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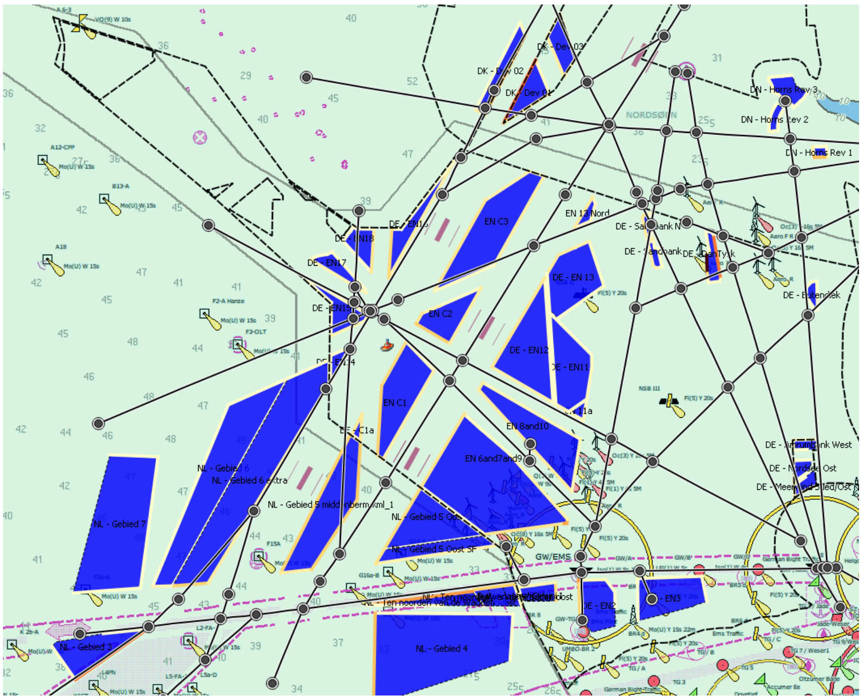
NORTH AND BALTIC SEA

Navigation Shipping Study

Expert's study on shipping traffic flows in the North and Baltic Seas and options to enhance the safety of shipping in the future

Work Packages 2, 3, 5 – Analysis of SN 10



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1 EXECUTIVE SUMMARY

ABL performed a nautical risk study in the North Sea focused on route SN 10, the main traffic route that connects the Dutch, German, and Danish waters, carrying traffic from the Channel and northern European hubs to Skagerrak and the Baltic Sea.

The traffic study was performed with a particular interest in the current and future offshore windfarm development areas, to inform the stakeholder nations as they undertake the development of their maritime spatial planning. This work was commissioned by the German Federal Maritime and Hydrographic Agency.

The purpose of the study was to analyse from a navigational and risk perspective the area around route SN 10, in the North Sea, in and around the German EEZ, for possible areas for offshore wind development, with particular interest to examine the feasibility of additional offshore wind developments at the central, or eastern part of the route, within the German MSP.

The study considered the existing offshore wind developments in the area of relevance and based on engagement with other stakeholder nations – Denmark and The Netherlands – the study considered the best current knowledge on areas allocated for future offshore wind development in their respective EEZs.

The study was focused on the implications to the traffic system of SN 10 of introducing additional development areas within the current footprint of the Route, to inform the development of the German MSP for the North Sea. In addition, the fact that the system around Route SN 10 has been modelled provided the opportunity to test and assess the impact of introducing small, additional areas on or outside the boundary of the Route SN 10.

The benchmark scenario on which the impact of additional developments was evaluated, represents a future arrangement with developments on either side of the existing SN 10 route anticipated for the year 2031. Its development was based on assumptions in terms of the potential developments, traffic volume, patterns, and consistency. The study was performed to the best current knowledge, with input from the Dutch and Danish authorities.

After the establishment of the benchmark scenario, two main scenarios were considered in terms of additional development areas in the footprint of Route SN 10. Scenario A1, introduces three additional development areas on the east edge of route SN 10, with traffic condensed to the remaining space to the west of these developments. Scenario C also introduces three additional areas, however, in the middle of Route SN 10, separating the east and west routes.

The analysis of the benchmark scenario model identified an annual combined allision probability of 1.674, which converts to a return period of just over 7 months and a cumulative annual probability for the occurrence of an event of any type of 1.976, which converts to a return period between incidents of 6 months. Scenario A1 returned an annual allision probability of 1.365 which constitutes a 19% reduction compared to the benchmark, but a combined annual probability for the occurrence of an event of any type of 1.919, which converts to a return period between incidents of just over 6 months. This is due to the doubling of the vessel-to-vessel collision risk. Scenario C returned an annual probability of an allision incident of 2.248, which converts to a return period between events of slightly less than 5.5 months and a combined annual probability for an incident of any type of 2.563, which corresponds to a return period between incidents of just over 4.5 months.

The study selected Scenario C as the preferred scenario for further development. The preference was based on the fact that mitigation of allision probability is more likely to be achieved as it is influenced by routing measures, geometric adjustments, as well as the provision of tugs, while ship-to-ship collisions are limited in terms of possible interventions to the introduction of routing measures that affect the route axis and lateral distribution and are thus more elaborate to pursue. The allision risks that were noted were dominated by risks from drifting vessels, dependent mainly on traffic volumes and the proximity of routes to the boundaries of the development areas.

7 different mitigation scenarios were analysed to investigate improvements to the risk profile developed. The first mitigation scenario that was considered, Scenario C_M1, was based on adjusting the width of the west branch of SN 10 to gradually match the width of the route in the Danish jurisdiction, and for the east branch, providing a 12km-wide shipping lane. Recommended routes were added to match the axis of the two branches, west and east. The gradual crossing of traffic from the west to the east route and vice-versa was replaced by a more direct crossing involving a more proclaimed course change. The analysis returned a 10% reduction in the allision risk, compared to that noted for Scenario C and a cumulative improvement in risk approaching the order of 10% compared to the basic scenario C.

The second mitigation scenario C_M2 was aimed at addressing allision risk on either side of the west branch, and the western edge of the east branch by reducing the area of the western developments shifting the axis of the eastern route by approximately 1.5km to the East. This scenario returned a 9% reduction in the allision risk, compared to that noted for mitigation scenario C_M1 and a cumulative annual probability for the occurrence of an event of any type of improvement of the order of 17% compared to the basic scenario C, and 8% compared to the previous mitigation scenario.

The third mitigation scenario C_M3 was targeted to mitigate the allision risk to the development areas in the middle-berm via the reduction in the area of the developments at the centre of SN 10, to incorporate a buffer zone to the east of the west branches and also, test the impact of the removal of area C1 south that was found to concentrate abnormally high levels of risk. The analysis returned a 10% reduction in the allision risk, compared to that noted for mitigation scenario C_M2 and a 27% reduction compared to the basic scenario C. No change was noted in vessel-to-vessel collisions compared to the previous scenario, and thus risk of any type showed an improvement approaching the order of 24% compared to the basic scenario C, and 9% compared to the previous mitigation scenario.

The fourth mitigation scenario C_M4 was also focused on the reduction of the allision risk on either side of the Western route, however, this time with the provision of an Emergency Tow Vessel near the developments of interest, stationed at the SW corner of area EN C1. Also, area C1 south has been reinstated, as the risk-benefit from its removal was offset by the risk increase on area C1. The analysis returned an annual combined allision probability reduction of 56% compared to that noted for mitigation scenario C_M3 and a 75% reduction compared to the base scenario C. Also, an improvement of the overall risk of the order of 66% compared to the basic scenario C, and 56% compared to the previous mitigation scenario.

The fifth mitigation Scenario C_M5 was considered as a means of limitation to the risk intensity on area EN 16, without causing substantial detriment to the risk intensities of the remaining development areas in the German EEZ, through the shift to the north and placement of the ETV at the western corner of development area EN C2, closer to EN 16. The relocation of the ETV station resulted in an annual combined allision probability increase of 0.6% compared to that noted for mitigation scenario C_M4, albeit a 75% reduction compared to the base scenario C. The cumulative sum of the risks showed an improvement of the order of 66% compared to the basic scenario C and was of marginal detriment compared to the previous mitigation scenario.

The sixth mitigation Scenario C_M6 was analysed in response to a query by GDWS on the effect to navigational safety on the routes and waypoints of the model should the system of recommended routes for the east and west routes on SN 10 be replaced by a system of Traffic Separation Schemes (TSSs). This iteration also served as an opportunity to move the ETV to a position intermediate to that of the two scenarios C_M4 and C_M5, at the NW corner of area EN C1. The analysis returned a 4% reduction in the allision risk, compared to that noted for mitigation scenario C_M5 and an improvement in the overall risk approaching the order of 67% compared to the basic scenario C, and 4% compared to the previous mitigation scenario.

The final mitigation Scenario C_M7 was analysed as a follow-up case relevant to a discussion with the GDWS and addressed the issue of providing additional safety zone to the developments exposed to high traffic volumes, in a way that geometrically preserves the request for a 2nm +500m allowance between the development areas and the main traffic routes of SN 10. This included further adjustment to the geometries of the development areas, and the realignment of the East route to match the heading of the boundary of the development areas to the East. The analysis returned a further reduction of 4% in the allision risk, and an improvement in the overall risk approaching the order of 69% compared to the basic scenario C, and 4% compared to the previous mitigation scenario.

Overall, except for mitigation scenario C_M5, where a small net increase in the allision risk was noted, all mitigations scenarios attempted generated a net benefit in risk compared to the preceding. The main point from the study is that the provision of an ETV next to the middle-berm development areas as a means of allision risk mitigation is necessary to manage the relevant risks. Based on the assumed parameters for the ETV, its placement near the centre of the main route junction proved very effective in mitigating allision risk within the German EEZ.

The study also examined the impact on the risk profile of the SN 10 system of developing an area to the north of area EN 13, to comment on whether its development is in line with the safety and efficiency of shipping.

The analysis results showed that the development is not viable from an allision risk perspective without the provision of an ETV within Route SN 10. With the provision of an ETV, the annual probability of allisions appeared to reduce substantially for all tested positions of the ETV station. Whilst the return periods of allision incidents noted in the analyses with ETV presence are lower than the 100-year return period considered desirable by guideline [01] for a single development, return periods were found well above the limit of categorical rejection of an application that is set in the same references at 50 years. Because the development of this area is expected to be one of the last in the implementation of the MSP, ABL recommends that the assessment and final decision on the development of area EN 13 – North be deferred to the future. This will enable the assessment that will inform the final decision, to be made with a large part of the new environment in and around Route SN 10 already implemented and the use of contemporary traffic volume and data consistency.

As part of the scope of Work Package 2 of the main study, ABL was also asked to run a navigation simulation of the selected option from the original study (Option C_M7), inclusive of mitigation proposals in the area of the German North Sea surrounding route SN10. The simulation was also aimed to provide insights on the post-development environment, and at the same time identify if the available room of maritime space resulting from the introduction of offshore installations is enough to allow the traffic to be navigated safely.

In this regard, two main risk hotspots were identified in the study area. One where the traffic diverts between the eastern and western branches of SN 10 near the boundary between the Danish and German EEZs (North Scenario); and a second one at the crossing of SN10 with the western routes of SN 04, SN 15, and SN 17 (West Scenario). The assumptions made for the simulation intended to exaggerate the number of vessels and the crossing situation of both scenarios to verify the capacity of vessels in the simulation to take evasive manoeuvres without being jeopardised by the limited availability of navigating waters.

In summary, given the current traffic volumes and future growth of the shipping traffic in the area, the maritime space appears to be sufficient for the safe navigation of the vessels in the area of SN 10 and its immediate surroundings.

Simulations also show that the most hazardous area, or the area which would require particular attention to the navigation, is the junction between SN 17 and the SN 10 system. A ship can be required to take several evasive manoeuvres and find itself in an unfavourable position when the maritime space reduces between the offshore wind installations. An attentive Officer of the Watch would plan their action in advance and attempt to manoeuvre to be where they want to be in terms of navigating through the system. Nevertheless, external factors such as inclement weather, low visibility, and poor communication, might lead to situations where the same Officer of the Watch may find their vessel in situations they would not have normally opted for.

To obtain a real benefit from the Wartsila simulator, more specific scenarios might need to be built up to stress and focus on particular conditions in specific areas of SN 10. This should take place as a series of studies and in sequence as the new OW developments begin to appear in the maritime space. This will allow issues to be addressed as they arise from the incremental changes imposed to the traffic system as formed at the time of development. This way, the process can be targeted on the main issues picked up in navigational hazard identification studies as well as on particular concerns raised by specific stakeholders.

2 INTRODUCTION

2.1 General

The European Union's “2030 Climate and Energy Framework” requires the member states’ compliance with set EU-wide targets and policy objectives for the period from 2021 to 2030. This framework requires that by the year 2030:

At least 40% cuts are achieved in greenhouse gas emissions (from 1990 levels)

At least 32% share of the energy comes from renewable sources

At least a 32.5% improvement is achieved in energy efficiency

The achievement of these climate targets by the EU-member countries is expected to involve heavy investment in renewable energy, most of which is anticipated to come in the form of offshore wind turbines. To achieve the required output, the new offshore wind developments would have to cover a significant area in the maritime space off the coastline of European Union Member States.

Areas of interest include the North Sea and the Baltic Sea. The eastern part of the North Sea is already heavily trafficked by merchant and work vessels, and thus spatial demand is expected to become an important issue in achieving the balance between attributing space to offshore wind developments and maintaining safe and effective shipping traffic. The spatial demand may also increase due to other developments with spatial requirements, such as aquaculture. It is noted however that what is currently envisaged is that in most cases there can be an efficient overlap between offshore wind and aquaculture. In the Baltic, a similar picture is formed, as maritime space is expected to increasingly be claimed by offshore wind developments. This is of particular interest in narrow areas on the West side of the Baltic, including the North of Rugen area that is of interest to the study.

Route SN 10 in the North Sea constitutes a major trade route for global and regional trade. Its two constituent sub-routes carry most of the vessel traffic from Western Europe and the Atlantic into the Baltic Sea and deem this route critical both in terms of the export and import of goods to the Baltic States. In the future, the route is anticipated to gradually accommodate more traffic to/from the Northern Passage. It is therefore imperative that navigational safety and route efficiency is ensured in the aforementioned areas as new offshore windfarm and other offshore developments are planned.

2.2 Scope of ABL study

The scope of work for the study is split into five work packages:

- WP 1: Traffic analysis

- WP 2: Analysis of SN10
- WP 3: Analysis of EN13
- WP 4: Analysis of EO2
- WP 5: Ad-hoc analysis

The present report comprises Report one of Work Package 2, reporting the outcome of the traffic study for the area of interest around route SN 10 in the North Sea, as well as Work Packages 3 and 5.

2.2.1 Work Package 2

ABL was commissioned to perform an analysis of the area of route SN 10, to explore the potential for Offshore Wind (OW) developments within the current footprint of the route. The route currently comprises two separate navigation corridors, SN 10 West which corresponds to the deep-water route and notionally services the traffic coming from/to TSS West Friesland, and SN 10 East which notionally services the traffic from/to TSS Vlieland Nord.

The scope of the study includes a navigational risk assessment, and the proposal of mitigation measures, and is performed in consultation with the neighbouring countries. The study is based on the routeing system of the Eastern North Sea that influences the study area, including primary and secondary routes, TSS schemes, and other considerations relevant to navigation.

The present work package is based on the traffic analysis conducted as part of WP1 and will consider the possible impact of different scenarios of OWF development within route SN 10 on the safety and efficiency of navigation. The study considers best nautical practices to examine if the installation of OWFs is feasible given the spatial requirements for shipping and whether certain space is necessary for the safety and efficiency of navigation.

Focus is given to the existing offshore wind farms surrounding route SN 10, as well as other facilities and factors influencing maritime traffic in the area.

The outcome of the study will be informed by running TRANSAS simulations of the resulting scenarios, to obtain the navigator’s perspective of the induced changes.

2.2.2 Work Package 3

ABL was asked to investigate, if and to what extent the possible development of an area to the north of area EN 13, onwards referred to as EN 13 Nord, is in line with the safety and efficiency of shipping. This is considered based on the best current knowledge of the potential effects of ice-free arctic waters on the local shipping patterns. The study is performed for the preferred layout option for the development of the area within route SN10, in consideration of the area alongside other changes expected to navigation as part of the preferred scenario.

2.3 Assumptions and limitations

The analysis is based on the current maritime traffic situation based on Automatic Identification System (AIS) data.

Maritime traffic information was sourced through the availability of historic AIS data for the area of interest assessed in the study as defined in the following paragraphs of the present report.

Safety of Life at Sea (SOLAS) Convention requires all vessels of 300 gross tonnage or more employed in international voyages are equipped with an AIS transceiver since 2002. In recent years, given the improvement of technology and reduced cost of transmitter and receiver equipment, together with the introduction of an additional AIS class standard, several units with a gross tonnage <300 voluntarily became AIS-compliant.

The figures presented in the results of the traffic analysis include all the vessels for which AIS signals were picked up in the study area, SOLAS, and non-SOLAS.

However, a certain number of the latter vessels, such as pleasure craft, military-operation-involved units, fishing boats, etc.) are subsequently not included in the dataset for the risk study and will not be considered in the risk modelling. Although this is a limitation on the overall number of vessels, the erratic transit of a variety of smaller units would not be representative of the commercial marine traffic in the area of analysis, and thus are of no value to the present assignment.

2.4 Analysis software

The traffic and risk analyses will be performed using the IWRAP (IALA Waterway Risk Assessment Program) Mk2 Version 6.6.2.

IWRAP is a traffic analysis and collision/grounding frequency calculation tool recommended by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA).

2.5 Model development

This section intends to familiarise the reader with the modelling assumptions and parameters used in developing the environment for the present assessment.

2.5.1 Study area Boundaries, North Sea

The study area in the North Sea covers the area of the German jurisdiction in the North Sea, as well as the Dutch jurisdiction to the North of TSS Vlieland Nord, and the Danish jurisdiction up to the latitude of Lyngvig. The study area is presented in Figure 1.

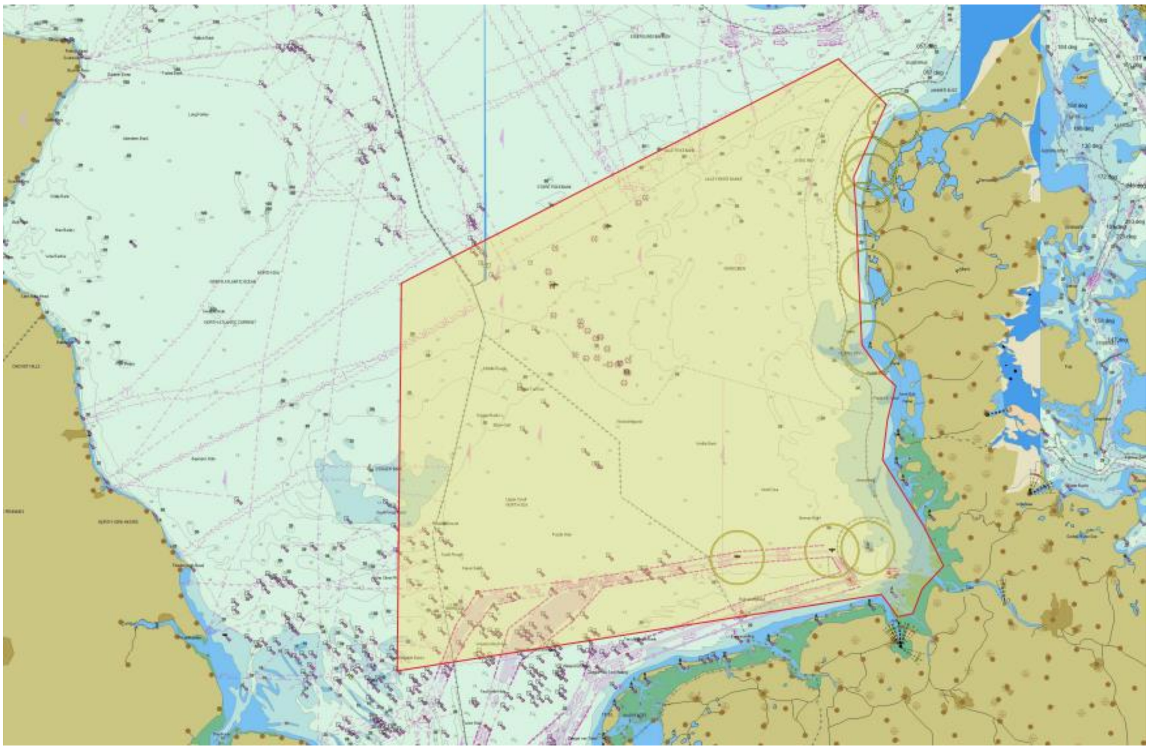


Figure 1: Area of study in the North Sea

The model area extends further to the eastern part of the German Bight, to pick up traffic out of the ports of Hamburg and Bremerhaven which enters the main area of interest for the study. To the West, the model extends to cover the traffic intake from TSS West Botney Ground and TSS West Friesland, whilst to the South, the model captures the flow from TSS Vlieland Nord. The study area excludes inland navigable waters as well as port approaches, harbours, anchorages, and roads. These particular areas are generally regulated by the pertinent port authorities. In addition, waters where pilotage is mandatory, are subject to a regulatory regime which might differ from coastal and high sea waters, and as such, it might mislead the overall analysis of the marine traffic in said specific areas.

2.5.2 Vessel Traffic and AIS datasets used

ABL was provided with two separate datasets of AIS terrestrial data for the years 2019 and 2020. The first dataset was made available by Kystverket (Norwegian Coastal Administration) and provided through North Sea Server. This dataset is comprised of static and dynamic AIS terrestrial data fed into the Norwegian server by the North Sea and North European Coastal States Administrations. The data was provided in csv files (stored separately for each month) with position reports at an interval of approximately 15 minutes for the dynamic data and separate csv files for static data. The data once loaded on the model appeared to have significant inconsistencies in the frequency of reporting in the dataset (Figure 2). Whilst fluctuations are generally expected and acceptable, the resulting pattern noted in the study area was one with very few points on some days and substantially more on others, especially in the spring and summer months. Further examination revealed that there were two hotspot areas with high coverage, and the remaining areas had no coverage in the dataset. The issues with the reliability of the dataset were reported to Kystverket. This is unusual, and thus we are not certain of the reliability of the dataset for use in the study. The relevant dataset was not used in the study.

