NAVIGATIONAL RISK – OMØ SYD WIND FARM

Navigational Risk Assessment Omø Syd Offshore Wind Farm

Orbicon A/S

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Customer:	Orbicon A/S,	Tuborg Parkvej 8, 2nd Floor
Contact person:	Kristian Nehring Madsen	DK2900 Hellerup
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Applicable contract(s) governing the provision of this Report:

Objective:

Assessment of the navigational risk associated with establishment of the Omø Syd Offshore Wind Farm

Prepared by:	Verified by:	Approved by:
Lasse Sahlberg-Nielsen Engineer	Peter Friis Hansen Senior Principal Researcher	Jonathan Rahbek Engineer

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Contents

Nomenclature

AIS	Automatic Identification System
EIA	Environmental impact assessment
HAZID	Hazard Identification
IMO	International Maritime Organization
IWRAP	IALA Waterway Risk Assessment Programme

1 SUMMARY

Omø Syd Offshore Wind Farm is a project subject to pre-investigations under the “open-door” arrangement issued by Danish Energy Agency dated march 2014. The scope of the present report is to assess the navigational risk associated with establishment of the Omø Syd Offshore Wind Farm

The overall approach for this navigational risk assessment follows IMO’s (international Maritime Organization) guidelines for evaluation of navigational safety assessment. A stepwise approach is adopted meaning that results are presented after each step and evaluated together with the Danish Maritime Authority (Søfartsstyrelsen) whether or not the next step needs to be executed.

Step 1: A frequency analysis based on ship traffic and proposed offshore wind farm layout is executed and results are presented to the Danish Maritime Authority.

Step 2: If the Danish Maritime Authority does not find it possible to conclude from the results of the frequency analysis that the navigational risks will be acceptable, a consequence analysis must be executed and combined with the frequency results. The navigational risk assessment will then be updated with the resulting risk derived by combining the frequency and the consequence analyses.

Step 3: If the Danish Maritime Authority cannot approve the estimated risk, possible risk reducing measures have to be identified, analyzed and adopted if considered feasible. This risk reduction process must continue until the risk reaches an acceptable level. Otherwise it has to be concluded that the project will not be feasible when required to be associated with an acceptable ship collision risk.

For the present Omø Syd Offshore Wind Farm it is judged that Step 1 is sufficient for the risk assessment. This implies that only a frequency analysis is carried out for the present study. The ship traffic around the proposed area for the Omø Syd Offshore Wind Farm is established based on available AIS data and used as the basis for the navigational risk assessment. The HAZID report concludes that the hazards related to navigational risk are all related to the risk of ships colliding with a turbine or ship-ship collision due to the presence of the Offshore Wind Farm. A wind farm layout consisting of 80 turbines of 3MW (240 MW total) has been used as the worst case scenario (this is a scenario that is expected to produce the largest navigational risk) for this evaluation.

The frequency analysis gives a return period for ship-wind turbine collisions of 1290 years for powered collisions (i.e., typical human error), and 5199 years for drifting collisions (i.e., typical technical errors). The combined return period for powered and drifting collision is thus estimated to 1033 years. The largest contribution to the calculated collision return period is from ship traffic on the north and south going routes west of the wind farm, while the ship traffic on surrounding routes gives relatively low contribution. The risk of ship-ship collision and grounding around the offshore wind farm under existing conditions has been compared to the imposed traffic change due to the wind farm and is evaluated to be insignificant.

Based on these evaluations it is judged not to be necessary to perform a consequence analysis (Step 2) and, hence, neither to perform a detailed evaluation of risk reducing measures (Step 3). The conclusions from the frequency analysis (Step 1) indicate that the occurrence of ship-turbine collisions will be low and hence the increase in navigational risk due to establishment of the Omø Syd Offshore Wind Farm is acceptable.

The impact on the navigational risk during the installation and decommissioning phases has not been evaluated since there are still too many unknown parameters to complete this analysis. The risk assessment for the installation and decommissioning would normally be part of the scope of work for the appointed contractor.

2 INTRODUCTION

On February 22 2012 European Energy A/S applied for a permit for feasibility studies and preparation of an EIA for the establishment of an offshore wind farm at Omø Syd. The permit was given by Energistyrelsen on March 3 2014. In connection with the feasibility studies a navigational risk analysis shall be carried out.

DNV GL has been contracted to perform a navigational safety analysis in connection with the preparation of the environmental impact assessment (EIA) for the Omø Syd wind farm project.

2.1 Objectives

The objective of the present navigational risk assessment is to evaluate how and to what extent the ship traffic in the area will be influenced by the Omø Syd Offshore Wind Farm and to identify and estimate any associated increase in the navigational risk in the region near the wind farm.

3 PROJECT DESCRIPTION

Omø Syd Offshore Wind Farm is a near shore farm. The entire survey area is shown in figure 3.1. Refer to appendix A for a navigational chart.

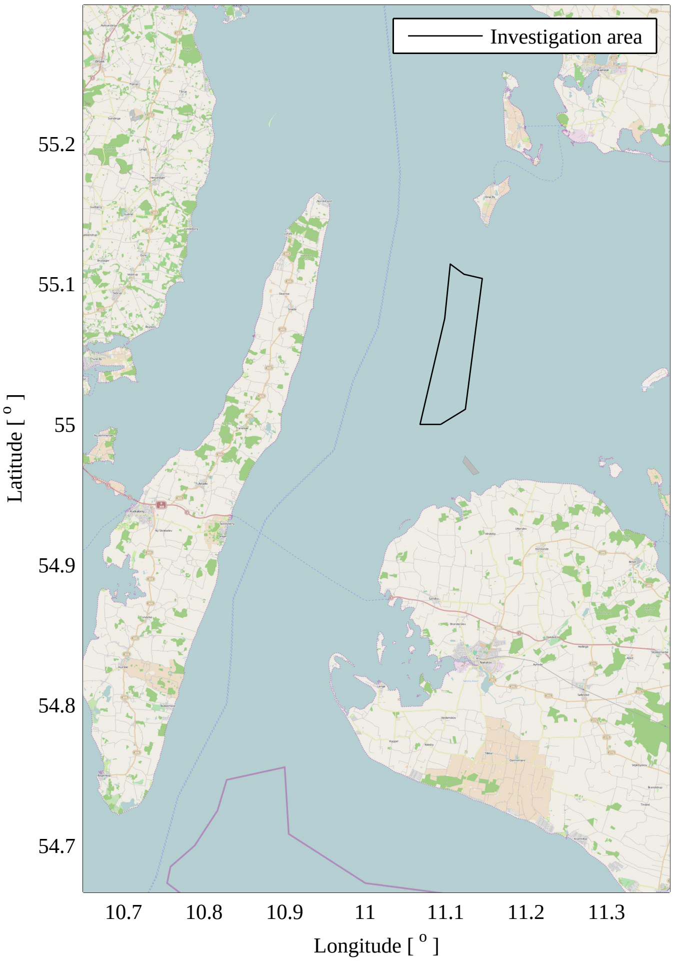


Figure 3.1

3.1 Installations offshore

Omø Syd Offshore Wind Farm will be located within an approximate 50 km^2 survey area, which covers an area, situated 4-5 km off the south coast of Omø and 6 km north of Lolland. Water depths in the area vary between 5 and 10 m. The offshore wind farm will possibly be established with a maximum capacity of 320 MW and will possibly take op the whole survey area.

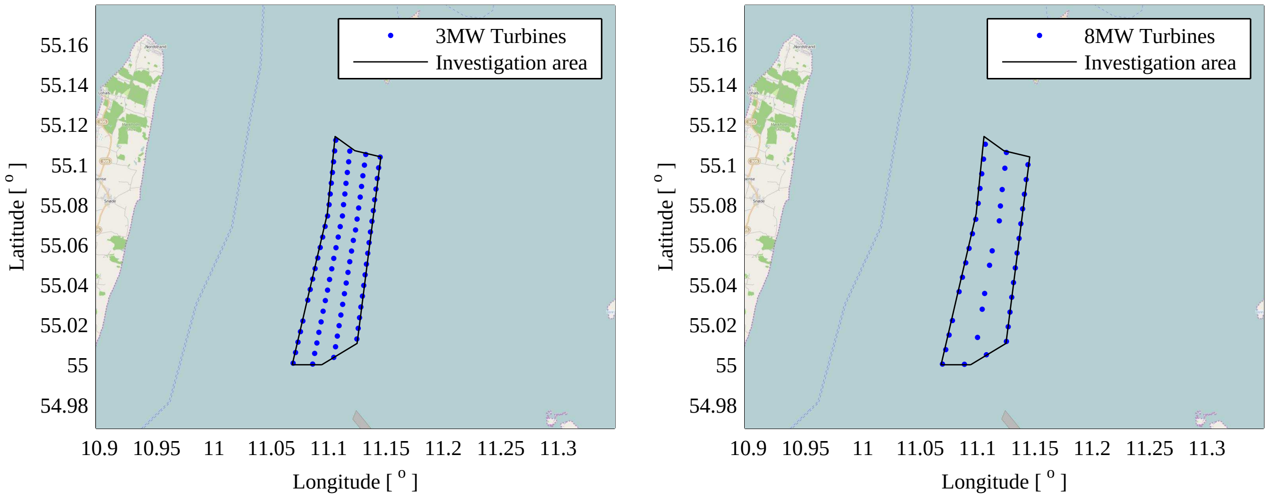
Turbine capacity	Rotor diameter	Total height	Hub height	Max number
3 MW	112 m	150 m	94 m	80 pcs
8 MW	164 m	200 m	118 m	40 pcs

Table 3.1: Specifications of possible turbines

The power will be exported directly to land thus no offshore substation will be needed.

3.2 Wind farm layout

The possible positions for the 80 3MW and 40 8MW turbines are shown in appendix C.1-C.2. The turbine layout is shown in figure 3.2.



(a) 3MW turbine layout

(b) 8MW turbine layout

Figure 3.2: Turbine layouts

4 BACKGROUND

The navigational risk assessment presented in the present report is part of the total EIA (Environmental Impact Assesment) for the Omø Syd Offshore Wind Farm project.

The overall approach for this navigational risk assessment follows IMO's (international Maritime Organization) guidelines for evaluation of navigational safety assessment. A stepwise approach is adopted meaning that results are presented after each step and evaluated together with the Danish Maritime Authority (Søfartsstyrelsen) whether or not the next step needs to be executed.

Step 1	A frequency analysis based on ship traffic and proposed offshore wind farm layout is executed and results are presented to the Danish Maritime Authority.
Step 2	If the Danish Maritime Authority does not find it possible to conclude from the results of the frequency analysis that the navigational risks will be acceptable, a consequence analysis must be completed and combined with the frequency results. The navigational risk assessment will then be updated with the resulting risk derived by combining the frequency and the consequence analyses.
Step 3	If the Danish Maritime Authority cannot approve the estimated risk, possible risk reducing measures have to be identified, analyzed and adopted if considered feasible. This risk reduction process must continue until the risk reaches an acceptable level. Otherwise it must be concluded that the project will not be feasible when required to be associated with an acceptable ship collision risk.

The basis for the evaluation covered in Step 1 (The frequency analysis) is described in the following subsections. The objective of Step 1 is to estimate the frequency of ship collisions with the wind turbines and this is performed based on a worst case layout of the offshore wind farm. The results are initially used to assess if the risk associated with collisions can be concluded acceptable without quantifying the consequences of these collisions. This would be the case if the frequencies are so low that the associated risks would be acceptable even with the most conservative assessment of the consequences. If this is not the case Step 2 (The consequence analysis) has to be carried out.

4.1 Method

The following describes the method for performing Step 1, - the frequency analysis. The frequency analysis is based on acknowledged mathematical models typically used for such analyses and with input based on historical (statistical) data. The applied calculation tool IWRAP MKII is a part of the IALA Recommendation [IALA O-134] on risk management.

4.1.1 Analysis tool

The IWRAP MKII software calculates the probability of collision or grounding for a vessel operating on a specified route. The applied model for calculating the frequency of grounding or collision accident involves the use of a so-called causation probability that is multiplied onto a theoretically obtained number of grounding or collision candidates. The causation factor models the probability of the officer on the watch not reacting in time given that he is on collision course with another vessel (or – alternatively – on grounding course), refer to Engberg [2010] for detailed theoretical model description. Appendix B lists probabilistic model assumptions applied in the current analysis1.

A description of the ship traffic constitutes the central input for a navigational risk assessment. Automatic Identification System (AIS) data provides a detailed geographic and temporal description of the ship traffic in a region and has been used as the primary data basis. Because the predominant part of the ship traffic is following navigational routes – which can be more or less well defined – the modelling of the ship traffic and the associated models of the risk of collisions and groundings usually adopts a route based description of the traffic.

The ship traffic description based on AIS is thus subsequently used as basis for definition of the routes in the probabilistic model in IWRAP MKII.

4.1.2 Risk scenarios

Installation of an offshore wind farm will introduce obstacles that the ship traffic has to avoid. If not successful in doing this a collision to a wind turbine will be the result. However, the deviations required of the ship traffic to avoid the wind turbines may also increase the potential for ship-ship collisions. A navigational risk analysis shall therefore cover the following three risk contributions:

- Ship-turbine collision risk for powered vessels (i.e., typically human error).
- Ship-turbine collision risk for drifting vessels (e.g., vessel with technical error).
- Changes in ship-ship collision risk due to increased traffic density around the offshore wind farm area.

The frequency analysis shall determine how often the above-mentioned three scenarios are expected to occur when the offshore wind farm has been introduced and based on this it can initially be judged if the risk associated with such collisions is readily acceptable. If not, the likely consequences of the collisions have to be determined to establish the fully detailed risk picture.

4.2 Worst case assumptions

As described in section 3.1 either 3MW or 8 MW turbines are to be installed. Since the final layout of the turbines in the offshore wind farm is not known at present, the navigational risk assessment is performed such that it will represent a worst case for all possible turbine layouts i.e. both with regards to turbine size and location of the turbines within the offshore wind farm area.

The collision frequency analysis is based on a layout of wind turbines that, in the context of navigational risk, is considered as the worst case scenario. The chosen worst case scenario is 80 3MW turbines since this will result in the highest risk of collision. It is noted that a layout with 40 8MW turbines would take up approximately the same area, but the lower number of turbines would present fewer obstacles to the ship traffic which would lead to a reduced potential of ship collisions. The 80 3MW turbines are in the worst case scenario distributed over the entire offshore wind farm area since this represents the case where the existing ship traffic will be disturbed the most.

The diameter of the tower at the water surface, which is relevant for the ship-turbine collision is assumed to be 10 meters.

4.3 Before and after

The ship traffic before and after the construction of the wind farm will be modeled in order to compare the impact of the offshore wind farm on the navigational risk. According to the HAZID report DNV GL [2014] some traffic will most probably be narrower on certain routes and furthermore fishing and leisure vessels will change patterns. Ship-ship collision and grounding of ships will thus be modeled in cases predicting before (i.e. existing conditions) and after construction of the wind farm.

Scenario	Existing routes	Relocated routes	Turbines included
1 (Before)	x		
2 (After)	x	x	x

Table 4.1: Calculated scenarios

5 EXISTING CONDITIONS

In the context of navigational risk the relevant existing conditions are constituted by the ship traffic in the area. The existing ship traffic in the vicinity of the offshore wind farm area is shown in figure 5.1. The figure is based on AIS data collected in the period from November 1 2013 to October 31 2014 and hence represents the existing conditions undisturbed by the presence of an offshore wind farm. The collection of ship traffic data and subsequent modifications in order to use it for the frequency analysis is described in the following subsections.

5.1 Ship traffic based on AIS data

This subsection describes the ship traffic used as input for the frequency analysis. The ship traffic is determined from regional AIS data collected for twelve months. The AIS data handled in the analysis is within the following geographic bounds:

	55°26.024′ N	
010°09.203′ E		012°18.976′ E
	54°44.138′ N	

Table 5.1: Geographic bounds of AIS

The mapped AIS data and its extents are shown in figure 5.1

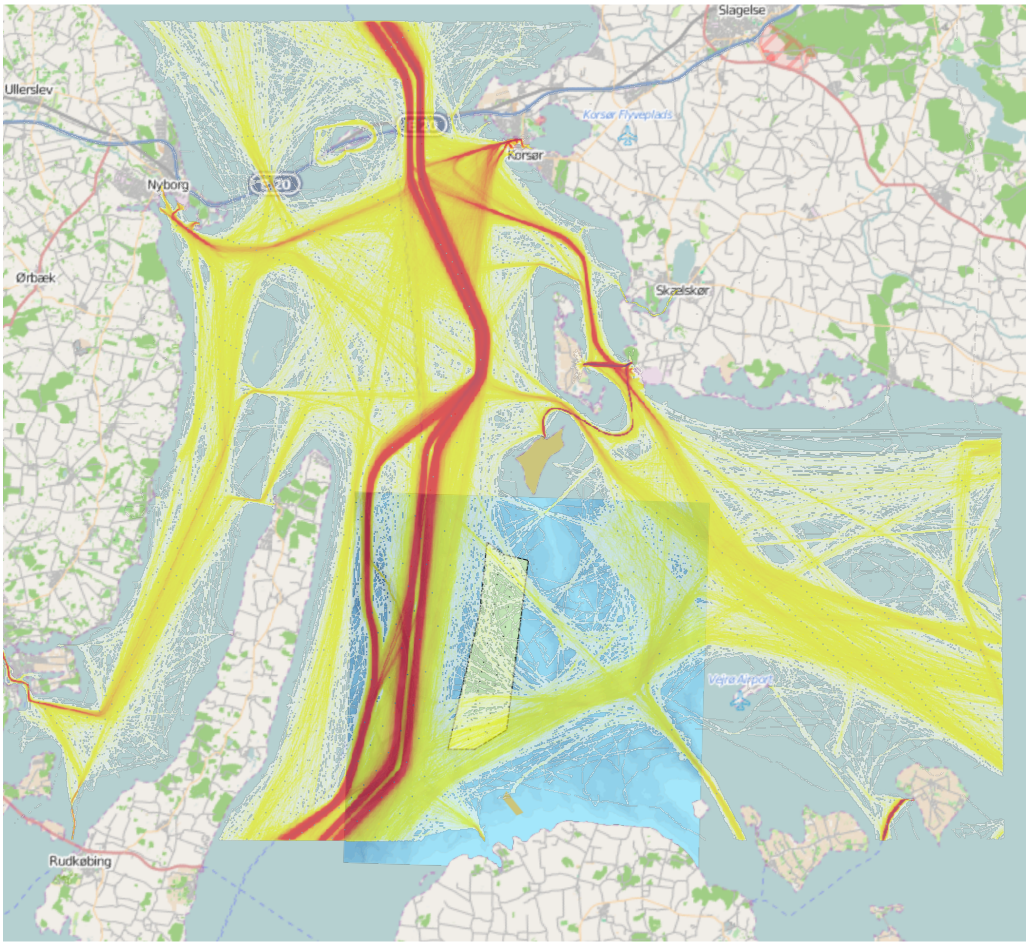


Figure 5.1: Ship traffic density based on AIS data from November 1 2013 to October 31 2014. The turbine area is shown for information only

5.2 Analysis of AIS data

The AIS data consists basically of successive position reports from each individual vessel that are within the selected geographic area. The first step in the analysis is to separate the position reports for each vessel, arrange them chronologically and combine them in sequence to form tracks that describe their passage within the area. These tracks form the basis for the subsequent analysis. The first result of the analysis is the density of tracks that is shown in figure 5.1.

