	0,2
58,2577	6,0872	3,2249	01.04.2011 14:39	0:15:09	12,8	12,8	0,2
58,2077	6,1195	3,1712	01.04.2011 14:54	0:14:51	12,8	12,5	-0,2
58,1075	6,1842	6,3533	01.04.2011 15:24	0:30:19	12,6	12,4	-0,1
58,0065	6,2493	6,4077	01.04.2011 15:54	0:29:19	13,1	13,1	-0,4
57,9528	6,2840	3,4059	01.04.2011 16:09	0:15:20	13,3	13,2	-0,2
57,8490	6,3505	6,5853	01.04.2011 16:39	0:30:10	13,1	13,0	0,0
57,7975	6,3833	3,2654	01.04.2011 16:54	0:15:10	12,9	12,7	-0,1
57,5602	6,5347	15,0549	01.04.2011 18:06	1:11:50	12,6	12,6	0,1
57,3430	6,6918	13,9923	03.04.2011 00:03	29:56:24	0,5	12,8	12,2
57,4648	6,6155	7,7204	03.04.2011 00:39	0:36:41	12,6	12,5	0,0
57,5622	6,5517	6,1959	03.04.2011 01:09	0:29:19	12,7	12,8	0,0

57,6128	6,5200	3,2082	03.04.2011 01:24	0:15:20	12,6	12,4	0,0
57,9205	6,3175	19,5776	03.04.2011 02:54	1:29:51	13,1	13,0	-0,4
57,9718	6,2833	3,2687	03.04.2011 03:09	0:15:10	12,9	12,8	0,0
58,0227	6,2488	3,2435	03.04.2011 03:24	0:15:09	12,8	12,9	0,0
58,0738	6,2143	3,2618	03.04.2011 03:39	0:15:01	13,0	13,0	-0,1
58,1267	6,1788	3,3662	03.04.2011 03:54	0:15:10	13,3	13,1	-0,3
58,1800	6,1428	3,3992	03.04.2011 04:09	0:15:05	13,5	13,6	-0,2

Table 20 Data export, Ahtela

This vessel did, however, not sail in an area prone to groundings and despite the promising results the method would also have to work in coastal waters.

7.1.2.2 Coastal example – Nordstjernen

Nordstjernen is the oldest of the Hurtigruta ferries that is still sailing the same Bergen – Kirkenes – Bergen route. The data excerpt below is from the trip north through Lofoten in early April.

Ship name	Lat	Long	Distance	Timestamp	Difference	Avg. speed	Sog	Var.
NORDSTJERNEN	67,9658	13,9630	18,1576	07.04.11 16:59	1:14:42	14,6	15,0	0,3
NORDSTJERNEN	68,0245	13,9065	3,7447	07.04.11 17:14	0:15:06	14,9	14,8	0,0
NORDSTJERNEN	68,0825	13,8520	3,6908	07.04.11 17:29	0:15:06	14,7	14,8	0,1
NORDSTJERNEN	68,1210	13,8405	2,3259	07.04.11 17:44	0:15:12	9,2	0,0	-1,8
NORDSTJERNEN	68,1210	13,8405	0,0000	07.04.11 17:59	0:15:20	0,0	0,0	0,0
NORDSTJERNEN	68,2237	14,5607	17,2181	07.04.11 19:29	1:29:34	11,5	9,7	-6,7
NORDSTJERNEN	68,2307	14,5667	0,4410	07.04.11 19:44	0:15:11	1,7	0,0	3,1
NORDSTJERNEN	68,2298	14,5678	0,0564	07.04.11 20:44	0:59:37	0,1	3,7	1,8
NORDSTJERNEN	68,2275	14,6722	2,3276	07.04.11 20:59	0:15:12	9,2	14,4	-0,1
NORDSTJERNEN	**68,2222**	**14,8138**	**3,1715**	**07.04.11 21:14**	**0:15:07**	**12,6**	**15,2**	**2,2**
NORDSTJERNEN	68,3512	15,0400	9,2318	07.04.11 21:58	0:44:23	12,5	14,6	2,4
NORDSTJERNEN	68,4047	15,1120	3,5854	07.04.11 22:13	0:15:00	14,3	13,5	-0,3
NORDSTJERNEN	68,4560	15,1917	3,5484	07.04.11 22:28	0:15:03	14,1	15,0	0,1
NORDSTJERNEN	68,5780	14,9453	9,1100	07.04.11 23:13	0:45:02	12,1	9,2	0,0
NORDSTJERNEN	68,6395	15,3830	10,2710	08.04.11 0:29	1:15:20	8,2	15,0	3,9
NORDSTJERNEN	68,8420	15,4820	12,3477	08.04.11 1:59	1:29:42	8,3	15,1	6,8
NORDSTJERNEN	68,9755	15,9928	13,6404	08.04.11 3:29	1:30:34	9,0	14,6	5,8
NORDSTJERNEN	68,7993	16,5497	16,0279	08.04.11 5:14	1:44:42	9,2	0,0	-1,9
NORDSTJERNEN	68,8253	16,6522	2,7174	08.04.11 6:14	0:59:51	2,7	14,7	4,6

Table 21 data export, Nordstjernen

It is clear that this data is not as detailed as the ones for Ahtela as more than a quarter of the reported positions are more than one hour after the last. Several other vessels were investigated when searching for one with sufficient data points – all of which had a similar lack of data. For the data points that are about 15 minutes apart, however, a larger variation between calculated and reported speeds can be seen. As a visual inspection not suggested that anything out of the ordinary happened this implies that the method is not feasible for coastal waters.

At closer inspection the reason for this becomes obvious. The map below shows the vessel over the time period written in bold in the above table (approx. 21:00 – 21:15). Despite the fact that no data points are registered in this time period the map clearly show the vessel turning 90^0 (the vessel does not, as the map suggests, go to port, but keep sailing down the strait). By constructing a straight line between the position at 21:00 and the position at 21:14 the vessel position at 21:05 was measured to be approximately 1 km away from the straight line used for calculating speed. This also reveals the fact that course alterations on up to 1 km, if not more, are being washed away by the algorithm used on the exported data.

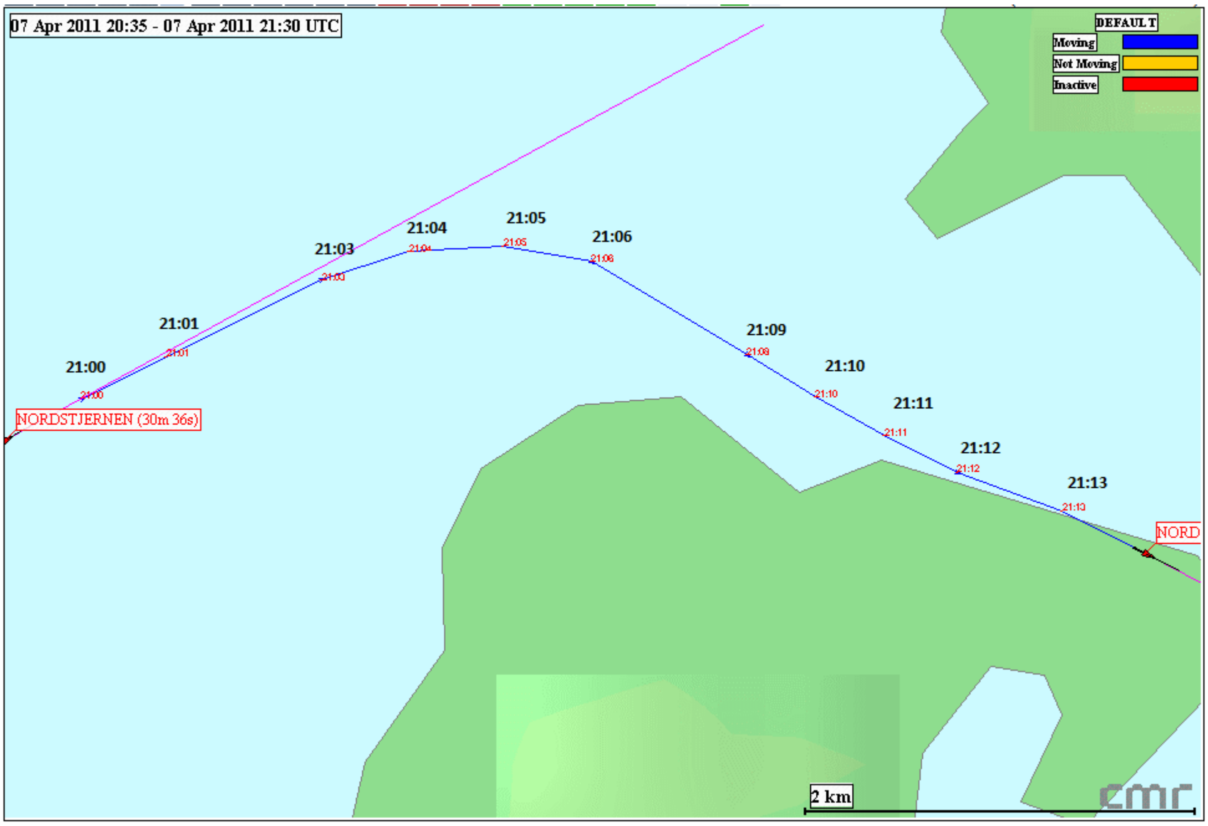


Figure 33 Nordstjernen

A method for estimating the vessel path has been proposed (Aarsæther & Moan, 2009) where the vessel path is made up from either straight lines or circle sections, defined by:

- Straight line: Course angle of the line and speed
- Circle section: Radius of turning circle, course change and speed

The method is, however, yet to be applied to a larger area and is thus not used in this report.

The above examples show that the method provides good results for a vessel on a straight course and not useful results for a vessel in coastal waters. The reason for the poor results for the ferry is lack of data, and it is reasonable to assume that the method would provide good results for calculated speed if number of data points was increased. Still, calculating all speeds for all vessels with time steps of only about 1 minute would require large amount of processing power and would most likely not reveal any accidents (as reported sog would drop as the vessel is stranded – and such not give a large value for “variation”). If all data points actually were available the reported speed over ground, and more specifically a drop in speed over ground, would be a greater indicator of an accident.

7.2 Collisions

It is reasonable to assume that most collisions will be reported, due to the fact that there are (at least) two vessels involved and generally visible consequences. What could go by unreported, though, are incidents where collision is avoided only by luck or a "desperate" avoidance maneuver.

Both an incident and an actual accident were investigated in detail looking for a way to "expose" the happening from the AIS data. In short, the idea was to assume that all vessels will be traveling on a straight course at the same speed between reportings and such develop an algorithm for calculating and comparing vessel positions. If two vessels have calculated positions within a certain distance of each other, this would have to be looked into in detail.

7.2.1 Incident – Saga Rose and Heilhorn

Saga Rose and Heilhorn are both passenger vessels and this incident occurred in the geographical area "*Dønna N pynt, Rana – Støtt"* on July 12th, 2009. An excerpt of the corresponding entry in the NDM database is given below. The time registered in the database is Norwegian time, which equals UTC +1 for normal time and UTC +2 for summer time. The time of the incident below should therefore, using the time notation given from AIS, be UTC 14:55. When looking at the vessel positions, though, it appears that this specific accident was actually registered in UTC.