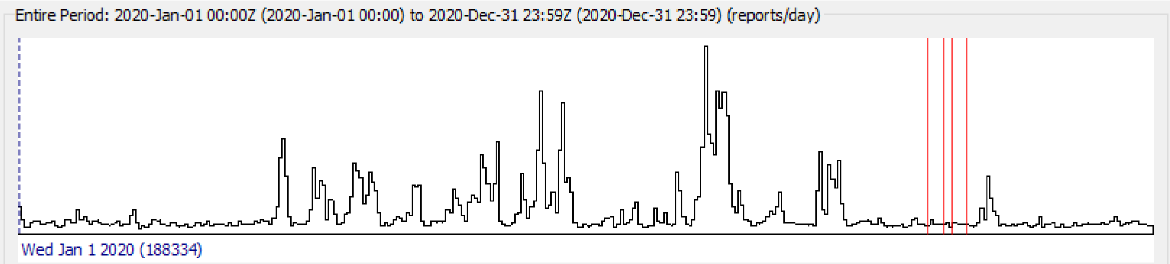
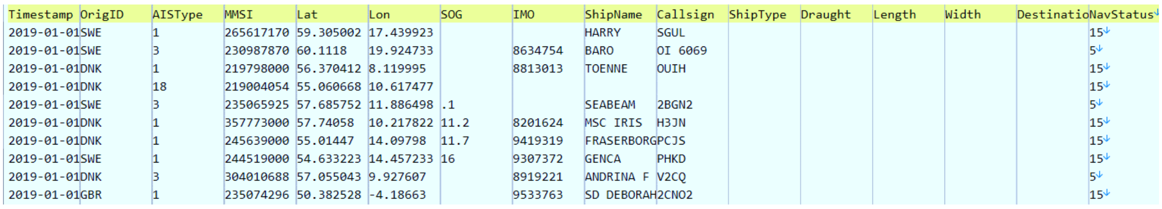


Figure 2: Sample of Kystverket AIS data time distribution.

The second dataset was provided by the BSH and was sourced by the European Maritime Safety Agency (EMSA). This dataset, also for the years 2019-2020 comprised of daily records; Line entries also include the state origin of the entry, AIS type, speed over ground and vessels name for most entries (Figure 3). The reporting intervals on this dataset are slightly denser than the Kystverket dataset but not regular, with the average interval at approximately 12 minutes. The dataset was found to contain a notable number of degraded or warped entries. The latter were repaired or removed.

Vessel size data was obtained as required from Seaweb (maritime.ihs.com). The combined information was compiled into a static list.



Timestamp	OrigID	AISType	MMSI	Lat	Lon	SOG	IMO	ShipName	Callsign	ShipType	Draught	Length	Width	Destinatio	NavStatus
2019-01-01	SWE	1	265617170	59.305002	17.439923			HARRY	SGUL						15
2019-01-01	SWE	3	230987870	60.1118	19.924733		8634754	BARO	OI 6069						5
2019-01-01	DNK	1	219798000	56.370412	8.119995		8813013	TOENNE	OUIH						15
2019-01-01	DNK	18	219004054	55.060668	10.617477										15
2019-01-01	SWE	3	235065925	57.685752	11.886498	.1		SEABEAM	2BGN2						5
2019-01-01	DNK	1	357773000	57.74058	10.217822	11.2	8201624	MSC IRIS	H3JN						15
2019-01-01	DNK	1	245639000	55.01447	14.09798	11.7	9419319	FRASERBORG	PCJS						15
2019-01-01	SWE	1	244519000	54.633223	14.457233	16	9307372	GENCA	PHKD						15
2019-01-01	DNK	3	304010688	57.055043	9.927607		8919221	ANDRINA F	V2CQ						5
2019-01-01	GBR	1	235074296	50.382528	-4.18663		9533763	SD DEBORAH	2CNO2						15

Figure 3: Sample of EMSA AIS data.

ABL pre-processed the dataset in an attempt to filter out irregularities in the form of Maritime Mobile Service Identity (MMSI)[1] duplication leading to vessels' false location and AIS signal jumps.

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[1] MMSI is a 9-digit number assigned by Administrations to each ship station as per Article 19 of ITU Regulations.

Additional filtering was applied to MMSIs starting with 0 and 1 (denoting coast stations and search and rescue aircraft). Similarly, MMSIs starting with 8 (handheld devices) and 9 (freeform identity) were also purged from the dataset. A summary of the filtration process is presented in Table 1.

Table 1: First filtering of AIS data summary

Total number of MMSI in identifiers in the set	25025
Total number of MMSI in identifiers between 2xx and 7xx	21781
Remaining vessels in model	21781

The final AIS data timeline loaded in the model is presented in Figure 4 below.

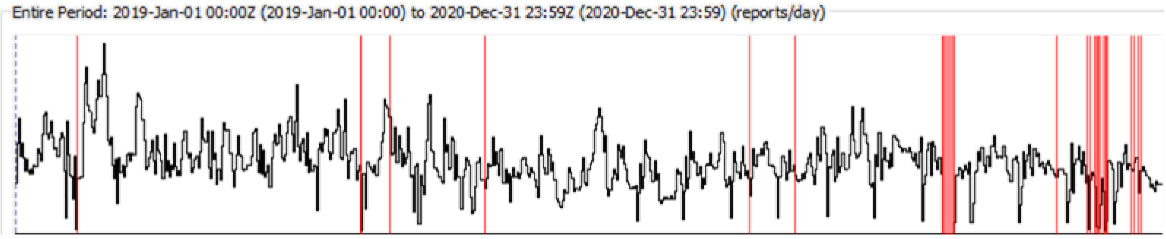

Figure 4: EMSA AIS data time distribution.

The sample consistency is of moderate uniformity, with roughly 86,900 reports/day, and a standard deviation of 31,781.

Notable gaps were found within the 2020 dataset, with the largest being the period between 13-08-2020 and 21-08-2020, a gap of 7.5 days. Also, notable gaps observed in the dataset are the following:

- 31h-long gap starting on 24-11-2020
- 20h-long gap starting on 21-11-2020
- 18h-long gap starting on 15-11-2020
- 16h-long gap starting on 19-11-2020
- 15h-long gap starting on 26-11-2020
- 8h-long gap starting on 17-12-2020
- 6h-long gap starting on 13-08-2020
- 4h-long gap starting on 13-11-2020
- 4h-long gap starting on 22-11-2020
- 3h-long gap starting on 21-11-2020
- 3h-long gap starting on 20-11-2020
- 2h-long gap starting on 11-05-2020
- 2h-long gap starting on 17-12-2020
- 2h-long gap starting on 27-08-2020

19 More gaps of smaller duration have also been noted in the 2-year dataset. The influence of all the aforementioned gaps is considered in the factor that converts traffic to an annuity.

A further challenge associated with the AIS dataset stemmed from the poor coverage that is noted at the central part of SN 10, which affects the route's footprint within the German jurisdiction. This, as identified in previous studies (both by ABL and others), leads to underestimated traffic counts, as vessel tracks are interrupted in the area, and thus not picked up by the counting lines or traffic model legs. ABL's "Shipping Analysis of the North Sea"[2] report noted that in parts of the German jurisdiction, this underestimate of traffic count can reach or exceed 70%.

To address this issue, an additional localised dataset was obtained from the Danish Maritime Authority (DMA), covering the area around the Danish offshore installations for the years 2019 – 2021. The area covered in this dataset is presented in Figure 5.

The data for 2019 and 2020 from the DMA dataset was added to the traffic analysis model. The dataset is significantly denser compared to the BSH dataset, with reporting frequency in the order of 2 mins.

A gap of 16 days was noted for September 2019, and a gap of 14 days for October 2019, however, the rest of the dataset appeared complete, with minimal other gaps noted.

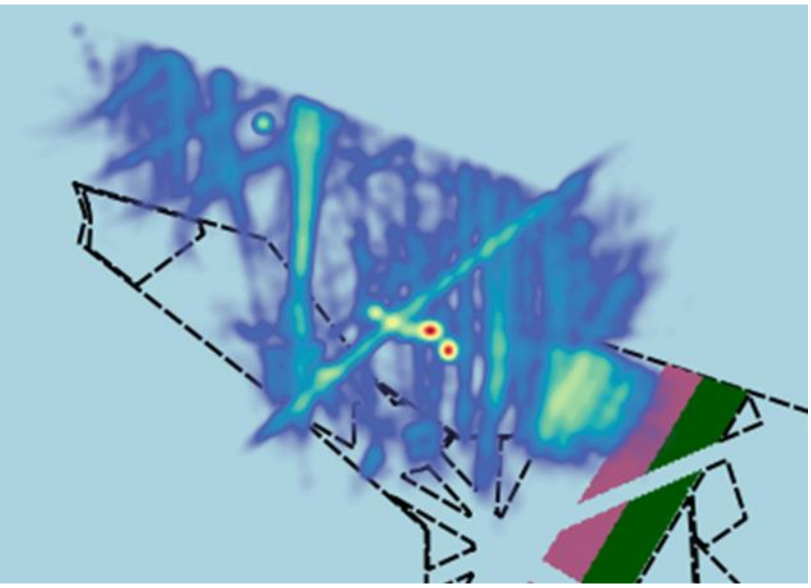

Figure 5: Coverage of additional AIS data provided by DMA

Following the introduction of the additional data, the sample consistency remained of moderate uniformity, also because the additional dataset was localised and covered a small extent of the modelled area. Due to the high reporting frequency in the DMA dataset, the number of observations per day substantially increased.

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[2] Shipping Analysis of The North Sea, undertaken on behalf of the Deutsches Bundesministerium des Innern, für Bau und Heimat, ABL 2021 (Web link).

Whilst there are methods to enhance and complete gaps in vessel tracks (such as simple or kinematic interpolation), these become less effective and accurate as the length of the data gap increases. With data gaps present in vessel tracks of up to 10 hours (and in limited cases even longer) kinematic interpolation was not found to be a good means of mitigation. The process often would result in tracks with abstract paths within the footprint of route SN 10. This, in turn, is a likely indication that vessels leave the area of SN 10 before they re-join the route further North/South, with likely diversions, stops, or non-standard route patterns.

Any attempt to bridge over data gaps is a conscious compromise between traffic count and positional accuracy. As both parameters are important in quantifying collision/allision risk, achieving a point of compromise is a challenging process.

ABL has undertaken an iterative exercise to quantify potential improvements in the vessel count picked up by the traffic model along route SN 10, based on increasing the tolerance the algorithm assumes to split consecutive time-series observations for a vessel into separate tracks (leaving a gap in between). This process is discussed in detail in the report of work package WP 1.

The dataset maintained for the risk study is focused on merchant vessels including those regularly employed in offshore operations defined as work vessels. Units such as military, patrol vessels, search and rescue vessels, accommodation platforms, non-propelled barges, lightvessel/buoys, drilling rigs, research vessels, FSOs/FPSOs, dredgers, museum vessels, pilot vessels, salvage ships, small fishing vessels, pleasure and recreational crafts and wind turbine generators fitted with AIS transceivers were filtered out of the AIS dataset used for the present study.

Before their removal, their position and distribution in the area were reviewed for hotspots that may affect navigation, however, no notable such for the level of the study were identified as these vessels generally do not follow the main shipping routes and adjust their course to avoid larger vessels. However, the AIS transceiver is fitted, as required, on board ships: <300GT engaged on international voyages; <500GT not engaged on international voyages and passenger ships irrespective of their size. All vessels maintained in the dataset and used in the analysis bear an IMO number, namely and similarly to the AIS requirement, all passenger vessels of 100 gross tonnage or more and all cargo vessels with a gross tonnage above 300 are enrolled in the ship identification scheme

For the risk assessment, the requirement from [01], and [02] is that only SOLAS vessels, of more than 500GT, are considered in the quantitative risk assessment. The guideline however allows the inclusion of smaller vessels in the case the latter are of importance to navigation in the area and follow the standard shipping routes. In the present study, therefore, passenger and crew vessels exceeding 100 GT were kept in the dataset for risk analysis. A summary of this second filtering process is presented in Table 2.

Table 2: Second AIS Data filtering Summary

Total number of MMSI in identifiers in the set	25,025
Total number of MMSI in identifiers not between 2xx and 7xx	3,238
Remaining vessels in the traffic model	21781
Cargo and work vessels ≤ 300 GT, passenger vessels ≤ 100 GT, military, small fishing, and pleasure craft removed	8,992
Total considered in quantitative risk assessment	12,789

The final AIS data timeline loaded in the model is presented in Figure 6 below.

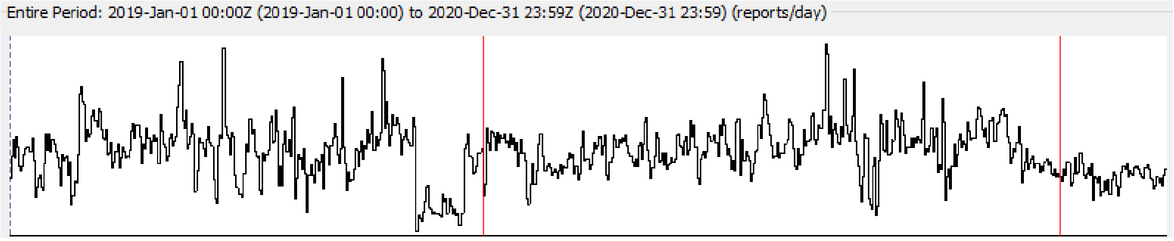

Figure 6: Final AIS data time distribution.

The sample consistency is of moderate uniformity, with roughly 201,000 reports/day, and a standard deviation of 61,150. Small gaps include the ones marked in red, where the number of samples appears to be missing for intervals of approximately 1-hour on two occasions. It is to be noted, however, that these are the resultant gaps from the overlap of the EMSA and DMA datasets that are of a localised nature, and thus, the true gaps are as described earlier in the reporting for the EMSA dataset.

2.5.3 Offshore windfarm development areas

The baseline scenario for the risk does not represent the current situation at the time of the study before any interventions. The reason is that the sequence of the potential development scenarios is expected to follow the implementation of the largest part of the German and Dutch MSPs. As a result, at the time when the benchmark risk is considered for this study, the current layout of the traffic corridors in the area that was captured in the traffic study of WP1 will have changed.

The benchmark case, therefore, considers that all areas nominated for offshore wind development to the east of route SN 10, will have been developed into OWFs, with an area coverage of 90%. This comprises development areas EN 6, EN 7, and EN 9 combined in a single cluster, EN 8 and EN 10 combined in a second cluster, and EN 11, EN 12, and EN 13 combined to form a third cluster. Also, the study assumes that the cluster of the development areas to the West of route SN 10 that are the closest to the route will also be developed for the benchmark scenario on the same coverage assumption. This comprises the easternmost parts of EN 14, EN 15, EN 16, EN 17, and EN 18.

On the Dutch side, the benchmark case includes all the developments of the latest MSP, except Gebied 5 Middenberm, which forms a development within the footprint of route SN 10 and is incorporated in the analysis together with the relevant areas in the German jurisdiction. A comparison of the benchmark scenario against the current case in the area of interest is presented in Figure 7.

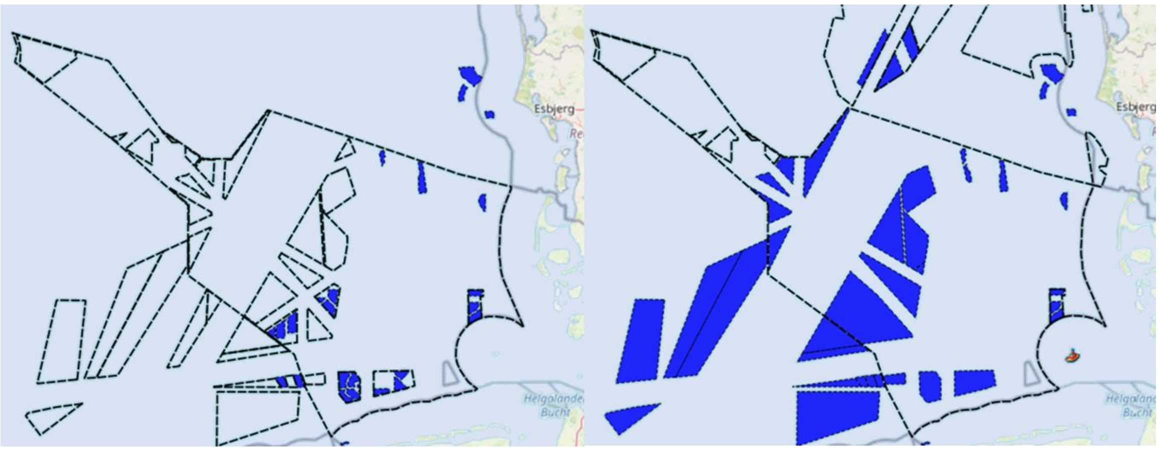

Figure 7: Current case OWF developments vs Benchmark case for study

The existing OWF developments in the study area between 2019 and 2020 are presented in Table 3. The existing developments in the area of interest form part of the nominated areas for OW development on the national MSPs.

Table 3: Existing OWFs in the North Sea study area

Denmark	Germany	The Netherlands
Horns Rev 1	Albatros	Buitengaats / Gemini I
Horns Rev 2	Alpha Ventus	ZeeEnergie / Gemini II
Horns Rev 3	Amrumbank West	
	BARD Offshore 1	
	Borkum Riffgrund 1	
	Borkum Riffgrund 2	
	Butendiek	
	DanTysk	
	Deutsche Bucht	
	EnBW Hohe See	
	GlobalTech I	
	Gode Wind 01	
	Gode Wind 02	
	Meerwind Sued/Ost	
	Merkur Offshore	
	Nordergrunde	
	Nordsee One	
	Nordsee Ost	
	Riffgat	

	Sandbank	
	Trianel Windpark Borkum 1	
	Trianel Windpark Borkum 2	
	Veja Mate	

2.5.4 The layout of traffic corridors

The traffic corridors for the study were derived based on the transformation of the existing network of traffic routes as derived from the analysis of the AIS data for 2019 and 2020 by the algorithm used by the IWRAP Mk2. The latter composes individual AIS data points into a time series for each vessel. Subsequently, using proximity and speed criteria it extracts the pertinent trips for each vessel. Each trip is a complete and distinct track of the vessel's movement across the area of interest and contributes to qualitative and quantitative information for the assessment. A density map was generated from the extracted trips, at a resolution of 250m x 250m and is presented in Figure 8.

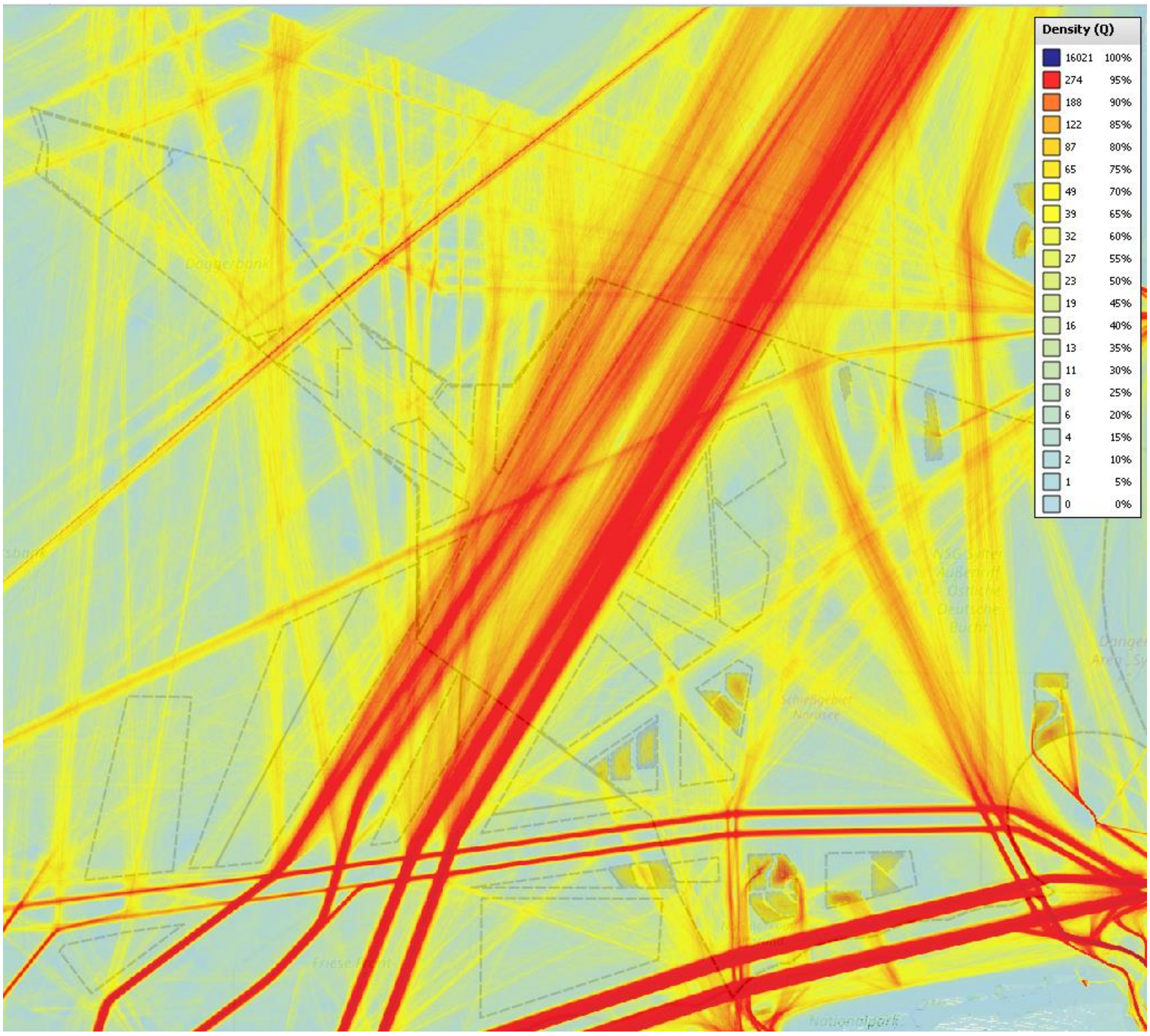

Figure 8: Density map generated for North Sea study area (resolution: 250m x 250m)

Based on the traffic distribution of Figure 8, a network of traffic corridors ("legs" in IWRAP Mk2) was developed to reflect the current system in place in the area of interest to the study. Each leg was attributed a specific width, reflecting the zone in which the software will look for vessel trips to attribute to it. This was chosen based on what appeared to be the requirement to cover the pertinent path as it is discernible on the density plot. A directional filter angle of 10 degrees was used in most cases[3] as the alignment tolerance for each leg. This means that any vessel trip that intersects the leg in its width and has a heading deviating up to +/- 10 degrees from the direction of the leg axis, is added to the distribution for the leg. The network of legs comprising the analysis model is depicted in Figure 9.