Of main regard for the wind farm the traffic density is dominated by 1) a densely trafficked corridor of ship traffic that is either passing north towards the great belt bridge and south towards Germany, and 2) traffic passing north of Lolland towards Næstved.

The traffic modelling is approximated by poly-linear center-lines – the route – and a probabilistic description of the traffic distribution transverse to this ideal center line. Based on successive definition of routes and association of the AIS tracks to these routes, a set of routes have been found necessary and relevant in order to model the ship traffic considered in the present study which is of particular concern to the proposed Omø Syd Offshore Wind Farm.

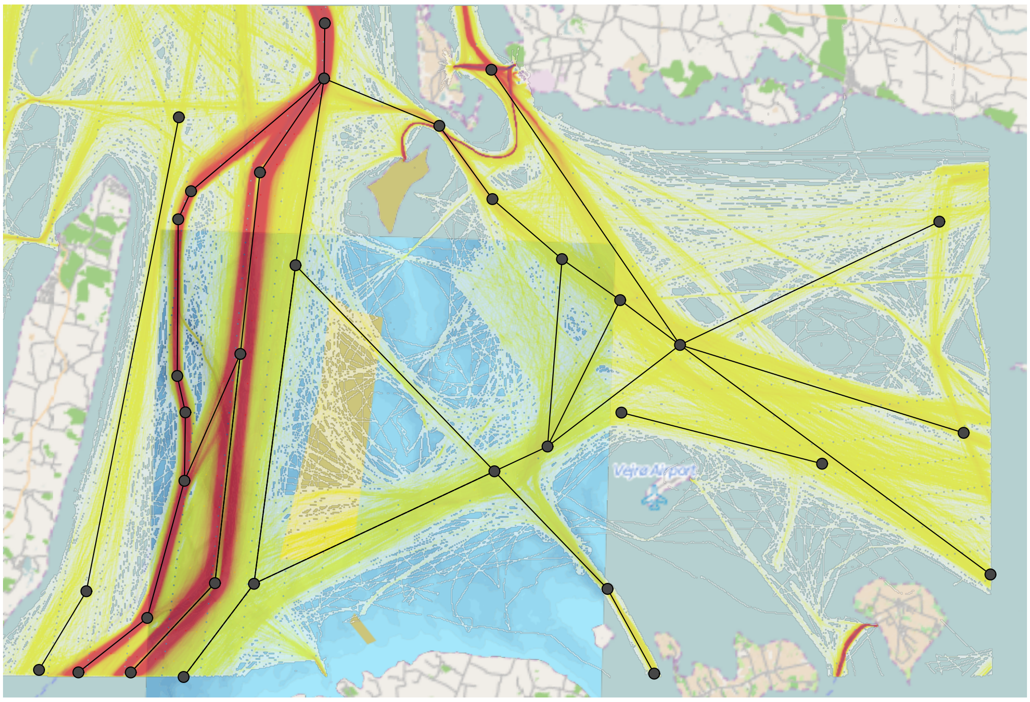


Figure 5.2: Ship traffic routes and AIS data, refer appendix D for route and waypoint numbers. Turbine area shown for information only

Based on the AIS and associated routes in figure 5.2 (refer appendix D for waypoint and route details), it is evident that the ship traffic on the routes passing through the site or in close proximity, will be forced to adapt to the presence of the proposed Omø Syd Offshore Wind Farm. It is noted that route 4 and 5 are passing directly through the proposed Omø Syd Offshore Wind Farm area and route 2 is in very close proximity. Hence, the traffic pattern after the offshore wind farm has been established will change. Section 6 deals with the anticipated reaction of the ship traffic due to the presence of the wind farm i.e. the traffic will tend to stay outside the wind farm and at a reasonable distance.

The association of routes does not necessarily utilize all the observed tracks in the AIS database. However all tracks has been evaluated and the ones found important for the present analysis has been included.

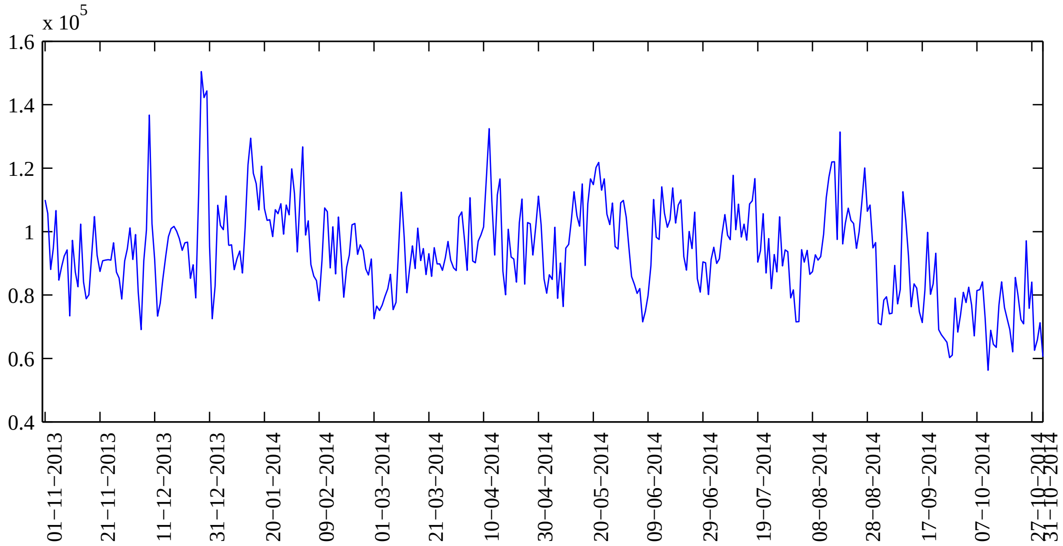


Figure 5.3: Variation of number of AIS records per day for the survey period

5.3 Ship classification

The ships are classified according to information contained in AIS signal message 5 (see ITU-R-1371-5 section 3.3 "Ship static and voyage related data" and section 3.3.2 "Type of ship"). Based on the identifier number contained in message 5 the following ship types are categorized as follows:

	Ship type					
	Fishing ship	Pleasure boat	Support ship	Passenger ship	General cargo ship	Oil Products tanker
Type Of Ship And Cargo	30	37	31-35 50-59	40-49 60-69	70-79	80-89

* All tankers are placed into the category "Oil Products tanker"

* All cargo ships are placed into the category "General cargo ships"

* Passenger ships which travels faster than 30 knots are placed in the category "High speed ferry"

* If AIS is class B and not "Fishing ship" then "Pleasure boat"

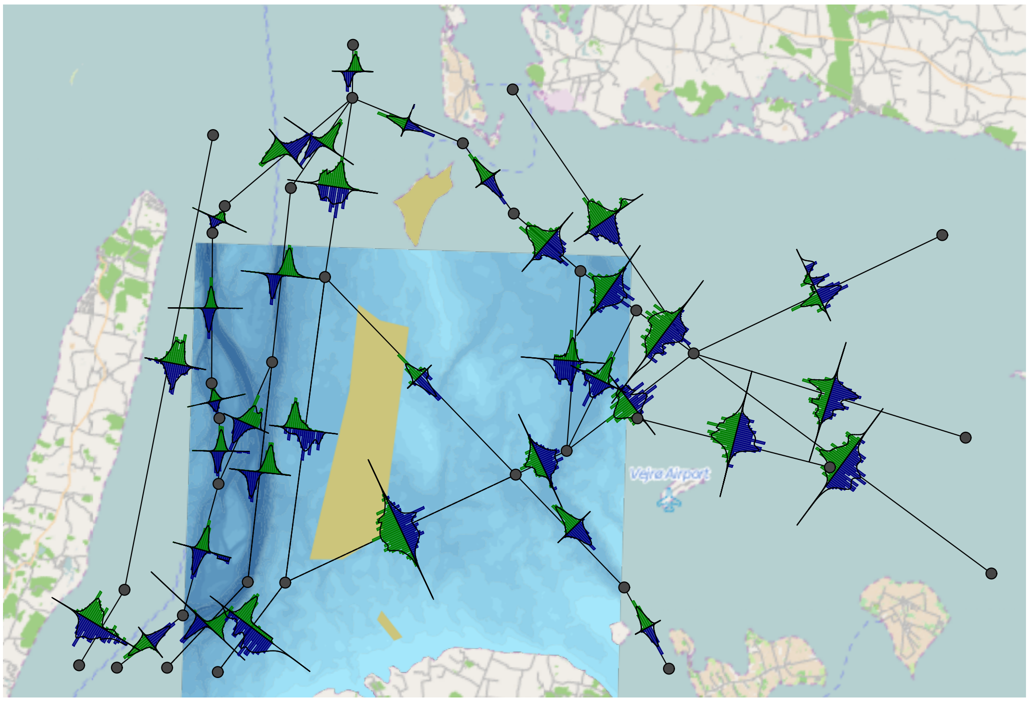
Table 5.2: Ship classification according to AIS identifier number

5.4 Modeling of traffic distribution across routes

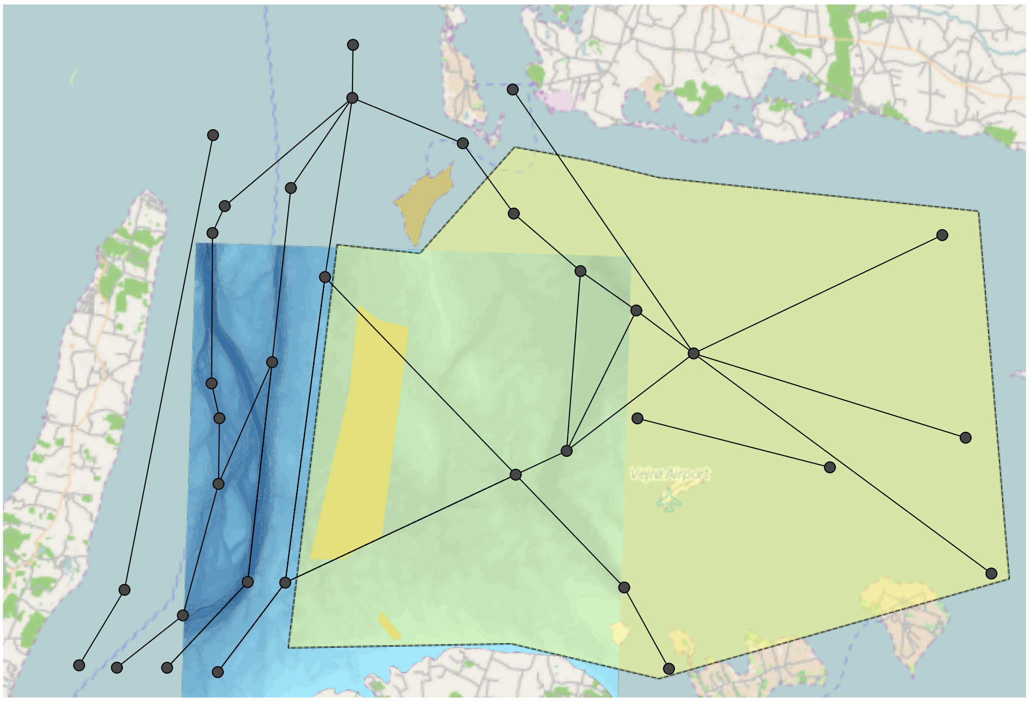
The ship traffic as identified through the AIS data has been associated with ideal – or generic – routes described in terms of the ideal centerlines. In order to calculate the risk of collisions to the offshore wind farm structures it is required that the deviation of the ship traffic from these ideal centerlines is described by a probabilistic model.

In some cases the description of the deviations can be extracted from the observed deviations – i.e., via the spread of the observed traffic density. But, in other cases, the establishment of the proposed offshore wind farm will impose changes to the navigational pattern to ensure a safe passing distance to the offshore wind farm structures. In these cases the spread and distribution type of the traffic has to be assumed on the basis of the presently observed spread combined with the proximity and restriction that the offshore wind farm structures is considered to constitute to the ship traffic.

The transverse distribution is composed of a number of superposed probability distributions (normal, gumbel, lognormal, uniform, weibul or beta) which are fitted to the recorded AIS data. A graphic overview of the fitted distributions are shown in figure 5.4a.



(a) Defined routes and distributions. Turbine area shown for information only



(b) Leisure traffic modeled in the yellow area. Turbine area shown for information only

Figure 5.4

5.5 Traffic areas

By traffic area is understood that traffic that do not follow ordinary routes. The area traffic is composed of leisure crafts and fishing vessels. These vessels will cross the routes at which the line traffic operates at random angles. The number of collisions between the area traffic and the line traffic is calculated by assuming that the area traffic crosses the route the line traffic operates on at eight different directions.

The traffic areas is included to predict the ship-ship collision frequencies and does not influence the ship grounding or ship-turbine collision results.

Since the traffic is not based on AIS statistics it is thus defined manually in terms of size, number and some parameters determining how the traffic is assumed to behave during a year.

5.5.1 Leisure traffic

The leisure vessels will usually travel in patterns that are more irregular than that of the merchant ship traffic. As mentioned in the HAZID report DNV GL [2014] these traveling patterns are not well described in the route structure that is used for the merchant traffic, and a different more diffuse modeling of this ship traffic is required for use in a frequency analysis.

Based on the input from the HAZID participants the number of leisure vessels in "Bøgestrømmen" is between 20.000 to 30.000 and can be used as a rough estimate of the traffic in the area. In the model the following is assumed

Length [m]	Number of ships [per year]	Number of days [per ship per year]	Visits [per day]	Movement time [hours per visit]	Stationary time [hours per visit]
15 m	20000	10	1	8	0

Table 5.3: Assumed leisure traffic

The leisure vessels are included in the model as a "traffic area". In these areas the vessels will cross the routes at which the line traffic operates at random angels. The number of collisions between the area traffic and the line traffic is calculated by assuming that the area traffic crosses the route the line traffic operates on, at eight different directions.

The leisure traffic is modeled as an traffic area extending from Lolland to Omø and extending west to Femø thus simulating the traffic in "Smålandsfarvandet" see figure 5.4b.

In the HAZID DNV GL [2014] it was predicted that the traffic as a result of the wind farm would divert from the farm area and Omø Stålgrunde and instead concentrate in the areas around Route 4 and Route 7. The traffic area is thus not extended west to Langeland.

5.5.2 Fishing traffic

As during the HAZID DNV GL [2014] it was estimated that approximately 45 fishing vessels at the size of around 12m are not covered by AIS. The assumed fishing traffic is shown in table 5.4 (note that number and size of ships has been taken as 20 and 100 m respectively). It is assumed that these vessels are present in the same area as shown in figure 5.4b.

Length [m]	Number of ships [per year]	Number of days [per ship per year]	Visits [per day]	Movement time [hours per visit]	Stationary time [hours per visit]
20	100	100	1	6	2

Table 5.4: Assumed fishing traffic

5.6 Modeling of grounds

The grounds in the area are as shown in figure 5.5. As argued in section 6 the traffic on route 4 is expected to move further south to keep safe distance, the grounds in this area is thus of special interest. The grounds inside the marked area in figure 5.5 have been included in the model.

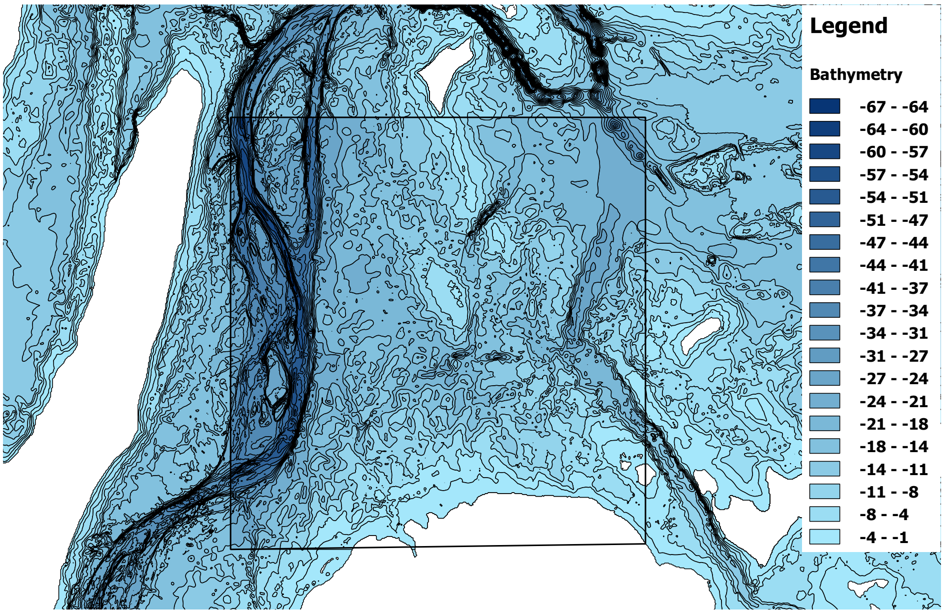
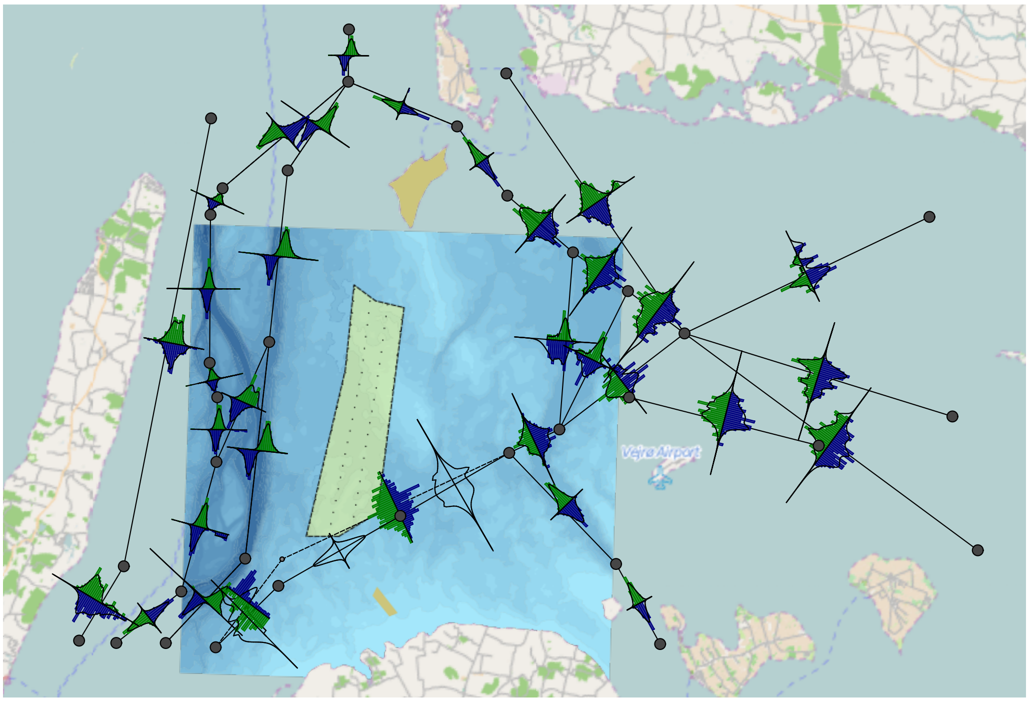