Time	Latitude	Longitude	Waters	Ship name	Country
12.07.2009 16:55	66,73333333	13,5	Trangt kystfarvann	SAGA ROSE	Bahamas
12.07.2009 16:55	66,73333333	13,5	Trangt kystfarvann	HEILHORN	Norway

The trails from both vessels were found from the AIS interface and the reporting closest to the accident, as well as the three before and after, for Heilhorn and Saga Rose, respectively, are given below:

Latitude	Longitude	Time stamp	sog	cog	Heading	rot	Tail speed
N 66°43.22'	E 013°28.56'	2009-07-12T14:00:39Z	.0	0	160	720	.00
N 66°43.23'	E 013°28.56'	2009-07-12T14:35:40Z	.0	0	157	-0.0	9.38
N 66°43.40'	E 013°28.65'	2009-07-12T15:02:58Z	9.7	38	46	-0.0	.47
N 66°43.66'	**E 013°29.31'**	**2009-07-12T16:35:17Z**	**10.6**	**42**	**44**	**-0.0**	**.00**
N 66°43.23'	E 013°28.56'	2009-07-12T17:04:29Z	.5	155	157	-0.0	.00
N 66°44.29'	E 013°30.77'	2009-07-12T17:35:31Z	4.2	220	43	-0.0	.00
N 66°43.23'	E 013°28.56'	2009-07-12T18:16:43Z	.6	182	162	-720	5.37

Table 22 AIS export, Heilhorn

Latitude	Longitude	Time stamp	sog	cog	Heading	rot	Tail speed
N 66°35.75'	E 013°04.27'	2009-07-12T14:39:24Z	17.7	351	353	-0.0	16.77
N 66°40.01'	E 013°07.30'	2009-07-12T14:54:43Z	18.0	20	22	-0.0	17.84
N 66°42.40'	E 013°34.30'	2009-07-12T15:52:45Z	12.6	106	89	-0.0	14.61
N 66°43.91'	**E 013°30.06'**	**2009-07-12T16:54:15Z**	**14.3**	**277**	**276**	**-0.0**	**13.29**
N 66°44.46'	E 013°20.71'	2009-07-12T17:09:45Z	15.3	274	275	-0.0	14.78
N 66°45.36'	E 013°12.51'	2009-07-12T17:24:50Z	13.0	355	17	720	14.72
N 67°04.11'	E 013°53.73'	2009-07-12T19:09:17Z	17.3	38	40	-0.0	15.50

Table 23 AIS export, Saga Rose

It is clear from this that the algorithm used to simplify the data also removed any obvious clues of an incident happening. Also, by printing the map over the day of the accident no obvious signs of the incident can be seen (except for the two vessels crossing paths). The picture below shows the paths over four hours.

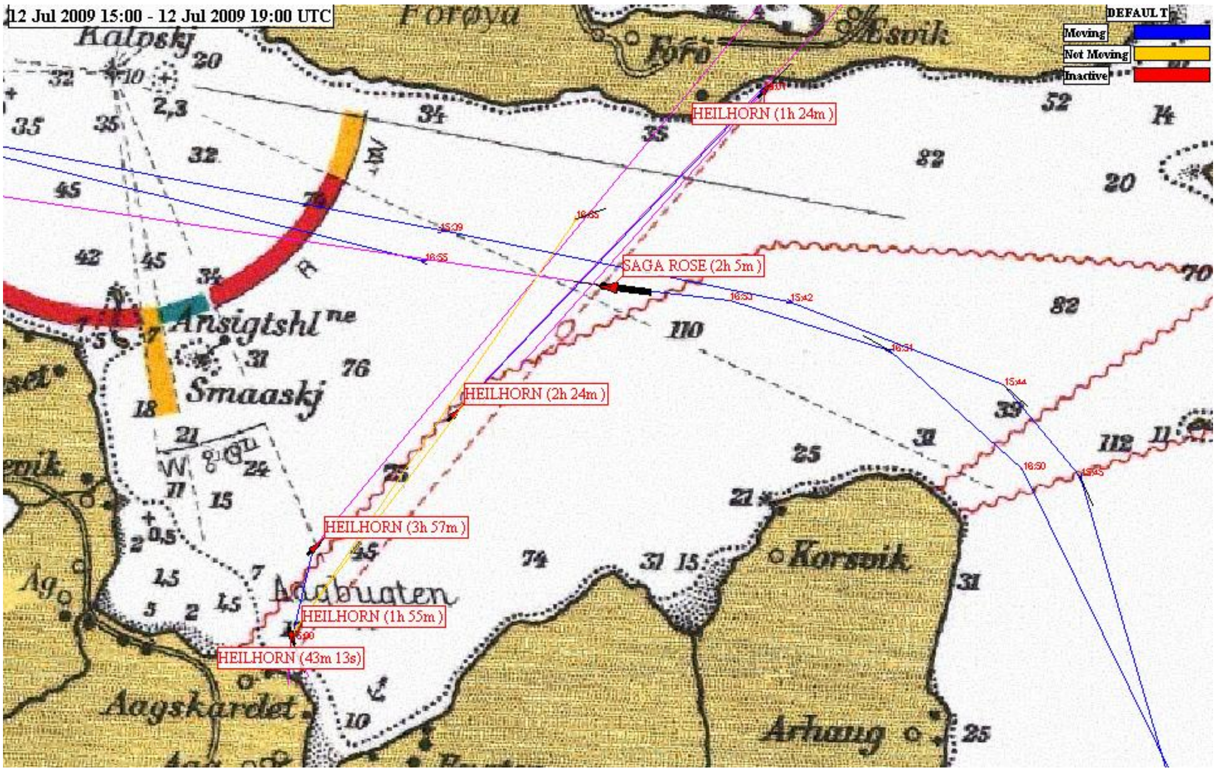


Figure 34 Heilhorn - Saga Rose, incident

Further investigation could be performed in two ways; one could either use the reported vessel speed and course to calculate when and where the vessels would have the closest point of approach (cpa) or one could calculate the distance and travel time to the position where the incident was reported. The second approach is the easiest by far, though for a larger data-set without a registered incident site only the first approach would be feasible. Unfortunately, as the Douglas Peucker algorithm does not take course changes into account (only actually registered positions) too many data points are omitted for this to be possible (for instance, the exported data for Saga Rose sailing the above path did not include the vessel sailing around the point to the lower right).

By using the reported speed (at the point closest to the incident) for both vessels, travel time to the incident was calculated (assuming a straight course). As seen from the table below the vessels were, respectively, 14 seconds and 1:29 minutes away from the incident site at the nearest reporting. Still, with the two reportings being almost 20 minutes apart this implies a safe crossing of pathways, not a near-accident.

	Latitude	Longitude	Timestamp	sog [kn]	Distance [nm]	Sailing time [h]
Accident	66,44	13,30	16:55:00			
SAGA ROSE	66,4391	13,3006	16:54:15	14,3	0,06	00:00:14
HEILHORN	66,4366	13,2931	16:35:17	10,6	0,26	00:01:29

The reason for this becomes apparent when running a tail process over one hour (accident time ± 15 minutes) and zooming in on the two vessels. The little pin to the upper right of the two paths shows the registered position for the incident, while the two marked positions are vessel positions at 16:55 as given by the AIS. From this picture it is clear that the vessels were really close, though this is unfortunately not reflected in the exported AIS data. It should be noted that Heilhorn was sailing south along the marked path.

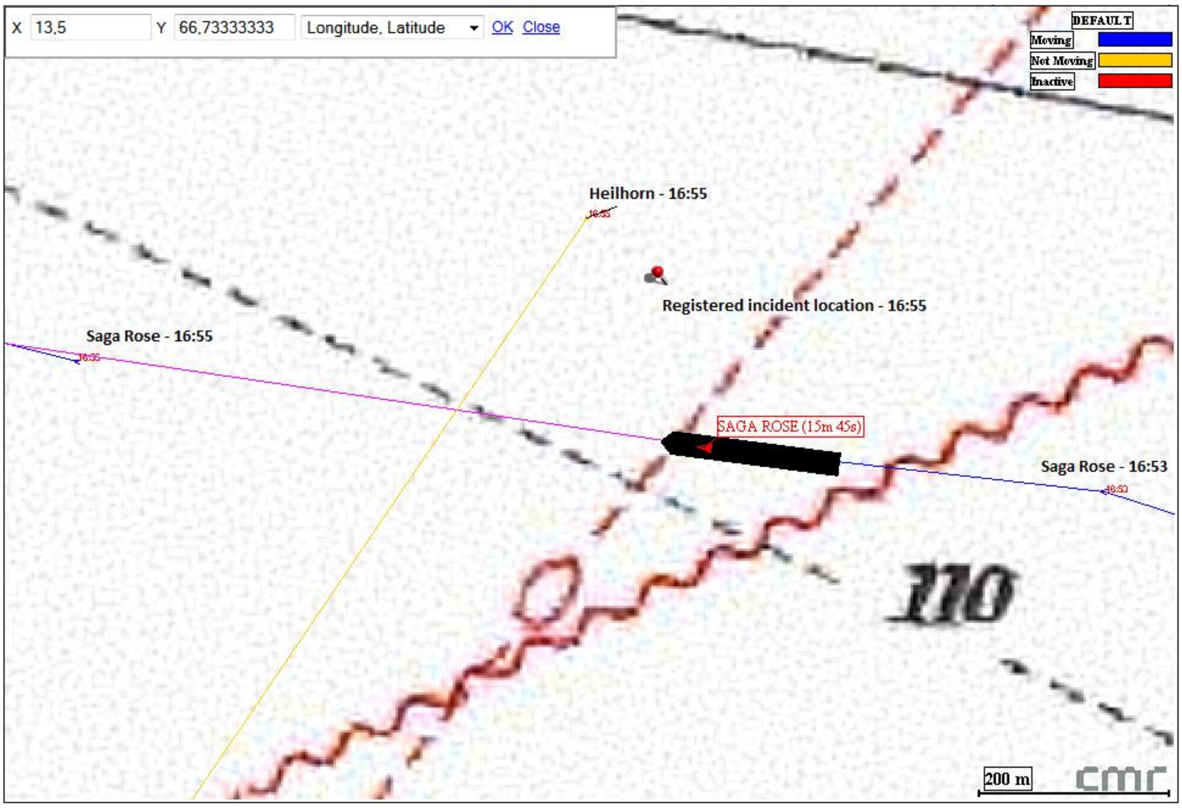


Figure 35 Heilhorn - Saga Rose

Exporting the data from the same tails process (namely data for both vessels from 16:40 to 17:10 with a time step of 0.000001) gives the table below. This once again reveals that far more data is used for drawing the graphical display than what is actually exported as raw data. The reported speed for Heilhorn is due to the vessel approaching port, and is not related to the incident.

ship name	latitude	longitude	time stamp	sog	heading	pos accuracy
HEILHORN	N 66°43.23'	E 013°28.56'	2009-07-12T17:04:29Z	.5	157	> 10m
SAGA ROSE	N 66°43.91'	E 013°30.06'	2009-07-12T16:54:15Z	14.3	276	> 10m
SAGA ROSE	N 66°44.46'	E 013°20.71'	2009-07-12T17:09:45Z	15.3	275	> 10m

Table 24 Heilhorn - Saga Rose, data export

7.2.2 Accident – Prosper and Edda Fjord

The two supply vessels Prosper and Edda Fjord collided at the approach to Tananger (by an islet called Melingsholmen) while Edda Fjord was anchoring. Prosper was leaving the quay and was made aware of other vessels they had to take into consideration. A short while later the VTS noticed Prosper on an unexpected course, though by then the vessels had already collided. The OOW on Edda Fjord had noticed the vessel coming, but had no time for corrective actions.