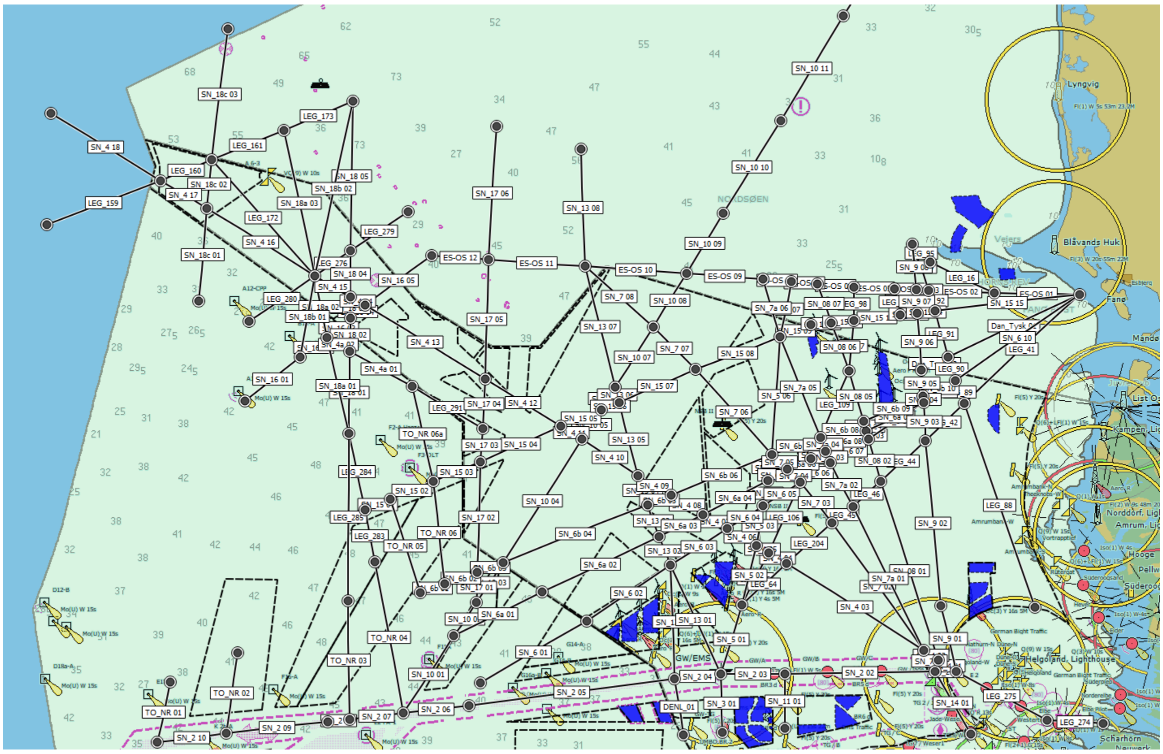

Figure 9: Network of traffic legs comprising the traffic analysis model

To aid with referencing the paths comprising the model developed, names were assigned where possible at each leg based on the routeing reference of the German MSP. This is merely a referencing convention and does not imply that vessels identified by the software on the pertinent legs necessarily travel from/to these destinations. The reference names of the modelled legs and the associated lane width assumed in the model are presented in detail in the report HHR22475 - Study on shipping traffic flows in the North and Baltic Seas - WP1, Report 1, 01 DEC 2022.

The coverage achieved by the assigned leg width is presented in Figure 10 overleaf. This constitutes the layout for the base model. As different scenarios are tested, changes are

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[3] For detailed information please refer to HHR22475 - Study on shipping traffic flows in the North and Baltic Seas - WP1, Report 1, 01 DEC 2022.

introduced to the network of legs and waypoints. The leg and waypoint mapping for the significant base and mitigation scenarios is presented in Appendix B.

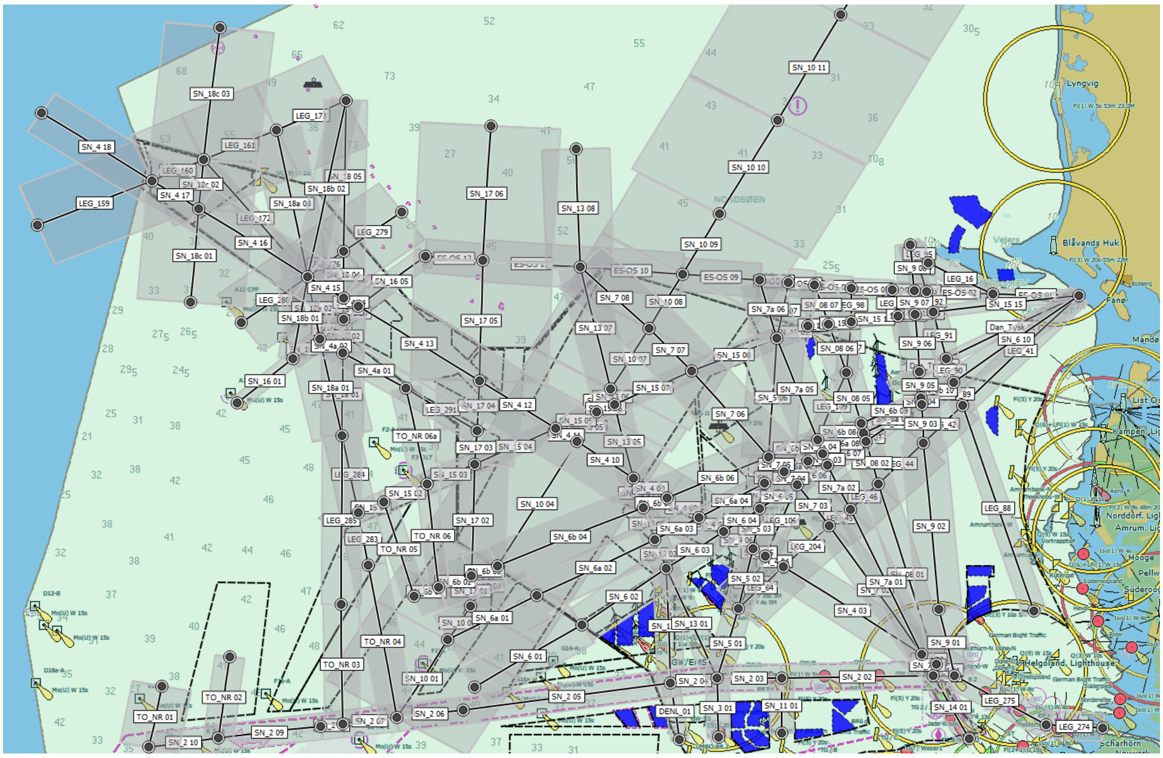

Figure 10: Coverage of tracks achieved by modelled legs

2.5.5 Lateral distribution of leg traffic

2.5.5.1 Existing conditions

The software used utilizes trips that are calculated as part of the traffic density analysis, along with the leg width and true heading of the vessels to assign a vessel's trips to the pertinent legs. To compute the lateral distribution of vessels in the lane, it also uses the distance of the path of the trip from the axis of each leg they are attributed to. This is numerically expressed as a composition (summation) of different distributions, which in turn is used to perform risk calculations. Traffic volumes and composition (vessels' sizes and types) will be generated for each leg in the study area relevant to the assessment.

2.5.5.2 Following the introduction of changes

The fact that the benchmark case model does not represent the current situation in the area, but a future scenario requires the implementation of changes in the model. These are in the form of shifting, merging, or re-directing routes. The introduction of such changes in the model, whether in the form of channelling traffic from one route to another, or changing the alignment of a route, will require an adjustment to the lateral distribution of traffic on the altered routes.

The approach used for the revised lateral distribution will be discussed later in the report.

2.5.6 Metocean conditions

The metocean conditions are important in terms of both determining the drifting parameters for vessels not under command (e.g., subjected to engine breakdown or blackout) following aberrant courses that can lead to a collision, as well as the potential of collision aversion through the intervention of tugs in the case of drifting vessels.

In the case of the former, the distribution of wind and current directions is important in determining the direction of drift, which takes part in the geometric probability calculation within the software. Metocean data are also significant in terms of determining the drifting speed of the vessels.

For this project, two areas are considered:

- South Baltic Sea Area (Area 1)
- South-East North Sea Area (Area 2)

The metocean parameters were derived for each. These areas are presented in Figure 11.

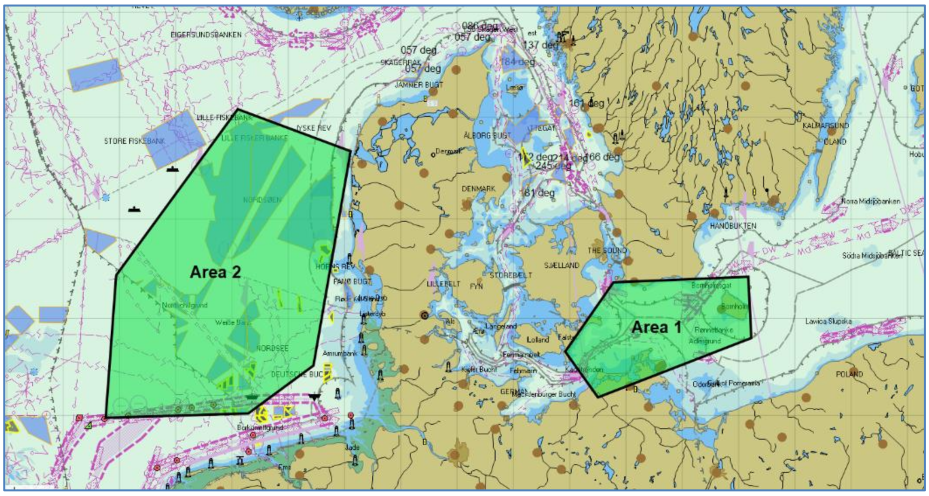

Figure 11: Area breakdown for metocean analysis

In both areas, long-term offshore wind and wave time series data were collected from the ECMWF-ERA5 database.

The ECMWF (European Centre for Medium-range Weather Forecasting) is an intergovernmental organization that uses state-of-the-art numerical models to deliver global weather forecasts in support of the national meteorological services. Both satellite and conventional data are daily collected from an extensive data collection network and analysed to set the initial conditions of the models. Wave data distributed by ECMWF are simulated by the spectral third generation WAM model coupled with the wind fields simulated by the global meteorological model. ERA-5 is a global atmospheric reanalysis from 1979, continuously updated up to the end of 2019. Data are provided on an hourly basis over a grid of 0.5° x 0.5°. This data is provided over a regular grid fully calibrated and homogenized against satellite data and (where available) in-situ buoy data. An example is presented in Figure 12.

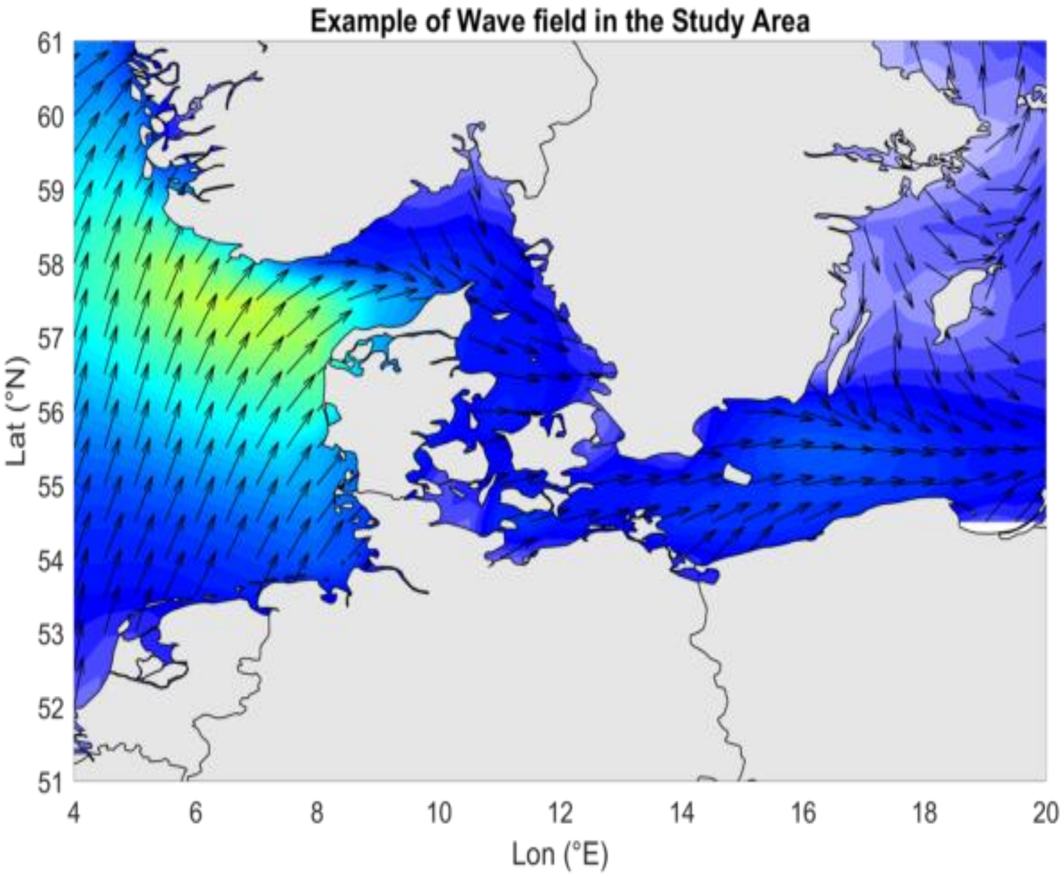

Figure 12: Example of Wave Field in the Study Areas.

Data on currents were obtained from historical archives of current data hindcasted through the HYCOM numerical model (Hybrid Coordinate Ocean Model) to assess the typical climate regime of the selected areas. The HYCOM consortium is a multi-institutional effort funded by the National Ocean Partnership Program (NOPP), as part of the U. S. Global Ocean Data Assimilation Experiment (GODAE). HYCOM is a primitive equation general circulation model which is isopycnal in the open, stratified ocean, but uses the layered continuity equation to make a dynamically smooth transition to a terrain-following coordinate in shallow coastal regions, and to z-level coordinates in the mixed layer and/or un-stratified seas. It maintains the significant advantages of an isopycnal model in stratified regions while allowing more vertical resolution near the surface and in shallow coastal areas. This results in the provision of a better representation of the upper ocean physics. The surface current climate is provided based on data provided by the HYCOM database. An example of the currents field within the study areas is shown in Figure 13.

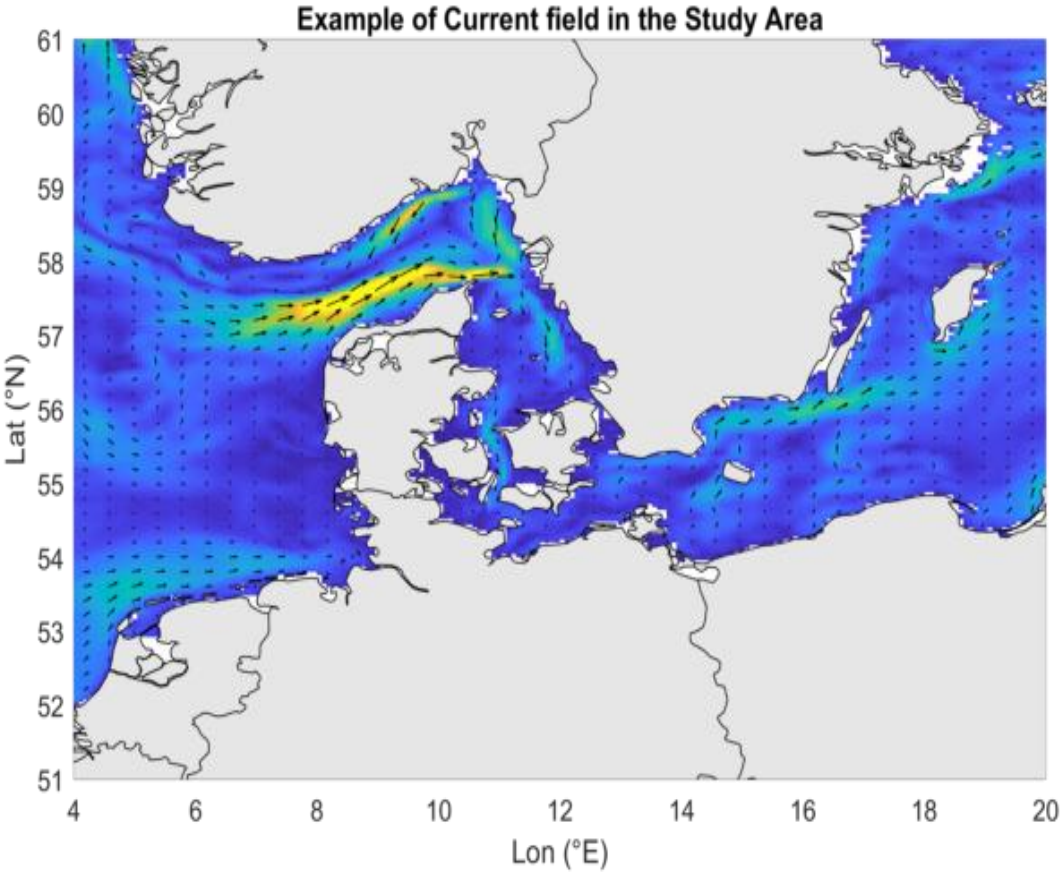

Figure 13*: Example of Instantaneous Currents Field in the Study Areas.*

Metocean parameters were analysed to provide seasonal statistics (in a table and graphical format), suitable for a correct drifting vessel assessment, in both Areas, South Baltic Sea Area, and South-East North Sea Area, respectively Area 1 and Area 2 in Figure 11. These derived statistics are presented in Appendix A.

2.5.7 South-East North Sea Area

The North Sea, a semi-enclosed basin within the north-west European shelf sea, is one of the most productive regions of the world ocean.

An important factor for the marine weather of the North Sea are the inflowing water masses from the Atlantic and the continental freshwater run-off. The salty Atlantic water and the fresh water drained via a number of rivers and via the Baltic Sea from the huge hinterland of western Europe are merged and mixed by the action of the tides and of the atmospherically induced turbulence of waves and currents.

The dominant atmospheric forcing of the North Sea is provided by the spacetime distribution of the winds and the air pressure. The most energetic situation is found in winter, with strong wind blowing up to 28-30 m/s.

The general direction of the current circulation varies only little between the seasons, and it is characterized by a cyclonic (contraclockwise) pattern.

Fog is associated with wind directions of between south-east and south-west and can reduce visibility to less than 1km 3-4% of the time. Radiation fog can form for 3-6 days per month between October and April and tends to occur during the night, being dispersed by the sun on all but the coldest days (UKHO 2013).

2.6 Risk assessment methodology and basic parameters

There are two main components to calculating collision risk.

The first is the geometrical probability (or frequency) which is related to the position of vessels in either direction of a traffic corridor (model leg), or route to a junction across each corridor, and the number of crossings. This expresses in effect the proportion of the total trips that would end in a collision if all vessels were navigating blindly (i.e., at their usual course with no reaction taken to avoid a collision). It shows the proportion of trips that would result in a collision if nobody could see one coming or act to avoid the other.

The second is the causation factor (or causation probability) which is related to the frequency in which a vessel will not take the necessary/correct action to avert a potential collision or will not diagnose the collision potential at all.

The overall collision risk is equal to the product of the two aforementioned parameters. The number of cases that would result in a collision if aversion were not possible, times the frequency of a vessel reacting to avert an incident fails.

2.6.1 Geometrical probability

IWRAP Mk2 uses the trip information extracted from AIS data to derive the lateral distribution of vessel traffic across the traffic corridors set up in the model. This distribution is converted to a summation of mathematical distributions for each leg and traffic direction, along with the geometric characteristics of each vessel in the model (length, width, draught) and the number of trips identified for each leg, it works out the geometrical probability.

For each leg, the identified number of collision candidates related to head-on, course alterations, and crossings is calculated for each vessel group and is subsequently multiplied by a causation factor.

2.6.2 Causation Factors

2.6.2.1 IALA approach

IWRAP Mk2 uses a set of default ‘Causation Factor’ values accepted by IALA for the different collision types described above. The values of these ‘Causation Factors’ correspond to the mean values of the range recommended by Fujii and Mizuki [11] and are presented in Table 4. Whilst different states/authorities may specify different values for the causation factors, internationally, the causation factors proposed by IALA are widely accepted.

Table 4: IALA Causation Factors

Collisions		Allisions		Grounding	
Merging	$1.30\cdot10^{-4}$	Powered	$1.60\cdot10^{-4}$	Powered	$1.60\cdot10^{-4}$
Crossing	$1.30\cdot10^{-4}$	Drifting	1.00	Drifting	1.00
Bend	$1.30\cdot10^{-4}$				
Head-on	$0.50\cdot10^{-4}$				
Overtaking	$1.10\cdot10^{-4}$				

2.6.2.2 GL approach

Germany, on the back of the Safety at Sea project that looked into the potential of a common approach to navigational risk studies for offshore wind, has assembled a group of experts to agree on risk acceptance criteria. The product of this initiative is referenced in the report [01]. This document also forms the basis for the subsequent guideline document prepared by GL for the BSH [02] that defines the parameters for risk analyses in the approval procedure and the effectiveness of collision prevention measures for offshore wind developments.

The aforementioned documents specify a different set of causation factors, which are on the conservative side compared to the ones adopted by IALA. They consider a single causation factor of $3.0\cdot10^{-4}$ to express the probability of a ship identified on a collision course will not make a course correction before it impacts the obstacle, due to technical or human causes.

2.6.2.3 Risk Reduction Factors

The presence of aids to navigation and other automated or non-automated risk mitigation systems and processes results in an improvement in the overall risk. Their effect on the reduction of overall risk is quantified and documented in guidelines and other scientific publications.

A risk reduction factor of 1.25 is considered for allisions to OWF installations, as a result of the latter being fitted with AIS transponders. This is endorsed by [01] and [02]. This factor will be applied to the OWF installation areas in the model.