Figure 5.5: Grounds inside highlighted area used in analysis

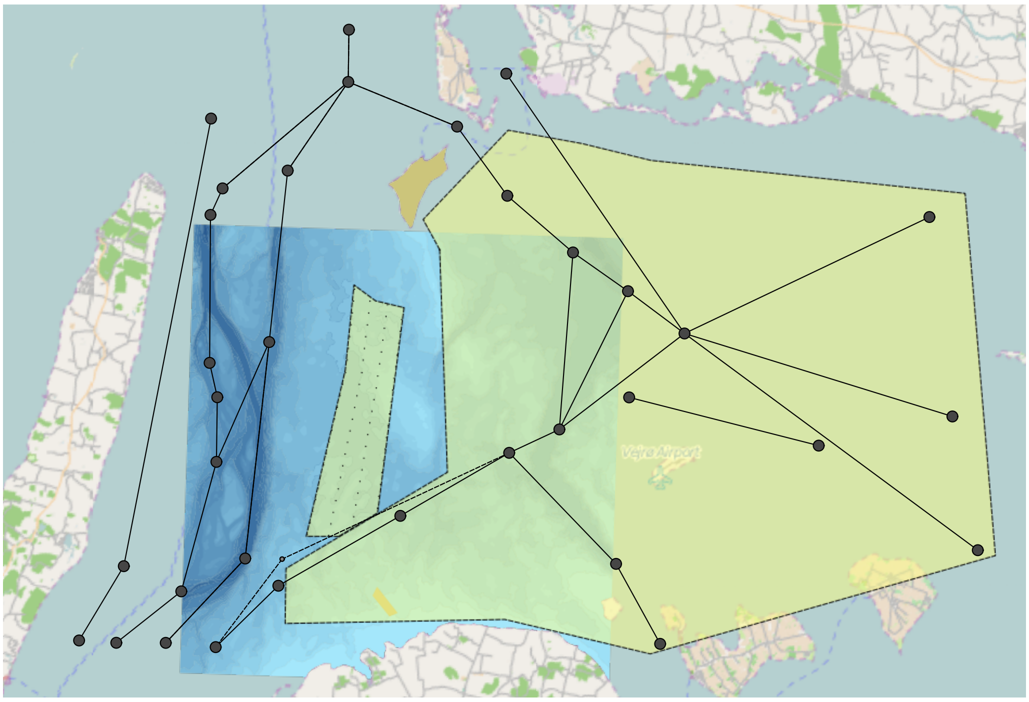
6 REVISED CONDITIONS

The presence of the offshore wind farm under investigation is assumed to result in that some of the ship traffic will relocate to avoid passing through the offshore wind farm. The routes used to model these components of the ship traffic in the frequency analysis will be adjusted accordingly based on the assumed future behavior of this traffic i.e. how the traffic will tend to relocate.

In the analysis it is assumed that ship traffic will not travel through the farm. The proposed revisions to these routes are discussed in the following.



(a) Revised routes due to wind farm. The dashed lines shows moved legs. Route4b is split into Route4b1 and Route4b2



(b) Revised traffic area due to windfarm

Figure 6.1

6.1 Revised modeling of traffic distribution across routes

As mentioned in section 5.2 the traffic on routes 4 and 5 are passing straight through the wind farm area and route 2 is in very close proximity. It is predicted that the traffic will respond as in the following:

Route 2	The traffic will keep safe distance to the farm and concentrate on route 1. In the revised model the traffic from route 2a[1] (in total 285 ships north and 24 south) is added to route 1b-e thus increasing the probability of ship-ship collisions.
Route 4	The traffic will migrate further south (in total 1197 ships north and 1204 ships south). The traffic on route 4b1 will be forced to narrow since it have to pass north of the buoy indicated in figure 6.2.
Route 5	Due to Omø Stålgrund the traffic cannot migrate north. It is assumed that the ships on route 5c (in total 18 ships north and 20 ships south) will sail through Omø sund on routes 4c, LEG_52 and 7c-7e.

Refer to appendix D for route information.

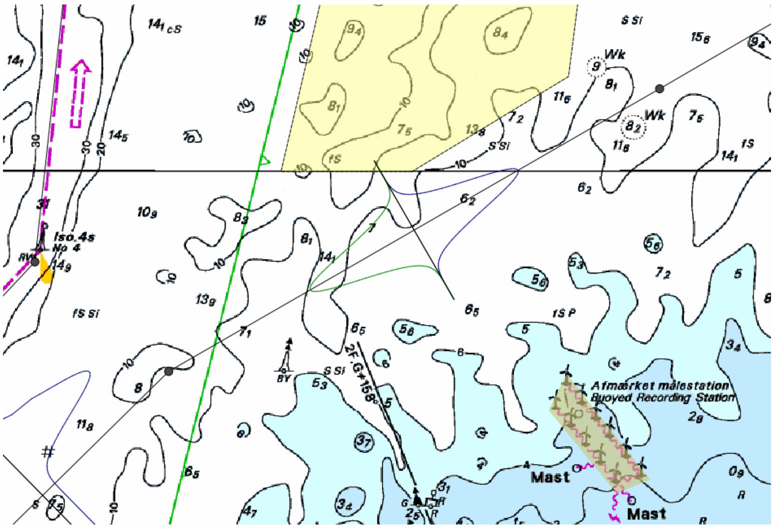


Figure 6.2: Traffic corridor between turbine area and buoy

6.2 Leisure traffic

The wind conditions inside the wind farm is not ideal for sailing purposes. As discussed in the HAZID DNV GL [2014] leisure vessels from Germany and "Bøgestrømmen" will likely tend to go through Omø Sund. The revised traffic area is shown in figure 6.1b.

6.3 Fishing traffic

As discussed in the HAZID DNV GL [2014] the foundations of the turbines will create an artificial reef which can give beneficial conditions for certain types of fish. It is thus not expected that the fishing pattern will be different from the one described in section 5.5.2. The vessels are however conservatively (with regard to ship-ship collision) assumed to be in the same area as the leisure traffic discussed above.

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[1] The traffic from route 2b could be used as well

7 IMPACT ASSESMENT DURING INSTALLATION PHASE

The present report focuses on the operation phase. Key parameters necessary for performing a thorough risk assessment of the installation phase (installation technique, type of installation vessels and transport route of components from onshore fabrication facility to the offshore site etc) will be chosen by the contractor. Hence the risk assessment for the installation phase cannot be carried out before the necessary decisions have been taken by the appointed contractor. The risk assessment would normally be part of the scope of work for the appointed contractor. Furthermore the choice of foundation type for the turbines and the amount of turbines to be installed (80 3MW or 40 8MW) will also influence the duration of the installation and hence also the risk assessment. It is assumed that a “safety zone” will be laid out during the installation work in order to protect the installation vessels, the personnel and the installed assets from collision with incoming vessels.

8 IMPACT ASSESMENT DURING OPERATION

8.1 Hazard identification

In the HAZID report DNV GL [2014] hazards for the operation phase have been identified. The majority of the identified hazards relate to the risk that:

- Ships in the area will collide with a turbine
- Ships colliding with each other due to the potential increased traffic density caused by the wind farm and narrowing of routes.
- Ship groundings at shallower waters due to changed traffic pattern.

8.2 Collision and grounding frequencies

8.2.1 Ship-turbine collision

The ship-turbine collision frequencies are calculated for the two scenarios below:

- Collision from drifting vessels
- Collision from powered vessels

The frequency results are derived based on the worst case scenario defined in section 4.2 which is evaluated to constitute the largest risk of ship collision. The ship routes and traffic are as defined in section 6 and reflects the presence of of the Omø Syd Offshore Wind Farm. It is noted that the calculated collision frequencies cover all cases of collision, i.e. both minor collisions as well as severe collisions where repair of ship is needed.

The accumulated results are presented in table 8.1

	Powered collision	Drifting collision	Sum
All routes & all vesseltypes	1290 years	5199 years	1033 years

Table 8.1: Collision return period in years

From table 8.1 it is seen that the total return period for collisions is estimated to 1033 years without any risk reducing measures implemented. The cumulative collision frequencies for powered and drifting vessels distributed on ship routes are shown in figure 8.1.

This is under the assumption that the traffic will relocate to avoid passing through the wind farm as discussed in section 6.

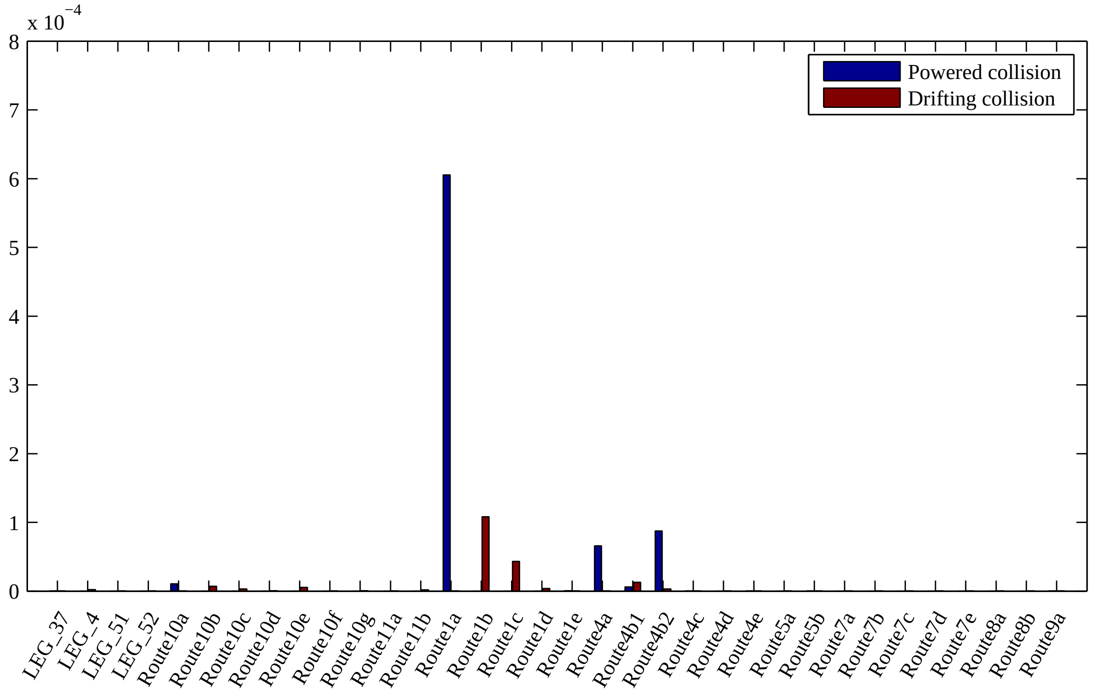

Figure 8.1: Collision frequencies for powered and drifting vessels distributed on ship routes

8.2.2 Ship-ship collision and grounding

In order to evaluate the change in navigational risk in the area a before and after scenario has been established as discussed in section 4.3. The accumulated results are presented in table 8.2.

	Grounding incidents	Ship-ship collision incidents
Before	41.88 years	18.51 years
After	40.33 years	18.00 years

Table 8.2: Impact on navigational risk due to presence of wind farm. Return period in years.

Detailed results distributed on ship routes are shown in appendix F.

8.3 Total impact

From the hazard identification process, refer section 8.1, it is determined that the main risk is posed by ship-turbine collision, ship-ship and grounding incidents.

This risk is evaluated by performing a frequency analysis with results provided in table 8.3.

	Phase	Impact	Comments
Ship-turbine collision	Operation	1033 years	-
Ship-ship collision	Operation	Return period reduced from 41.88 years to 40.33 years	-
Grounding	Operation	Return period reduced from 18.51 years to 18.00 years	-

Table 8.3: Total impact

Based on results shown in table 8.3 it was not deemed necessary to perform a consequence analysis or to perform a detailed evaluation of risk reducing measures. The conclusions from the frequency analysis alone indicate that the occurrence of ship-turbine collisions, ship-ship and grounding incidents will be low and hence the increase in navigational risk due to establishment of theOmø Syd Offshore Wind Farm is acceptable.

9 IMPACT ASSESSMENT DURING DECOMMISSION

Risk of collision during the decommissioning phase has not been evaluated in present report. This should be the responsibility of the appointed contractor taking care of the decommissioning and should not be evaluated in detail before the offshore wind farm is close to the end of the defined service life.

10 MITIGATION MEASURES

It is not found necessary to implement mitigation measures in addition to the usual precautions that by default are required for offshore installations, refer conclusion in section 8.3. These default requirements include that; turbine foundations must be painted yellow, turbine foundations must have identification signs that are illuminated, and the offshore wind farm must have light marking. These measures have already been taken into account in the risk assessment since the risk calculation models have been calibrated against observed collisions and these have happened under usual conditions and thus under the precautions normally required. Additional mitigation measures are as previously stated not included in the risk assessment.

11 CONCLUSION

The impact of the Omø Syd Offshore Wind Farm on the navigational risk is evaluated based on hazards identified in a HAZID and a subsequent calculation of collision frequencies. The risk assessment is performed on this basis.

In the HAZID report DNV GL [2014] the majority of identified hazards for the operation phase relate to the risk that ships in the area will collide with a turbine. Also the risk of two ships colliding with each other was identified.

A frequency analysis is performed to evaluate the likelihood of ship-turbine collision. An offshore wind farm layout consisting of 80 turbines of 3MW distributed over the entire offshore wind farm area is used as worst-case scenario for the assessment. The ship traffic is established based on AIS data and routes have been adjusted where necessary to reflect the reaction of the ship traffic to the presence of the offshore wind farm.

The frequency analysis gives a return period for ship-wind turbine collisions of 1290 years for powered collisions (i.e., typical human error), and 5199 years for drifting collisions (i.e., typical technical errors). The combined return period for powered and drifting collision is thus estimated to 1033 years.

The change in ship-ship collision risk and the increase of grounding incidents has been found to be insignificant.

Based on these evaluations it is not deemed necessary to perform a consequence analysis (Step 2) or to perform a detailed evaluation of risk reducing measures (Step 3). The conclusions from the frequency analysis alone (Step 1) indicate that the occurrence of ship-turbine collisions will be low and hence the increase in navigational risk due to establishment of the Omø Syd Offshore Wind Farm is acceptable.

The impact on the navigational risk during the installation and decommissioning phases has not been evaluated since too many parameters are unknown. The risk assessment for the installation and decommissioning would normally be part of the scope of work for the appointed contractor.

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A Navigational chart

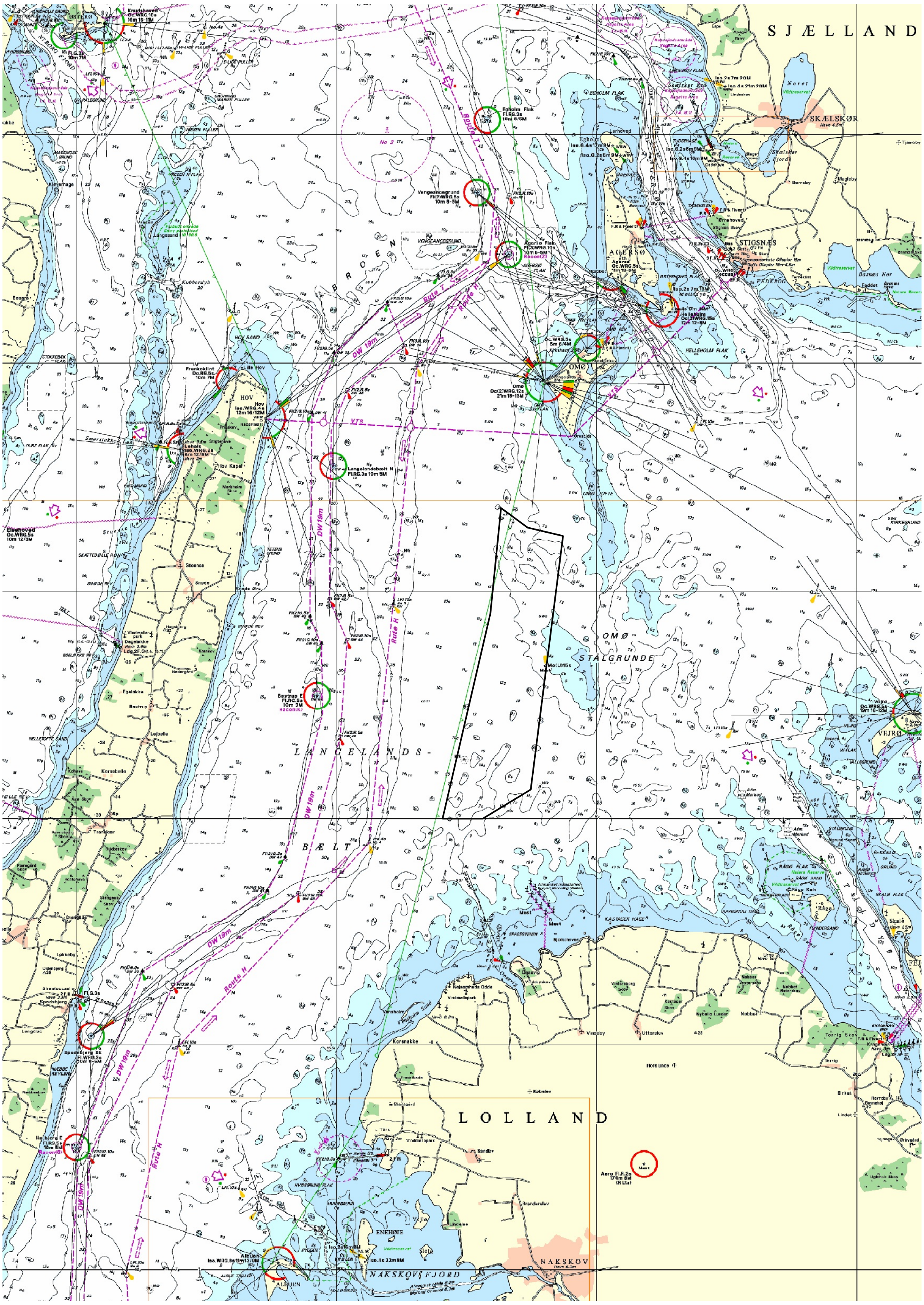


Figure A.1

B Probabilistic model assumptions

Already in 1974 Fujii and Mizuki [1974] and also MacDuff [1974] initiated more systematic and risk based approaches for grounding and collision analysis. MacDuff studied grounding and collision accidents in the Dover Strait and calculated a theoretical probability of the both the grounding and the collision event. This probability was calculated by assuming all vessels to be randomly distributed in the navigational channel. MacDuff denoted the thus obtained probability the geometric probability, since this probability was entirely based on a geometric distribution of ships that were "navigating blind". By comparing to the observed number of grounding and collision it was found that the geometric probability predicted too many events and a correction factor P_c was introduced to account for the difference. The correction factor was denoted the causation probability and it models the vessels and the officer of the watch's ability to perform evasive manoeuvres in the event of potential critical situation.