Prosper was being towed at the time of the accident (by Nautilius Mamut with assistance from Island Valiant).

The accident happened on November 8th, 2010 and is thus not registered in the publicly available accident database. An AIS map over the accident area is given below.

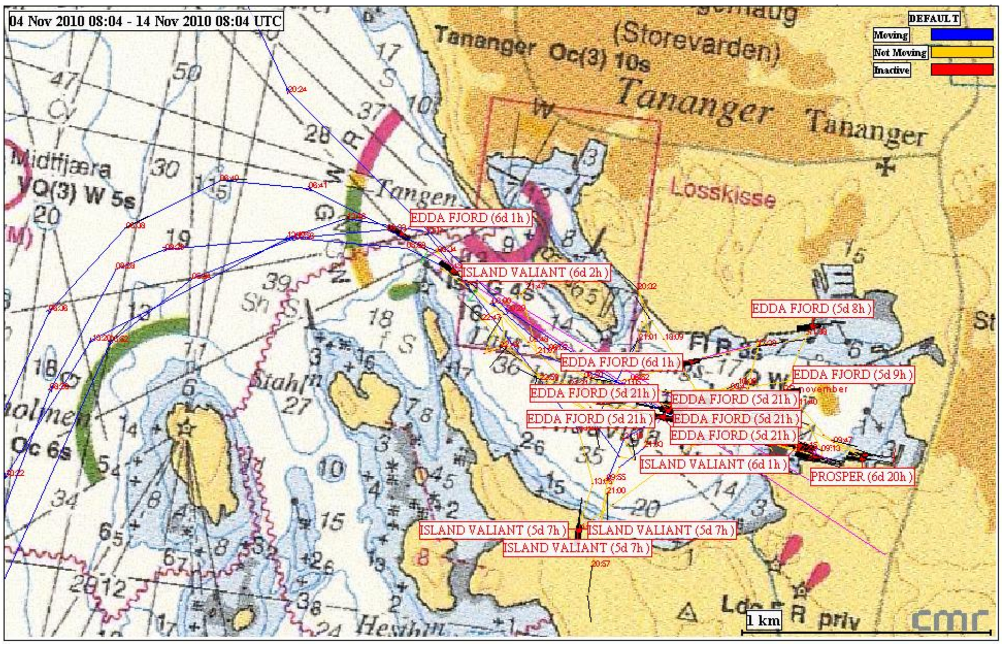


Figure 36 Proser - Edda Fjord, accident

By running a tails process over one hour showing only Prosper and Edda Fjord, it is apparent that they were really close at 21:04 UTC. It does, however, show Prosper continue seemingly unaffected and thus does not really display that a collision occurred. Again, when exporting the data from the same time frame, all signs of an accident are removed.

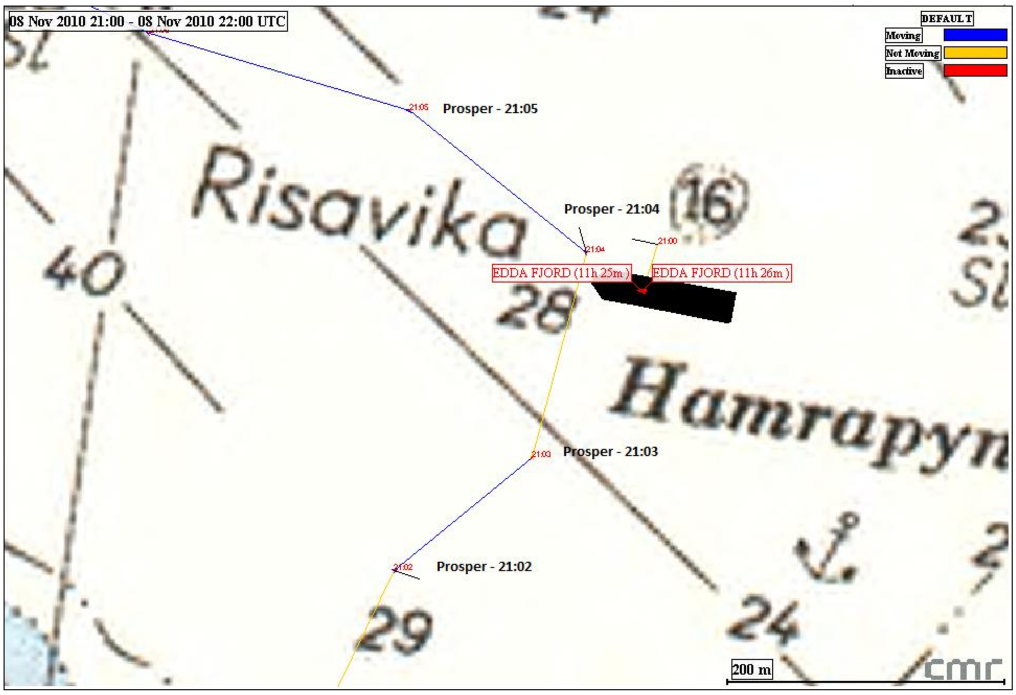


Figure 37 Adda Fjord - Prosper, collision

ship name	latitude	longitude	time stamp
EDDA FJORD	N 58°55.51'	E 005°35.30'	2010-11-08T21:29:55Z
EDDA FJORD	N 58°55.51'	E 005°35.30'	2010-11-08T21:59:25Z
PROSPER	N 58°55.71'	E 005°34.60'	2010-11-08T21:59:27Z

Table 25 AIS export, Edda Fjord and Prosper

This example shows that even an actual collision is not obvious from the AIS data (apart from the vessels being “close” on the map). To develop an algorithm that “defines” a collision more exported data would be required and it is likely to assume that Prosper would show a significant drop in speed over ground.

7.3 Contact Damage

No method for revealing contact damage accidents was found, as the current detail level from the AIS is too coarse. It could be possible with if one had access to all the data points and added in a (simple) model for stopping length, though even with this the reported position might not be correct down to the exact meter. In general, though, one could look at each reporting, calculate distance to quay and compare this distance to the calculated stopping distance (calculated from vessel dimensions and speed over ground). This model would also require that a layer with all quays is added to the AIS interface, in addition to as much weather data as possible (most importantly wind).

As this was deemed impractical, no further study was performed.

7.4 Engine Failure

As an example of engine failure the ferry MF Herlaug was chosen. The failure happened on March 23rd, 2011 in shallow waters and fair weather. The map below clearly shows the vessel drifting.

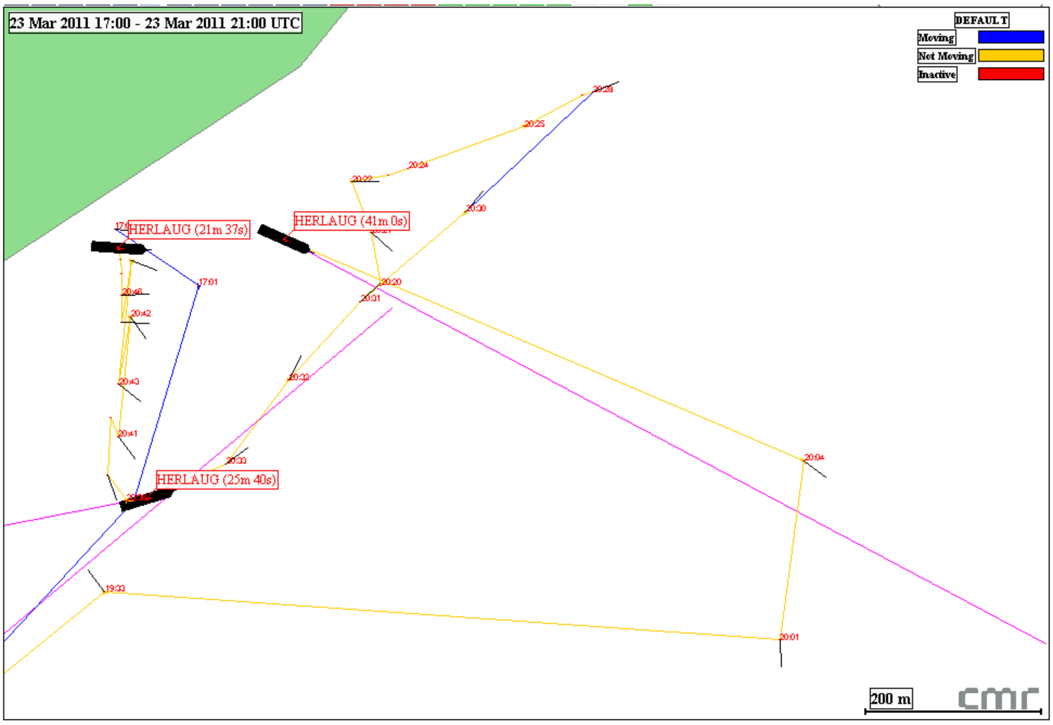


Figure 38 Herlaug, engine failure

From the exported data it can be seen that "nav status" changed (in other words, the incident was reported as it is supposed to) and, interestingly, "position accuracy" changed at the same time. Apart from that a clear drop in sog and tail speed can be seen and the difference in course and heading seem to increase somewhat.

latitude	longitude	time stamp	sog	cog	heading	nav status	pos acc.	tail speed
N 64°49.16'	E 011°36.13'	2011-03-23T17:04:20Z	12.6	224	221	under way, using engine	> 10m	9.21
N 64°46.55'	E 011°37.04'	2011-03-23T17:19:30Z	12.5	152	149	under way, using engine	> 10m	12.55
N 64°46.68'	E 011°36.91'	2011-03-23T18:19:10Z	.6	147	208	under way, using engine	> 10m	19.09
N 64°46.41'	E 011°37.41'	2011-03-23T18:49:03Z	.5	013	181	under way, using engine	< 10m	.00
N 64°47.56'	E 011°35.27'	2011-03-23T19:04:20Z	6.3	322	310	under way, using engine	< 10m	6.09
N 64°48.90'	E 011°35.26'	2011-03-23T19:19:20Z	6.5	050	048	under way, using engine	< 10m	6.41
N 64°49.64'	E 011°37.05'	2011-03-23T20:19:00Z	3.8	118	114	not under command	> 10m	2.11
N 64°49.48'	E 011°36.85'	2011-03-23T20:34:20Z	2.6	259	073	not under command	> 10m	2.92

Table 26 herlaug, data export

This indicates the best sign of an engine failure is, unsurprisingly, a drop in speed over ground – meaning the method by calculating average speed would be suitable also for revealing engine failures.