The study area is covered by an integrated Vessel Traffic Service (VTS), comprising the VTS zones German North Sea Traffic (controlled out of Cuxhaven) and German Bight Traffic (controlled out of Wilhelmshaven). This justifies the application of a risk reduction factor in line with references [01] and [02]. The system currently in place is manned and operational 24h/day monitoring AIS and Radar signals of navigating vessels in the area of interest, with the ability to contact and provide warnings/instructions to navigating vessels since these are requested to report their position at regular intervals, with reporting positions marked on the charts and to maintain a continuous watch on dedicated VHF channels. This justifies the use of the highest proposed reduction factor of 4.0 for the collision of manoeuvrable vessels, and a reduction factor of 1.1 for drifting vessels in the form of communicative support. The latter is applicable for 98% of drifting ships that can be detected by the VTS system. The combination of these factors will be applied in the model by factoring down powered and drifting allision probabilities respectively by:

- $3.0 \cdot 10^{-4} / (0.98 \times 4.0) = 7.65 \cdot 10^{-5}$ for powered allisions
- $1.0 / (0.98 \times 1.1) = 0.928$ for drifting allisions

The same factors will also be considered for powered and drifting groundings respectively.

The causation factors to be used in the risk analysis are summarised in Table 5:

Table 5: Model Causation Factors

Collisions		Allisions		Grounding	
Merging	$3.00 \cdot 10^{-4}$	Powered	$0.765 \cdot 10^{-4}$	Powered	$0.765 \cdot 10^{-4}$
Crossing	$3.00 \cdot 10^{-4}$	Drifting	0.928	Drifting	0.928
Bend	$3.00 \cdot 10^{-4}$				
Head-on	$3.00 \cdot 10^{-4}$				
Overtaking	$3.00 \cdot 10^{-4}$				

A further risk reduction factor of 1.15 is applied directly to the risk calculated for legs where there is a traffic-separation scheme in place, based on the work of MacDuff [12]. Where legs were only partially part of a TSS and did not lie between successive TSS schemes, this reduction is conservatively not considered.

Also, a risk reduction factor can be applied to the parts of the model where vessels are subject to pilotage. There is a plethora of studies that quantify the impact of pilotage, both in general and area-specific terms. Typically, the effect of pilotage reduces navigational risk to half.

IALA considers additional risk reduction factors for passenger ships and fast ferries. Based on the work of Fujii, the latter have smaller collision probabilities than ordinary merchant vessels. IALA recommends a reduction factor of 20 compared to ordinary merchant vessels, which means that ferries carry 5% of the collision risk of cargo vessels. This is because passenger ferries typically operate with two navigators on the bridge, and also follow standard repeated routes hence the navigators are more familiar with the risks in their area of operation compared to the navigators of cargo vessels. Furthermore, ferries are typically more manoeuvrable compared to cargo vessels and are thus much more effective in performing avoidance manoeuvres.

In debating this with the GDWS, the point was raised that whilst it is agreed that there are navigational and manoeuvrability benefits for passenger-carrying vessels compared to cargo vessels for the reasons mentioned above, these are not present when navigating under very severe weather or over wind Beaufort Force (BF) 8. As we do not have accurate information on whether passenger vessel services are carried out or are suspended under BF8 conditions, the study conservatively assumes that the risk reduction factor of 20 is applicable only in the proportion of the time annually that the weather conditions are below BF8, with a factor of 1 (i.e., no reduction of risk) assumed for the proportion of time where conditions equal or exceed BF8. The impact of this adjustment is minimal since conditions overall exceed the limit of BF8 for 1.78% of the time. This results in a reduction factor of:

- (100.00%-1.78%) x 20+1.78% x 1 = 19.66

2.6.3 ETV stations and consideration in the study

Identifying Emergency Towing Vessel (ETV) stations in the area associated with the model and defining the available tugboats parameters allows the IWRAP software to consider tug intervention in cases of drifting vessels, to potentially avert allisions.

For the North Sea, the study considers four tugboat stations, based on information obtained from research in the public domain and the information provided by the Coastal States. These are presented in Table 6.

Table 6: ETV availability in the study area

ETV	BP (t)	Max. Speed (kts)	Stationed	Stand-by location	BP Displ. (t)
NORDIC	201	19.9	Cuxhaven	BF8: 8nm S of buoy GW/C[4]	268,000
MELLUM	100	16.0	Wilhelmshaven	BF8: 5nm SW of Heligoland	100,000
NEUWERK	114	15.0	Cuxhaven	BF8: 20nm W of Island Suderoogsand	120,000
GUARDIAN	134	15.0	Den Helder	BF5: Always at sea	156,000

2.6.3.1 Tug availability and response time

From the information gathered, the vessels provided in Table 6 are the only active emergency response that can be considered for the study area. It is noted that the ETVs

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[4] ‘nm’ stands for nautical mile equal to 1,852m.

are deployed to their stand-by locations when weather conditions are equal or excess BF8 in Germany and BF5 in the Netherlands.

However, based on the required conditions to perform a successful tow discussed later in the report, the probability of ETVs successfully intercepting vessels ceases at BF8. Therefore, the station positions are used for the German tugs in the model, vs the stand-by locations.

The ETV based in the Netherlands is a vessel patrolling the extent of the Dutch jurisdiction, and thus will not always be available/effective in the area of interest. Its presence in the area of the model in 2019-2020 adds up to a total of 29d 14h approximately. At this time, the vessel appears to be patrolling the waters off Vlieland. Its availability therefore will be considered for 4% of the calendar year, at a location off Vlieland.

In lack of more accurate information, the study assumes that the German tug availability is 7 days per calendar week. However, the tug availability is conservatively assumed to be at 96% based on data from previous studies. This converts to a cumulative downtime of 15 days per year.

Report SO-ER2010.095 - Offshore wind farms - parameters for risk analyses in the approval procedure and effectiveness of collision prevention measures [02] advises that there is a 98% probability of a drifting vessel to be tracked by the authorities using a detective combination of AIS & Radar detection.

The study assumes a response time of 30 minutes, from the time the tug receives the call to the time it mobilises. This is a reasonable response time for an ETV to set off on a rescue mission.

2.6.3.2 Bollard pull capacity

The capacity of ETVs is measured by their rated bollard pull which is the tractor force a tug can exert at zero forward speed in calm water conditions, with the main engine running at 100% of the maximum power output it can safely generate continuously.

There are different factors affecting the capacity of a tug to tow a determined object. These are primarily related to the tug’s propulsion system and design, then to the nature of the tow, its size and shape, and of course the prevailing weather conditions.

Using the bollard pull capacity above, the study set a limit to the largest vessel the tug can be effective against. This was hence used to work out the percentage of the model fleet each tug would be able to successfully intercept.

Requirements for the minimum bollard pull are defined by the Der Norske Veritas (DNV) Rule for planning and execution of marine operations 2015 [04] as the minimum towing force required for open sea towing to maintain zero speed under the following conditions:

- Wind 20 m/s
- Head current 1 m/s
- Significant wave height 5 m

For the present study, tugs are considered effective for the weather window that is equal to or milder than the above parameters.

As seen above there are several factors involved in a tow that requires an accurate assessment for a sound and safe result. However, it is possible to use a simplified formula for the approximate calculation of the required bollard pull as follows [04]:

Bollard Pull = (Displacement (t) x 60 /100.000) + 40

From the above formula, the maximum displacement of the tow at a given bollard pull as presented in Table 7 was calculated.

Table 7: Tug suitability as % of the fleet

Tugboat	Certified BP (t)	Max. Displacement (t)	Percentage of risk model fleet (%)
NORDIC	201	268,000	99.0
MELLUM	100	100,000	85.6
NEUWERK	114	120,000	87.2
GUARDIAN	134	156,000	93.5

2.6.3.3 Tug intervention success probability

The success probability of each tug is calculated based on the following equation:

$P_{s.tug}$ = (% time availability) x (% Probability of identification of drifting vessel) x (% fleet it can intercept) x (% weather window)

The calculated success probabilities for the three tugs are:

- NORDIC: $P_{s.tug}$ = (96.0%) x (98.0%) x (99.0%) x (99.9%) = 93.0%
- MELLUM: $P_{s.tug}$ = (96.0%) x (98.0%) x (85.6%) x (99.9%) = 80.5%
- NEUWERK: $P_{s.tug}$ = (96.0%) x (98.0%) x (87.2%) x (99.9%) = 82.0%

- GUARDIAN: $P_{s.tug} = (4.0\%) \times (98.0\%) \times (93.5\%) \times (99.9\%) = 3.7\%$

2.6.4 Lateral traffic distribution

The introduction of changes in the model, which can occur in the form of channelling traffic from one route to another, merging routes, or altering the alignment of a route, will require an adjustment to the lateral distribution of traffic on the altered routes. This process is of high importance, as the result of the risk analysis regarding powered collisions, allisions, and groundings is heavily dependent on the position of the centreline of the route (leg axis) and the distribution of vessel traffic on either side of this axis. The position of the axis is either dictated by the implementation of the MSP (changes that take place as new developments occupy maritime space) or determined empirically, based on the available space, shallow waters or other obstructions, navaids etc.

German guidelines for the approval of offshore windfarms issued in 2005 [01], and subsequently updated in 2010 [02], require that the lateral distribution of 98% of the traffic on a leg is performed based on Gaussian distribution and 2% based on a uniform distribution. The reference value for the width of the uniform distribution is 6 times the standard deviation. The reference values for the standard deviation (in nm) of the Gaussian distribution at route endpoints are presented in Table 8.

Table 8: Reference values for the standard deviation to be considered in lateral traffic distribution

Fairway Type	Standard Deviation (nm)
Port approach	0.2 to 0.3
Approach points, e.g., navigation marks, buoys	0.3 to 0.4
Traffic separation areas	0.5
Waypoints in wide shipping lanes	0.5 to 1.0
Waypoints in open sea areas	2.0

When changes to the current traffic are considered either in the form of channelling traffic to a different leg or re-routing it to a new track, the diverted traffic will be laterally distributed across the leg in line with the recommendations of the aforementioned German guidelines. The present model mainly comprises routes in the wide shipping lane category. Three different distributions are considered. One with a standard deviation (SD) value of 0.50 nm for traffic through the route corridors formed between development areas in the MSP, and two more for open routes. One with an SD value of 1.00 nm and one with an SD of 0.75 nm, depending on the pre-existing traffic distribution of the pertinent route captured in the traffic density analysis.

For the constituent routes of SN 10, mainly the East and West routes, it is expected that vessels will be using all available space to the extent it is consistent with sailing with the minimum number of course variations. At the same time, where no other measures are introduced, the majority of traffic will maintain some directionality across the waterway. In areas where recommended routes are introduced, navigation about the recommended route becomes more structured, with a pronounced level of directionality that sees the majority of traffic navigating on either side of the recommended route marks, for example, based on direction. Where Traffic Separation Schemes (TSS) are introduced, there is a clear separation between the two directions of traffic, enforced via the separation zone.

In the analysis, standard deviations down to 0.50 nm are used in either direction of non-regulated segments of the routes. The 0.50 nm standard deviation is used on either side of the newly formed routes of the trial scenarios, and transition values between that and the actuals noted in the traffic analysis for routes contributing traffic into the studied system are used where relevant. The 0.50 nm standard deviation value is maintained for traffic on either side of a recommended route. Where TSS schemes are introduced, the standard deviation used for the lateral distribution of traffic is determined by the width of the lane through the TSS system. A standard deviation value of 1/6th of the lane width is used, i.e., 99.7% of crossings take place within each lane, and the distribution is curtailed within the separation zone.

Traffic volumes and composition (vessel sizes and types) will remain the same as in the leg that is replaced, only increased in cases where future risk is considered by a factor that captures the anticipated traffic increase, or where traffic merges or diversion from other legs occurs.

2.6.5 Other considerations

2.6.5.1 Mechanical failure frequency

Mechanical failure frequency is an important parameter to consider in looking at drifting vessel allisions, as it determines how frequently a vessel is expected to be unable to navigate under her own powers and become a vessel not under command.

References [01], [02] tie the probability of a vessel becoming non-manoeuvrable to the failure rate of the propulsion and steering gear. The average failure rate assumed for all ship types is considered as $2.5 \cdot 10^{-4}$ per hour.

A window for adjustment is left however for ships with two or more propulsion units, in terms of using lower breakdown frequencies. These vessels are typically passenger vessels (cruise ships, ferries, high-speed craft, etc.) or special vessels fitted with Dynamic Positioning Systems that operate on a high degree of built-in redundancy in the engine room and hence they have a low frequency of mechanical failure that can leave the vessel out of control.

IALA considers a return period of 1 in 10 years for Ro-Ro and passenger vessels (failure probability per year of 0.1), and one in 1.3 years (failure probability per year of 0.75) for all other vessels. These are the default values in the IWRAP software, which considers the failure probability on an annual basis.

In the present study, the failure rate of the GL guidelines will be used for cargo vessels, and that proposed by IALA for passenger vessels. For the GL recommendation to be used in the model, it has to be converted to an annual failure rate. As a mechanical failure only leads to a drifting vessel during the time the vessel is sailing (ex. Not whilst in port, docked, or at lay-by), we have obtained the annual sailing hours of the non-passenger vessels in the analysis model dataset and obtained information on their total time spent at sea in the time interval of interest from the EMSA Thetis/MRV database[5]. The average time at sea of the non-passenger vessels in our model, weighted by the number of tracks of each in the model over the total extracted was calculated to be 3,718hrs. This suggests an annual failure rate of 0.93, ~25% more conservative than the rate proposed by IALA.

For the present study, mechanical failure probabilities leading to a drifting vessel will be considered as:

- 0.10 failures per year for passenger vessels
- 0.93 failures per year for all other vessels

2.6.5.2 Repair time distribution

Repair time also constitutes a significant parameter in looking at the risk of accidents from drifting vessels. Mechanical failures that will be repaired in time, will constitute a drifting vessel navigable again, thus eliminating the risk. The time it will take for a failure to be repaired, is assumed based on the Samson distribution (Figure 14), in line with the requirements of [01], [02].

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[5] https://mrv.emsa.europa.eu/#public/emission-report

For the first 15 minutes, the probability of a successful repair is zero.

From that point on, and up to the 24h mark from the time of the failure, the probability of the vessel stopping to drift as a result of a successful repair, is calculated from the formula:

$$1 - \left(\frac{1.0}{1.5 \times (t - 0.25) + 1}\right)$$

After the 24h mark, the vessel is no longer considered to be drifting, as if it has not collided or got stranded, it would have been intercepted and secured. The probability thus of the vessel exiting drift becomes equal to 1.

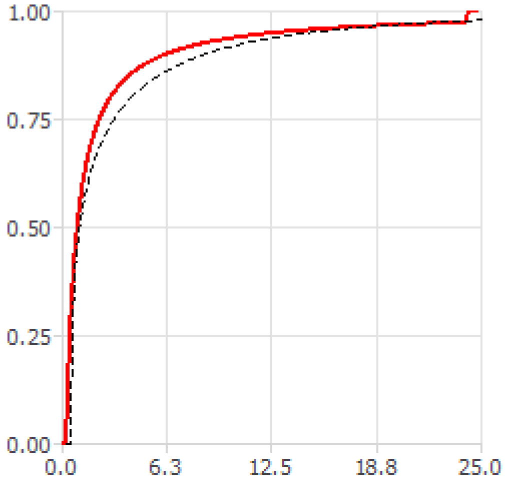


Figure 14:Samson distribution for the probability of successful repair vs time

2.6.5.3 Drifting vessel speed

The drifting speed of vessels is an important parameter in the risk analysis as it will determine the time interval between the time the vessel becomes out of control, and the time it may be intercepted by tugs, re-gain control following a repair, or be intercepted by tugs, before it collides or grounds.

For the purpose of the present analysis, the drifting speeds of the vessels in the set under conditions between BF3 and BF8 were calculated and weighted against the corresponding duration of these conditions in a year. Further, the weighted average for each vessel was weighted against the number of tracks of each vessel in the model over the total extracted. The drift speed for the model was thus calculated to be 1.50 kts.

Drift speeds are also influenced by the intensity of the marine currents, which is added or subtracted from the drift speed vector depending on its direction of action on the vessel's hull. Currents in the study area are of speed lower than 0.33 kts for approximately 90% of the duration of the year, with the weighted average current speed calculated at 0.25 kts. The highest current speeds are noted in the westerly direction, which also applies to the predominant speed of 0.33 kts component is almost equally distributed in all directions.

Considering the effects of the currents, the study conservatively assumes the global drift speed for the model to be at 1.50+0.5·0.33 = 1.67 kts.

It is noted that guidelines [01], and [02] impose a maximum value of 4kts for the drift speed.

2.6.5.4 Emergency anchoring to stop vessel drift

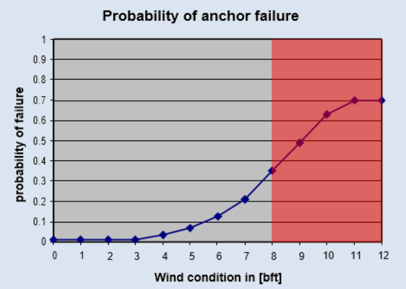
Apart from being intercepted by a tug, or being repaired whilst adrift, a drifting vessel may drop its anchors as a means of stopping if the water depth and seabed permit so.

As anchors do not descend directly under the ship, but some ship lengths away, the anchor needs to grip some distance before grounding or allision to a fixed object. As the length of anchor chains is determined based on the equipment number of a vessel, and thus its size, it is considered that the minimum reasonable value for this distance is 3 times the length between perpendiculars of the vessel.

For the anchor to be able to reach the seabed in this domain, the depth cannot exceed 7.0 times the design draught of the vessel. In waters deeper than that, the probability of successful emergency anchorage is considered zero.

Guidelines [01], [02] provide the following recommendations in terms of the probability of failure of emergency anchorage operations (Table 9):

Table 9: Emergency anchoring failure probability

Conditions	Anchor failure probability	Anchor success probability	
≤BF3	0.010	0.990	
BF4	0.035	0.965	
BF5	0.070	0.930	
BF6	0.126	0.874	
BF7	0.210	0.790	
≥BF8	1.000	0.000	

The above success probabilities, weighted against the annual duration of each set of the weather conditions in Table 9, result in an overall success probability for the analysis model of 0.89.

2.6.6 OWF interaction with marine radars

Concerning the risk associated with radar interference induced by OWF developments, a review of available literature on the issue has been carried out, to identify points of relevance to the current study.

Whilst there is a significant amount of literature on OWF effects on radars and vessel navigation, qualitatively discussing the effects that they can cause such as interference and radar clutter, there is a lack of information directly relating, or able to be used in a quantitative assessment.

It is expected that in the future there will be more information to work with, as with the expansion of offshore wind, and its significance in achieving net zero emissions, significant efforts are being put in by various groups to investigate and mitigate the effects of radar interference. Particularly so from a military/air defence standpoint, with significant funding for example being awarded in the UK to such projects as part of the 'Windfarm Mitigation for UK Air Defence' competition. In the US, a similar initiative has been established, the 'Wind Turbine-Radar Interference Mitigation Working Group'.

Much of the research currently available, proposes mitigation measures which are thought to reduce the risk to an acceptable level that does not significantly compromise marine navigation or safety. The risk itself is mainly seen in the potential for accidents involving small vessels, on which AIS is not compulsory/available. For larger vessels, AIS can be used to verify vessel positions, and avert collisions between them.

The UK Marine and Coastguard Agency (MCA) in the early 2000s, run a programme intended to investigate the effect of OWFs on marine positioning and communications systems in operational scenarios. As part of the trials for this programme, all practical communications systems used at sea and with links to shore stations, shipborne and shore-based, radar, position fixing systems, and the Automatic Identification System (AIS) were assessed.

The results of this in-field assessment found the effects on the majority of systems tested not to be significant enough to affect navigational efficiency or safety. The exception to that was the effect of OWFs on shipborne and shore-based radar systems. It was found that interference could be reduced by reducing receiver amplification (gain) which, however, would also reduce the amplitude of other received signals such as the ones emitted by small vessels, buoys, etc. within or close to the OWF, to the extent they may not be detectable. It was also noted that the performance of a vessel's automatic radar plotting aid (ARPA), could be affected when tracking targets in or near an OWF.

At around the same time, QinetiQ performed further trials, on various navigational aids, amongst which the radar shadowing effect was investigated. The radar shadowing trials resulted in very little evidence that shadowing of targets would present any significant problems, and the field effect proved less than what the theoretical study that preceded the testing had predicted. Whilst clutter was observed both in the form of ring-around and false plots, it was observed that problems could be suppressed by successfully adjusting the gain. The latter mitigation, however, corroborated the findings of the MCA, in that some smaller targets could not always be detected.

The AIS systems function was found undisturbed in both trials. Further information on this work may be found in the original proprietary publication [16]. This work fed into the development of the MCA guideline MGN 371 (M+F) [17], which considers the risk of navigation to a distance smaller than 0.45nm from the boundary of an OWF as intolerable, as a result of radar effects, whilst distances between 0.45nm and 1nm entail tolerable medium to high risk, subject to adherence to COLREGS and respecting vessel domains. Distances above that are considered low risk.

Another study performed in the UK [19], notes that not all vessels showed effects from the wind farm on their radar. However, some pilots were concerned that 'spurious echoes' from wind farms could cause actual targets to be missed. Many of the radar effects seen were also caused due to the positioning of radar scanners on vessels, causing more reflections and other effects. This was also reflected in the navigational risk assessment carried out for Hornsea 3 OWF, and these effects and reflections can also be seen if passing vessels provide reflective surfaces. This is, therefore, more likely in areas with more vessels and heavy traffic, such as where many vessels are re-routed onto the same routes. It is stated in this risk assessment that the main issues are caused when there is also reduced visibility as mariners cannot confirm visually the presence of other nearby vessels.

Steamship Mutual, a Protection & Indemnity insurer, as part of their loss prevention risk bulletins to members, provide guidance on 'Navigation in the vicinity of offshore renewable energy installations' [18], highlighting that radar returns from wind farms are quite strong, however at close range (from approximately 1.5nm), they can produce multiple echoes which could hide real radar targets. The note proceeds to recommend that 'it would be prudent for vessels when engaged in passage planning to lay off courses at least 2 nautical miles clear of windfarms.'

A recent study, Wind Turbine Generator Impacts to Marine Vessel Radar, published in 2022 by the National Academies of Science, Engineering and Medicine [21], concluded that wind turbines in the maritime environment affect marine radar with the most common impact being a substantial increase in strong, reflected energy cluttering the operator's display, leading to complications in navigation decision-making. The study also recommended to focus and improve research on wind turbine generator and mitigate interference using radar reflector on small vessels, introducing reference buoys and new radar designs optimized for operation in windfarm environments, and developing turbine generators with reduced radar signatures.