Using an approach similar to MacDuff [1974], Fujii and Mizuki [1974] introduced a probability of mismanoeuvres on the basis of grounding statistics for several Japanese straits. For the considered straits the probability was found to be in the range from 0.6E-4 to 1E-3.

The IWRAP default values for human failure which been applied are shown in table B.1. The values are mainly rooted in the observations Fujii and Mizuki [1998].

Assumed machine failure relevant are reflected in table B.1 as well

Human failure relevant parameters

Ship-ship collision incidents	Causation factors
Merging	1.3E-4
Crossing	1.3E-4
Bend	1.3E-4
Headon	0.5E-4
Overtaking	1.1E-4
Area moving	0.5E-4
Area stationary	0.5E-4
Ship grounding incidents	
Grounding - forget to turn	1.6E-4
Ship-turbine collision incidents	
Collision - forget to turn	1.6E-4
Ship type specific reductions	Causation reduction factors
Passenger ships	20
Fast ferries	20

Machine failure relevant parameters

Drift speed	1 knot(s)
Probability of successful anchoring	0.98
Probability of self-repair	$p(t) = \begin{cases} 0 & t \leq 0.25 \\ \frac{1}{1.5(t-0.25)+1} & t > 0.25 \end{cases}$
Blackout frequencies	
RoRo and passenger ships	0,1 per year
Other vessels	1,75 per year

Probabilty of drift direction

N	NE	E	SE	S	SW	W	NW
9.1%	18.2%	18.2%	18.2%	9.1%	9.1%	9.1%	9.1%

Table B.1

C Turbine coordinates

C.1 Turbine coordinates 3MW

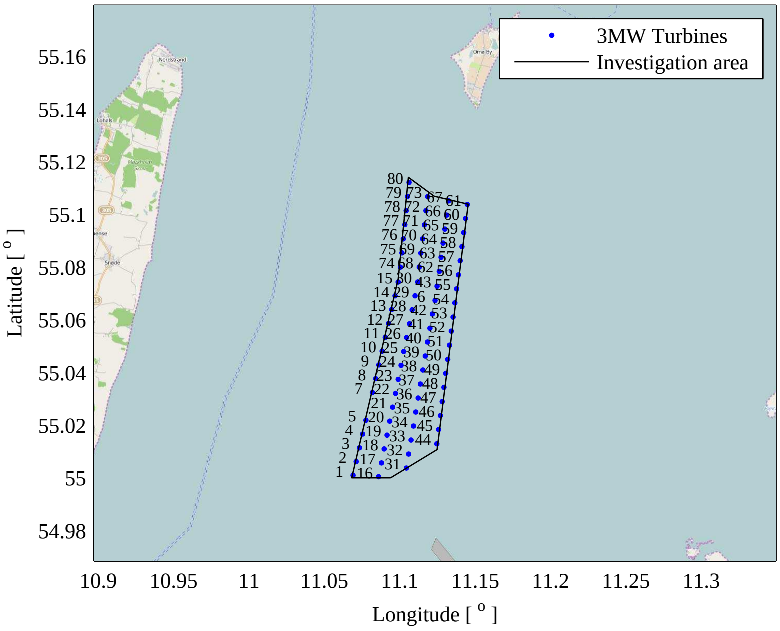


Figure C.1: 3MW turbine layout

	Longitude [°]	Latitude [°]
1	55.0009	11.0690
2	55.0061	11.0711
3	55.0114	11.0733
4	55.0166	11.0754
5	55.0219	11.0775
6	55.0673	11.1234
7	55.0324	11.0818
8	55.0376	11.0840
9	55.0429	11.0861
10	55.0481	11.0882
11	55.0533	11.0904
12	55.0586	11.0925
13	55.0638	11.0947
14	55.0691	11.0968
15	55.0743	11.0990
16	55.0004	11.0860
17	55.0056	11.0878
18	55.0109	11.0897
19	55.0162	11.0915
20	55.0215	11.0934
21	55.0268	11.0952
22	55.0321	11.0971
23	55.0373	11.0989
24	55.0426	11.1008
25	55.0479	11.1027
26	55.0532	11.1045

27	55.0585	11.1064
28	55.0638	11.1082
29	55.0691	11.1101
30	55.0743	11.1120
31	55.0037	11.1043
32	55.0090	11.1059
33	55.0143	11.1075
34	55.0196	11.1090
35	55.0249	11.1106
36	55.0302	11.1122
37	55.0356	11.1137
38	55.0409	11.1153
39	55.0462	11.1169
40	55.0515	11.1184
41	55.0568	11.1200
42	55.0621	11.1216
43	55.0728	11.1247
44	55.0129	11.1246
45	55.0182	11.1258
46	55.0236	11.1270
47	55.0289	11.1282
48	55.0343	11.1293
49	55.0396	11.1305
50	55.0450	11.1317
51	55.0503	11.1329
52	55.0557	11.1341
53	55.0610	11.1353
54	55.0664	11.1365
55	55.0717	11.1377
56	55.0771	11.1389
57	55.0824	11.1401
58	55.0878	11.1413
59	55.0931	11.1424
60	55.0984	11.1436
61	55.1038	11.1448
62	55.0784	11.1262
63	55.0837	11.1274
64	55.0891	11.1286
65	55.0944	11.1299
66	55.0998	11.1311
67	55.1051	11.1323
68	55.0800	11.1129
69	55.0853	11.1140
70	55.0907	11.1151
71	55.0960	11.1162
72	55.1014	11.1173
73	55.1067	11.1185
74	55.0800	11.1004
75	55.0854	11.1014
76	55.0907	11.1023
77	55.0961	11.1033
78	55.1014	11.1042
79	55.1068	11.1052
80	55.1122	11.1061

C.2 Turbine coordinates 8MW

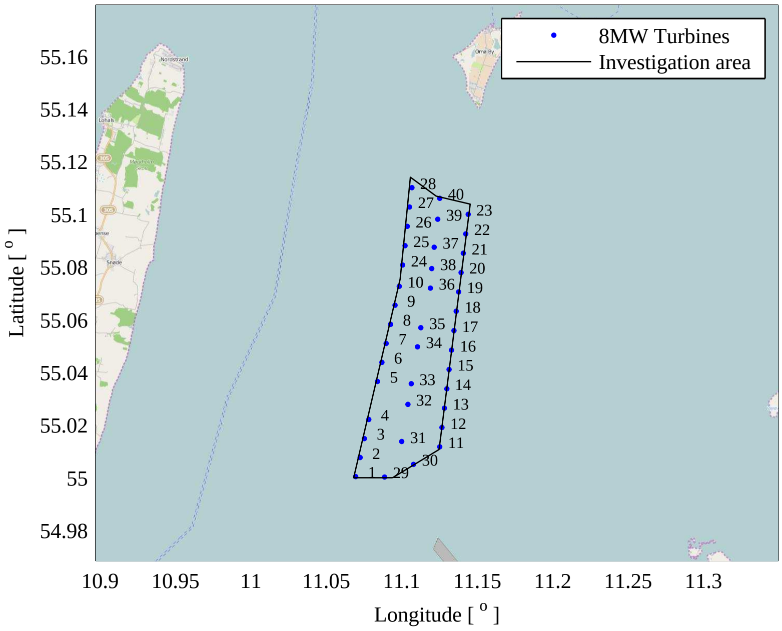


Figure C.2: 8MW turbine layout

	Longitude [°]	Latitude [°]
1	55.0004	11.0694
2	55.0076	11.0723
3	55.0149	11.0752
4	55.0221	11.0781
5	55.0365	11.0839
6	55.0438	11.0868
7	55.0510	11.0897
8	55.0582	11.0926
9	55.0654	11.0955
10	55.0726	11.0984
11	55.0117	11.1251
12	55.0190	11.1267
13	55.0264	11.1282
14	55.0337	11.1298
15	55.0411	11.1314
16	55.0484	11.1330
17	55.0558	11.1345
18	55.0632	11.1361
19	55.0705	11.1377
20	55.0779	11.1392
21	55.0852	11.1408
22	55.0926	11.1424
23	55.0999	11.1440
24	55.0807	11.1006
25	55.0881	11.1021
26	55.0954	11.1036
27	55.1028	11.1052
28	55.1101	11.1067

29	55.0002	11.0886
30	55.0051	11.1078
31	55.0137	11.0999
32	55.0278	11.1040
33	55.0357	11.1062
34	55.0497	11.1105
35	55.0570	11.1127
36	55.0720	11.1190
37	55.0875	11.1215
38	55.0794	11.1199
39	55.0982	11.1238
40	55.1061	11.1251

D Waypoint coordinates and route definitions

D.1 Before scenario

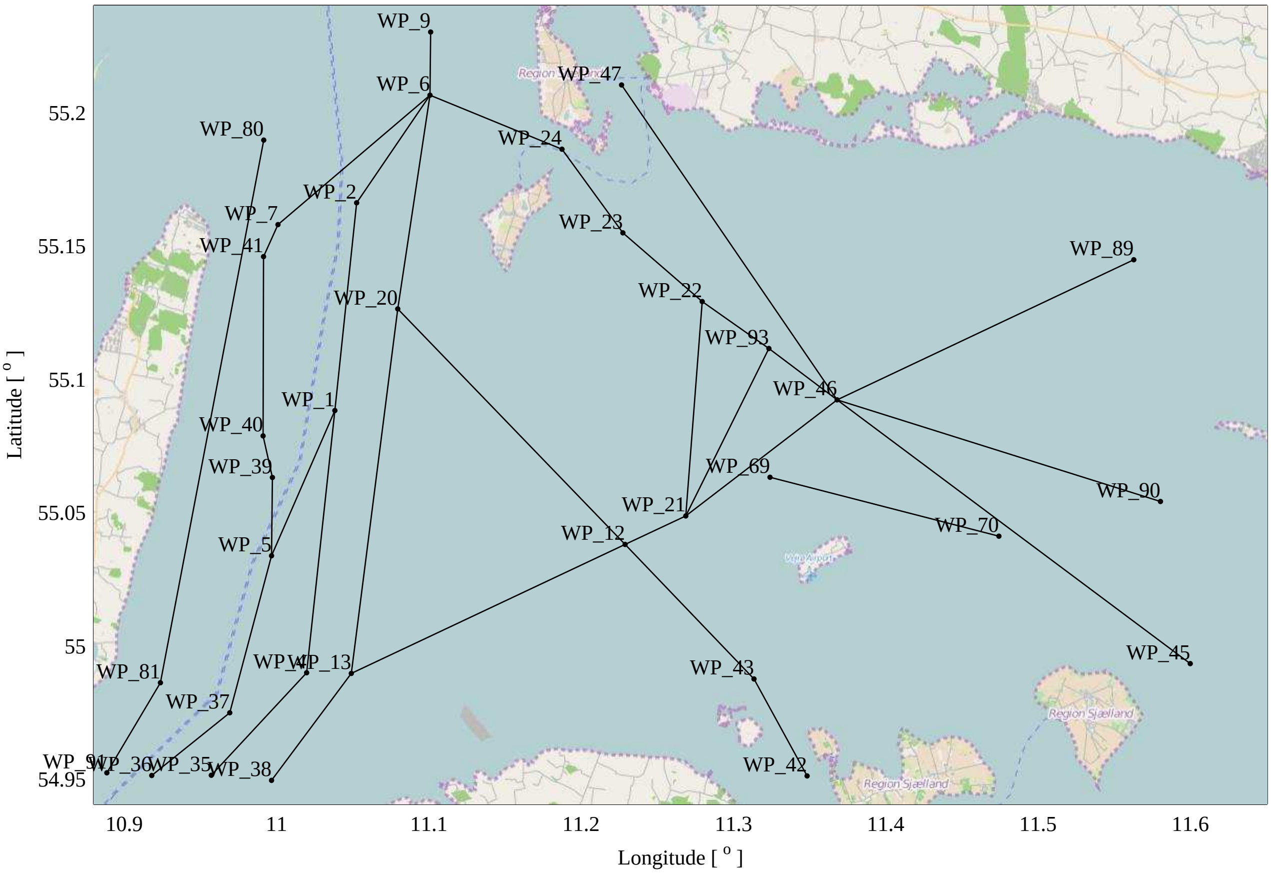


Figure D.1: Waypoints

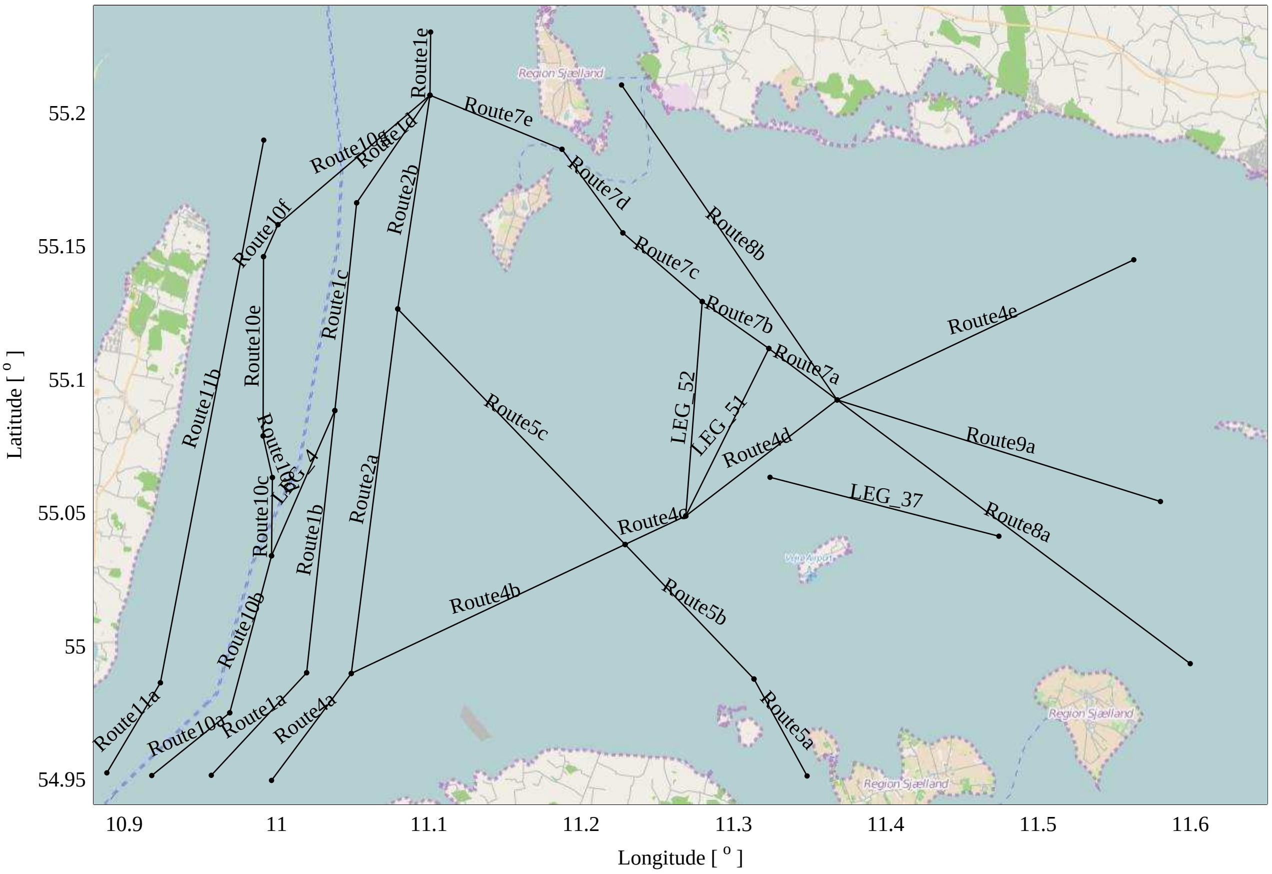


Figure D.2: Routes

	Longitude [°]	Latitude [°]
WP_1	55.0881472	11.038339
WP_2	55.1660533	11.0526576
WP_4	54.9898	11.0198167
WP_6	55.206399	11.1006941
WP_5	55.0336548	10.996769
WP_7	55.1578737	11.000926
WP_9	55.2301127	11.1011559
WP_12	55.0379806	11.2288539
WP_13	54.9895667	11.04905
WP_20	55.1262547	11.079555
WP_21	55.0486157	11.2686473
WP_22	55.1289886	11.279538
WP_23	55.1547424	11.227328
WP_24	55.1861583	11.1873912
WP_35	54.9513513	10.9571609
WP_36	54.9512897	10.9180328
WP_37	54.9747744	10.9692954
WP_38	54.949498	10.9966633
WP_39	55.0630107	10.9972805
WP_40	55.078611	10.991098
WP_41	55.1458232	10.991379
WP_42	54.951153	11.3482783
WP_43	54.9875167	11.3134765
WP_45	54.9932043	11.599961

WP_46	55.0921238	11.3680125
WP_47	55.2102258	11.2265009
WP_69	55.0631269	11.3240006
WP_70	55.0410227	11.4742648
WP_80	55.1895869	10.9915845
WP_81	54.9861047	10.9237048
WP_89	55.1446472	11.5628851
WP_90	55.0540109	11.5803875
WP_91	54.9522651	10.8885879
WP_93	55.1113778	11.3231837