7.5 Total loss

Total loss would simply have to be revealed by the vessel suddenly omitting to send AIS signals, an action that could be either voluntary (the OOW would, for some reason, not want his position to be reported) or involuntary (vessel sinking, capsizing, major fire including the bridge, etc). An example of a total loss is the Norwegian flagged bulk carrier Langeland, who capsized outside of Sweden early morning on Jul 31st, 2009. The exported data is once again severely lacking, but two images with a five minute time difference are given below. These clearly show the vessel disappearing between 3:20 and 3:25 UTC (5:20 and 5:25 Norwegian summer time).

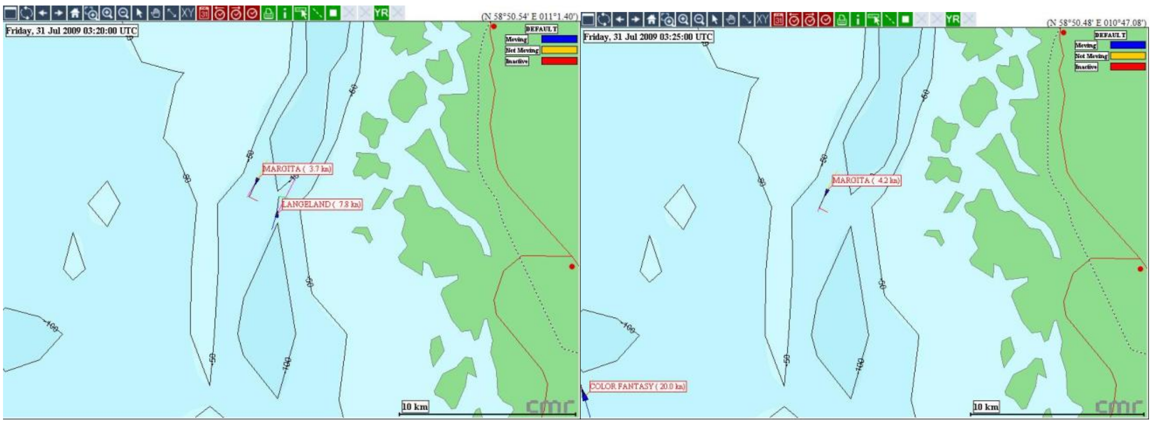


Figure 39 Langeland, total loss

This accident type was not investigated further as it is merely a matter of implementing a system that alerts the VTS if a vessel suddenly omits to send out signals.

7.6 Conclusions

Several accidents and accident types were investigated trying to identify "common factors" – unfortunately with most attempts being limited by the lack of exported data. As expected, the one data point that is central in all accidents is the reported speed over ground, though SOG only will not reveal unreported near-accidents. Also, the data washing performed before exporting makes estimating the "SOG drop" that implies an accident impossible. Several theoretical models for vessel stopping length have been suggested (Galor, 2005)(Stopping of Ships) and these could be used as a starting point, but using the actual reported data would be more interesting as it would also account for any uncertainty from the AIS.

Calculating the average speed proved to give good results for a vessel traveling in open sea and this method should reveal all happenings that slow the vessel down (e.g. grounding, collision, engine failure, etc). If a vessel shows an unexpected variation between calculated and reported speed a visual check could be done to determine the cause of the slow down. Unfortunately, this method proved to not be feasible in the areas where most accidents actually happen; in narrow coastal waters.

For coastal waters it was shown that calculating average speed gives a frequent "false alarm" and that signs of collision in the exported data are washed away by the Douglas Peucker algorithm. What did seem to be worthwhile is counting over known barriers/reeves, though this method also gives a large amount of false alarms and requires the counted vessels to be checked manually (as the average speed method did not work for coastal waters).

Due to limitations in the AIS interface revealing unreported accidents seems to be complicated. Four smaller improvements that would simplify this process are, however:

- Capability to import .tsv (or similar) files. Capability to create filters from a table would simplify the process of creating advanced filters significantly – and would have saved several hours of typing during this project. As databases exist not only over previous grounding sites, but also over warning poles, lighthouses, etc, this would make it possible to count over all areas where groundings are assumed to be likely. Ideally, one should also be able to start the tails process by simply uploading the .tsv file (and specify time step and period in the file).
- Settings for the Douglas Peucker algorithm. As of today the use of the algorithm varies based on the length of the time interval chosen, but no matter how small the time interval is one cannot export all data points. If all data points were available it would be a simple task to investigate a number of accidents to find the SOG drop that implies that an accident has happened. Since it was also shown that the exported AIS data did not include vessel positions 1 kilometer away from the “exported path”, the need for an ability to tune the algorithm is apparent. Also, the data used for the graphical display is more detailed than the data exported – making it hard to understand why more detailed data not is readily available. As an alternative to exporting all data points more emphasis could be put on the reported vessel course – that is data points were the course change is large should be included even if the position is not far away from the “exported path”.
- Increasing the time-out period for how long a tails process is saved on the server. A minor annoyance, but several processes were run only to be deleted before I had a chance to export the data. Alternatively, a setting allowing for downloading the .tsv file automatically when the process is completed would be a welcome addition.
- Make a note that the standard background, “world map”, is not perfectly aligned and give a faulty impression of the vessel position. “Raster sjokart”, however, proved to give the correct positions.

Implementing these changes would greatly increase the AIS relevance for revealing ship accidents and are assumed to be rather straight forward to implement. Especially the first two points would be welcome addition as it would allow for:

1. Develop a large data set of probable grounding sites (previous groundings, warning poles, etc)
2. Import the data set to the AIS interface and run a tails process to count vessels that had been within a certain radius (approx. 150 meters)
3. Create a new data set of vessels and timestamp for when they were registered (from the process in #2).
4. Import this data set to the AIS interface and run a process for each vessel over a ten minute period around the time she was registered. This time the full data should be exported (not using the Douglas Peucker algorithm).
5. Look for sudden drops in SOG. This would imply that a grounding has happened.

On a longer term, the following changes would improve the situation even more:

- Include water depth as part of the maps and make it possible with a real-time comparison of water depth and reported vessel draught (i.e., the exported data could also include a column with water depth at the registered position). Of course, this would require a lot of resources to implement and is most likely not feasible in short term.
- Use the vessel safety domain as a filter. As of today all filters are static and a process is run over a fixed area. Making it possible to have a filter that follows a vessel would make it easy to reveal both collisions and near-accidents. The concept of the ship safety domain is well documented (Szlapczynski, 2006) and would be a good starting point for this kind of filter.
- Have quays registered as “objects” in the same way as vessels. Especially combined with the filter suggested above this would make revealing contact damage rather trivial, as one could look at the vessel speed as the quay enters the vessel safety domain.

8 Conclusion

As the report is written in several parts, the reader is referred to chapter 4.6, 5.2 and 7.6 for more in-depth conclusion. Only a summary is given below.

Based on traffic and accident statistics, the following factors were found to influence accident probability:

- Accident probability seems to increase in winter
- Vessels under 100 meters seem to be more at risk
- Norwegian flagged vessels have a higher probability of being involved in an accident in Norwegian waters during a 12 month period
- Wind speed and wave height are not major accident indicators
- Good visibility decrease accident probability and accident probability is higher at certain time of the day
- Vessels older than 20 years seem to have a higher accident probability

The risk model based on conditional accident probabilities for the different vessel types proved to give promising results as it predicts the accident rate better than by using the average accident probability. The major error sources are assumed to be:

- Basing the conditional accident probabilities on the vessel being present as opposed to per nautical mile or total sailing time
- The vessels break-down of 17 categories not being sufficient
- Simply finding the fairway factor from a similar fairway, not basing it on probabilities are done for the traffic factor
- Weighting the fairway and the traffic factor equal

A suggestion for how to use conditional probabilities combined with exact traffic distributions for only one fairway crossing was developed, and based on experiences from the work with this project it is assumed to give good results. The model was not tested, however, but further work to develop the concept is recommended.

A list of recommendations for extensions to the AIS interface that would increase its usefulness for risk analysis was developed:

- A “polyline” filter that registers vessels every time it changes (as opposed to at certain time intervals)
- Capability to import .tsv files
- Ability to change settings for the Douglas-Peucker algorithm
- Increasing the time-out period on the server
- Include water depth as part of the charts
- Include a filter using the vessel safety domain
- Have quays registered as objects similar to vessels

9 Further Work

Further work is also described in chapter 5.2 and 7.6, with the main areas where more work is recommended repeated below.

First, the risk model should be based on sailing time or distance, not the vessel being present in the fairway. This is assumed to be a major error in the risk model. Another area where more work is needed is for finding a good weighting between fairway related factors and traffic/vessel related factors (i.e., the relationship between internal and external risk influencing factors).

Also, a model based on the outline given in chapter 5.2.5 is assumed to give good results, and work in this area is thus recommended.

Concerning AIS feasibility for revealing unreported accidents, it is first recommended to make the improvements in the AIS interface listed in chapter 8 (and described in chapter 7.6).

10 Bibliography

(u.d.). *Journal of Shanghai Jiaotong University* .

Aarsæther, K. G., & Moan, T. (2009). Estimating Navigation Patterns from AIS. *Journal of Navigation* .

AIS 2010. (u.d.). Hentet fra http://www.fargisinfo.com/AIS2010/

BlueMM. (u.d.). Hentet fra http://bluemm.blogspot.com/2007/01/excel-formula-to-calculate-distance.html

Easy AIS. (u.d.). Hentet fra http://www.easyais.de/en/easyais_introduction.php

Eide, M. S., Endresen, Ø., Breivik, Ø., Brude, O. W., Ellingsen, I. H., Røang, K., et al. *Prevention of oil spill from shipping by modelling of dynamic risk.*

Eide, M. S., Endresen, Ø., Brett, P. O., Ervik, J. L., & Røang, K. *Intelligent ship traffic monitoring for oil spill prevention: Risk based decision support building on AIS.*

Galor, W. (2005). THE MOVEMENT OF SHIP IN WATER AREAS LIMITED BY PORT STRUCTURES. *ANNUAL OF NAVIGATION* .

German Accident Investigation Board. (u.d.). Hentet fra http://www.vht-marine.de/vht2008/pdf/dft_masafety_030084.pdf

Hänninen, M., & Kujala, P. *The Effects of Causation Probability on the Ship Collision Statistics in the Gulf of Finland.*

Jakub Montewka, T. H. (2009). Probability Modelling of Vessel Collisions. *Reliability Engineering and System Safety* .

Kujala, P., Hänninen, M., Arola, T., & Ylitalo, J. (2008). *Analysis of the marine traffic safety in the Gulf of Finland.* Helsinki: Helsinki University of Technology.

Maritime Research Insitute Netherlands. (u.d.). Hentet fra www.marin.nl

Mathwave. (u.d.). *Easy Fit XL*. Hentet fra http://www.mathwave.com/easyfitxl-distribution-fitting-excel.html

Montewka, J. (u.d.). *Jakub Montewka - Work*. Hentet fra http://www.jakubmontewka.com/Work.php

Montewka, J. (2009). Predicting risk of collision for oil tankers in the Gulf of Finland. *KONBiN* .

Montewkta, J., Kujala, P., & Yliato, J. (2009). The Quantitative Assessment of Marine Traffic Safety in the Gulf of Finland, on the Basis of AIS Data. *Scientific Journals of Maritime University of Szczecin* .