This interference might also cause disturbance to VTS radars, which are similar to marine radars fitted on ships when the false echo phenomena generate a blind sector and targets on the same bearing cannot be detected and visualised on the plan positioning indicator (radar screen). However, an experienced radar observer, like a certified radar operator, can spot the false echo present on the radar screen and he will therefore apply extra cautions in the interpretation of the echoes shown in the vicinity. When the hypothetical echo moves, or due to its relative motion misaligns with the bearing at which the false targets are generated, it will reappear on the radar screen as a single echo and the observer will be able to confirm its actual presence in the sea.

However, keeping a distance of approximately 2nm from the windfarm turbines would allow the observer enough time to take countermeasures in case such phenomena had taken place.

In other parts of the study[6], areas were encountered where navigational traffic is using the space in the proximity of OWFs. Vessels on the current ferry route from Swinoujscie to Ystad for instance, navigate at distances down to 1nm from the boundaries of the Arkona and Wikinger OWFs. Looking at navigation that crosses the EnBW Baltic 2, a distance of as close as 0,7nm, whilst at the EnBW Baltic 1 OWF, vessel traffic appears to navigate as close as 0.4nm on either side (north/south). Considering these levels of proximity, especially in the case of the latter two, it is bound that some radar scatter will be experienced by vessels transiting the relevant routes, especially in the case of EnBW Baltic 1, where two routes are found converging to the west of it. The HELCOM accidents database currently does not record any incidents in the vicinity of these windfarms, which are the longest in operation within the model.

For the North Sea area, the situation is different as several routeings are defined with a width of just over 3nm and therefore cannot entail the minimum distance of 2nm on both sides of the so created channel. However, where the highest trafficked area is considered, such as the route SN 10 is, the minimum distance between any shipping lanes and the boundary of the OWF should be considered over 2nm.

2.6.7 Future Traffic

2.6.7.1 Traffic growth projection

For a projection of maritime traffic in the North Sea between now and 2040, a literature review was undertaken. The most recent and reliable information comes from the ITF Transport Outlook 2021 published by the Organisation for Economic Co-operation and Development (OECD) [03].

The report points out that freight demand grows at a slower rate than previously estimated and reported in the relevant 2017 and 2019 reports. This is attributed to the effects of the pandemic, and the period that followed with the re-opening of the markets that highlighted the need for more robust and more local supply chains, thus lower average distances. The relevant projection, forming the “recover” scenario, sees the annual compound growth rate

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[6] HHR22475 - Study on shipping traffic flows in the North and Baltic Seas - WP1, Report 1, 01 DEC 2022.

between 2015 and 2050 at 2.7%, substantially lower than the pre-pandemic 3.4% projection of the 2019 report (3.3% through 2030, and 3.6% through 2050).

Two further scenarios in addition to the “recover” scenario are explored in the same document. The “reshape” and the “reshape+” scenarios. In the reshape scenario, “*governments adopt transformational transport decarbonisation policies in the post-pandemic era. These encourage changes in the behaviour of transport users, uptake for cleaner energy and vehicle technologies, digitalisation to improve transport efficiency, and infrastructure investment to help meet environmental and social development goals*”. In the “reshape+” scenario, “*governments seize decarbonisation opportunities created by the pandemic, which reinforce the policy efforts in ‘reshape’*”. Also considers the influence of decisions not directly related to transport, but constitute influencing factors, such as the regionalisation of trade as a result of near sourcing to improve resilience.

For the “reshape” and “reshape+” scenarios, the forecasted growth is even slower compared to that of the “recover” scenario, with annual compound growths of 2.4% and 2.1% respectively. For Europe, in specific, the drop in the growth rate in the latter scenarios is foreseen to be even higher, due to its current heavy reliance on fossil fuels.

Isolating maritime trade from the above figures, based on the downloadable data behind figure 5.8 of the same report, the forecasted annual average growth rate for shipping freight demand is calculated to be 3.7%, 2.4%, 2.3% respectively between 2020 and 2030, and 2.9%, 3.0%, 2.5% respectively between 2030 and 2050.

Considering the narrative of the scenarios of the OECD report, as well as the acceleration of the process of lowering dependency from fossils adopted by EU countries following the invasion of Ukraine in February 2022 that succeeded the OECD report, reshape+ appears to be the most reasonable scenario to assume in the study.

On this basis, with the baseline year of the model being set at 2031, an increase of the current maritime trade demand of the order of 29% from 2020 is forecasted.

In practice, this demand increase between now and 2031 is not expected to fully convert to additional vessel journeys, as part of it can be satisfied by changes in the size and design of merchant fleet vessels. Whilst the latter is not easily quantifiable, it is estimated that the replacement of currently ageing assets and improved efficiency of new designs, will allow optimisation of the carrying capacity of vessels by roughly 10% without changes in size. The effect of this will reduce the required growth factor to an additional 17% on the current.

Vessels are also expected to keep increasing in size, but not to the rate of increase we witnessed since the turn of the century. Stock trafficking in the North Sea main hubs, where spatial restrictions are expected to be a limiting factor in adapting infrastructure, is expected to undergo a milder change in dimensions compared to the rest of the global fleet. We estimate that in the next two decades, this change will not exceed 5% (compared to the 10% - 15% envisaged for the global fleet). This reduces the vessel number increase requirement by a factor of 1.16.

Based on these parameters, the total adjustment factor to merchant traffic to reflect traffic in the year 2031 is expected to be an increase in the number of journeys of 1% compared to the 2020 figures.

Work vessel traffic in the area of interest to the study is mostly influenced by the development of the offshore windfarm industry. Existing vessel traffic is expected to be maintained, and additional traffic will be introduced as new facilities are constructed and then operated. As new developments move away from the coast into more remote offshore locations there will be a tendency towards the utilisation of larger CTVs and OSVs.

To consider the effects of this additional traffic, an exercise was undertaken based on the area measurements of the nominated areas for OW development. The study assumes that 90% of the areas nominated for OW development on the MSP will be covered by Wind Turbine Generators (WTGs). Each WTG is assumed to occupy 1 square km, and each 50 WTGs to be serviced by a single CTV/OSV vessel for 250 days per calendar year for light operational inspection and maintenance. It is also assumed that 10% of the WTGs will require some form of heavier maintenance or component exchange annually, which will require one jack-up vessel return trip per 3 such WTGs, and 1 trip of an OSV per 3 such WTG to be carried out. This applies to the developments to the east branch of route SN 10, and potentially to developments within the footprint of SN 10. Developments to the west of SN 10, where daily transit of CTV vessels is not sensible from a journey time perspective will either be serviced by helicopters in the future, or by OSV vessels that will transit to the facility on weekly campaigns, stationing there, and use CTVs to access the WTGs. For these developments, spreads of 1 OSV and 2 CTVs per 50 WTGs were considered on weekly return journeys.

For Oil & Gas service vessel traffic, the only point of relevance to the study is the crossing of vessels from Esbjerg to the Danish offshore fields. The pertinent traffic in the Netherlands is at a distance that does not influence the Route SN 10 system. There are different viewpoints on the future of Oil & Gas facilities in the North Sea overall, however, for the study, and in the lack of specific information on the long-term plans for the Danish fields, it is assumed that the 2020 traffic will remain in place.

2.6.7.2 Additional O&M traffic for the new developments

In addition to the above, traffic will also be generated by the development of the OW areas, in the form of Operation and Maintenance (O&M) traffic. Whilst it is difficult to predict what this traffic will be and where it will originate from, as a lot of the areas considered in the MSP are at distances from the shore well beyond the ones of existing offshore wind installations, for the study we used best endeavours to come up with a reasonable assumption.

In the process, we consulted our colleagues in ABL that currently support O&M activities to obtain their best insight in terms of how such campaigns could look in the future, and what is the best way to quantify the relevant traffic. Their opinion was that the development areas as shown on the MSP, would either be serviced from vessels out of the ports of the Ems estuary or Esbjerg, depending on which facility is placed closest to each development area. For areas that are effectively equidistant from the two, the assumption is that the ports of the Ems estuary will be the preferred option.

For the spread considered for the O&M campaign for each structure, the requirements were derived based on forecasted numbers of WTGs per plot, and the feasibility or not, of deployment of a jack-up vessel with respect to the water depths and the distance from the project port.

To estimate the number of WTGs, a 90% coverage was assumed for the development areas (the remaining to be used for access corridors and safety zones), and subsequently 1 WTG per square km of developed area. This is in line with current estimates, and whilst it may be the case that modern WTGs in a decade will be larger and thus occupy more than 1 square km each, it constitutes a conservative assumption in terms of overestimating the number of WTGs to be visited in the traffic calculation.

For developments that are considered accessible from a home port in a way that a normal regime with CTV and jack-up vessels can operate the following is assumed:

- Light inspection and maintenance: 1 CTV vessel per 50 WTGs for 250 round trips in a calendar year.
- Heavier component maintenance: 1 Jack-up vessel trip and one CTV trip per 3 WTGs, for 10% of the installed WTGs per annum. One OSV trip per WTG for 10% of the WTGs per annum.

For developments that are further away from the shore, or in deep waters where the aforementioned approach is not feasible, a different O&M activity regime was assumed. A light inspection would be conducted by CTVs running to and from OSV vessels stationed in the field on week-long campaigns. Better equipped CTVs are also expected to replace jack-ups in heavier component exchange operations. Thus, the following is assumed.

- Light inspection and maintenance: 2 CTV vessels and 1 OSV per 50 WTGs for 36 round trips in a calendar year, to support week-long campaigns in-field.

- Heavier component maintenance: 1 additional CTV per 3 WTGs for 10% of the installed WTGs per annum, in addition to the ones operating in-field as overnight stations for the light maintenance operations.

A summary of the additional trips considered as a result of O&M operations is presented in Table 10:

Table 10: Summary of O&M operations induced trips added to model legs

Cluster	Combined Area (km^2)	Forecasted WTGs (90% coverage)	CTV trips/year	Jack-up trips/year	OSV trips/year	Route
EN 11, EN 12, EN 13	1136	1022	5034	34	102	Esbjerg via DT SB 01-06A
EN 8, EN 10	448	403	2013	13	40	Ems via SN 3 -> SN 5 01-02 -> SN 13 01 -> TO EN 08
EN 6, EN 7, EN 9 - existing	1199	952	4782	32	95	Ems via SN 3 -> SN 5 01-02 -> SN 13 01 and SN 3 -> SN2 06 -> SN 12
EN 14	145	131	220		112	Ems via SN 3 -> SN 5 01-02 -> SN 13 01-03 -> SN 15 02
EN 15	137	123	148		76	Ems via SN 3 -> SN 5 01-02 -> SN 13 01-03 -> SN 15 02
EN 16	295	266	369		189	Ems via SN 3 -> SN 5 01-02 -> SN 13 01 -> TO EN 04
EN 17	83	75	147		75	Ems via SN 3 -> SN 5 01-02 -> SN 13 01 -> TO EN 04
EN 18	105	95	147		75	Ems via SN 3 -> SN 5 01-02 -> SN 13 01 -> TO EN 04
EN C1	465	419	2014	14	42	Ems via SN 3 -> SN 5 01-02 -> SN 13 01-03
EN C2	244	220	1007	7	22	Ems via SN 3 -> SN 5 01-02 -> SN 13 01-03
EN C3	479	431	2264	14	43	Esbjerg via SN 15 11-04
EN A1 1	466	419	2014	14	42	Ems via SN 3 -> SN 5 01-02 -> SN 13 01-03
EN A1 2	629	566	2769	19	57	Ems via SN 3 -> SN 5 01-02 -> SN 13 01-03
EN A1 3	468	421	2014	14	42	Esbjerg via SN 15 11-04

In the classification of the above trips in terms of vessel types and sizes, parameters from the latest existing plant used in such operations were considered:

- CTV was considered of 24m LOA, based on recent Seacat models

- OSV was considered of 91m LOA, based on the vessel REM Energy, which was delivered in early 2022, built to serve on a maintenance-SOV charter for 5 years.

- Jack-up vessel was considered of 141m LOA, based on the JDN Vol au Vent.

3 TRAFFIC STUDY – ROUTE SN 10 BROADER AREA

This chapter aims to report the traffic patterns, identify the traffic corridors and their distribution, and provide an understanding of the current use of maritime space.

3.1 General

The traffic density plot which reflects the existing patterns in the south-eastern part of the North Sea, in the area surrounding route SN 10, the main access from the northwest-coast European transport hubs and the Atlantic into Skagerrak and the Baltic Sea is presented in Figure 15 below. The plot is based on 2019 and 2020 AIS data:

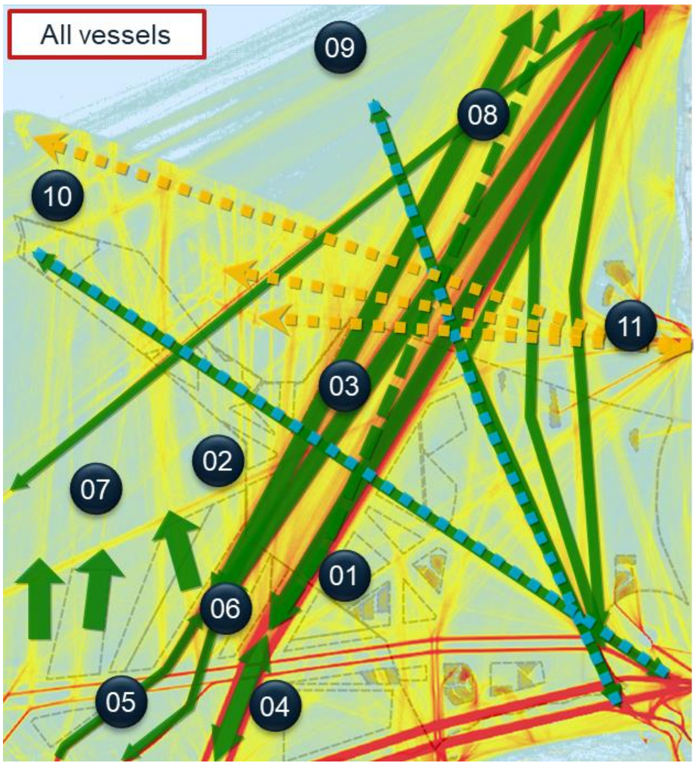


Figure 15: East North Sea Traffic, all vessel types – Density Plot 250m x 250m.

Route SN 10 is perceived to comprise two distinct traffic corridors. The eastern branch/route, which typically carries General Cargo, Ro-Ro Cargo, and small to medium Tankers (Note 01), and the western branch/route which constitutes the route followed by vessels intending to proceed towards the deep-water route Off Skagen (Note 02) and carries larger Tanker and Bulk Carrier Assets. There is a notional third, distinct spur route (Note 03) that connects the southern end of the deep-water route to the northern end of the eastern route.

The presence of the latter is attributable to the fact that the southern end of the Eastern traffic route coincides with the end of the main route out of the Dutch hub ports of Amsterdam and Rotterdam through TSS Off Vlieland (Note 04), and the southern end of the Western route coincides with the end of the Atlantic route through TSS West Friesland

(Note 05). Vessels from the latter that do not require the deep-water route, opt for the shortest, tight passage to Skagerrak, thus gradually spurring to the East as they transit route SN 10. This, combined with the fact that vessels coming from TSS Off Vlieland divert to the West to follow the Northern route (Note 07), creates an area at the southern end of SN 10 where vessel traffic is crossing and merging (Note 06).

At the North-western end of SN 10, there is a second notional spur corridor forming, with vessels leaving the deep-water route to join the Eastern route (Note 08). Vessels appear to join the Eastern route as early as the intersection with route SN4 (Note 12) or as late as the southern end of SN 10.

Route SN 10 within the German jurisdiction is crossed by two main routes out of the ports of Hamburg and Bremerhaven. The first corresponds to Route SN 7, which carries SE-NW traffic through the German Bight (Note 09). Part of this traffic joins Route SN 10 to/from Skagerrak, whilst a small part of this traffic crosses to the North of the Danish offshore installations to head towards the Northern Passage. The second (Note 10) is of far lesser traffic volumes and follows Route SN 4 crossing the main route SN 10 almost at right angles, carrying traffic headed towards the Northern Passage, or the Scottish coasts.

A further significant crossing point to route SN 10, occurs at the boundary between Danish and German Jurisdictions, and to its immediate North (Note 11), where vessels out of Esbjerg cross the main route to serve the Danish offshore installations to the West of SN 10.

3.2 Merchant traffic

Merchant vessel traffic typically uses the primary routes described in the general section, however, there are also secondary corridors that are of significance to this traffic. These are presented in Figure 16 overleaf.

The point annotated as 12 on the figure, presents the point where traffic from the ports of Hamburg and Bremerhaven merges before vessels follow their intended courses to the North-west and North, or the West via TSS East of Friesland or TSS Terschelling – German Bight.

North-west-bound vessels, typically follow the routes denoted as 09 and 10 in Figure 15, discussed earlier. Traffic on these routes comprises predominantly Container and General Cargo Ships, with notable Bulk Carrier and Tanker traffic.

North-bound vessels, use three distinct routes to navigate to the North from the German ports of Hamburg and Bremerhaven. The westernmost aligned route (Note 13) uses the SN 7 corridor until the area just before crossing SN 10 East, where vessels veer to the East to join the latter. The main users of this route appear to be Bulk Carriers and General Cargo Ships.

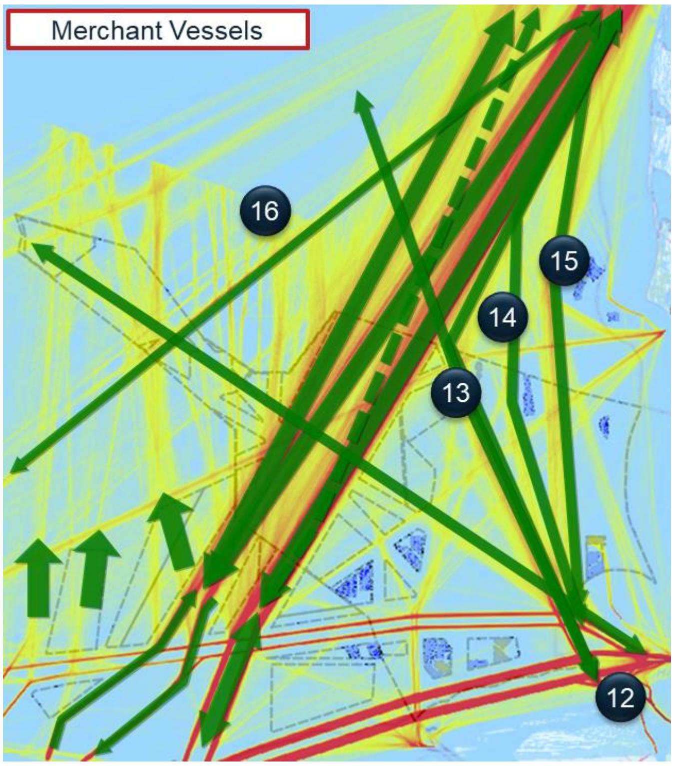


Figure 16: NE of North Sea Traffic, merchant vessels – Density Plot 250m x 250m.

To the East of the former, between OWFs Sandbank and Dansk Tysk, a second N-S route is running, aligned with SN 08 (Note 14). This route is trafficked less compared to that of SN 07 and is typically used by smaller vessels, with General Cargo Ships being the primary user.

The third N-S route, to the East of OWF Dan Tysk (Note 15), is the one that carries the highest traffic volumes of the three. Route SN 09 is primarily used by Container and General Cargo Ships, and also sees substantial Ro-Ro Cargo traffic. This route is the most direct route to the North out of the German Ports.

To the West of SN 10, there is a converging SW-NE route that joins SN 10 at the entrance to Skagerrak (Note 16), which carries traffic from the UK Ports of Hull and Immingham. Ro-Ro Cargo vessels are the predominant user of this route, whilst there is also substantial General Cargo Ship traffic noted.

3.3 Passenger traffic

Passenger vessel traffic is not a key contributor to vessel traffic in the area of the study. Most passenger traffic noted pertains to Cruise Ships operating out of Hamburg, with smaller passenger ferry traffic noted near the German coastal zone. These routes are presented in Figure 17.

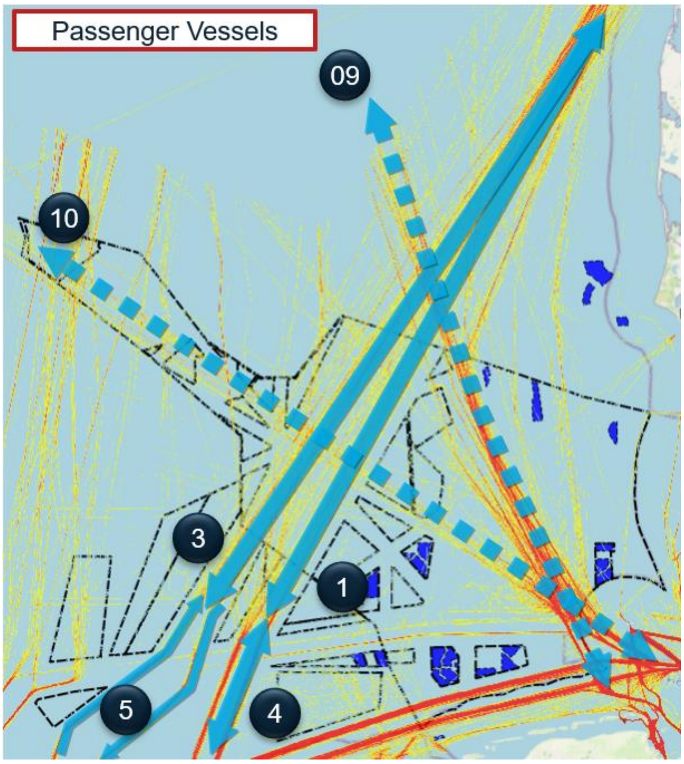


Figure 17: NE of North Sea Traffic, passenger vessels – Density Plot 250m x 250m.

Passenger vessels typically use the same routes as described in the general section. Most traffic enters/leaves the area from the main route out of the Dutch hub ports of Amsterdam and Rotterdam through TSS Off Vlieland (Note 04), and the southern end of the Western route coincides with the end of the Atlantic route through TSS West Friesland (Note 05). The latter veers way to the East once it joins SN 10, away from the deep-water route (Note 03), navigating the shortest distance to Skagerrak (to join Note 01 North).