D.2 After scenario

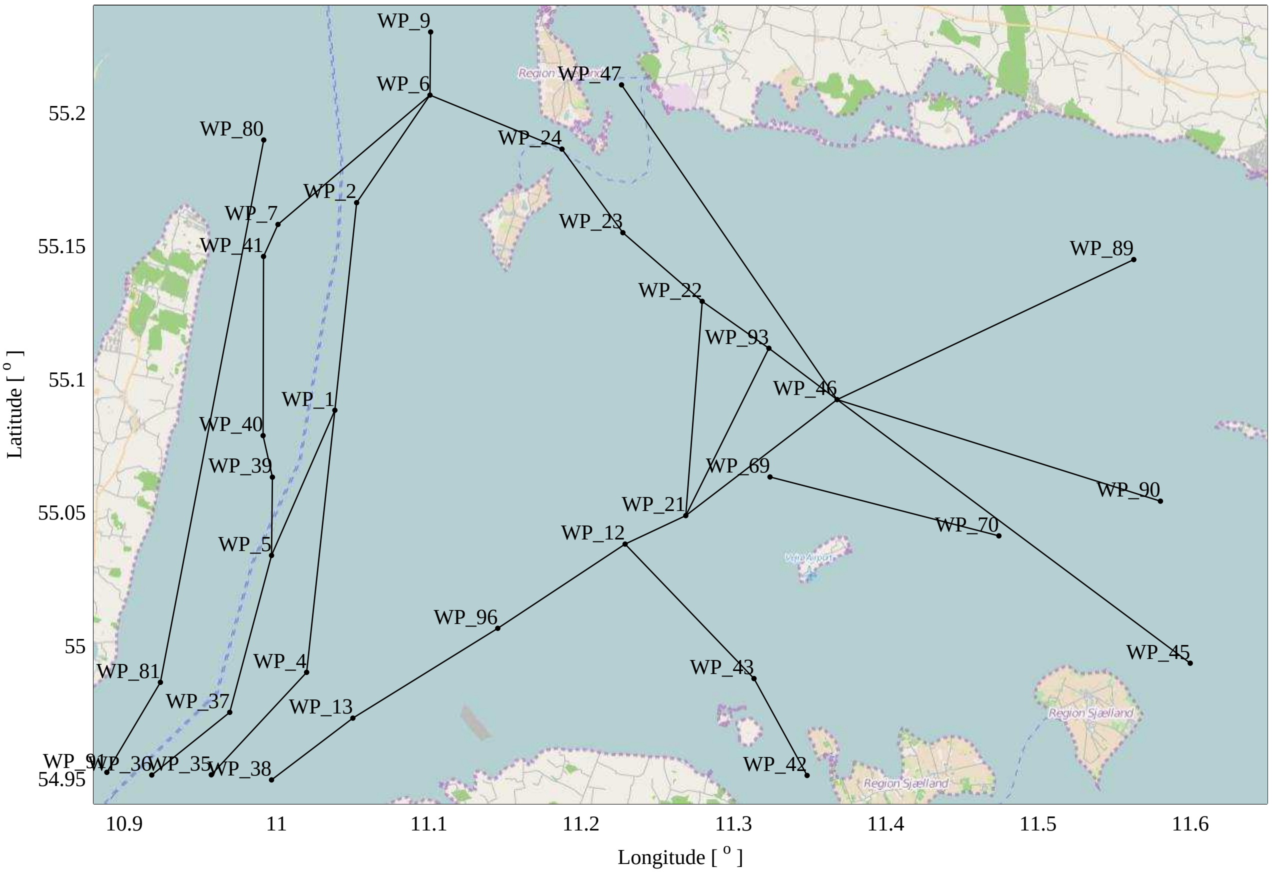


Figure D.3: Waypoints

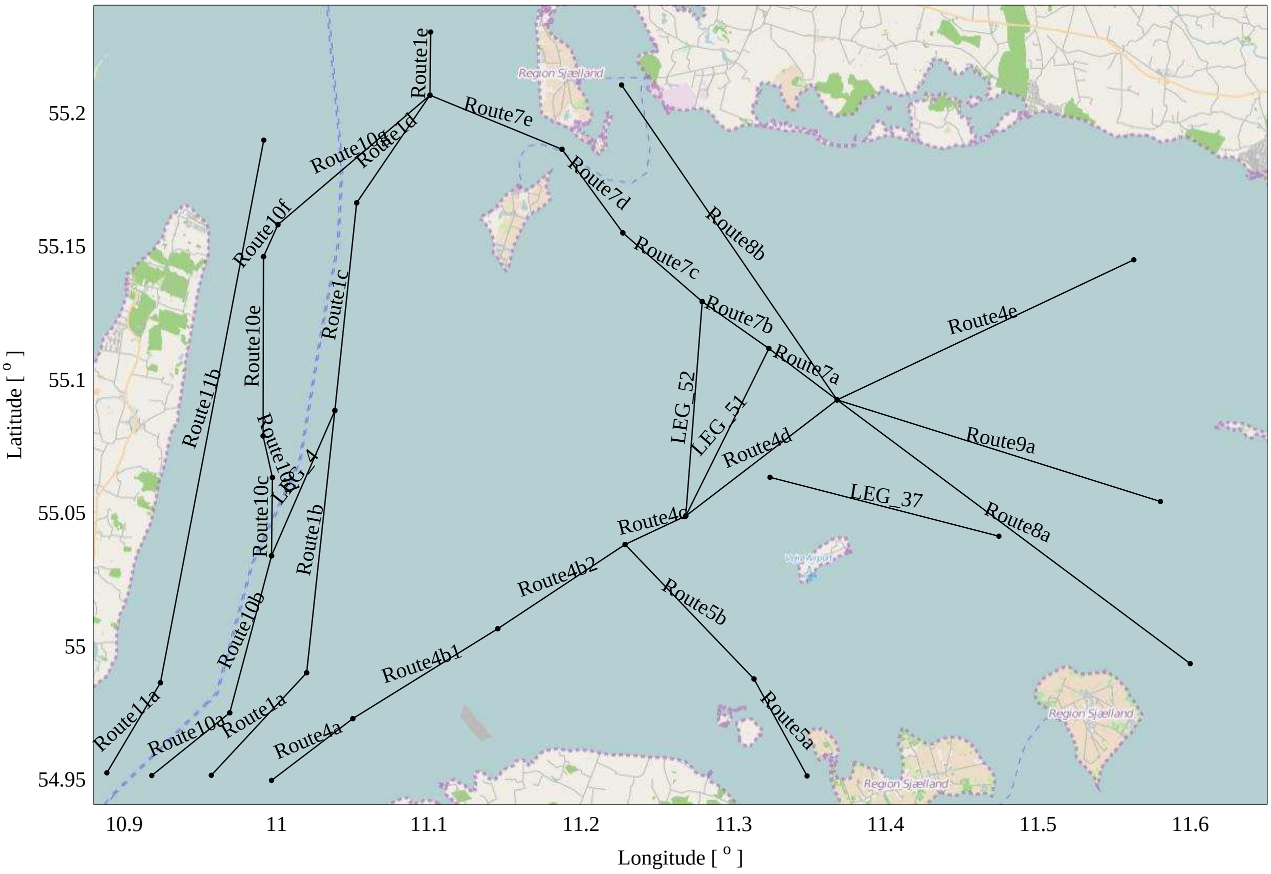


Figure D.4: Routes

	Longitude [°]	Latitude [°]
WP_1	55.0881472	11.038339
WP_2	55.1660533	11.0526576
WP_5	55.0336548	10.996769
WP_7	55.1578737	11.000926
WP_9	55.2301127	11.1011559
WP_12	55.0379806	11.2288539
WP_13	54.9726127	11.0501022
WP_21	55.0486157	11.2686473
WP_22	55.1289886	11.279538
WP_23	55.1547424	11.227328
WP_24	55.1861583	11.1873912
WP_35	54.9513513	10.9571609
WP_36	54.9512897	10.9180328
WP_37	54.9747744	10.9692954
WP_38	54.949498	10.9966633
WP_39	55.0630107	10.9972805
WP_40	55.078611	10.991098
WP_41	55.1458232	10.991379
WP_42	54.951153	11.3482783
WP_43	54.9875167	11.3134765
WP_45	54.9932043	11.599961
WP_46	55.0921238	11.3680125
WP_47	55.2102258	11.2265009
WP_69	55.0631269	11.3240006

WP_70	55.0410227	11.4742648
WP_80	55.1895869	10.9915845
WP_81	54.9861047	10.9237048
WP_89	55.1446472	11.5628851
WP_90	55.0540109	11.5803875
WP_91	54.9522651	10.8885879
WP_93	55.1113778	11.3231837
WP_96	55.0063203	11.1452294
WP_4	54.9898	11.0198167
WP_6	55.2063833	11.1006833

E Traffic on routes

E.1 Before scenario

Traffic distribution

	FishingShip	OilProducts	CargoShip	PassengerShip	PleasureBoat	SupportShip	OtherShip	Sum
LEG_37	0	2	66	0	1	19	17	105
LEG_4	0	178	135	401	0	0	0	714
LEG_51	0	0	19	0	0	9	0	28
LEG_52	0	0	7	0	0	30	5	42
Route10a	3	172	612	572	0	2	21	1382
Route10b	0	1985	1648	592	0	0	72	4297
Route10c	0	1709	1419	37	0	0	63	3228
Route10d	4	1701	1410	35	0	0	64	3214
Route10e	6	1710	1428	37	1	10	74	3266
Route10f	10	1703	1397	36	0	10	63	3219
Route10g	29	111	551	35	0	1	31	758
Route11a	6	2	25	0	6	14	6	59
Route11b	1	5	37	0	3	22	7	75
Route1a	2	1078	2587	160	11	147	159	4144
Route1b	2	1180	2701	218	11	112	175	4399
Route1c	11	1458	2890	773	12	124	178	5446
Route1d	6	1390	2787	756	11	106	177	5233
Route1e	90	3124	4548	805	18	150	306	9041
Route2a	6	23	199	0	7	29	21	285
Route2b	0	28	296	0	6	38	31	399
Route4a	1	14	330	1	4	45	46	441
Route4b	0	2	117	1	3	29	23	175
Route4c	0	1	80	0	2	19	21	123
Route4d	0	0	40	0	0	1	11	52
Route4e	0	0	24	0	0	0	5	29
Route5a	0	0	43	0	2	30	4	79
Route5b	0	0	38	0	0	25	1	64
Route5c	0	0	12	0	0	5	1	18
Route7a	6	14	121	0	2	27	37	207
Route7b	5	5	77	0	1	31	22	141
Route7c	2	5	77	0	0	29	24	137
Route7d	4	5	93	2	3	65	82	254
Route7e	3	5	52	0	1	36	32	129
Route8a	0	31	123	0	1	5	14	174
Route8b	4	23	144	0	0	17	38	226
Route9a	8	0	87	0	1	41	44	181

Table E.1: Northbound traffic

Traffic distribution

	FishingShip	OilProducts	CargoShip	PassengerShip	PleasureBoat	SupportShip	OtherShip	Sum
LEG_37	0	0	81	0	0	12	19	112
LEG_4	0	78	87	496	0	2	0	663
LEG_51	0	0	46	0	0	9	1	56
LEG_52	0	0	11	0	0	17	0	28
Route10a	6	2124	1758	647	0	0	74	4609
Route10b	0	300	786	563	4	20	47	1720
Route10c	0	123	590	43	1	4	27	788
Route10d	0	110	555	34	0	2	27	728
Route10e	11	110	556	34	1	6	33	751
Route10f	35	107	538	33	5	9	31	758
Route10g	13	1717	1420	46	0	1	62	3259
Route11a	3	2	38	0	10	26	22	101
Route11b	3	4	53	0	11	29	24	124
Route1a	15	1467	2617	159	15	84	176	4533
Route1b	16	1495	2597	221	14	74	174	4591
Route1c	15	1581	2720	743	17	81	186	5343
Route1d	14	1508	2534	734	12	69	176	5047
Route1e	108	1644	3173	781	13	90	218	6027
Route2a	0	0	13	0	1	5	5	24
Route2b	0	0	19	0	0	9	5	33
Route4a	5	0	62	0	1	29	15	112
Route4b	0	4	118	0	0	49	27	198
Route4c	0	2	86	0	1	13	23	125
Route4d	0	1	21	0	0	1	7	30
Route4e	0	0	21	0	0	0	6	27
Route5a	0	0	42	0	1	33	3	79
Route5b	0	0	47	0	1	32	3	83
Route5c	0	0	11	0	1	7	1	20
Route7a	5	9	133	0	1	33	27	208
Route7b	3	0	66	0	2	33	21	125
Route7c	3	0	67	0	4	34	18	126
Route7d	5	0	88	0	7	76	37	213
Route7e	6	0	55	0	1	46	13	121
Route8a	0	29	93	0	0	1	6	129
Route8b	1	22	142	0	0	29	34	228
Route9a	7	0	99	0	1	52	41	200

Table E.2: Southbound traffic

E.2 After scenario

Traffic distribution

	FishingShip	OilProducts	CargoShip	PassengerShip	PleasureBoat	SupportShip	OtherShip	Sum
LEG_37	0	2	66	0	1	19	17	105
LEG_4	0	178	135	401	0	0	0	714
LEG_51	0	0	19	0	0	9	0	28
LEG_52	0	0	19	0	0	35	6	60
Route10a	3	172	612	572	0	2	21	1382
Route10b	0	1985	1648	592	0	0	72	4297
Route10c	0	1709	1419	37	0	0	63	3228
Route10d	4	1701	1410	35	0	0	64	3214
Route10e	6	1710	1428	37	1	10	74	3266
Route10f	10	1703	1397	36	0	10	63	3219
Route10g	29	111	551	35	0	1	31	758
Route11a	6	2	25	0	6	14	6	59
Route11b	1	5	37	0	3	22	7	75
Route1a	2	1078	2587	160	11	147	159	4144
Route1b	8	1203	2900	218	18	141	196	4684
Route1c	17	1481	3089	773	19	153	199	5731
Route1d	12	1413	2986	756	18	135	198	5518
Route1e	90	3124	4548	805	18	150	306	9041
Route4a	5	0	62	0	1	29	15	112
Route4b1	0	2	117	1	3	29	23	175
Route4b2	0	2	117	1	3	29	23	175
Route4c	0	1	91	0	3	26	22	143
Route4d	0	0	40	0	0	1	11	52
Route4e	0	0	24	0	0	0	5	29
Route5a	0	0	43	0	2	30	4	79
Route5b	0	0	38	0	0	25	1	64
Route7a	6	14	121	0	2	27	37	207
Route7b	5	5	77	0	1	31	22	141
Route7c	2	5	89	0	0	34	25	155
Route7d	4	5	105	2	3	70	83	272
Route7e	3	5	64	0	1	41	33	147
Route8a	0	31	123	0	1	5	14	174
Route8b	4	23	144	0	0	17	38	226
Route9a	8	0	87	0	1	41	44	181

Table E.3: Northbound traffic

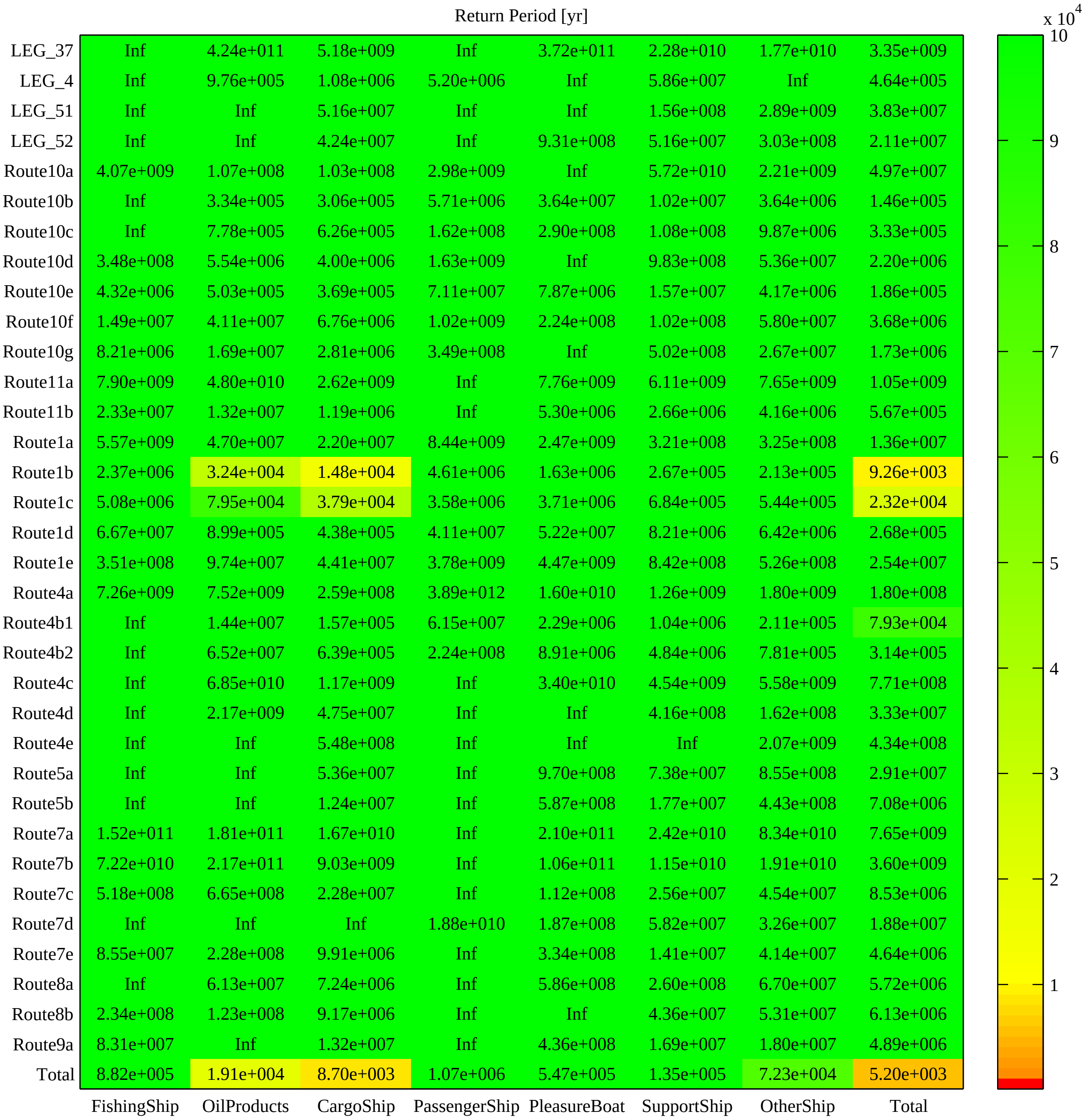
Traffic distribution

	FishingShip	OilProducts	CargoShip	PassengerShip	PleasureBoat	SupportShip	OtherShip	Sum
LEG_37	0	0	81	0	0	12	19	112
LEG_4	0	78	87	496	0	2	0	663
LEG_51	0	0	46	0	0	9	1	56
LEG_52	0	0	22	0	1	24	1	48
Route10a	6	2124	1758	647	0	0	74	4609
Route10b	0	300	786	563	4	20	47	1720
Route10c	0	123	590	43	1	4	27	788
Route10d	0	110	555	34	0	2	27	728
Route10e	11	110	556	34	1	6	33	751
Route10f	35	107	538	33	5	9	31	758
Route10g	13	1717	1420	46	0	1	62	3259
Route11a	3	2	38	0	10	26	22	101
Route11b	3	4	53	0	11	29	24	124
Route1a	15	1467	2617	159	15	84	176	4533
Route1b	16	1495	2610	221	15	79	179	4615
Route1c	15	1581	2733	743	18	86	191	5367
Route1d	14	1508	2547	734	13	74	181	5071
Route1e	108	1644	3173	781	13	90	218	6027
Route4a	1	14	330	1	4	45	46	441
Route4b1	0	4	118	0	0	49	27	198
Route4b2	0	4	118	0	0	49	27	198
Route4c	0	2	98	0	1	18	24	143
Route4d	0	1	21	0	0	1	7	30
Route4e	0	0	21	0	0	0	6	27
Route5a	0	0	42	0	1	33	3	79
Route5b	0	0	47	0	1	32	3	83
Route7a	5	9	133	0	1	33	27	208
Route7b	3	0	66	0	2	33	21	125
Route7c	3	0	78	0	5	41	19	146
Route7d	5	0	99	0	8	83	38	233
Route7e	6	0	66	0	2	53	14	141
Route8a	0	29	93	0	0	1	6	129
Route8b	1	22	142	0	0	29	34	228
Route9a	7	0	99	0	1	52	41	200