Moua, J. M., Tak, C. v., & Ligteringen, H. (2010). Study on collision avoidance in busy waterways using AIS data. *Ocean Engineering* .

Movable Type. (u.d.). Hentet fra http://www.movable-type.co.uk/scripts/latlong.html

Nikolaidis, G. P. (2002). *Analysis of Primary causes concerning Shipping Safety – Owner's and shipmaster's point of view.*

NVE. (u.d.). Hentet fra NVE - Vindkart: http://www.nve.no/no/Energi1/Fornybar-energi/Vindkraft/

Ombler, E. K., & Skollevold, C. (2010). *Risk analysis of ro/ro-passenger ferries.* Trondheim.

Pedersen, P. T. (2002). Collision risk for fixed offshore structures close to high-density shipping lanes. *Journal of Engineering for the Maritime Environment* .

Pedersen, P. T. (2010). Review and application of ship collision and grounding analysis procedures. *Marine Structures* .

ProNav. (u.d.). Hentet fra http://www.pronav.no/index.php?page=vis_nyhet&NyhetID=83&xpage=arkiv&seksjon=yrke

Rausand, M., & Høyland, A. (2004). *System Reliability Theory.*

Rausand, M., & Utne, I. B. (2009). *Risikoanalyse - Teori og Metoder.*

Review of collision and grounding risk analysis methods which can utilize the historical AIS data and traffic patterns in seawaters. (2007). *SKEMA Consolidation Study* .

Ristic, B., Scala, B. L., Morelande, M., & Gordon, N. *Statistical Analysis of Motion Patterns in AIS Data: Anomaly Detection and Motion Prediction.*

Sjøfartsdirektoratet. (2006). *Årsmelding 2006.*

Soma, T. (2005). *Blue-chip or Sub-standard.* Trondheim, Norway: The Norwegian University of Science and Technology.

SSB. (u.d.). Hentet fra http://www.ssb.no/havn/

SSB. (u.d.). Hentet fra Havnestatistikker: www.ssb.no/havn

SSB. (u.d.). Hentet fra Norske Flåten: http://www.ssb.no/emner/10/12/40/handelsfl/tab-2010-09-02-04.html

Stopping of Ships. (u.d.). Hentet fra Towage Salvage: http://www.towage-salvage.com/files/Chapter_04.pdf

Szlapczynski, R. (2006). A Unified Measure Of Collision Risk Derived From The Concept Of A Ship Domain. *The Journal of Navigation* .

Talley, W. K. (1999). Determinants of the property damage costs of tanker accidents. *ransportation Research Part D: Transport and Environment* .

Tam, C., & Bucknall, R. (2009). Collision Risk Assessment for Ships. *Mar Sci Technol* .

Toffoli, A., Lefevre, J. M., Monbaliu, J., Savina, H., & Bitner-Gregersen, E. (2003). Freak Waves: Clues for Prediction in Ship Accidents? *The Thirteenth (2003) International Offshore and Polar Engineering Conference.* Honolulu.

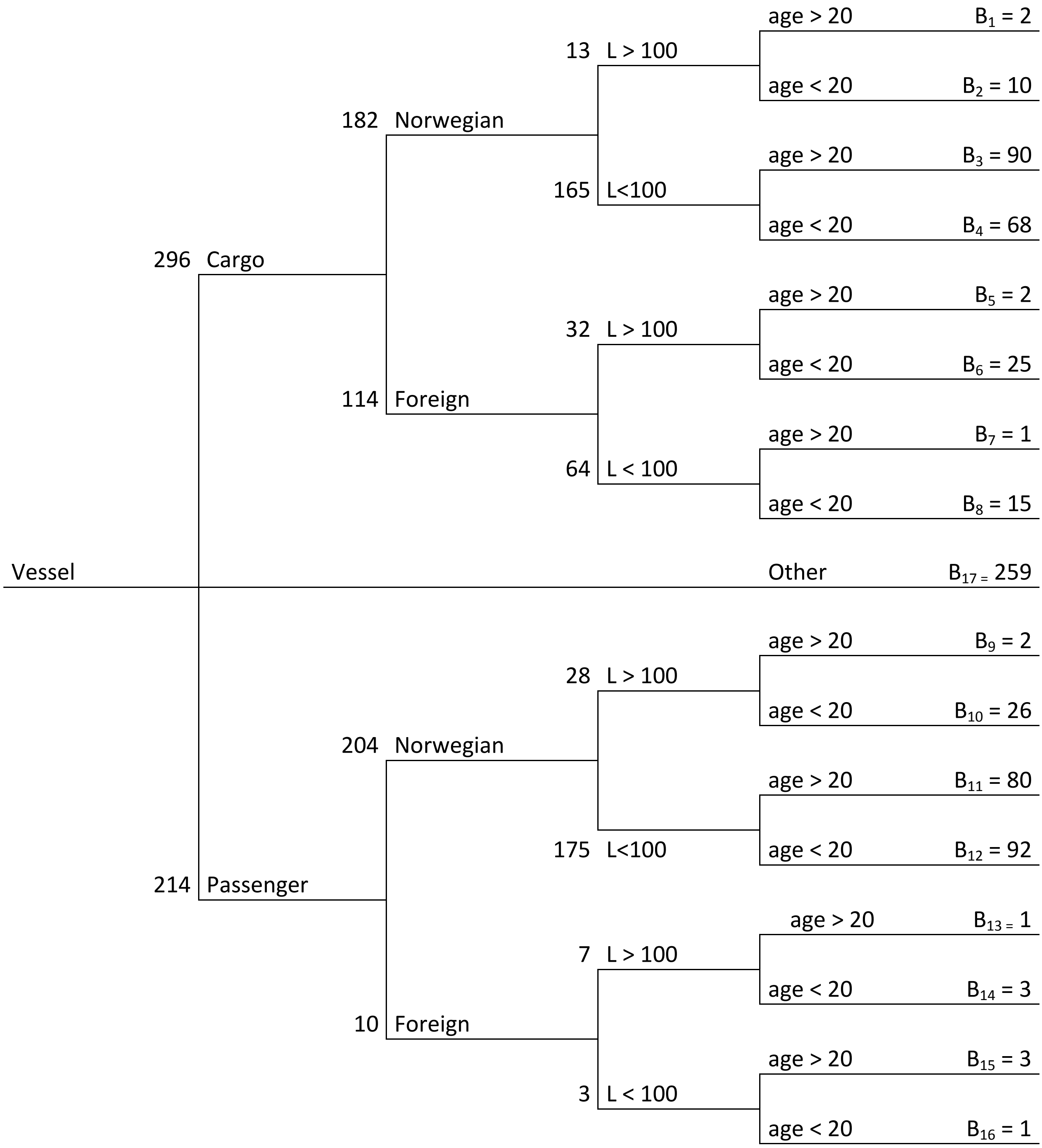
UNCTAD. (2007). United Nations Conference on Trade and Development.

Wikipedia. (u.d.). Hentet fra Ramer Douglas Peucker Algorithm: http://en.wikipedia.org/wiki/Ramer–Douglas–Peucker_algorithm

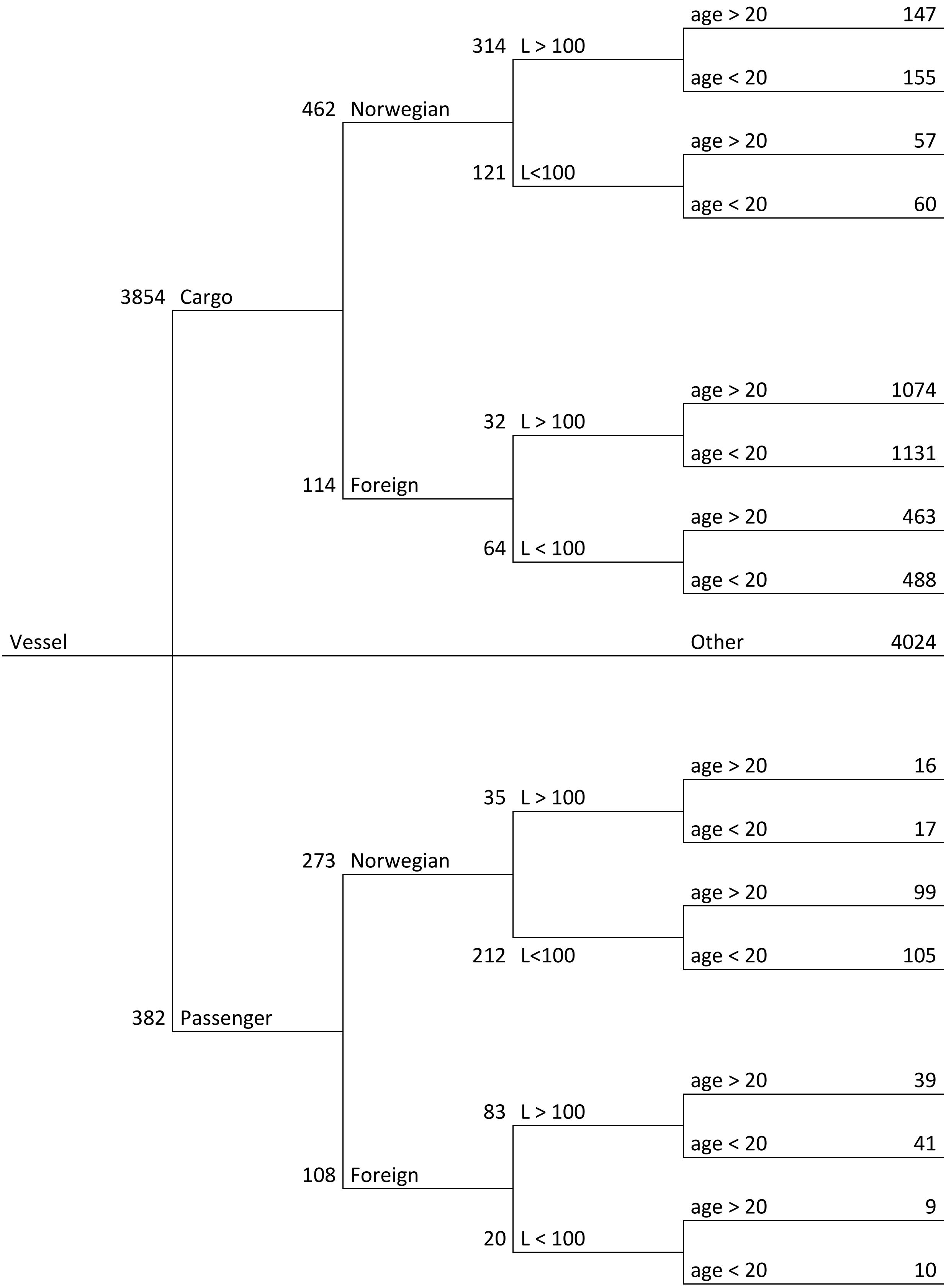
Winchester, T. A., & Nik. (2002). Flag States and Safety: 1997 - 1999. *Maritime Policy & Management* .