Cruise ships also use route SN 7 (Note 09) towards the Norwegian coastline, and route SN 4 (Note 10) to navigate toward the North Atlantic.

3.4 OWF support-vessel traffic

Support vessels operate heavily in the area of interest, although not directly using route SN 10 in large volumes. Support vessels typically operate out of regional project-home ports, to the offshore facilities they serve and back, on frequent repeatable patterns (Figure 18). The exception to this relates to the tracks noted at the southern end of the figure, where the relevant traffic coincides with the main merchant traffic corridors. These tracks, however, most likely correspond to mobilisation journeys from the vessels' base ports (usually in the Netherlands or Belgium) to project ports.

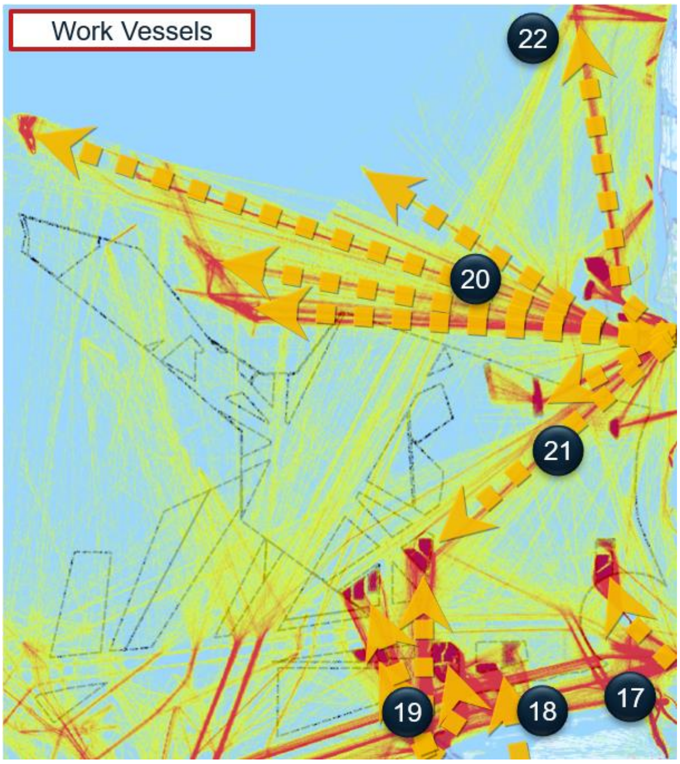


Figure 18: NE of North Sea Traffic, Support vessels – Density Plot 250m x 250m.

Note 17 shows Service Vessel traffic out of Cuxhaven and Helgoland to the OWFs within development area EN 04. OWFs within the development area EN 03 are typically served by vessels operating from Norddeich and Norderney (Note 18), whilst all other existing developments of the southern part of the German Bight (incl. EN 02, EN 06, EN 08) are serviced by vessels operating out of the aforementioned two ports, as well as Emden and Eemshaven in the Netherlands (Note 19).

Key routes operated by Service Vessels also originate from the Danish port of Esbjerg. The main routes are associated with the Danish offshore O&G developments to the west of Route SN 10 (Note 20). The safe accommodation and consolidation of these routes into a single crossing route as the future German and Danish MSPs materialise will need to be addressed in the future.

OWFs in the northern part of the German jurisdiction are typically served out of Esbjerg and Romo Havn (Note 21).

Additional service vessel traffic is also noted out of Esbjerg to the North (Note 22). This traffic may potentially be transit traffic towards the Baltic Sea or vessels associated with the development of the Danish energy island (although traffic to the latter is understood to originate primarily from Ronland.

3.5 Fishing vessel traffic

The assessment of fishing fleets is always a challenging task since AIS data available cannot include the entirety of the fishing vessels, being these commercial or recreational and not mandatorily compliant with AIS.

The current model includes a total of 929 vessels reported as ‘fishing’ in two years’ worth of data. The areas of transit for these vessels are presented in Figure 19.

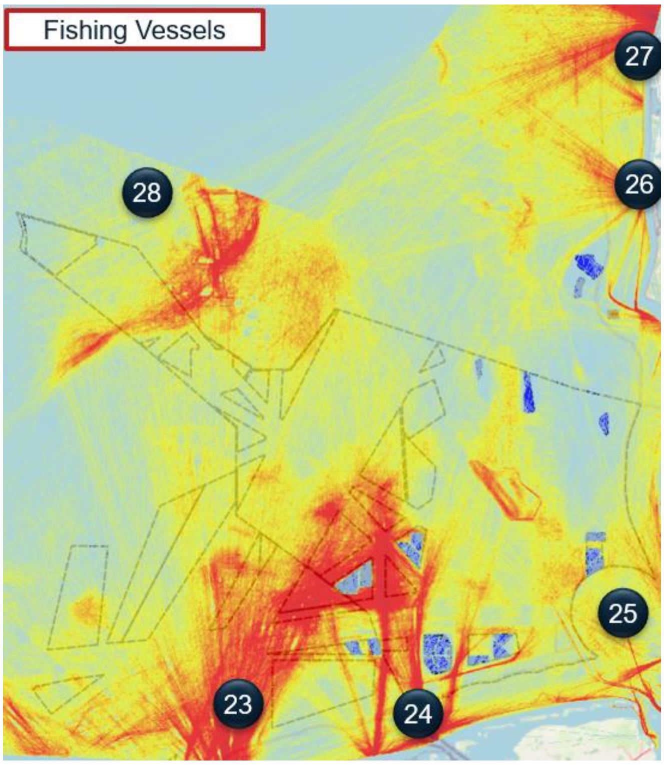


Figure 19: NE of North Sea Traffic, Fishing vessels – Density Plot 250m x 250m.

Vessels categorized as fishing vessels in the dataset, only appear to use the area of main traffic corridors in the southern part of the model. Fishing vessels operating out of the western coast of the Netherlands were noted to use the area between TSS Off Vlieland and the southern end of SN 10 (Note 23), and part of the space between the existing OWFs of the southern German Bight.

Vessels from the Northern Dutch and North-western German coastline, are noted to transit in the space between the existing OWFs, using routes SN 3 and SN 11 (Note 24). Limited transit activity from Fishing vessels is also noted out of the approach to Hamburg, in the area around and to the NW of Helgoland (Note 25).

Further North, off the Danish coast, Fishing vessels appear to operate out of Hvide Sande (Note 26) and Thyboron (Note 27).

Last, the transit of fishing vessels was noted around and to the West of the Danish offshore installations, most likely attributable to vessels from the UK East coast (Note 28).

To relate fishing traffic to fishing activity, ABL performed a speed analysis and plotted the density diagram for fishing vessel traffic at a speed of ≤ 5 kts. The result of this assessment is presented in Figure 20.

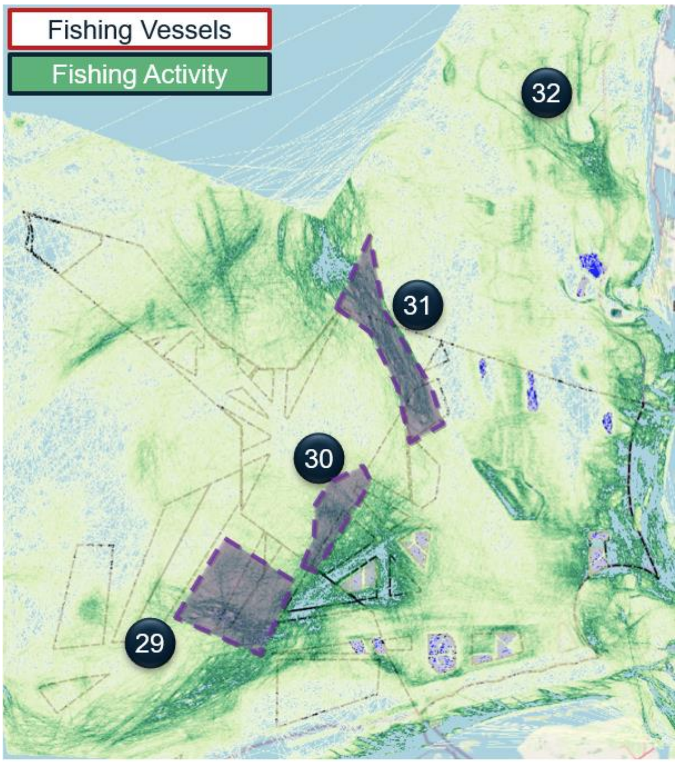


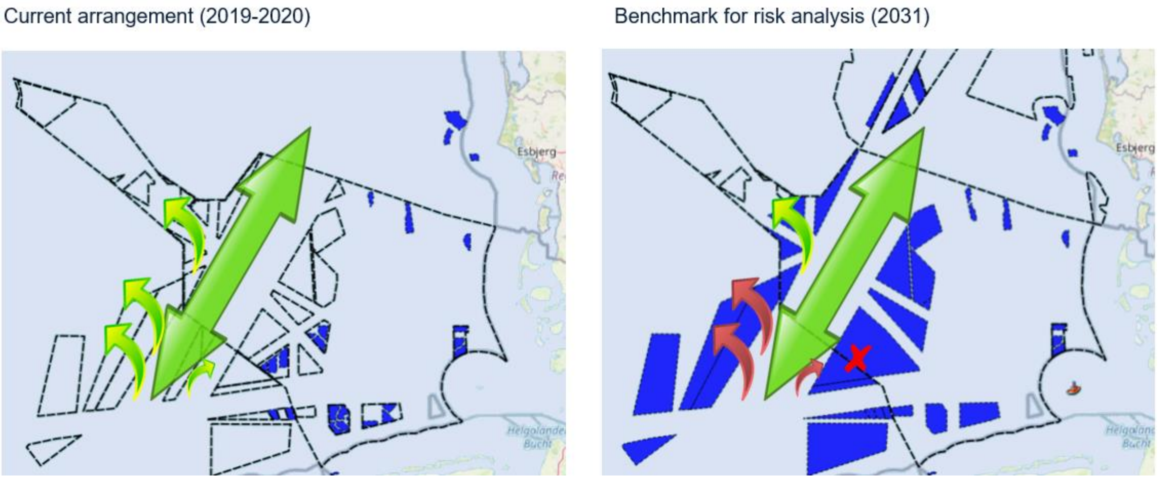
Figure 20: NE of North Sea Fishing Activity, Density Plot 250m x 250m.

4 NAVIGATIONAL RISK ASSESSMENT ON ROUTE SN 10

4.1 Main scenarios for the analysis

The fundamental step in assessing risk is to identify the current risk in the system before any spatial introduction would affect the free navigation in the area of interest, which would allow the study to understand what the current situation is, and thus assess the impact of changes. For the present study, however, the considered options constitute the final development stage, which will be implemented after the eastern and most of the western boundaries of route SN 10 have been developed for offshore wind. Based on the extended preliminary design site development plan published by the BSH in April 2022 [20], this point in time was placed in 2031.

In the process of development of the model, this entails that the model representing the current situation had to be modified to reflect the layout of route SN 10 in 2031, before the addition of offshore wind developments in the current footprint of the route. The main changes to the east, are the full development of OWFs along the eastern boundary of route SN 10 in the German and Dutch EEZs, including the blocking of route SN 6. On the west, the changes assumed are the development of the nearest OW clusters to the western boundary of the route in the German EEZ, and the development of areas Gebied 6 and Gebied 6 extra in the Dutch EEZ. It is noted that there is no finite plan to develop the latter at the moment, however, their development would limit the ability of vessels to leave the route from within the Dutch jurisdiction, and this would constitute the most conservative scenario in terms of traffic volumes within the German jurisdiction. This would leave a single gate to/from the Northern Sea Route via SN 17. Also, in consultation with the DMA, three hypothetical development plots were added to the Danish EEZ, to represent the boundary conditions that will be formed on either side of the deep-water route and the extension to route SN 7. The model of the existing situation and the model used to analyse the benchmark scenario are presented in Figure 21 below.


Current arrangement (2019-2020)

Benchmark for risk analysis (2031)

Figure 21: Risk Analysis Model, Benchmark Scenario (2031)

The benchmark scenario will form the basis for the relative assessment of the risk increments introduced by two others, distinct scenarios for the development of additional OWFs within the footprint of route SN 10. Scenario A1, with additional development areas on the eastern boundary of the route, and Scenario C, with additional development areas at the centre of the route (Figure 22).

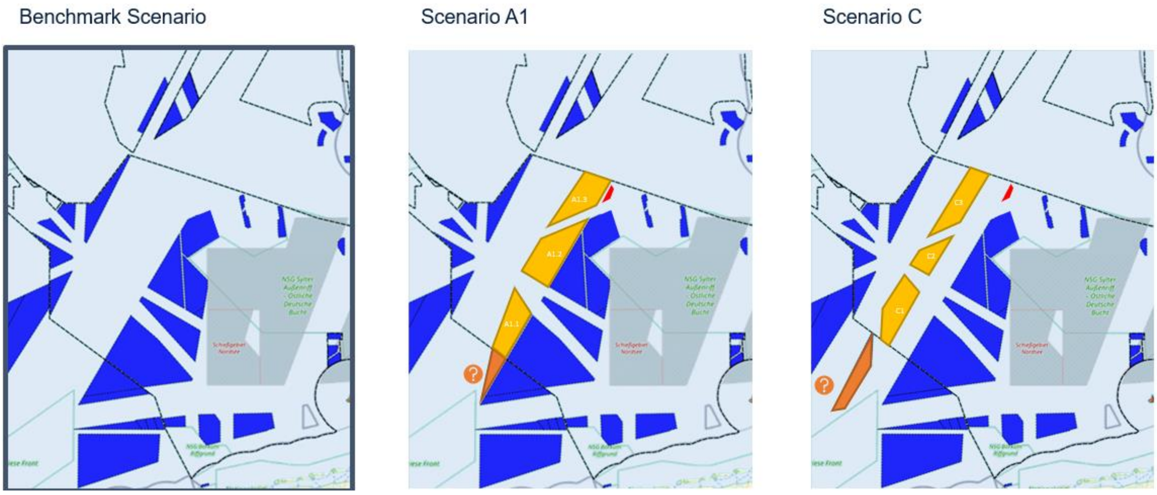

Benchmark Scenario
Scenario A1
Scenario C

Figure 22: Alternative scenarios for OW developments within the footprint of route SN 10

Scenario A1 comprises three additional development areas compared to the benchmark. Area A1.1 adjoins the combined area formed out of EN 6, EN 7, and EN9; area A1.2 adjoins the boundary of area EN 12 and area A1.3 standing north of route SN 15 and west of route SN 7. The model also assumes that the southern boundary of area A1.1 will be mirrored on the Dutch side of the border, with the formation of a new triangular area that closes out on the SW corner of Gebied 5 Oost & 5 Oost SF.

Scenario C also comprises three additional development areas compared to the benchmark. All three areas C1, C2, and C3 are placed as a middle berm in the route footprint, separated by routes SN 4 (and SN 13) and SN 15. The scenario also assumes one additional middle berm area developed in the Dutch jurisdiction, Gebied 5 middenberm.

It is noted that whilst the risk model will calculate risk in the full extent of the modelled area, the allision risk results should only be considered to be reliable for the area within the German EEZ in and around route SN 10. As a result, allision risk in the present report will be reported for the development areas in German EZZ only. The study will not advise or directly comment on the feasibility of proceeding with the implementation of the developments but will provide the level of risks yielded by the model for information to aid a decision by the German authorities.

It is also noted that the 50y and 100y return period criteria of the GL guideline for the feasibility of individual developments (from an allision risk perspective) should not be considered directly applicable to the planning development areas. This is mainly due to the vast differences in size. Development areas as per the MSP, will each form a cluster of developments, each of which will have to be assessed individually as part of the permitting and consent process.

To better enhance understanding concerning the implication of the size of a development area, the risk is reported both as an absolute value – annual allision probability – for each area, as well as a “risk intensity” – annual allision probability per km^2 of development area – for each area in the model. The absolute value is also reported in the form of a return period between events. As a measure for comparison, calculated annual allision risk intensities for development area EN 2 are also presented at the bottom of the relevant result tables. EN 2 has been chosen as a measure, as the plot is fully developed, and lies between two highly trafficked routes, SN 1, and SN 2. Risk intensity for EN 2 was calculated from a separate model comprising routes SN 1, SN 2, and the traffic in the space between them, used as part of an ad-hoc study on diversion scenarios presented later in the report (section 7.1).

A similar approach is used in terms of the reporting of the ship-to-ship collision risk for each of the legs comprising the model, with the risk intensity reported in terms of annual collision probability per km or route.

4.1.1 Benchmark Scenario

As per the explanation provided in the previous section, the main feature of the benchmark scenario is the presence of developments to the east and west of SN 10. The former, through the blocking of route SN 6, entails the diversion of the traffic using SN 6 to follow the Eastern route of SN 10 up to the junction with SN 15, and subsequently follow SN 15 to Esbjerg and the East side of the German Bight. To the west, the main implication is that vessels leaving/joining SN 10 just to the north of the junctions of SN 2 with TSS West Friesland and the projection of TSS Vlieland Noord are now limited, and thus have to use route SN 17 to enter/leave route SN 10. This is a notable intervention, as there is a substantial number of vessels (mainly Tankers and General Cargo vessels) that currently use the maritime space west of SN 10.

The analysis of the benchmark scenario model identified an annual combined allision probability of 1.674, which converts to a return period of just over 7 months. The risk profile of the area of interest in the German EEZ is presented in Figure 23 overleaf.

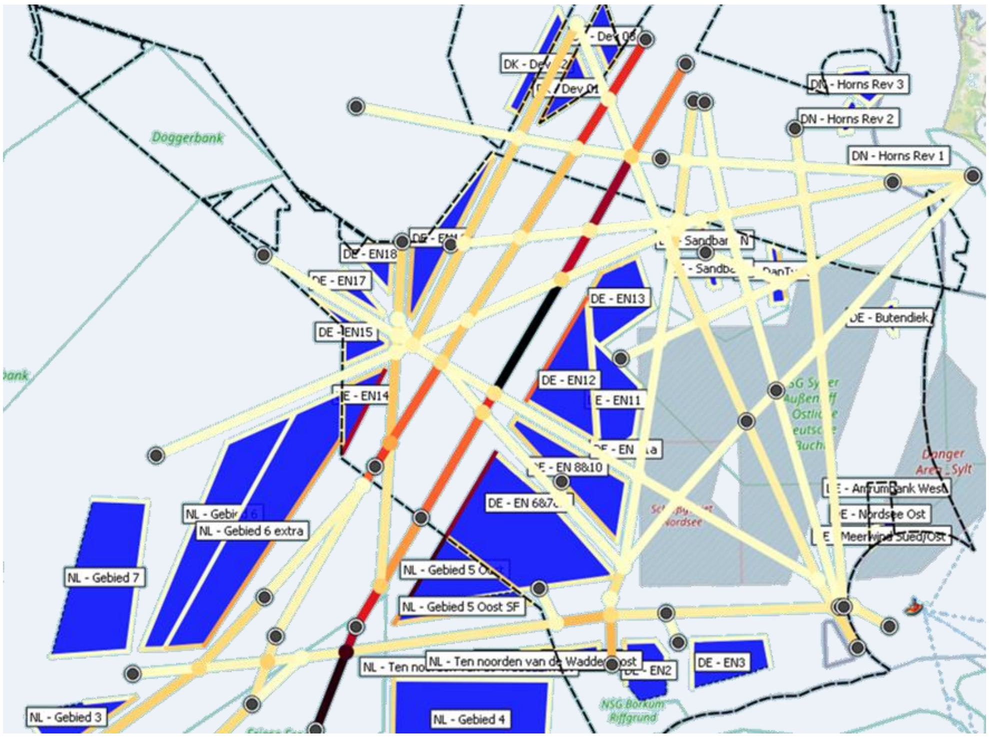
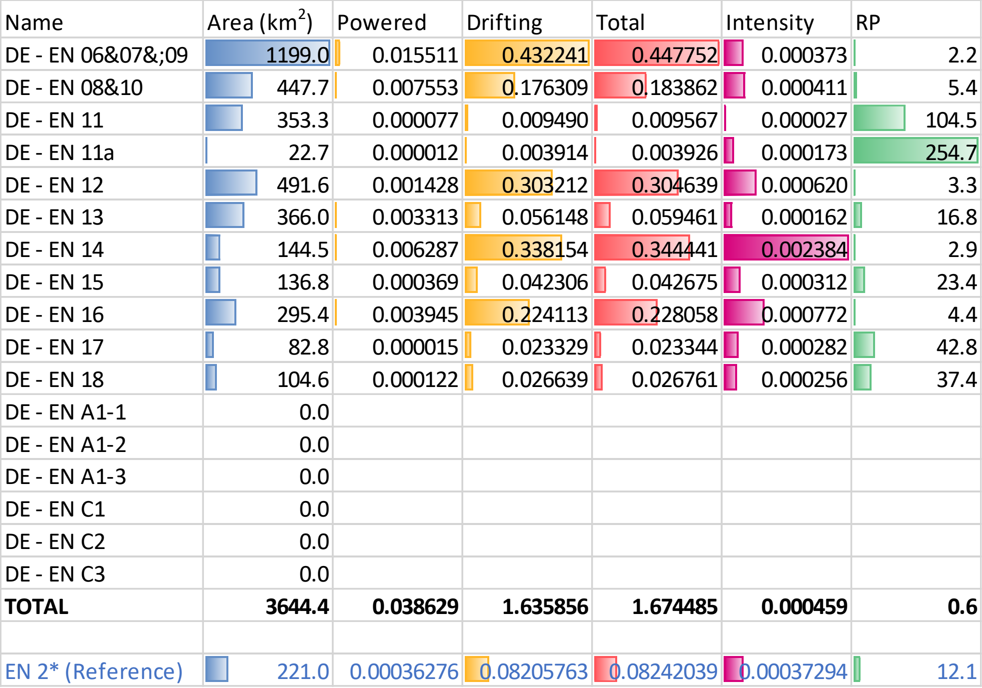


Figure 23: Risk profile of benchmark scenario for the modelled area (percentage basis)

The calculated annual allision probabilities for the development areas in the German EEZ are presented in Table 11.