Table E.4: Southbound traffic

F Results from frequency analysis

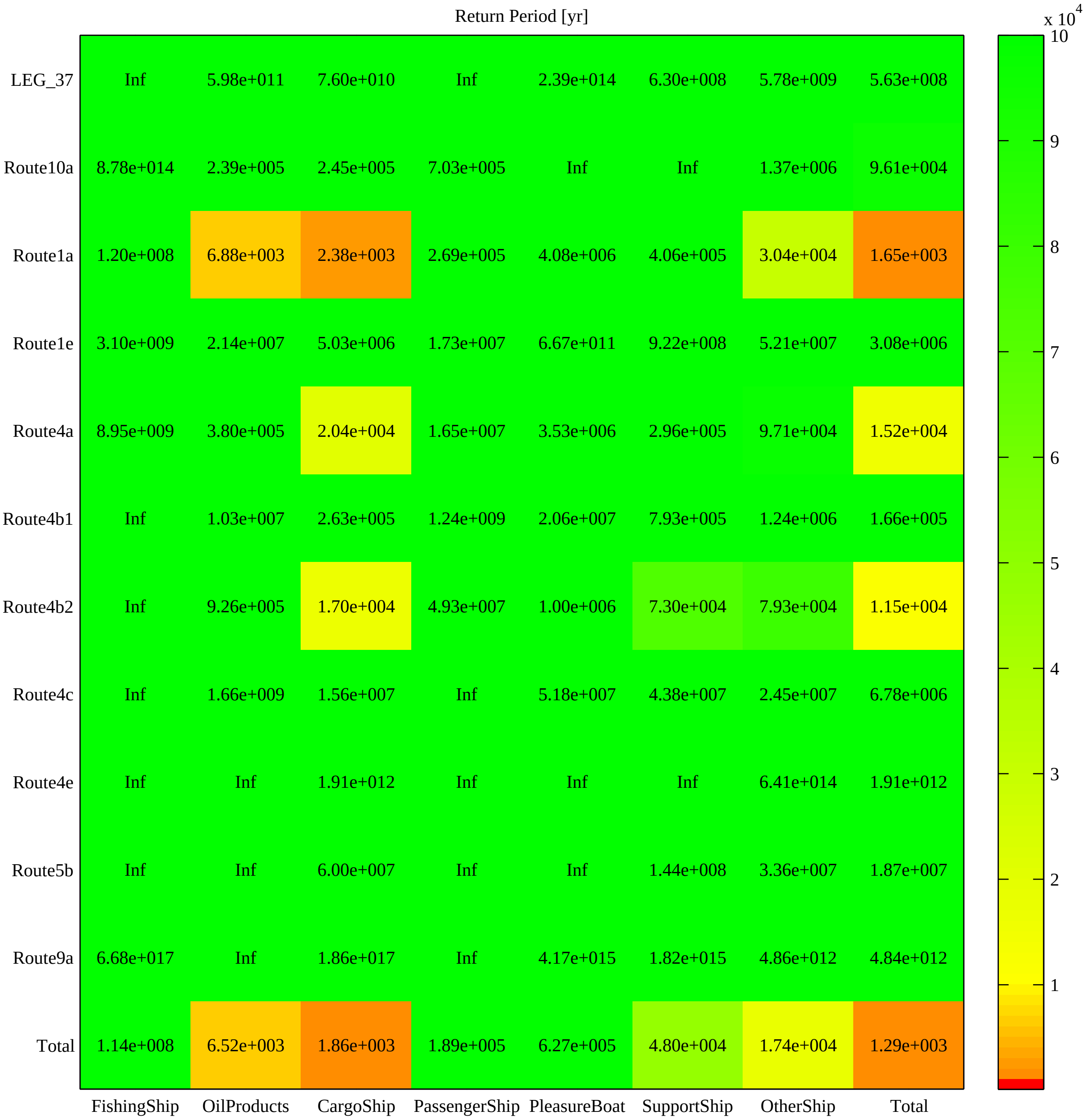
F.1 Ship-turbine collisions



Return Period [yr]

	FishingShip	OilProducts	CargoShip	PassengerShip	PleasureBoat	SupportShip	OtherShip	Total
LEG_37	Inf	4.24e+011	5.18e+009	Inf	3.72e+011	2.28e+010	1.77e+010	3.35e+009
LEG_4	Inf	9.76e+005	1.08e+006	5.20e+006	Inf	5.86e+007	Inf	4.64e+005
LEG_51	Inf	Inf	5.16e+007	Inf	Inf	1.56e+008	2.89e+009	3.83e+007
LEG_52	Inf	Inf	4.24e+007	Inf	9.31e+008	5.16e+007	3.03e+008	2.11e+007
Route10a	4.07e+009	1.07e+008	1.03e+008	2.98e+009	Inf	5.72e+010	2.21e+009	4.97e+007
Route10b	Inf	3.34e+005	3.06e+005	5.71e+006	3.64e+007	1.02e+007	3.64e+006	1.46e+005
Route10c	Inf	7.78e+005	6.26e+005	1.62e+008	2.90e+008	1.08e+008	9.87e+006	3.33e+005
Route10d	3.48e+008	5.54e+006	4.00e+006	1.63e+009	Inf	9.83e+008	5.36e+007	2.20e+006
Route10e	4.32e+006	5.03e+005	3.69e+005	7.11e+007	7.87e+006	1.57e+007	4.17e+006	1.86e+005
Route10f	1.49e+007	4.11e+007	6.76e+006	1.02e+009	2.24e+008	1.02e+008	5.80e+007	3.68e+006
Route10g	8.21e+006	1.69e+007	2.81e+006	3.49e+008	Inf	5.02e+008	2.67e+007	1.73e+006
Route11a	7.90e+009	4.80e+010	2.62e+009	Inf	7.76e+009	6.11e+009	7.65e+009	1.05e+009
Route11b	2.33e+007	1.32e+007	1.19e+006	Inf	5.30e+006	2.66e+006	4.16e+006	5.67e+005
Route1a	5.57e+009	4.70e+007	2.20e+007	8.44e+009	2.47e+009	3.21e+008	3.25e+008	1.36e+007
Route1b	2.37e+006	3.24e+004	1.48e+004	4.61e+006	1.63e+006	2.67e+005	2.13e+005	9.26e+003
Route1c	5.08e+006	7.95e+004	3.79e+004	3.58e+006	3.71e+006	6.84e+005	5.44e+005	2.32e+004
Route1d	6.67e+007	8.99e+005	4.38e+005	4.11e+007	5.22e+007	8.21e+006	6.42e+006	2.68e+005
Route1e	3.51e+008	9.74e+007	4.41e+007	3.78e+009	4.47e+009	8.42e+008	5.26e+008	2.54e+007
Route4a	7.26e+009	7.52e+009	2.59e+008	3.89e+012	1.60e+010	1.26e+009	1.80e+009	1.80e+008
Route4b1	Inf	1.44e+007	1.57e+005	6.15e+007	2.29e+006	1.04e+006	2.11e+005	7.93e+004
Route4b2	Inf	6.52e+007	6.39e+005	2.24e+008	8.91e+006	4.84e+006	7.81e+005	3.14e+005
Route4c	Inf	6.85e+010	1.17e+009	Inf	3.40e+010	4.54e+009	5.58e+009	7.71e+008
Route4d	Inf	2.17e+009	4.75e+007	Inf	Inf	4.16e+008	1.62e+008	3.33e+007
Route4e	Inf	Inf	5.48e+008	Inf	Inf	Inf	2.07e+009	4.34e+008
Route5a	Inf	Inf	5.36e+007	Inf	9.70e+008	7.38e+007	8.55e+008	2.91e+007
Route5b	Inf	Inf	1.24e+007	Inf	5.87e+008	1.77e+007	4.43e+008	7.08e+006
Route7a	1.52e+011	1.81e+011	1.67e+010	Inf	2.10e+011	2.42e+010	8.34e+010	7.65e+009
Route7b	7.22e+010	2.17e+011	9.03e+009	Inf	1.06e+011	1.15e+010	1.91e+010	3.60e+009
Route7c	5.18e+008	6.65e+008	2.28e+007	Inf	1.12e+008	2.56e+007	4.54e+007	8.53e+006
Route7d	Inf	Inf	Inf	1.88e+010	1.87e+008	5.82e+007	3.26e+007	1.88e+007
Route7e	8.55e+007	2.28e+008	9.91e+006	Inf	3.34e+008	1.41e+007	4.14e+007	4.64e+006
Route8a	Inf	6.13e+007	7.24e+006	Inf	5.86e+008	2.60e+008	6.70e+007	5.72e+006
Route8b	2.34e+008	1.23e+008	9.17e+006	Inf	Inf	4.36e+007	5.31e+007	6.13e+006
Route9a	8.31e+007	Inf	1.32e+007	Inf	4.36e+008	1.69e+007	1.80e+007	4.89e+006
Total	8.82e+005	1.91e+004	8.70e+003	1.07e+006	5.47e+005	1.35e+005	7.23e+004	5.20e+003

Figure F.1: Drifting turbine collisions



	FishingShip	OilProducts	CargoShip	PassengerShip	PleasureBoat	SupportShip	OtherShip	Total
LEG_37	Inf	5.98e+011	7.60e+010	Inf	2.39e+014	6.30e+008	5.78e+009	5.63e+008
Route10a	8.78e+014	2.39e+005	2.45e+005	7.03e+005	Inf	Inf	1.37e+006	9.61e+004
Route1a	1.20e+008	6.88e+003	2.38e+003	2.69e+005	4.08e+006	4.06e+005	3.04e+004	1.65e+003
Route1e	3.10e+009	2.14e+007	5.03e+006	1.73e+007	6.67e+011	9.22e+008	5.21e+007	3.08e+006
Route4a	8.95e+009	3.80e+005	2.04e+004	1.65e+007	3.53e+006	2.96e+005	9.71e+004	1.52e+004
Route4b1	Inf	1.03e+007	2.63e+005	1.24e+009	2.06e+007	7.93e+005	1.24e+006	1.66e+005
Route4b2	Inf	9.26e+005	1.70e+004	4.93e+007	1.00e+006	7.30e+004	7.93e+004	1.15e+004
Route4c	Inf	1.66e+009	1.56e+007	Inf	5.18e+007	4.38e+007	2.45e+007	6.78e+006
Route4e	Inf	Inf	1.91e+012	Inf	Inf	Inf	6.41e+014	1.91e+012
Route5b	Inf	Inf	6.00e+007	Inf	Inf	1.44e+008	3.36e+007	1.87e+007
Route9a	6.68e+017	Inf	1.86e+017	Inf	4.17e+015	1.82e+015	4.86e+012	4.84e+012
Total	1.14e+008	6.52e+003	1.86e+003	1.89e+005	6.27e+005	4.80e+004	1.74e+004	1.29e+003

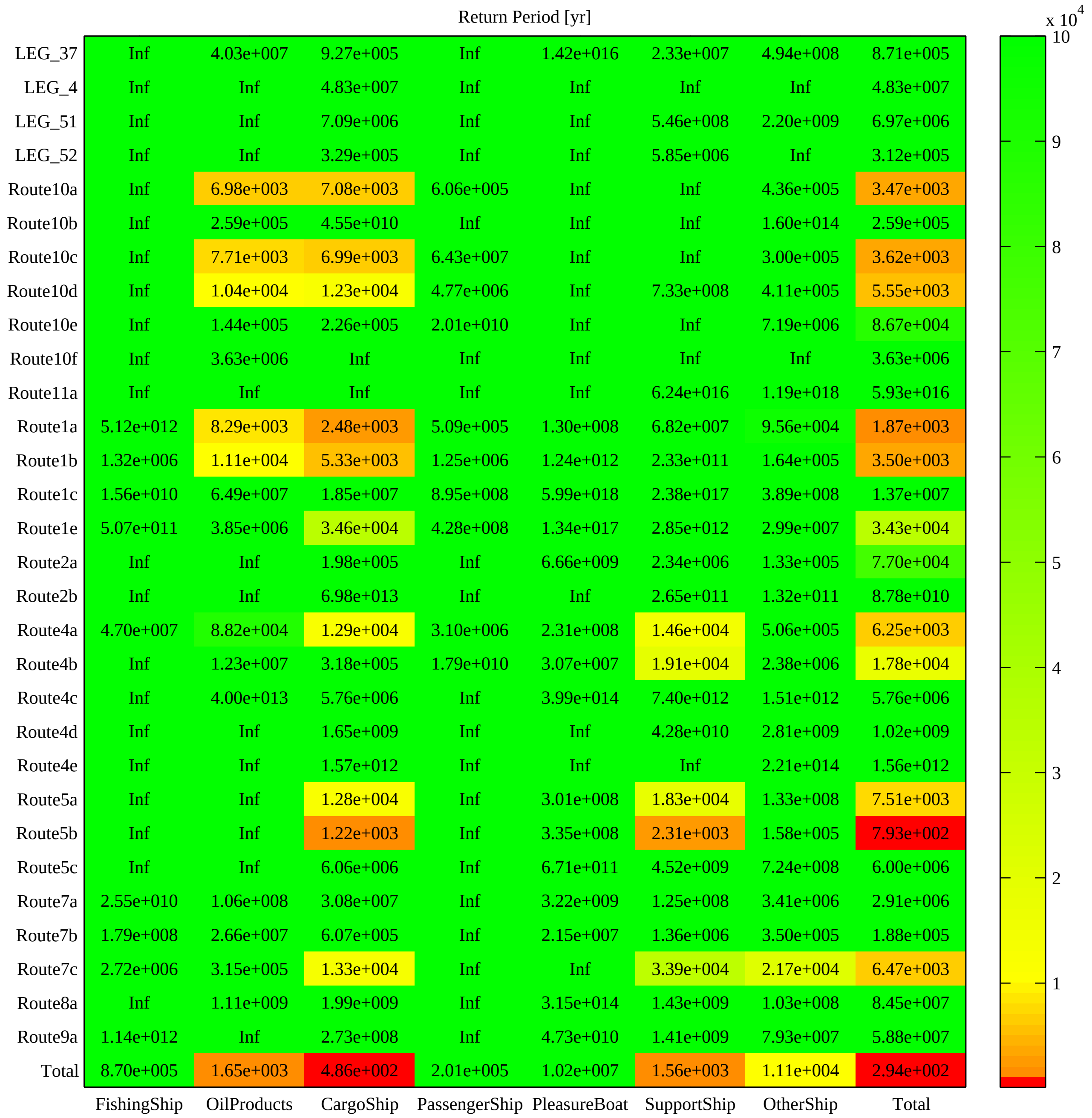
Figure F.2: Powered turbine collisions

F.2 Ship grounding incidents before

Return Period [yr]

	FishingShip	OilProducts	CargoShip	PassengerShip	PleasureBoat	SupportShip	OtherShip	Total
LEG_37	Inf	5.56e+006	5.00e+004	Inf	2.63e+007	1.92e+005	6.01e+004	2.38e+004
LEG_4	Inf	4.17e+004	4.95e+004	4.03e+005	Inf	6.51e+006	Inf	2.13e+004
LEG_51	Inf	Inf	2.73e+005	Inf	Inf	8.25e+005	1.53e+007	2.02e+005
LEG_52	Inf	Inf	9.44e+004	Inf	Inf	3.27e+004	5.17e+005	2.32e+004
Route10a	2.38e+006	1.00e+004	1.00e+004	8.41e+005	Inf	2.98e+007	2.90e+005	4.89e+003
Route10b	Inf	3.35e+003	3.38e+003	3.21e+005	2.50e+006	6.98e+005	9.14e+004	1.64e+003
Route10c	Inf	9.51e+003	9.65e+003	8.97e+006	2.50e+007	9.32e+006	2.44e+005	4.69e+003
Route10d	2.56e+007	2.86e+004	2.92e+004	2.43e+007	Inf	6.71e+006	2.14e+005	1.35e+004
Route10e	4.42e+005	3.19e+002	4.42e+002	7.42e+006	2.08e+006	5.77e+005	1.33e+004	1.83e+002
Route10f	7.61e+005	4.39e+003	6.04e+003	2.60e+007	3.39e+005	2.19e+005	8.77e+004	2.42e+003
Route10g	1.61e+005	6.13e+003	6.88e+003	5.37e+006	Inf	2.88e+005	4.07e+004	2.92e+003
Route11a	3.96e+007	2.60e+008	1.42e+007	Inf	2.29e+007	1.73e+007	2.92e+007	4.25e+006
Route11b	2.50e+006	1.03e+005	1.05e+004	Inf	7.71e+004	2.98e+004	3.89e+004	5.64e+003
Route1a	1.33e+006	8.18e+003	4.35e+003	1.91e+006	7.64e+005	8.63e+004	9.45e+004	2.65e+003
Route1b	3.48e+005	2.49e+003	1.44e+003	4.15e+005	2.28e+005	2.72e+004	2.71e+004	8.46e+002
Route1c	1.33e+005	1.33e+003	3.51e+002	2.14e+005	3.00e+004	4.38e+003	2.98e+003	2.37e+002
Route1d	2.08e+005	1.91e+003	3.92e+002	4.02e+005	4.00e+004	4.84e+003	2.82e+003	2.73e+002
Route1e	1.40e+005	4.49e+003	1.01e+003	1.79e+006	7.16e+004	1.08e+004	7.36e+003	6.85e+002
Route2a	6.66e+005	1.87e+005	2.27e+004	Inf	2.08e+005	1.58e+005	8.59e+004	1.36e+004
Route2b	Inf	2.84e+005	2.48e+004	Inf	9.38e+005	1.90e+005	3.09e+005	1.87e+004
Route4a	1.42e+007	1.66e+006	4.87e+004	9.22e+007	1.16e+007	5.77e+004	1.37e+006	2.54e+004
Route4b	Inf	6.99e+005	1.68e+004	2.93e+007	7.78e+005	4.48e+004	6.77e+004	1.01e+004
Route4c	Inf	2.14e+008	3.77e+006	Inf	6.98e+007	1.14e+007	1.77e+007	2.33e+006
Route4d	Inf	1.64e+007	3.59e+005	Inf	Inf	1.96e+007	1.23e+006	2.70e+005
Route4e	Inf	Inf	6.09e+005	Inf	Inf	Inf	2.30e+006	4.81e+005
Route5a	Inf	Inf	2.03e+003	Inf	6.91e+004	3.14e+003	4.37e+004	1.18e+003
Route5b	Inf	Inf	1.76e+004	Inf	5.64e+006	2.85e+004	1.89e+006	1.08e+004
Route5c	Inf	Inf	7.42e+004	Inf	5.70e+005	2.92e+005	1.10e+006	5.11e+004
Route7a	8.19e+007	7.29e+007	2.25e+006	Inf	1.79e+007	1.54e+007	3.37e+007	1.61e+006
Route7b	9.78e+007	1.90e+008	2.34e+006	Inf	1.10e+007	1.93e+007	2.63e+006	1.03e+006
Route7c	4.24e+006	5.45e+006	1.52e+005	Inf	2.85e+005	5.81e+005	1.21e+005	4.89e+004
Route7d	1.29e+006	3.14e+006	2.49e+004	3.62e+006	7.54e+004	1.39e+005	5.79e+003	4.26e+003
Route7e	1.13e+006	2.99e+006	1.47e+004	Inf	2.59e+005	2.13e+005	1.19e+004	6.17e+003
Route8a	Inf	1.83e+005	4.78e+004	Inf	4.45e+007	3.19e+006	3.55e+005	3.38e+004
Route8b	2.58e+006	3.48e+004	2.28e+004	Inf	Inf	1.80e+005	2.98e+005	1.22e+004
Route9a	2.12e+005	Inf	8.76e+003	Inf	1.95e+006	2.99e+004	8.38e+004	6.07e+003
Total	2.36e+004	1.62e+002	8.62e+001	5.47e+004	7.15e+003	8.94e+002	7.19e+002	4.88e+001