Yliato, J. (2009). *Ship-Ship Collision Probability of the Crossing Area between Helsinki and Tallinn.*

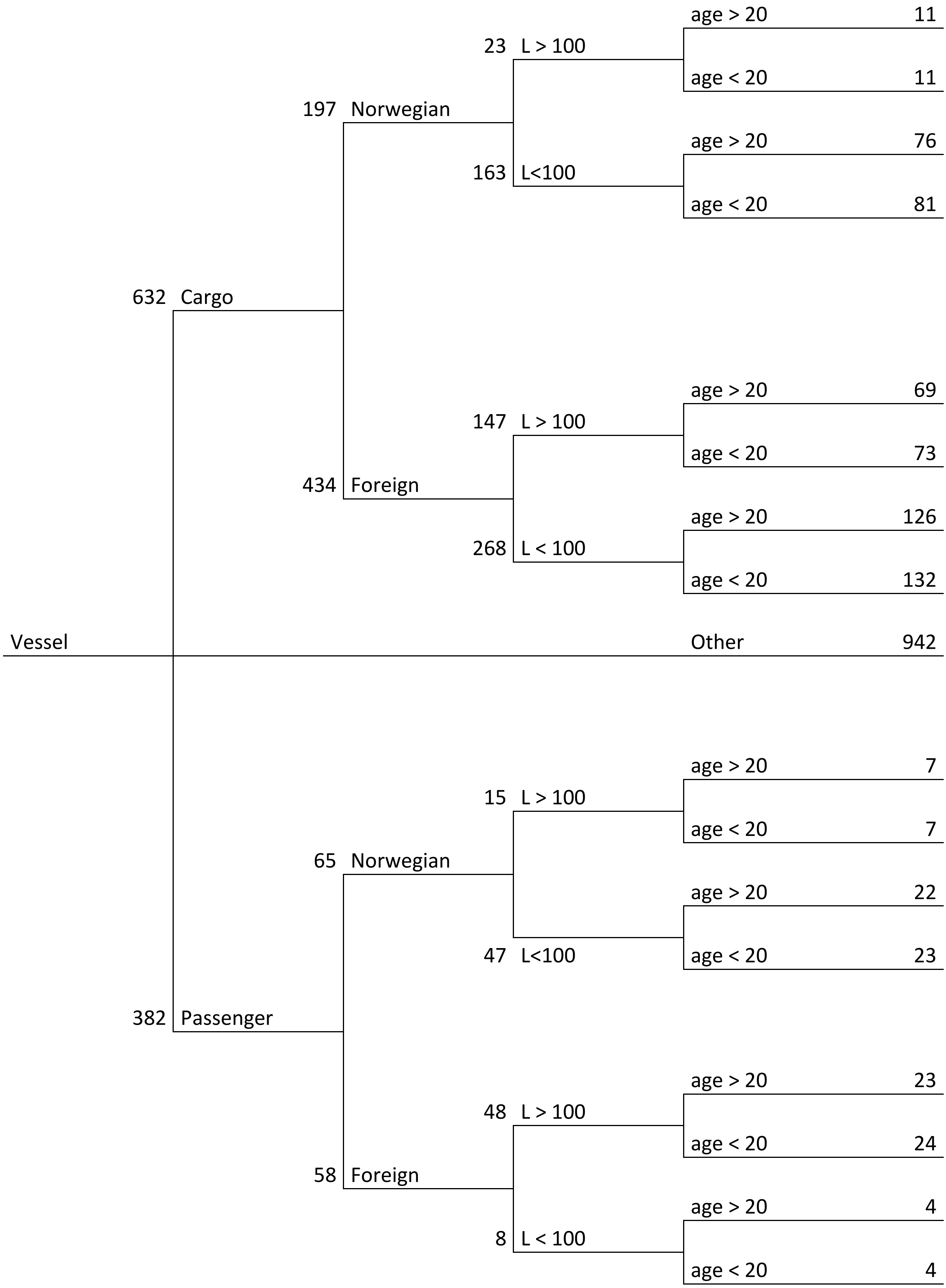
Appendix A – Vessel breakdown – Vessels involved in accidents



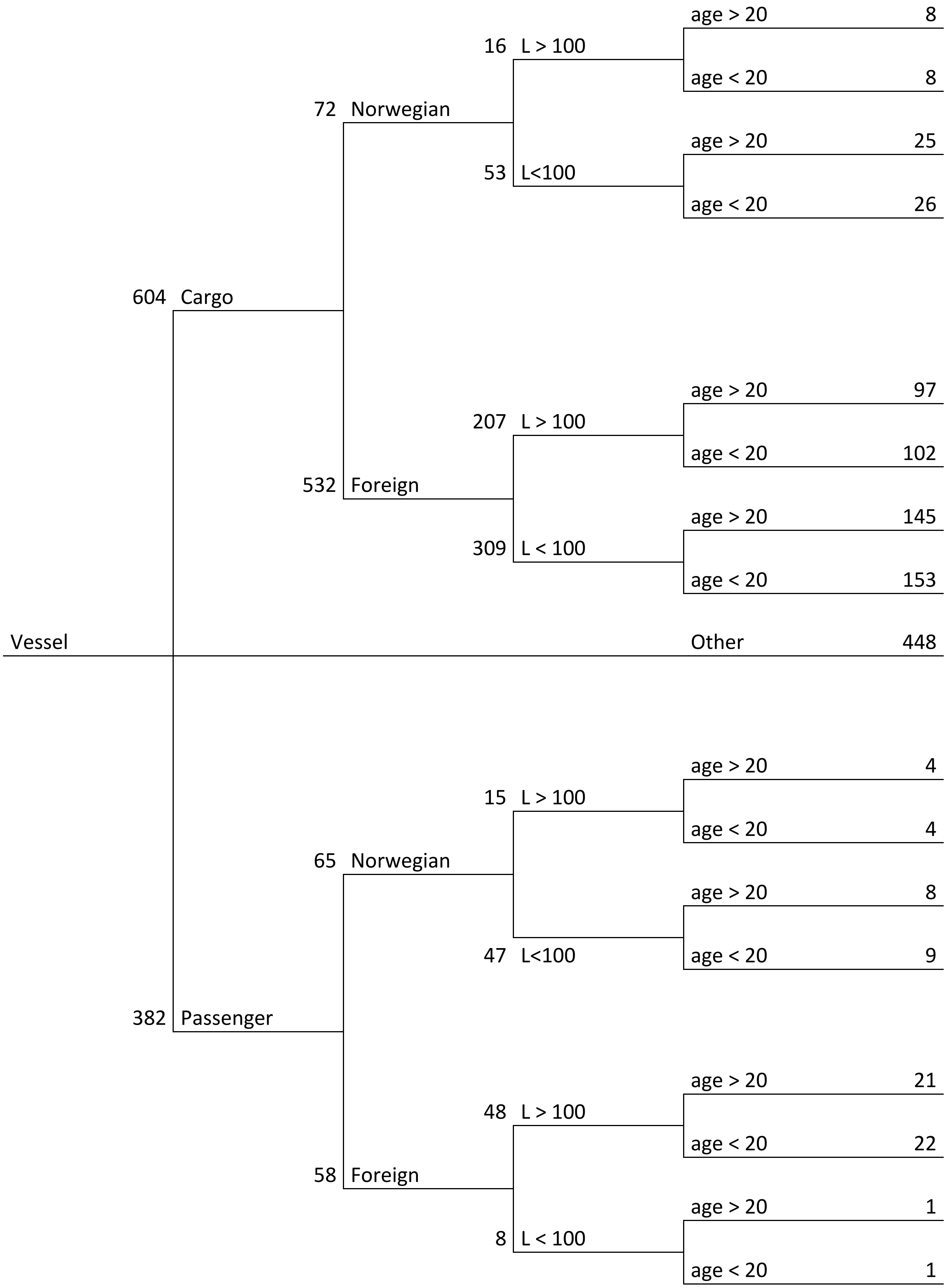
Appendix B – Vessel breakdown – Vessels in Norwegian waters



Appendix C – Vessel breakdown – Vessels in Korsfjorden



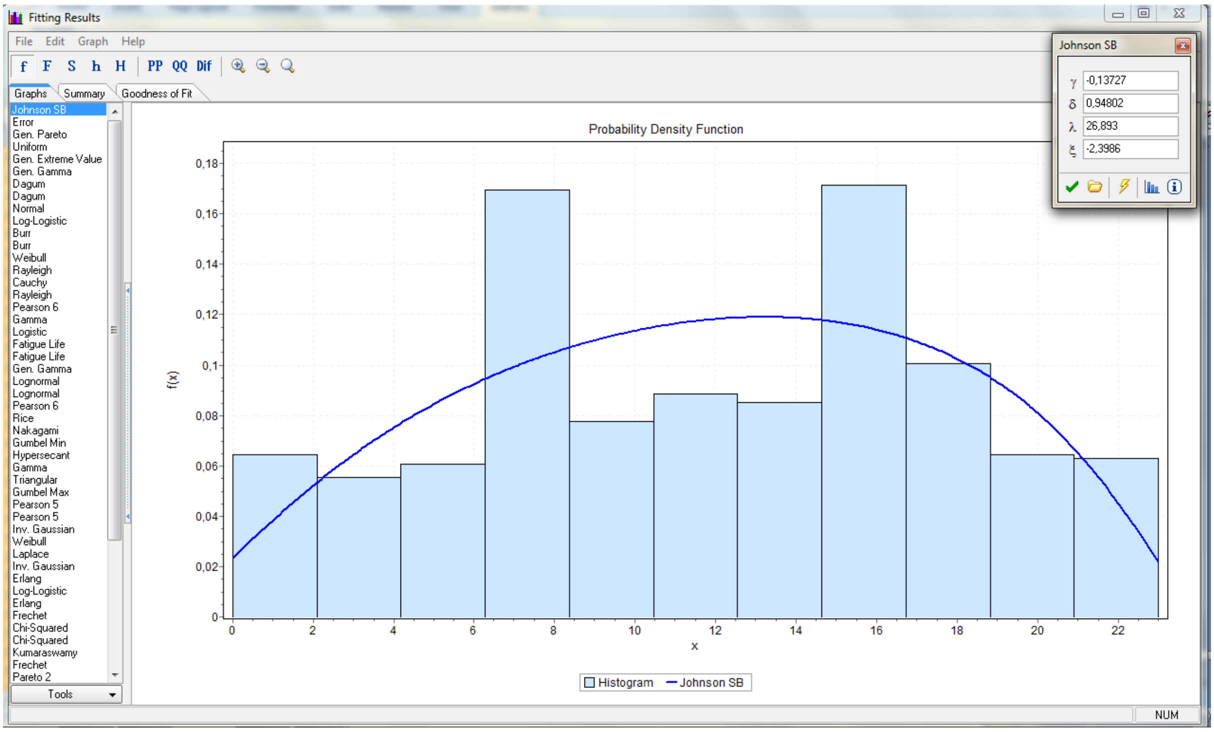
Appendix D – Vessel breakdown – Vessels in Oslofjorden