Table 11: Allision Risk of benchmark scenario for German EEZ development areas



Name	Area (km^2)	Powered	Drifting	Total	Intensity	RP
DE - EN 06&07&;09	1199.0	0.015511	0.432241	0.447752	0.000373	2.2
DE - EN 08&10	447.7	0.007553	0.176309	0.183862	0.000411	5.4
DE - EN 11	353.3	0.000077	0.009490	0.009567	0.000027	104.5
DE - EN 11a	22.7	0.000012	0.003914	0.003926	0.000173	254.7
DE - EN 12	491.6	0.001428	0.303212	0.304639	0.000620	3.3
DE - EN 13	366.0	0.003313	0.056148	0.059461	0.000162	16.8
DE - EN 14	144.5	0.006287	0.338154	0.344441	0.002384	2.9
DE - EN 15	136.8	0.000369	0.042306	0.042675	0.000312	23.4
DE - EN 16	295.4	0.003945	0.224113	0.228058	0.000772	4.4
DE - EN 17	82.8	0.000015	0.023329	0.023344	0.000282	42.8
DE - EN 18	104.6	0.000122	0.026639	0.026761	0.000256	37.4
DE - EN A1-1	0.0					
DE - EN A1-2	0.0					
DE - EN A1-3	0.0					
DE - EN C1	0.0					
DE - EN C2	0.0					
DE - EN C3	0.0					
TOTAL	**3644.4**	**0.038629**	**1.635856**	**1.674485**	**0.000459**	**0.6**
EN 2* (Reference)	221.0	0.00036276	0.08205763	0.08242039	0.00037294	12.1

The peak allision risk is noted on area EN 14, which returns a risk per square km that is an order of magnitude higher than that of the remaining areas in the model. Areas EN 16 and

EN 12 also appear to be risk intense. This is more or less the case with all areas that have a side directly exposed to the traffic of Route SN 10.

It is noted that powered allisions only constitute a small proportion of the overall allision risk noted (some 2% of the total), with the majority of the allision risk noted being attributable to allision from drifting vessels. This is normal and anticipated, due to the proximity between the highly trafficked routes and the boundary of the OWFs. Vessels that lose power/steering are at a very short distance from developments, and thus there is little opportunity for repair/intervention.

In terms of the ship-to-ship collision risk (Figure 24), the highest risk in the model is noted at the part of the East route on SN 10, just to the north of the crossing of SN 4 (Leg E SN 10 04), and it is almost identical to that noted to the route segment carrying traffic from/to TSS Vlieland Nord (Leg FM TSS VN 03). The highest risk intensities on the model appear on the East route of SN 10, as well as at the SW-NE crossing of the two branches constituting SN 10.

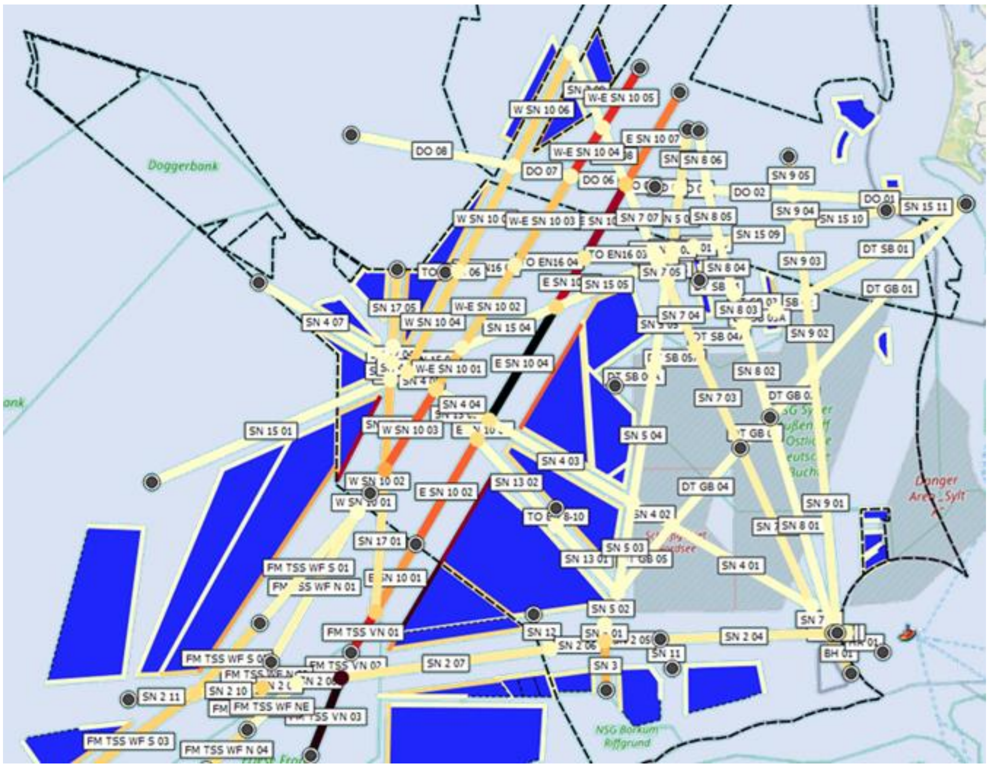
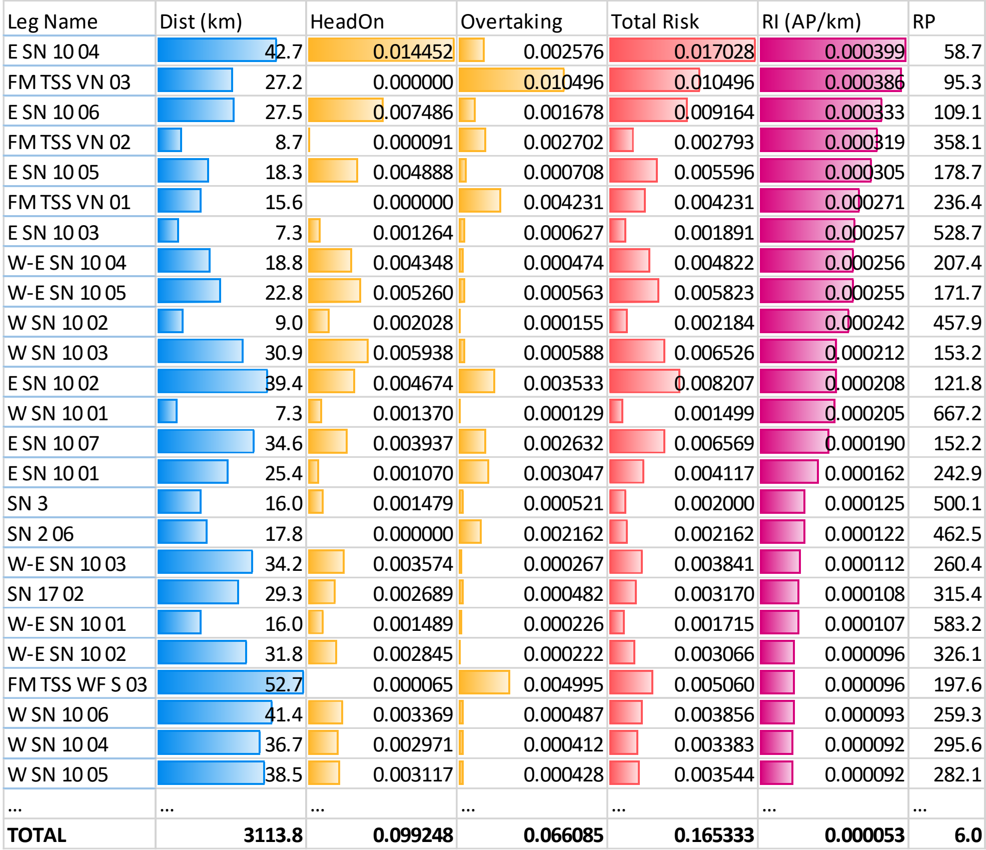


Figure 24: Ship-to-ship collision risk of benchmark scenario for the modelled area (percentage basis)

The peak 25 calculated annual ship-to-ship collision probabilities of the legs representing the routes in the study area are presented in Table 12.

Table 12: Ship-to-ship collision risk on model legs, benchmark scenario



Leg Name	Dist (km)	HeadOn	Overtaking	Total Risk	RI (AP/km)	RP
E SN 10 04	42.7	0.014452	0.002576	0.017028	0.000399	58.7
FM TSS VN 03	27.2	0.000000	0.010496	0.010496	0.000386	95.3
E SN 10 06	27.5	0.007486	0.001678	0.009164	0.000333	109.1
FM TSS VN 02	8.7	0.000091	0.002702	0.002793	0.000319	358.1
E SN 10 05	18.3	0.004888	0.000708	0.005596	0.000305	178.7
FM TSS VN 01	15.6	0.000000	0.004231	0.004231	0.000271	236.4
E SN 10 03	7.3	0.001264	0.000627	0.001891	0.000257	528.7
W-E SN 10 04	18.8	0.004348	0.000474	0.004822	0.000256	207.4
W-E SN 10 05	22.8	0.005260	0.000563	0.005823	0.000255	171.7
W SN 10 02	9.0	0.002028	0.000155	0.002184	0.000242	457.9
W SN 10 03	30.9	0.005938	0.000588	0.006526	0.000212	153.2
E SN 10 02	39.4	0.004674	0.003533	0.008207	0.000208	121.8
W SN 10 01	7.3	0.001370	0.000129	0.001499	0.000205	667.2
E SN 10 07	34.6	0.003937	0.002632	0.006569	0.000190	152.2
E SN 10 01	25.4	0.001070	0.003047	0.004117	0.000162	242.9
SN 3	16.0	0.001479	0.000521	0.002000	0.000125	500.1
SN 2 06	17.8	0.000000	0.002162	0.002162	0.000122	462.5
W-E SN 10 03	34.2	0.003574	0.000267	0.003841	0.000112	260.4
SN 17 02	29.3	0.002689	0.000482	0.003170	0.000108	315.4
W-E SN 10 01	16.0	0.001489	0.000226	0.001715	0.000107	583.2
W-E SN 10 02	31.8	0.002845	0.000222	0.003066	0.000096	326.1
FM TSS WF S 03	52.7	0.000065	0.004995	0.005060	0.000096	197.6
W SN 10 06	41.4	0.003369	0.000487	0.003856	0.000093	259.3
W SN 10 04	36.7	0.002971	0.000412	0.003383	0.000092	295.6
W SN 10 05	38.5	0.003117	0.000428	0.003544	0.000092	282.1
...	...	...	...	...	...	...
TOTAL	**3113.8**	**0.099248**	**0.066085**	**0.165333**	**0.000053**	**6.0**

In the results of the study, head-on collisions represent approximately two-thirds of the risk, whilst overtaking collisions the remaining one-third. Due to the crossing of routes between east and west, ship-to-ship collision risk on the routes is governed by head-on collisions. The exception to this is on parts of the route that come out of TSS Friesland, where the narrow distribution of traffic makes overtaking risk the prevailing component. Also, reasonably, the legs with the highest calculated risk intensity reflect high-trafficked parts of the model.

For ship-to-ship collision risk at the route waypoints which includes crossing, merging, and bend risk, was also calculated, and reported from the model. For the map of nodes presented on the risk profile, refer to Figure 25 overleaf.

The peak waypoint risk is noted at the point of crossing between the traffic from/to TSS Vlieland Nord and route SN 2, at the southern boundary of route SN 10 (Waypoint 21). The risk noted is dominated by crossing risk, as a result of the high traffic volumes that cross the junction almost at a right angle. Detailed results for the waypoints with the highest calculated risk are provided in Table 13.

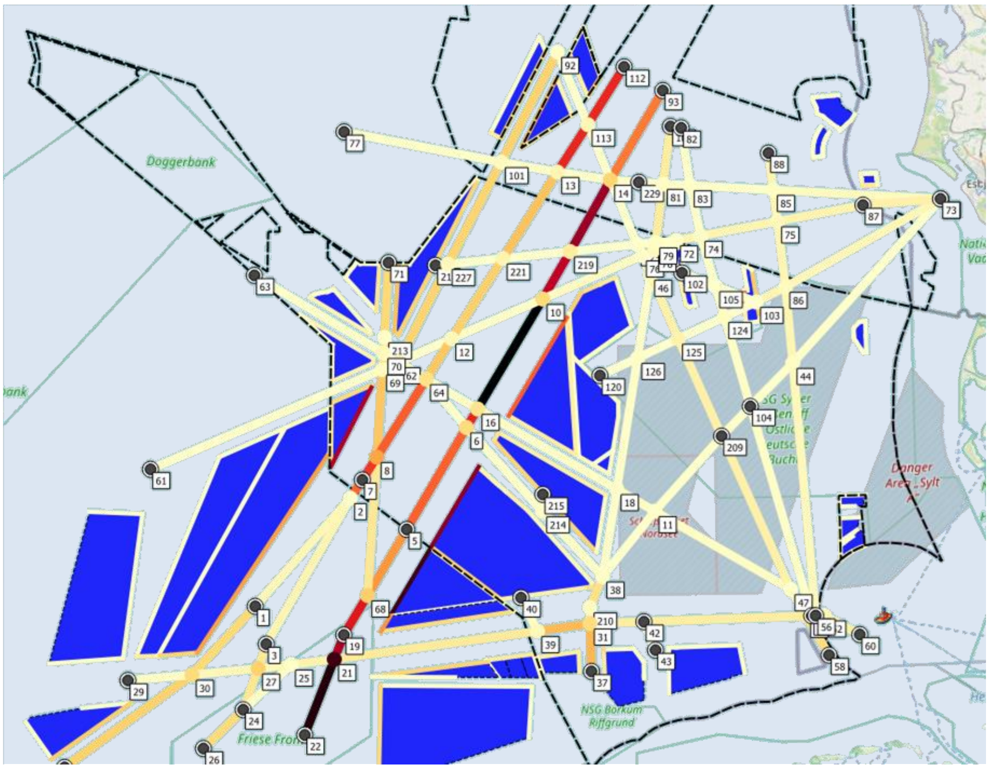


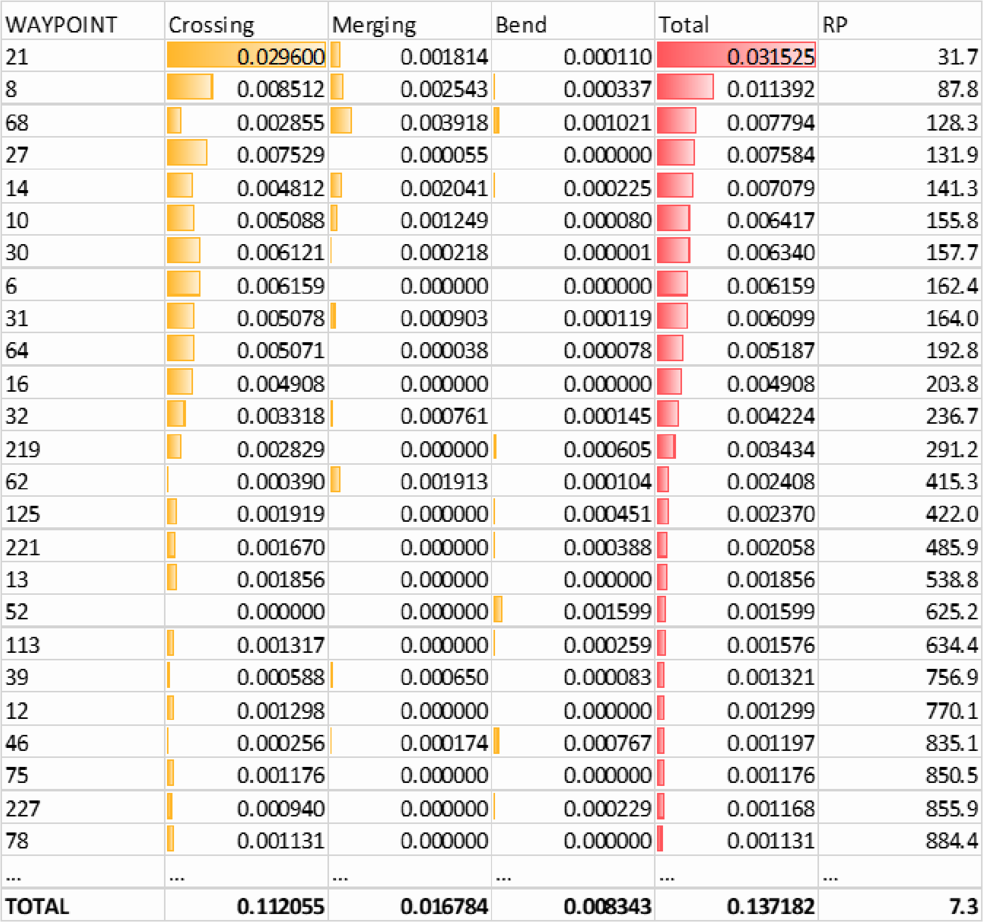
Figure 25: Waypoint collision risk of benchmark scenario for the modelled area (percentage basis)

Within the area of the German EEZ, the waypoint with the highest risk is waypoint 8, at the junction between the extension of route SN 17 and the West route of SN 10. The former is the route followed by vessels that access the SN 10 area from TSS Vlieland Nord and want to exit the SN 10 system to the NW. At waypoint 6, this traffic crosses the traffic of the West route of SN 10. At the same point, the portion of traffic on SN 10 West from/to TSS West Friesland changes course to enter/exit the SN 10 system from/to the NW.

Third in line risk-wise, with a more even distribution between crossing, merging, and bend risk is waypoint 68 where the aforementioned traffic joins/leaves the Eastern route of SN 10.

The sum of the risks captured and presented above adds up to a cumulative annual probability for the occurrence of an event of any type of 1.987, which converts to a return period between incidents of 6 months.

Table 13: Ship-to-ship collision risk on model waypoints, benchmark scenario



WAYPOINT	Crossing	Merging	Bend	Total	RP
21	0.029600	0.001814	0.000110	0.031525	31.7
8	0.008512	0.002543	0.000337	0.011392	87.8
68	0.002855	0.003918	0.001021	0.007794	128.3
27	0.007529	0.000055	0.000000	0.007584	131.9
14	0.004812	0.002041	0.000225	0.007079	141.3
10	0.005088	0.001249	0.000080	0.006417	155.8
30	0.006121	0.000218	0.000001	0.006340	157.7
6	0.006159	0.000000	0.000000	0.006159	162.4
31	0.005078	0.000903	0.000119	0.006099	164.0
64	0.005071	0.000038	0.000078	0.005187	192.8
16	0.004908	0.000000	0.000000	0.004908	203.8
32	0.003318	0.000761	0.000145	0.004224	236.7
219	0.002829	0.000000	0.000605	0.003434	291.2
62	0.000390	0.001913	0.000104	0.002408	415.3
125	0.001919	0.000000	0.000451	0.002370	422.0
221	0.001670	0.000000	0.000388	0.002058	485.9
13	0.001856	0.000000	0.000000	0.001856	538.8
52	0.000000	0.000000	0.001599	0.001599	625.2
113	0.001317	0.000000	0.000259	0.001576	634.4
39	0.000588	0.000650	0.000083	0.001321	756.9
12	0.001298	0.000000	0.000000	0.001299	770.1
46	0.000256	0.000174	0.000767	0.001197	835.1
75	0.001176	0.000000	0.000000	0.001176	850.5
227	0.000940	0.000000	0.000229	0.001168	855.9
78	0.001131	0.000000	0.000000	0.001131	884.4
...	...	...	...	...	...
TOTAL	**0.112055**	**0.016784**	**0.008343**	**0.137182**	**7.3**

4.1.2 Scenario A1, developments on the eastern side of route SN 10

Scenario A1 is built on the geometry of the Benchmark scenario in terms of the developments on either side of route SN 10, with the incorporation of additional development areas on the East side of the route. The blocking of route SN 6, and thus the diversion of the traffic using SN 6 along the eastern route of SN 10 and then on SN 15 to Esbjerg and the East side of the German Bight remains relevant. The same applies to the restrictions in terms of leaving the route towards the west, which can only be done using route SN 17.

The added areas abut on the west of the combined area formed out of EN 6, EN 7, and EN9, area EN 12, and also occupy the free space NW of area EN 13. The model also assumes that the southern boundary of the new areas is mirrored on the adjoining side of the Dutch EEZ, with the formation of a new triangular area that closes out on the SW corner of Gebied 5 Oost SF.

The reduction in available space will mean that the alignment of the routes as considered in the benchmark scenario will have to be altered. In planning a vessel's route, the OWW will generally attempt to plan and follow linear routes that reflect the shortest distance and include the smallest number of course adjustments/changes. The alignment of the routes has been selected based on applying this rule in conjunction with the entry and exit points of traffic to the SN 10 system, and the associated restrictions generated by the considered development areas, to sketch routes to/from every entry/exit point and the others. Subsequently, lateral distributions were selected based on the standard deviations recommended in the GL guideline [01], [02], and the mean set for each leg at the point of the plotted planned routes. A high-level depiction of the system is provided in Figure 26.

Figure 26: Route layout for scenario A1

The analysis of scenario A1 identified an annual combined allision probability of 1.365, which converts to a return period of approximately 7.5 months, a substantial improvement compared to the benchmark scenario. The risk profile of the area of interest in the German EEZ is presented in Figure 27 overleaf.