Figure F.3: Drifting groundings



Return Period [yr]

	FishingShip	OilProducts	CargoShip	PassengerShip	PleasureBoat	SupportShip	OtherShip	Total
LEG_37	Inf	4.03e+007	9.27e+005	Inf	1.42e+016	2.33e+007	4.94e+008	8.71e+005
LEG_4	Inf	Inf	4.83e+007	Inf	Inf	Inf	Inf	4.83e+007
LEG_51	Inf	Inf	7.09e+006	Inf	Inf	5.46e+008	2.20e+009	6.97e+006
LEG_52	Inf	Inf	3.29e+005	Inf	Inf	5.85e+006	Inf	3.12e+005
Route10a	Inf	6.98e+003	7.08e+003	6.06e+005	Inf	Inf	4.36e+005	3.47e+003
Route10b	Inf	2.59e+005	4.55e+010	Inf	Inf	Inf	1.60e+014	2.59e+005
Route10c	Inf	7.71e+003	6.99e+003	6.43e+007	Inf	Inf	3.00e+005	3.62e+003
Route10d	Inf	1.04e+004	1.23e+004	4.77e+006	Inf	7.33e+008	4.11e+005	5.55e+003
Route10e	Inf	1.44e+005	2.26e+005	2.01e+010	Inf	Inf	7.19e+006	8.67e+004
Route10f	Inf	3.63e+006	Inf	Inf	Inf	Inf	Inf	3.63e+006
Route11a	Inf	Inf	Inf	Inf	Inf	6.24e+016	1.19e+018	5.93e+016
Route1a	5.12e+012	8.29e+003	2.48e+003	5.09e+005	1.30e+008	6.82e+007	9.56e+004	1.87e+003
Route1b	1.32e+006	1.11e+004	5.33e+003	1.25e+006	1.24e+012	2.33e+011	1.64e+005	3.50e+003
Route1c	1.56e+010	6.49e+007	1.85e+007	8.95e+008	5.99e+018	2.38e+017	3.89e+008	1.37e+007
Route1e	5.07e+011	3.85e+006	3.46e+004	4.28e+008	1.34e+017	2.85e+012	2.99e+007	3.43e+004
Route2a	Inf	Inf	1.98e+005	Inf	6.66e+009	2.34e+006	1.33e+005	7.70e+004
Route2b	Inf	Inf	6.98e+013	Inf	Inf	2.65e+011	1.32e+011	8.78e+010
Route4a	4.70e+007	8.82e+004	1.29e+004	3.10e+006	2.31e+008	1.46e+004	5.06e+005	6.25e+003
Route4b	Inf	1.23e+007	3.18e+005	1.79e+010	3.07e+007	1.91e+004	2.38e+006	1.78e+004
Route4c	Inf	4.00e+013	5.76e+006	Inf	3.99e+014	7.40e+012	1.51e+012	5.76e+006
Route4d	Inf	Inf	1.65e+009	Inf	Inf	4.28e+010	2.81e+009	1.02e+009
Route4e	Inf	Inf	1.57e+012	Inf	Inf	Inf	2.21e+014	1.56e+012
Route5a	Inf	Inf	1.28e+004	Inf	3.01e+008	1.83e+004	1.33e+008	7.51e+003
Route5b	Inf	Inf	1.22e+003	Inf	3.35e+008	2.31e+003	1.58e+005	7.93e+002
Route5c	Inf	Inf	6.06e+006	Inf	6.71e+011	4.52e+009	7.24e+008	6.00e+006
Route7a	2.55e+010	1.06e+008	3.08e+007	Inf	3.22e+009	1.25e+008	3.41e+006	2.91e+006
Route7b	1.79e+008	2.66e+007	6.07e+005	Inf	2.15e+007	1.36e+006	3.50e+005	1.88e+005
Route7c	2.72e+006	3.15e+005	1.33e+004	Inf	Inf	3.39e+004	2.17e+004	6.47e+003
Route8a	Inf	1.11e+009	1.99e+009	Inf	3.15e+014	1.43e+009	1.03e+008	8.45e+007
Route9a	1.14e+012	Inf	2.73e+008	Inf	4.73e+010	1.41e+009	7.93e+007	5.88e+007
Total	8.70e+005	1.65e+003	4.86e+002	2.01e+005	1.02e+007	1.56e+003	1.11e+004	2.94e+002

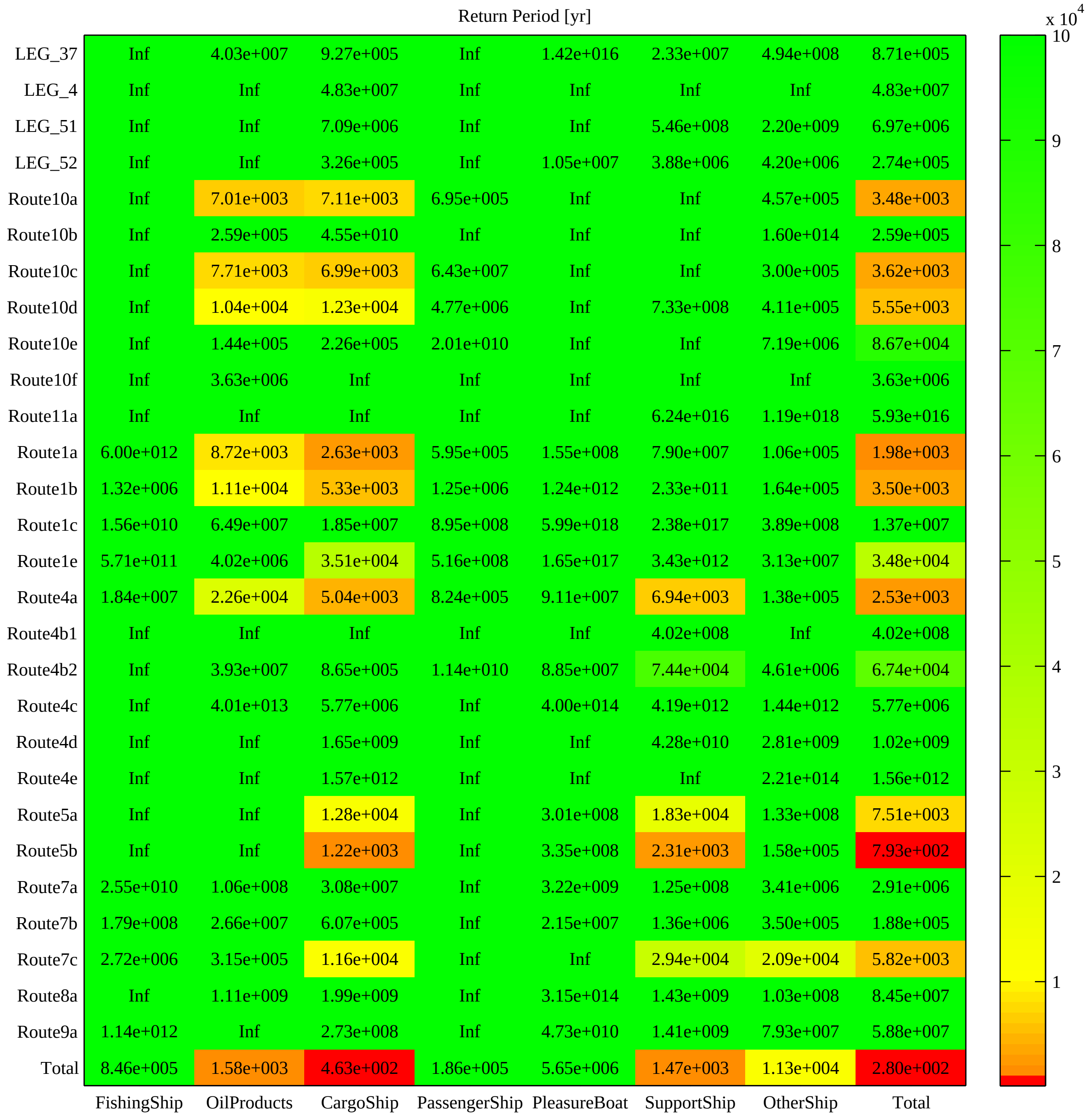
Figure F.4: Powered groundings

F.3 Ship grounding incidents After

Return Period [yr]

	FishingShip	OilProducts	CargoShip	PassengerShip	PleasureBoat	SupportShip	OtherShip	Total
LEG_37	Inf	5.56e+006	5.00e+004	Inf	2.63e+007	1.92e+005	6.01e+004	2.38e+004
LEG_4	Inf	4.30e+004	5.11e+004	4.24e+005	Inf	6.85e+006	Inf	2.21e+004
LEG_51	Inf	Inf	2.73e+005	Inf	Inf	8.25e+005	1.53e+007	2.02e+005
LEG_52	Inf	Inf	3.90e+004	Inf	2.94e+006	2.77e+004	3.82e+005	1.55e+004
Route10a	2.38e+006	1.00e+004	1.01e+004	8.42e+005	Inf	2.98e+007	2.91e+005	4.89e+003
Route10b	Inf	3.38e+003	3.41e+003	3.33e+005	2.60e+006	7.26e+005	9.30e+004	1.65e+003
Route10c	Inf	9.61e+003	9.78e+003	9.37e+006	2.60e+007	9.70e+006	2.48e+005	4.75e+003
Route10d	2.62e+007	2.87e+004	2.93e+004	2.47e+007	Inf	6.72e+006	2.15e+005	1.35e+004
Route10e	4.67e+005	3.20e+002	4.42e+002	7.81e+006	2.10e+006	5.87e+005	1.33e+004	1.83e+002
Route10f	7.85e+005	4.39e+003	6.05e+003	2.66e+007	3.39e+005	2.20e+005	8.78e+004	2.42e+003
Route10g	1.62e+005	6.14e+003	6.90e+003	5.43e+006	Inf	2.88e+005	4.07e+004	2.92e+003
Route11a	4.11e+007	2.71e+008	1.48e+007	Inf	2.32e+007	1.74e+007	2.98e+007	4.35e+006
Route11b	2.55e+006	1.03e+005	1.06e+004	Inf	7.76e+004	2.99e+004	3.90e+004	5.66e+003
Route1a	1.33e+006	8.19e+003	4.35e+003	1.92e+006	7.65e+005	8.65e+004	9.46e+004	2.66e+003
Route1b	2.67e+005	2.59e+003	1.46e+003	4.39e+005	2.13e+005	2.60e+004	2.69e+004	8.66e+002
Route1c	1.25e+005	1.29e+003	3.18e+002	2.21e+005	2.25e+004	3.74e+003	2.72e+003	2.17e+002
Route1d	1.91e+005	1.80e+003	3.45e+002	4.05e+005	2.74e+004	3.95e+003	2.56e+003	2.41e+002
Route1e	1.40e+005	4.48e+003	1.01e+003	1.79e+006	7.15e+004	1.08e+004	7.36e+003	6.85e+002
Route4a	1.37e+007	5.47e+005	1.83e+004	2.09e+007	2.04e+006	3.55e+004	1.95e+005	1.11e+004
Route4b1	Inf	1.03e+006	2.70e+004	1.28e+008	1.61e+006	6.28e+004	1.67e+005	1.65e+004
Route4b2	Inf	3.78e+006	9.69e+004	3.15e+008	5.17e+006	1.63e+005	5.22e+005	5.31e+004
Route4c	Inf	2.14e+008	3.36e+006	Inf	6.01e+007	9.12e+006	1.70e+007	2.05e+006
Route4d	Inf	1.64e+007	3.59e+005	Inf	Inf	1.96e+007	1.23e+006	2.70e+005
Route4e	Inf	Inf	6.09e+005	Inf	Inf	Inf	2.30e+006	4.81e+005
Route5a	Inf	Inf	2.03e+003	Inf	6.91e+004	3.14e+003	4.37e+004	1.18e+003
Route5b	Inf	Inf	1.76e+004	Inf	5.64e+006	2.85e+004	1.89e+006	1.08e+004
Route7a	8.19e+007	7.29e+007	2.25e+006	Inf	1.79e+007	1.54e+007	3.37e+007	1.61e+006
Route7b	9.78e+007	1.90e+008	2.34e+006	Inf	1.10e+007	1.93e+007	2.63e+006	1.03e+006
Route7c	4.24e+006	5.45e+006	1.36e+005	Inf	2.28e+005	4.75e+005	1.15e+005	4.36e+004
Route7d	1.29e+006	3.14e+006	2.41e+004	3.62e+006	6.20e+004	1.27e+005	5.70e+003	4.13e+003
Route7e	1.13e+006	3.02e+006	1.44e+004	Inf	1.31e+005	1.86e+005	1.14e+004	5.83e+003
Route8a	Inf	1.83e+005	4.78e+004	Inf	4.45e+007	3.19e+006	3.55e+005	3.38e+004
Route8b	2.58e+006	3.48e+004	2.28e+004	Inf	Inf	1.80e+005	2.98e+005	1.22e+004
Route9a	2.12e+005	Inf	8.76e+003	Inf	1.95e+006	2.99e+004	8.38e+004	6.07e+003
Total	2.36e+004	1.62e+002	8.23e+001	5.63e+004	6.14e+003	8.27e+002	6.90e+002	4.71e+001

Figure F.5: Drifting groundings



	FishingShip	OilProducts	CargoShip	PassengerShip	PleasureBoat	SupportShip	OtherShip	Total
LEG_37	Inf	4.03e+007	9.27e+005	Inf	1.42e+016	2.33e+007	4.94e+008	8.71e+005
LEG_4	Inf	Inf	4.83e+007	Inf	Inf	Inf	Inf	4.83e+007
LEG_51	Inf	Inf	7.09e+006	Inf	Inf	5.46e+008	2.20e+009	6.97e+006
LEG_52	Inf	Inf	3.26e+005	Inf	1.05e+007	3.88e+006	4.20e+006	2.74e+005
Route10a	Inf	7.01e+003	7.11e+003	6.95e+005	Inf	Inf	4.57e+005	3.48e+003
Route10b	Inf	2.59e+005	4.55e+010	Inf	Inf	Inf	1.60e+014	2.59e+005
Route10c	Inf	7.71e+003	6.99e+003	6.43e+007	Inf	Inf	3.00e+005	3.62e+003
Route10d	Inf	1.04e+004	1.23e+004	4.77e+006	Inf	7.33e+008	4.11e+005	5.55e+003
Route10e	Inf	1.44e+005	2.26e+005	2.01e+010	Inf	Inf	7.19e+006	8.67e+004
Route10f	Inf	3.63e+006	Inf	Inf	Inf	Inf	Inf	3.63e+006
Route11a	Inf	Inf	Inf	Inf	Inf	6.24e+016	1.19e+018	5.93e+016
Route1a	6.00e+012	8.72e+003	2.63e+003	5.95e+005	1.55e+008	7.90e+007	1.06e+005	1.98e+003
Route1b	1.32e+006	1.11e+004	5.33e+003	1.25e+006	1.24e+012	2.33e+011	1.64e+005	3.50e+003
Route1c	1.56e+010	6.49e+007	1.85e+007	8.95e+008	5.99e+018	2.38e+017	3.89e+008	1.37e+007
Route1e	5.71e+011	4.02e+006	3.51e+004	5.16e+008	1.65e+017	3.43e+012	3.13e+007	3.48e+004
Route4a	1.84e+007	2.26e+004	5.04e+003	8.24e+005	9.11e+007	6.94e+003	1.38e+005	2.53e+003
Route4b1	Inf	Inf	Inf	Inf	Inf	4.02e+008	Inf	4.02e+008
Route4b2	Inf	3.93e+007	8.65e+005	1.14e+010	8.85e+007	7.44e+004	4.61e+006	6.74e+004
Route4c	Inf	4.01e+013	5.77e+006	Inf	4.00e+014	4.19e+012	1.44e+012	5.77e+006
Route4d	Inf	Inf	1.65e+009	Inf	Inf	4.28e+010	2.81e+009	1.02e+009
Route4e	Inf	Inf	1.57e+012	Inf	Inf	Inf	2.21e+014	1.56e+012
Route5a	Inf	Inf	1.28e+004	Inf	3.01e+008	1.83e+004	1.33e+008	7.51e+003
Route5b	Inf	Inf	1.22e+003	Inf	3.35e+008	2.31e+003	1.58e+005	7.93e+002
Route7a	2.55e+010	1.06e+008	3.08e+007	Inf	3.22e+009	1.25e+008	3.41e+006	2.91e+006
Route7b	1.79e+008	2.66e+007	6.07e+005	Inf	2.15e+007	1.36e+006	3.50e+005	1.88e+005
Route7c	2.72e+006	3.15e+005	1.16e+004	Inf	Inf	2.94e+004	2.09e+004	5.82e+003
Route8a	Inf	1.11e+009	1.99e+009	Inf	3.15e+014	1.43e+009	1.03e+008	8.45e+007
Route9a	1.14e+012	Inf	2.73e+008	Inf	4.73e+010	1.41e+009	7.93e+007	5.88e+007
Total	8.46e+005	1.58e+003	4.63e+002	1.86e+005	5.65e+006	1.47e+003	1.13e+004	2.80e+002