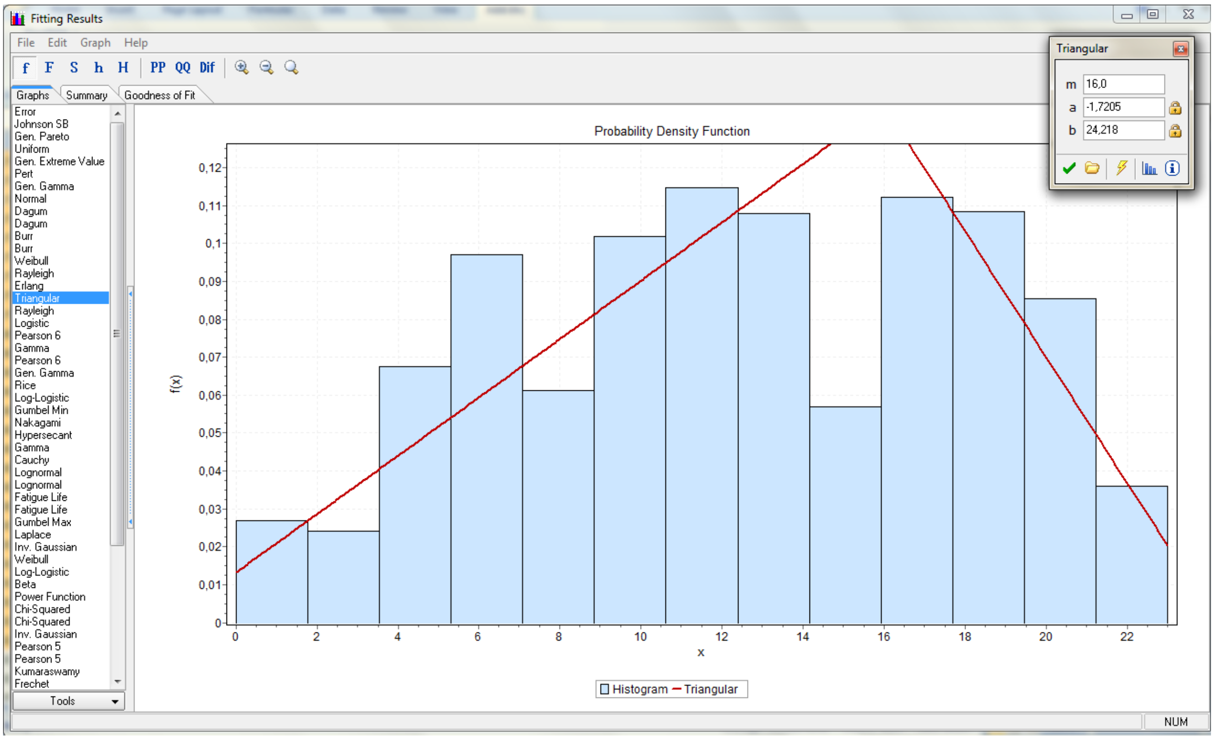
Appendix E - Risk model – Inner Oslo fjord

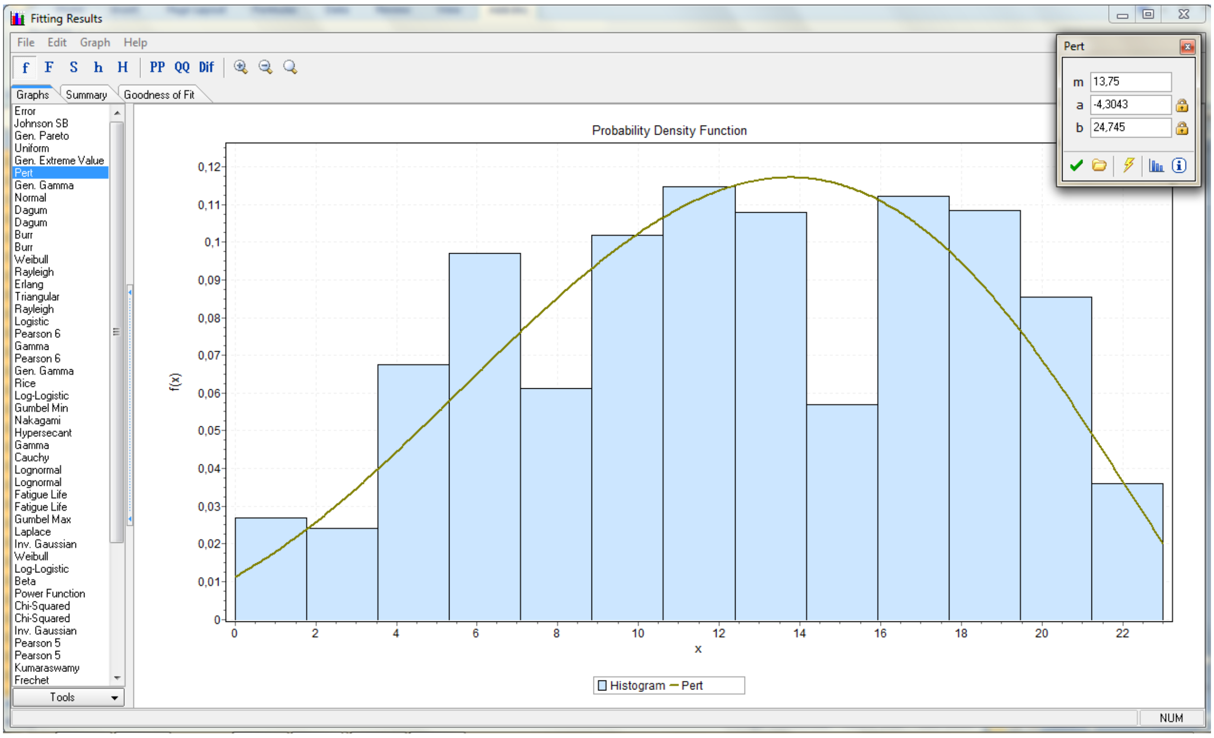
#	Probability	#	Probability	#	Probability	#	Probability
P(B$_1$)	0,69 %	**P(B$_1$|A)**	0,3 %	**P(A|B$_1$)**	0,46 %	**P(A∩B$_1$)**	3.17×10^{-5}
P(B$_2$)	0,73 %	**P(B$_2$|A)**	1,5 %	**P(A|B$_2$)**	2,20 %	**P(A∩B$_2$)**	1.61×10^{-4}
P(B$_3$)	2,30 %	**P(B$_3$|A)**	13,2 %	**P(A|B$_3$)**	52,43 %	**P(A∩B$_3$)**	1.25×10^{-2}
P(B$_4$)	2,42 %	**P(B$_4$|A)**	10,0 %	**P(A|B$_4$)**	38,13 %	**P(A∩B$_4$)**	9.23×10^{-3}
P(B$_5$)	8,96 %	**P(B$_5$|A)**	0,3 %	**P(A|B$_5$)**	0,06 %	**P(A∩B$_5$)**	5.38×10^{-5}
P(B$_6$)	9,44 %	**P(B$_6$|A)**	3,7 %	**P(A|B$_6$)**	0,74 %	**P(A∩B$_6$)**	6.99×10^{-4}
P(B$_7$)	13,38 %	**P(B$_7$|A)**	0,1 %	**P(A|B$_7$)**	0,05 %	**P(A∩B$_7$)**	6.69×10^{-5}
P(B$_8$)	14,09 %	**P(B$_8$|A)**	2,2 %	**P(A|B$_8$)**	1,02 %	**P(A∩B$_8$)**	1.44×10^{-3}
P(B$_9$)	0,35 %	**P(B$_9$|A)**	0,3 %	**P(A|B$_9$)**	4,09 %	**P(A∩B$_9$)**	1.43×10^{-4}
P(B$_{10}$)	0,36 %	**P(B$_{10}$|A)**	3,8 %	**P(A|B$_{10}$)**	49,40 %	**P(A∩B$_{10}$)**	1.78×10^{-3}
P(B$_{11}$)	0,78 %	**P(B$_{11}$|A)**	11,8 %	**P(A|B$_{11}$)**	27,00 %	**P(A∩B$_{11}$)**	2.11×10^{-3}
P(B$_{12}$)	0,82 %	**P(B$_{12}$|A)**	13,5 %	**P(A|B$_{12}$)**	29,25 %	**P(A∩B$_{12}$)**	2.40×10^{-3}
P(B$_{13}$)	1,95 %	**P(B$_{13}$|A)**	0,1 %	**P(A|B$_{13}$)**	0,58 %	**P(A∩B$_{13}$)**	1.13×10^{-4}
P(B$_{14}$)	2,05 %	**P(B$_{14}$|A)**	0,4 %	**P(A|B$_{14}$)**	2,20 %	**P(A∩B$_{14}$)**	4.51×10^{-4}
P(B$_{15}$)	0,13 %	**P(B$_{15}$|A)**	0,4 %	**P(A|B$_{15}$)**	9,53 %	**P(A∩B$_{15}$)**	1.24×10^{-4}
P(B$_{16}$)	0,14 %	**P(B$_{16}$|A)**	0,1 %	**P(A|B$_{16}$)**	2,38 %	**P(A∩B$_{16}$)**	3.33×10^{-5}
P(B$_{17}$)	41,40 %	**P(B$_{17}$|A)**	38,09 %	**P(A|B$_{17}$)**	2,15 %	**P(A∩B$_{17}$)**	8.90×10^{-3}
						P(A)	$\mathbf{4.02 \times 10^{-2}}$