Figure F.6: Powered grounding

F.4 Ship grounding incidents compared

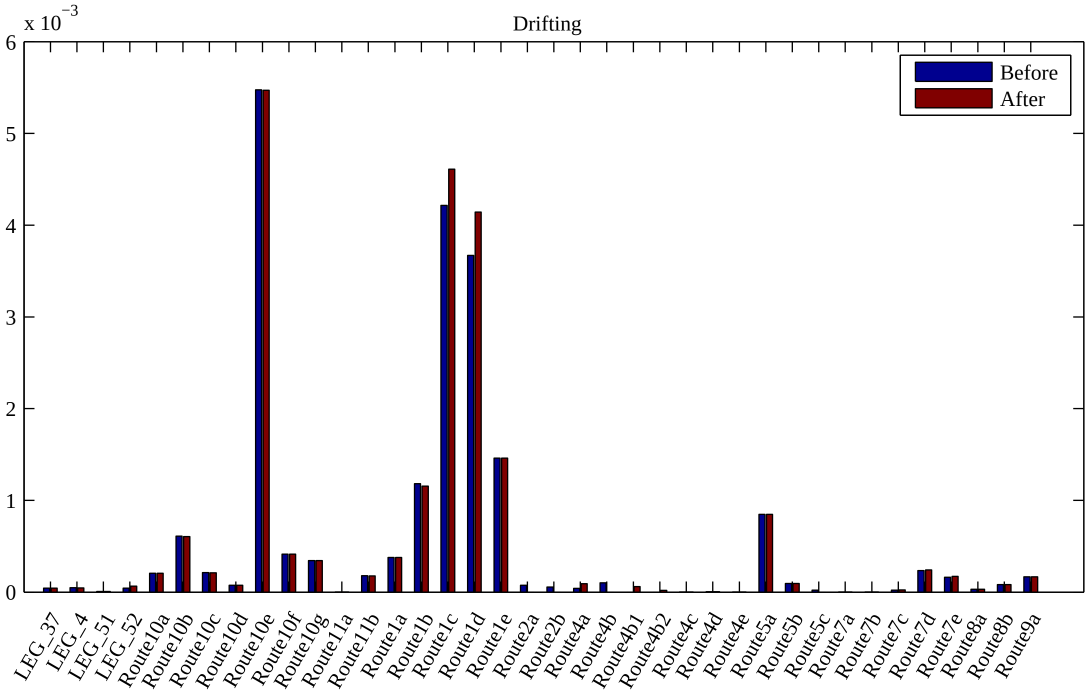


Figure F.7

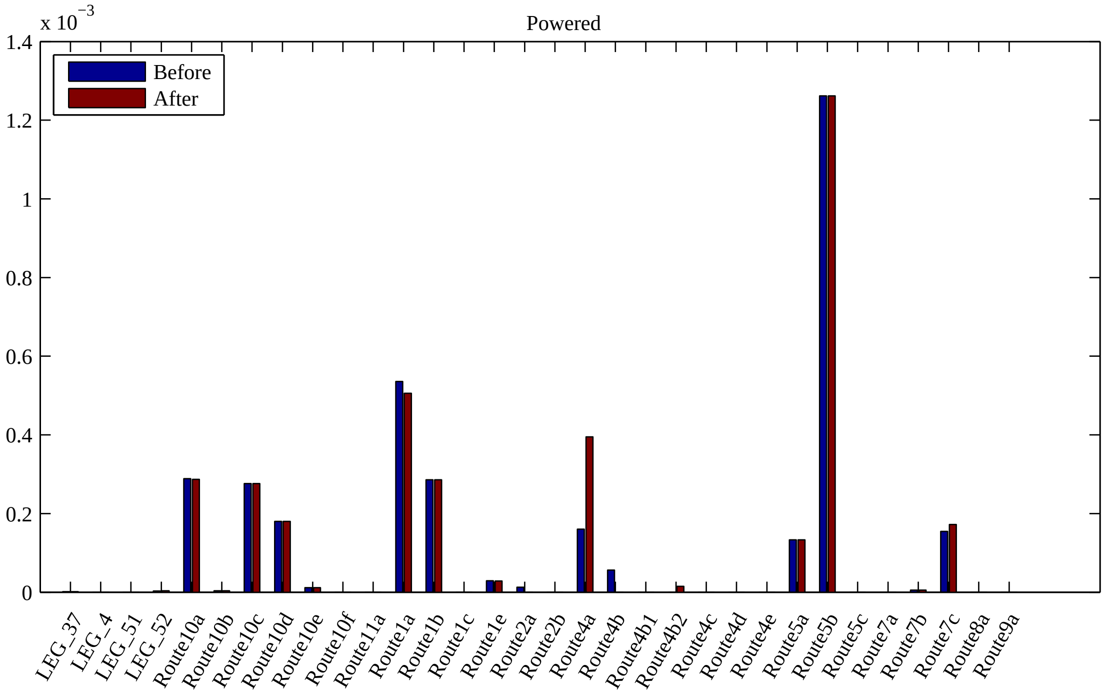


Figure F.8

F.5 Ship-ship collision incidents compared

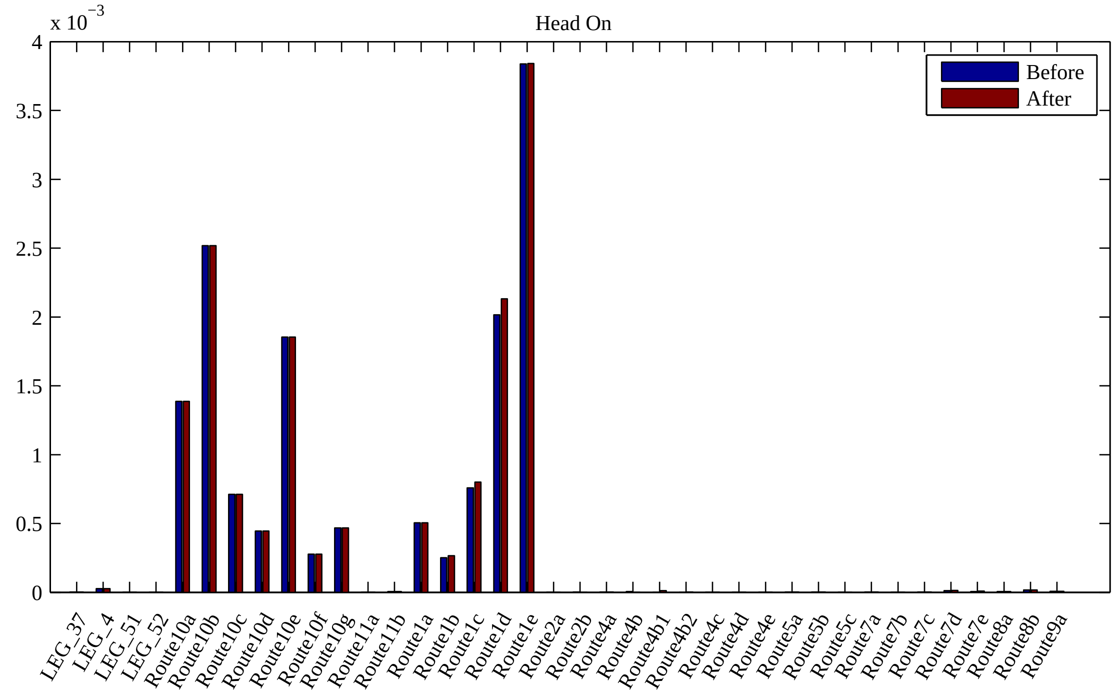


Figure F.9

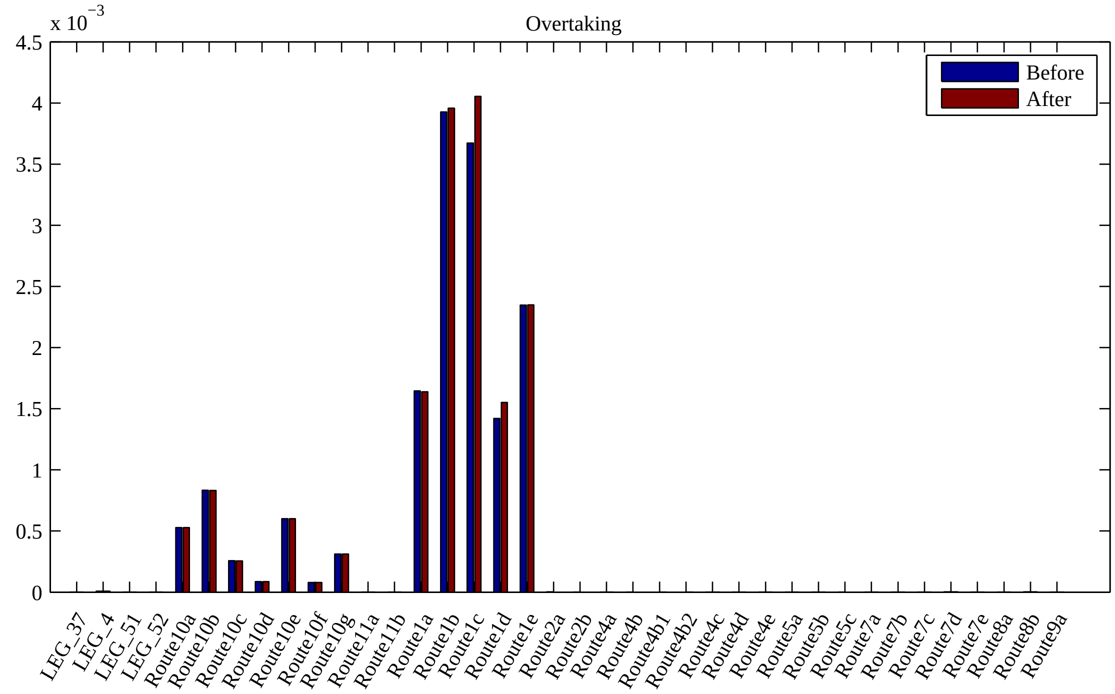


Figure F.10

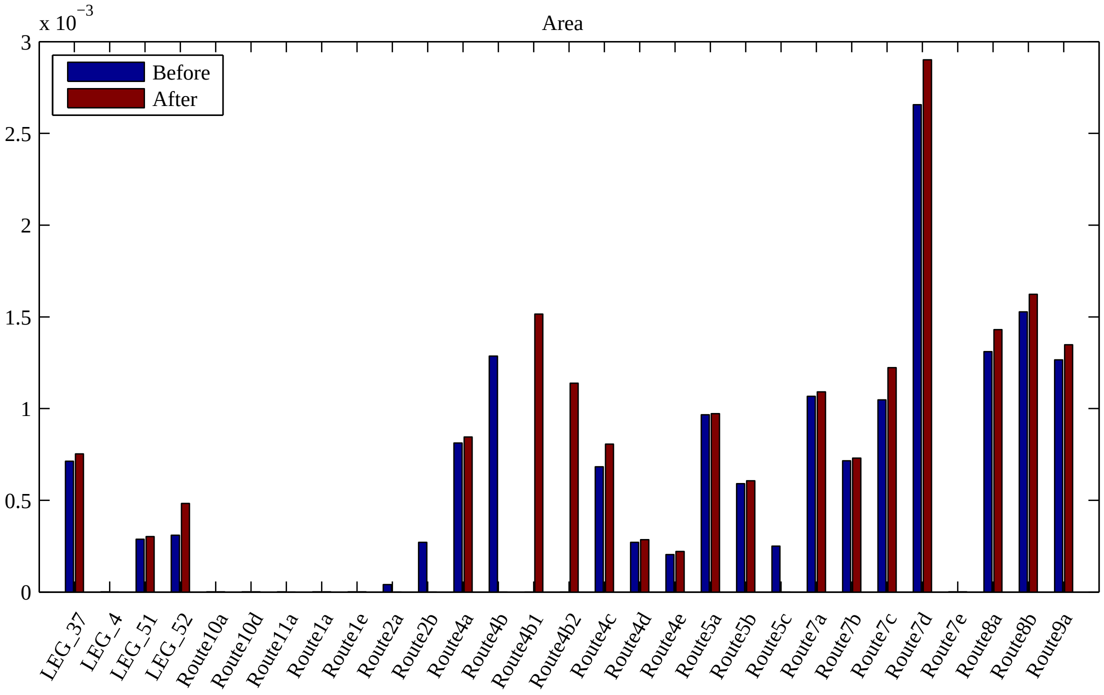


Figure F.11

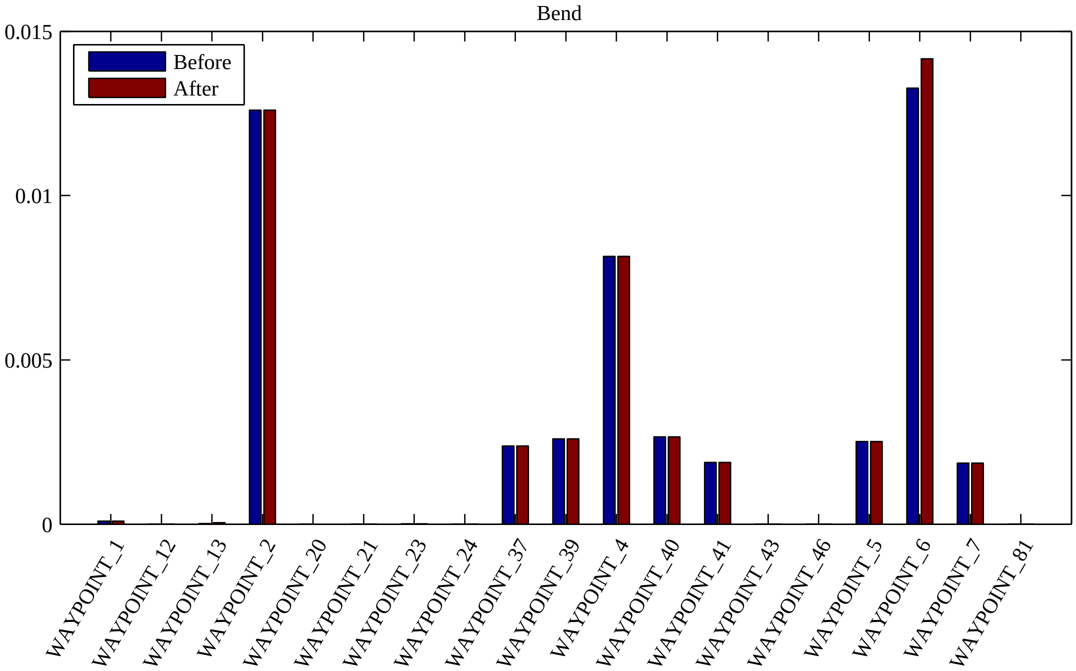


Figure F.12

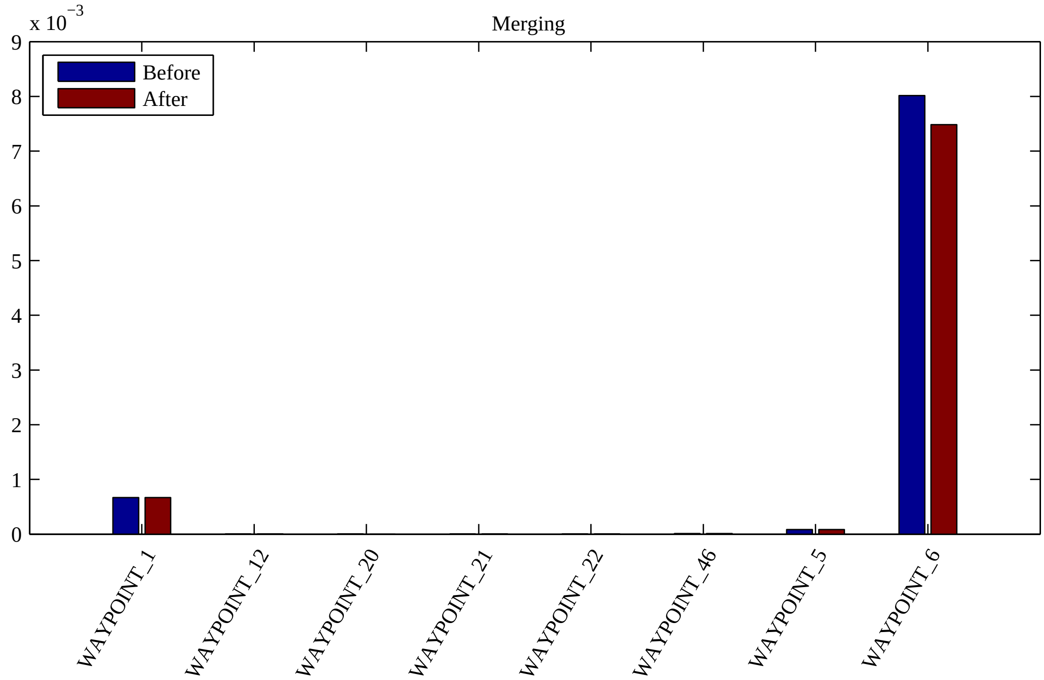


Figure F.13

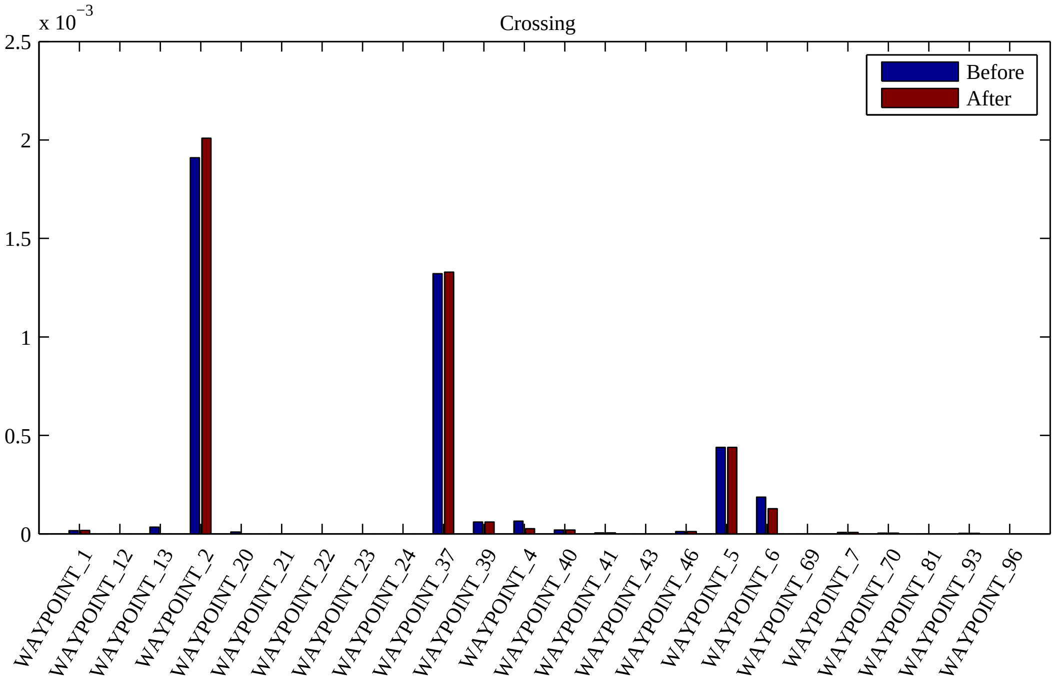


Figure F.14

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.