Appendix F – Vessel distribution by time – East – West



Appendix G – Vessel distributions by time – North – South





Appendix H – Goodness of fit, vessel distributions by time

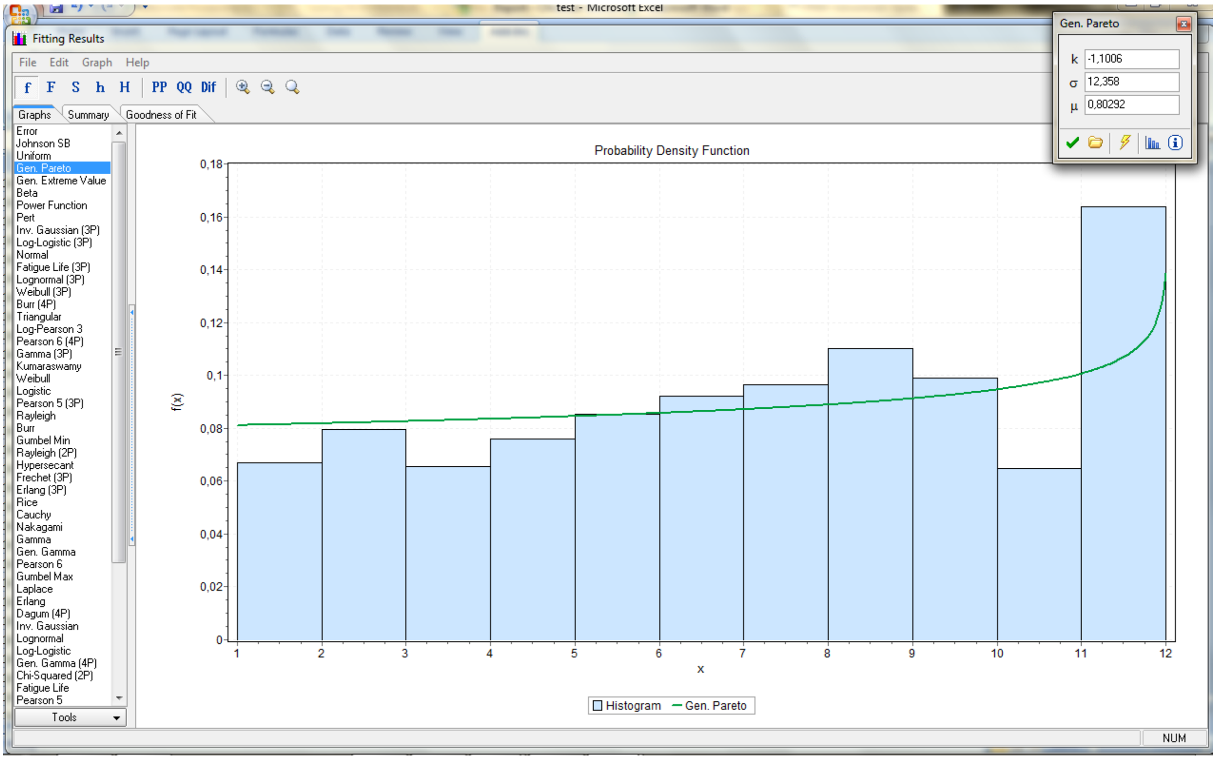
North - South

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
53	Triangular	0,08368	16	31,736	6	393,25	1
47	Pert	0,06257	6	17,467	3	414,26	2
23	Gen. Gamma	0,06882	7	121,4	11	441,49	3
9	Erlang	0,08012	15	173,64	22	455,16	4
51	Rice	0,10499	23	164,66	20	463,27	5
22	Gen. Gamma	0,1028	22	186,51	26	464,97	6
46	Pearson 6	0,09803	21	180,27	25	469,86	7
19	Gamma	0,09776	20	180,05	24	470,45	8
45	Pearson 6	0,09746	19	179,82	23	471,06	9
41	Normal	0,0742	8	29,647	5	480,35	10

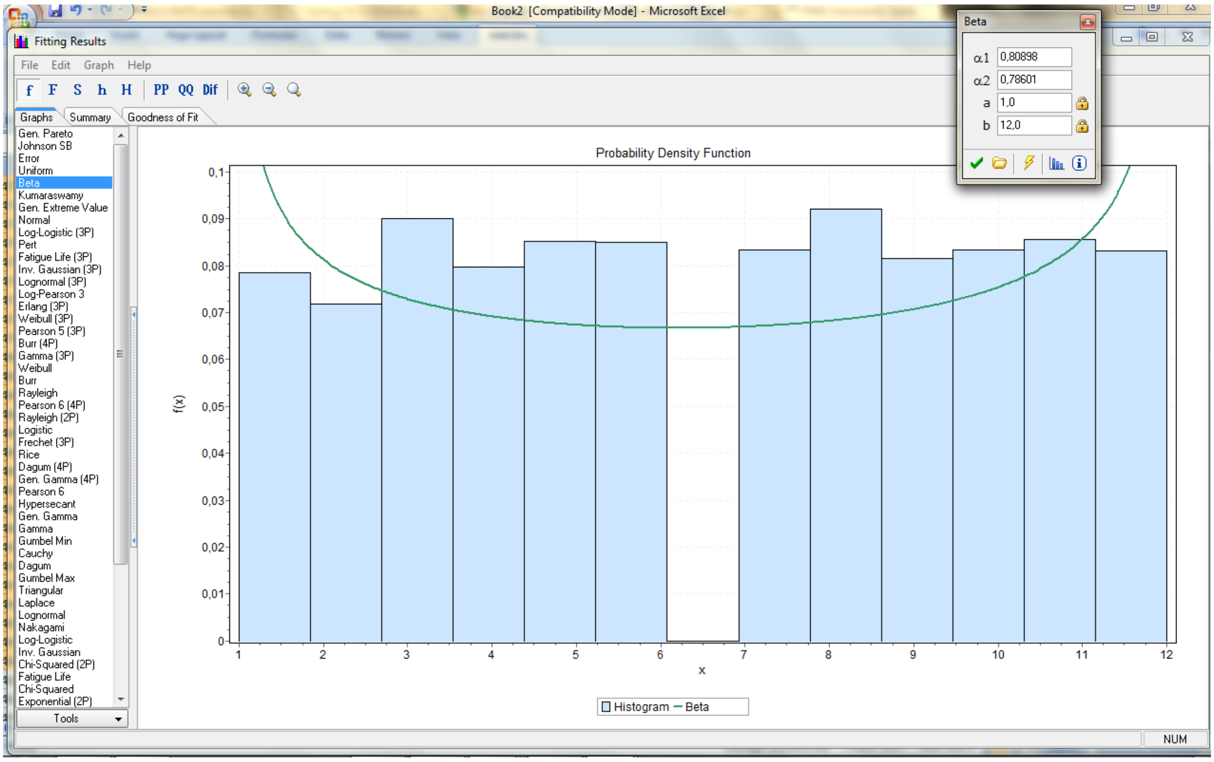
East - West

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
11	Error	0,07002	2	5,428	2	108,98	1
30	Johnson SB	0,0681	1	5,1284	1	197,22	2
21	Gen. Extreme Value	0,09067	5	8,4768	3	219,25	3
45	Pearson 6	0,12258	17	87,997	21	230,06	4
22	Gen. Gamma	0,13225	22	91,857	24	260,33	5
19	Gamma	0,1267	18	89,223	22	262,66	6
10	Erlang	0,17553	39	112,34	30	263,59	7
51	Rice	0,13497	26	83,083	20	263,91	8
50	Rayleigh	0,11952	16	77,467	16	265,6	9
49	Rayleigh	0,11811	14	77,2	15	265,9	10

Appendix I – Vessel distribution by month – East – West



Appendix J – Vessel distribution by month – North – South



Appendix K – Goodness of fit, vessel distributions by month

East - West

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
24	Gen. Pareto	0,0754	4	21,561	17	58,047	1
21	Gen. Extreme Value	0,07786	5	12,923	3	58,19	2
58	Uniform	0,06884	3	18,804	14	60,13	3
4	Cauchy	0,13642	32	35,181	27	68,302	4
51	Power Function	0,07955	7	176,73	47	69,66	5
1	Beta	0,07954	6	251,57	49	72,976	6
10	Erlang (3P)	0,12922	30	23,581	21	81,919	7
29	Inv. Gaussian (3P)	0,0908	9	16,212	4	83,284	8
41	Lognormal (3P)	0,09653	13	17,052	7	84,165	9
20	Gamma (3P)	0,10441	19	18,104	13	84,811	10

North - South

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Beta	0,08326	5	956,93	52	202,28	1
31	Kumaraswamy	0,08328	6	661,18	49	202,3	2
24	Gen. Pareto	0,0492	1	27,714	4	225,68	3
30	Johnson SB	0,04921	2	26,857	1	239,91	4
11	Error	0,05004	3	27,627	2	289,28	5
58	Uniform	0,05028	4	27,698	3	290,08	6
38	Log-Pearson 3	0,10071	14	69,913	9	341,5	7
47	Pearson 5 (3P)	0,10302	17	71,308	11	449,25	8
20	Gamma (3P)	0,10443	19	72,296	14	455,38	9

Appendix L – Traffic Characteristics

Vessel	Time	Lat.	Long.	Other vessels in fairway
KAIA CICILIE	11.02.2010 13:00	0000067	0000012	Not found
MARI UGLAND	28.02.2010 17:59	0000066	0000035	Not found
MALO	11.03.2010 13:00	0000068	0000012	Not found
HORDAFOR IV	13.03.2010 07:50	0000069	0000017	Not found
LURØY	17.04.2010 07:45	0000066	0000013	Kvitvarden; 12 metres, Norwegian, fishing, 2002
Livarden	29.06.2010 04:22	0000059	0000005	Vessel found, but accident time/position incorrect
HAKO	17.07.2010 18:10	0000059	0000011	Not found
EDDA FJORD	08.11.2010 22:05	0000059	0000006	Prosper; 75 meters, Faroe Island, tug, 1983 Island Valiant; 93 meters,Norway , tug, 2007
ICE CRYSTAL	15.11.2010 23:45	0000070	0000018	No other vessels registered
FLØGRUNN	18.11.2010 21:52	0000071	0000030	Not found

Vessel	Time	Lat.	Long.	TCPA
HERØYFISK	26.01.2010 04:30	0000065	0000012	A few minutes
VEAGUTT	22.02.2010 06:30	0000067	0000013	Not found
SEMO	09.04.2010 02:45	0000069	0000018	Not found
TURBO	10.07.2010 02:00	0000067	0000013	Not found
HORDAFOR III	12.09.2010 01:50	0000062	0000005	Not found
FJORDTOR I	06.10.2010 05:30	0000067	0000013	Not found
SVEBÅEN	26.11.2010 03:30	0000067	0000013	Not found

Appendix M – Problem description

Introduction

The accident rates in shipping seem to be increasing. However, accident statistics are incomplete, and statistics from different sources (Lloyds Register, Norwegian maritime directorate, insurers, class societies etc.) are seldom compared. In the context of FSA, risk analysis and rulemaking, the analysis of accident data is very important for providing factual input on developing more balanced, proactive and cost-effective regulations and for evaluating the potential effects of improvements in design and equipment. While some evidence of incomplete historical accidents records has been produced, the true extent of underreporting is not known. Furthermore, claims of rising accident rates are often being blamed on human errors, and claims of reduced crew quality/training in recent years combined with increased workloads and pressure to deliver in a heated marked.

Overall aim and focus

AIS og LRIT er teknologi som kan gi ytterligere informasjon om trafikkbildet i gitte farleder, samt gi tilleggsinformasjon omkring skipsulykker ut ifra tilgang til seilingshistorikk forut for en ulykke, samt vind og vær situasjonen i det aktuelle området.

Denne oppgaven skal se nærmere på de muligheter som ligger i bruk av data fra AIS og LRIT til å forbedre det statistiske grunnlaget over skipsulykker.

Scope and main activities

i. Beskrivelse av AIS og LRIT teknologi for monitorering av skipstrafikk, inkludert de muligheter og begrensninger som ligger i teknologiene.
ii. Etablere en strukturert oversikt over AIS data for et gitt farledsområde for en gitt tidsperiode.
iii. Analysere identifiserte skipsulykker i det samme farledsområde og tidsperiode, i forhold til registrert informasjon i skipsulykkesdatabaser, ulykkesrapport og fra AIS data.
iv. Undersøke sammenhengen mellom ulykker og skipstrafikk for å se om det er noe mønster i trafikken som kan indikere høyere sannsynlighet for ulykker.
v. Test av risikomodell basert på AIS data, sammenlignet med faktiske ulykkestall for norske farvann.
vi. Undersøke sammenhengen mellom vær og vind og erfarte ulykker. Er det spesielle værforhold som går igjen i de forskjellige ulykkene?
vii. Utarbeide forslag til hvordan korreksjonsfaktorer for underrapportering for relevante skip/flagg/områder kan utvikles basert på AIS/LRIT informasjon.

Modus operandi

Arbeidet vil gjennomføres i samarbeid med FARGE prosjektet (DNV), og med Bjørn Egil Asbjørnslett som ansvarlig veileder.

Arbeidet med masteroppgaven skal følge de retningslinjer som er gitt av NTNU for denne type arbeid.

Bjørn Egil Asbjørnslett

Prof./responsible advisor