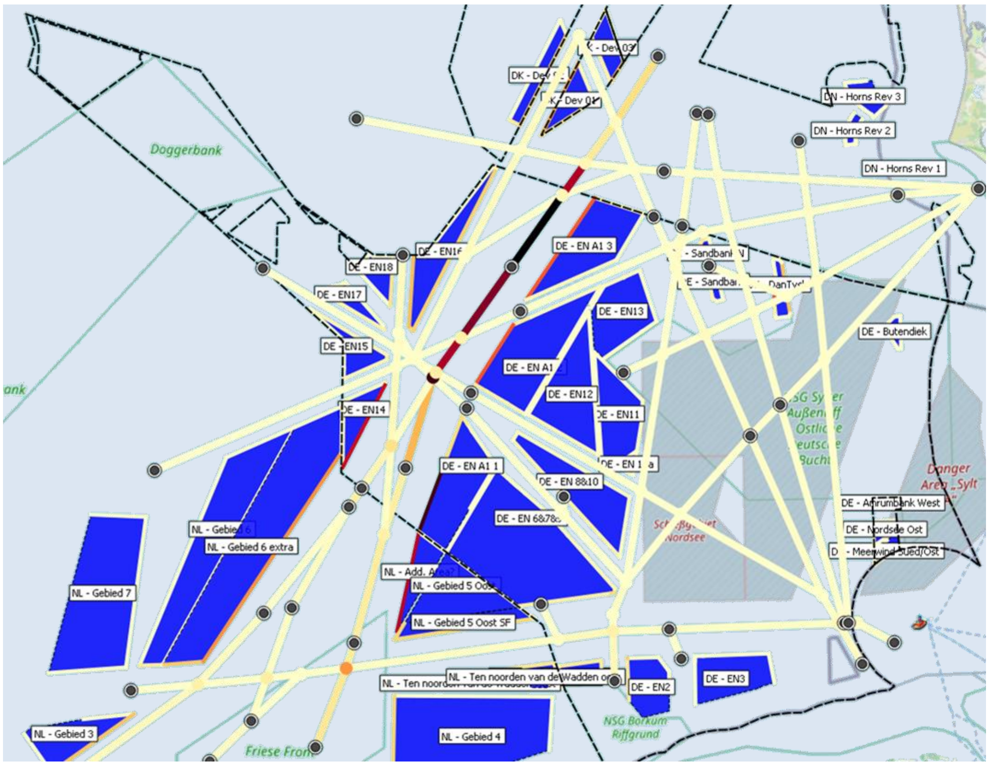
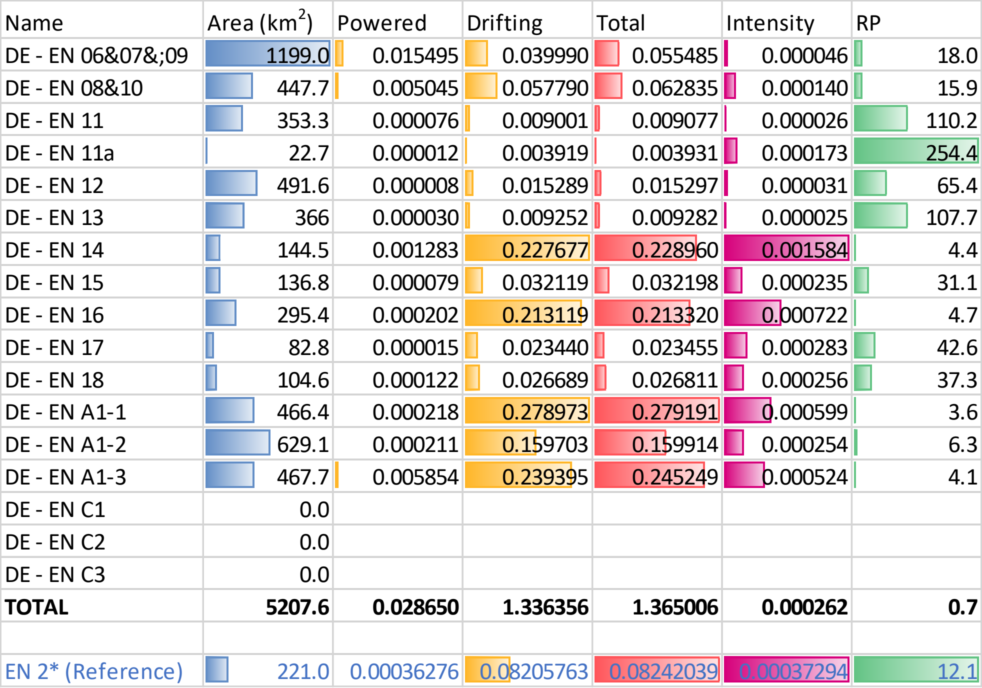


Figure 27: Risk profile of scenario A1 for the modelled area (percentage basis)

The calculated annual allision probabilities for the development areas in the German EEZ are presented in Table 14.

Table 14: Allision Risk of scenario A1 for German EEZ development areas



Name	Area (km^2)	Powered	Drifting	Total	Intensity	RP
DE - EN 06&07&;09	1199.0	0.015495	0.039990	0.055485	0.000046	18.0
DE - EN 08&10	447.7	0.005045	0.057790	0.062835	0.000140	15.9
DE - EN 11	353.3	0.000076	0.009001	0.009077	0.000026	110.2
DE - EN 11a	22.7	0.000012	0.003919	0.003931	0.000173	254.4
DE - EN 12	491.6	0.000008	0.015289	0.015297	0.000031	65.4
DE - EN 13	366	0.000030	0.009252	0.009282	0.000025	107.7
DE - EN 14	144.5	0.001283	0.227677	0.228960	0.001584	4.4
DE - EN 15	136.8	0.000079	0.032119	0.032198	0.000235	31.1
DE - EN 16	295.4	0.000202	0.213119	0.213320	0.000722	4.7
DE - EN 17	82.8	0.000015	0.023440	0.023455	0.000283	42.6
DE - EN 18	104.6	0.000122	0.026689	0.026811	0.000256	37.3
DE - EN A1-1	466.4	0.000218	0.278973	0.279191	0.000599	3.6
DE - EN A1-2	629.1	0.000211	0.159703	0.159914	0.000254	6.3
DE - EN A1-3	467.7	0.005854	0.239395	0.245249	0.000524	4.1
DE - EN C1	0.0					
DE - EN C2	0.0					
DE - EN C3	0.0					
TOTAL	**5207.6**	**0.028650**	**1.336356**	**1.365006**	**0.000262**	**0.7**
EN 2* (Reference)	221.0	0.00036276	0.08205763	0.08242039	0.00037294	12.1

The peak allision risk intensity, as in the benchmark, is noted on area EN 14, which also returns a risk per square km that is an order of magnitude higher than that of the remaining areas in the model. Area EN 16 follows. The new areas that have long edges exposed to the SN 10 traffic (A1.1 and A1.3) also appear to be risk intense, substantially exceeding that noted for the reference case of EN 2. The remaining areas on the model, as they are now sheltered by the new areas of the scenario, all return significantly reduced calculated allision risk.

Drifting allisions remain dominant in terms of their contribution to the risk in the present scenario, to a similar level as in the case of the benchmark.

For the vessel-to-vessel collision risk (Figure 28), the highest risk in the model is noted on the East route on SN 10, just south of the border with the Danish jurisdiction (Leg W-E SN 10 03). In the rest of the model, leg risk is concentrated on the East route on SN 10 between the junction with SN 4, and the route from Esbjerg to the Danish offshore installations. The risk intensity noted on that part of the route, substantially exceeds the intensities noted for the benchmark case, including that of the route originated from Vlieland Nord, which showed the peak intensity (Leg FM TSS VN 03). In general, the whole eastern route on SN 10 shows a high head-on collision risk.

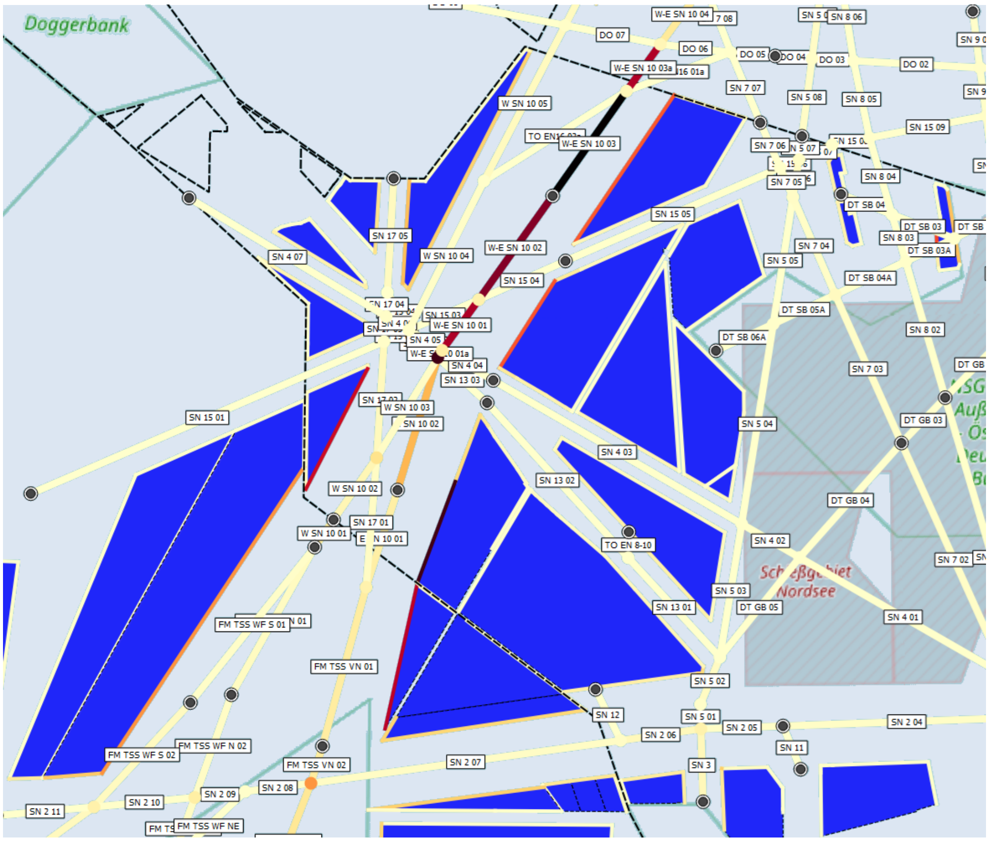
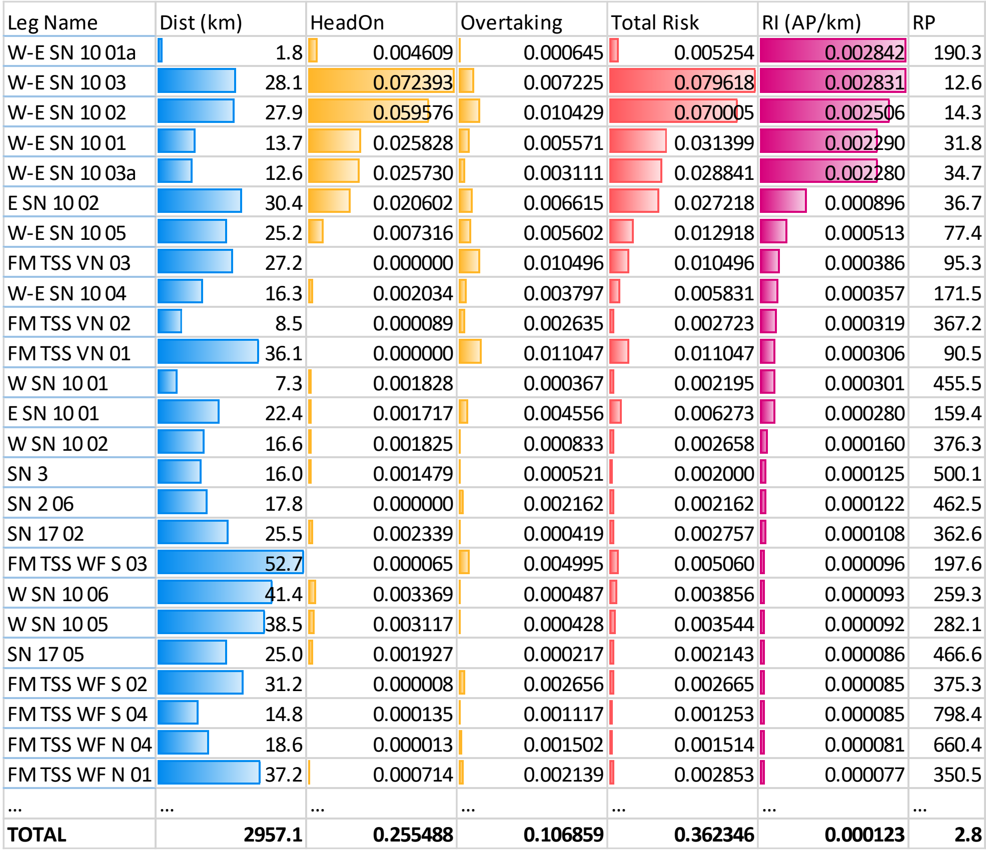


Figure 28: Ship-to-ship collision risk of scenario A1 for the modelled area (percentage basis)

It is noteworthy, at this point, to mention that the assumption made for the re-direction of the traffic along the SN 10 corridor within this option, encounters some limits when the software needs to analytically calculate the risk of ship-to-ship collision. The large cross section of water left available by the addition of the areas in option A1, would be available for shipping in its entirety, namely vessels might decide to sail everywhere at a safe distance of any installation/obstruction with the freedom to alter their course wherever is deemed feasible, safe, and commercially appealable. It is therefore extremely difficult to condensate the reasonable decision-making of an officer of the watch in a single track whilst he might have chosen a different route just 3 nm (i.e.) to the west or east of the same. It is thus challenging to realistically estimate the lateral distribution of traffic to be applied on the model legs via a normal distribution expression.

The peak 25 calculated annual ship-to-ship collision probabilities of the legs representing the routes in the study area are presented in Table 15.

Table 15: Ship-to-ship collision risk on model legs, scenario A1



Leg Name	Dist (km)	HeadOn	Overtaking	Total Risk	RI (AP/km)	RP
W-E SN 10 01a	1.8	0.004609	0.000645	0.005254	0.002842	190.3
W-E SN 10 03	28.1	0.072393	0.007225	0.079618	0.002831	12.6
W-E SN 10 02	27.9	0.059576	0.010429	0.070005	0.002506	14.3
W-E SN 10 01	13.7	0.025828	0.005571	0.031399	0.002290	31.8
W-E SN 10 03a	12.6	0.025730	0.003111	0.028841	0.002280	34.7
E SN 10 02	30.4	0.020602	0.006615	0.027218	0.000896	36.7
W-E SN 10 05	25.2	0.007316	0.005602	0.012918	0.000513	77.4
FM TSS VN 03	27.2	0.000000	0.010496	0.010496	0.000386	95.3
W-E SN 10 04	16.3	0.002034	0.003797	0.005831	0.000357	171.5
FM TSS VN 02	8.5	0.000089	0.002635	0.002723	0.000319	367.2
FM TSS VN 01	36.1	0.000000	0.011047	0.011047	0.000306	90.5
W SN 10 01	7.3	0.001828	0.000367	0.002195	0.000301	455.5
E SN 10 01	22.4	0.001717	0.004556	0.006273	0.000280	159.4
W SN 10 02	16.6	0.001825	0.000833	0.002658	0.000160	376.3
SN 3	16.0	0.001479	0.000521	0.002000	0.000125	500.1
SN 2 06	17.8	0.000000	0.002162	0.002162	0.000122	462.5
SN 17 02	25.5	0.002339	0.000419	0.002757	0.000108	362.6
FM TSS WF S 03	52.7	0.000065	0.004995	0.005060	0.000096	197.6
W SN 10 06	41.4	0.003369	0.000487	0.003856	0.000093	259.3
W SN 10 05	38.5	0.003117	0.000428	0.003544	0.000092	282.1
SN 17 05	25.0	0.001927	0.000217	0.002143	0.000086	466.6
FM TSS WF S 02	31.2	0.000008	0.002656	0.002665	0.000085	375.3
FM TSS WF S 04	14.8	0.000135	0.001117	0.001253	0.000085	798.4
FM TSS WF N 04	18.6	0.000013	0.001502	0.001514	0.000081	660.4
FM TSS WF N 01	37.2	0.000714	0.002139	0.002853	0.000077	350.5
...	...	...	...	...	...	...
TOTAL	**2957.1**	**0.255488**	**0.106859**	**0.362346**	**0.000123**	**2.8**

In terms of waypoint collisions between ships, the mapping of waypoints is presented on the risk profile of Figure 29 overleaf.

The peak waypoint risk for scenario A1 is noted at the point of merging of the traffic from/to TSS West Friesland and the traffic from/to TSS Vlieland Nord, at the junction of what used to be the West and East routes on the benchmark (Waypoint 242). This waypoint is the junction of the combined traffic of the East route and the traffic that crosses from the West to the East (and vice versa). The risk noted is more than double that of waypoint 21 at the crossing of the TSS Vlieland Nord traffic across route SN 2 that has dominated the benchmark scenario. The premier risk noted is the bend risk, as a large volume of traffic has to change course to clear the western edge of the new developments, followed by the crossing risk, and less so by merging risk. Detailed results for the waypoints with the highest calculated risk are provided in Table 16.

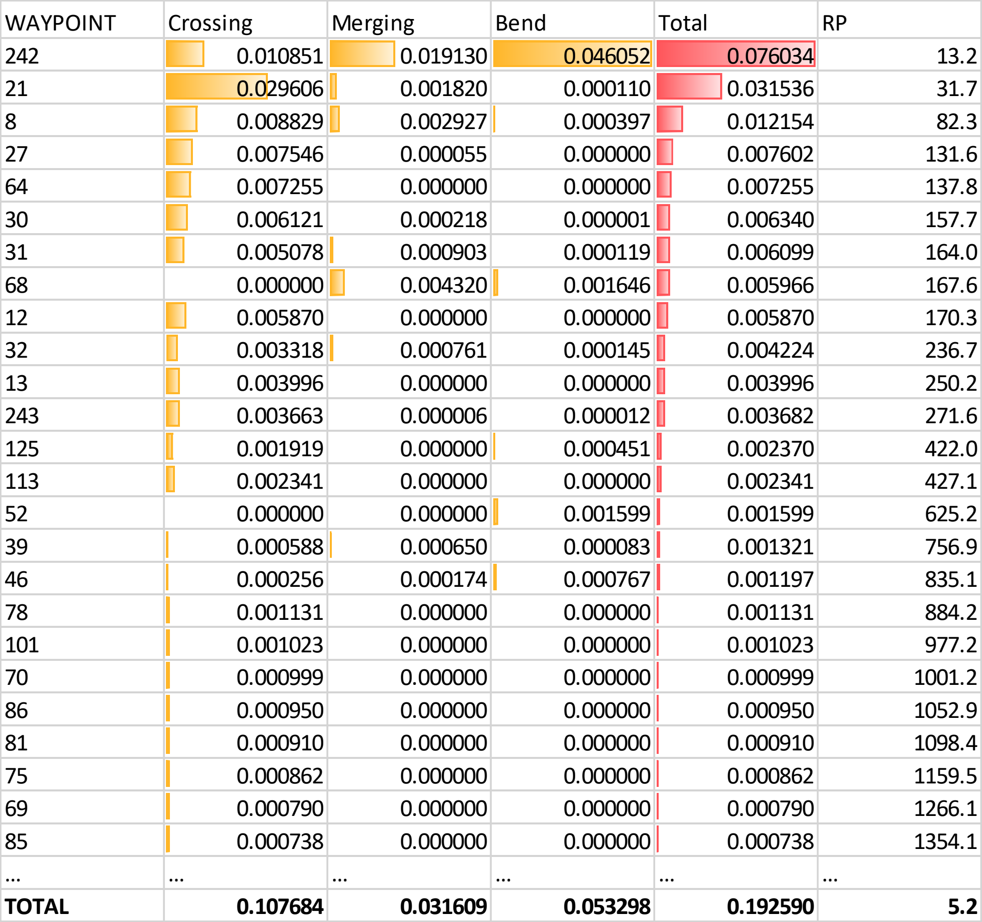
Figure 29: Waypoint collision risk of scenario A1 for the modelled area (percentage basis)

Within the area of the German EEZ, the waypoints with the highest risk are waypoints 8 (as in the benchmark model) and 64. Waypoint 8 is at the junction between the extension of route SN 17 and the West route of SN 10 that captures the traffic leaving the area of SN 10 to the NW. Waypoint 62 is the junction between route SN 13 carrying mainly in this case OW maintenance vessel traffic between the ports of the Ems estuary and the development areas to the west of SN 10 crossing the part of the SN 10 traffic transitioning along the West and the East route. The risk picked up on the latter exclusively comprises crossing risk and is substantially lower than the risk noted at waypoints 8 and of course at waypoint 242.

The sum of the risks for scenario A1 adds up to a cumulative annual probability for the occurrence of an event of any type of 1.916, which converts to a return period between incidents of slightly more than 6 months. Whilst this constitutes an improvement compared to the benchmark scenario, the ship-to-ship collision risk appears to almost double (+83%) compared to the former, which would pose a great challenge to manage and mitigate.

It is understood that modelling cannot fully capture the behaviour patterns and thus the risk that will materialise in the real-life implementation of the routing associated with scenario A1, especially since it involves an assessment of future route adaptation. However, as part of the process of quantitative analysis, the outcome reflects the best current assessment of the situation that would emerge from the development of additional OW installation areas in the east part of route SN 10.

Table 16: Ship-to-ship collision risk on model waypoints, scenario A1



WAYPOINT	Crossing	Merging	Bend	Total	RP
242	0.010851	0.019130	0.046052	0.076034	13.2
21	0.029606	0.001820	0.000110	0.031536	31.7
8	0.008829	0.002927	0.000397	0.012154	82.3
27	0.007546	0.000055	0.000000	0.007602	131.6
64	0.007255	0.000000	0.000000	0.007255	137.8
30	0.006121	0.000218	0.000001	0.006340	157.7
31	0.005078	0.000903	0.000119	0.006099	164.0
68	0.000000	0.004320	0.001646	0.005966	167.6
12	0.005870	0.000000	0.000000	0.005870	170.3
32	0.003318	0.000761	0.000145	0.004224	236.7
13	0.003996	0.000000	0.000000	0.003996	250.2
243	0.003663	0.000006	0.000012	0.003682	271.6
125	0.001919	0.000000	0.000451	0.002370	422.0
113	0.002341	0.000000	0.000000	0.002341	427.1
52	0.000000	0.000000	0.001599	0.001599	625.2
39	0.000588	0.000650	0.000083	0.001321	756.9
46	0.000256	0.000174	0.000767	0.001197	835.1
78	0.001131	0.000000	0.000000	0.001131	884.2
101	0.001023	0.000000	0.000000	0.001023	977.2
70	0.000999	0.000000	0.000000	0.000999	1001.2
86	0.000950	0.000000	0.000000	0.000950	1052.9
81	0.000910	0.000000	0.000000	0.000910	1098.4
75	0.000862	0.000000	0.000000	0.000862	1159.5
69	0.000790	0.000000	0.000000	0.000790	1266.1
85	0.000738	0.000000	0.000000	0.000738	1354.1
...	...	...	...	...	...
TOTAL	**0.107684**	**0.031609**	**0.053298**	**0.192590**	**5.2**

4.1.3 Scenario C, developments at the central section of route SN 10

Scenario C is also constructed on the geometry of the benchmark scenario in terms of the developments on either side of route SN 10. However, the additional development areas, in this case, are placed at the centre of the area of route SN 10, between the East and West routes. The shift of the development areas to the centre of the route forms a physical separation of the East and West routes. This has implications on the way the traffic can cross from one to the other, and also, on the routing of traffic that intends to leave the SN 10 system and sail to the NW. Also, the issue with blocking route SN 6, and thus the diversion of the traffic using SN 6 along the eastern route of SN 10 and then on SN 15 to Esbjerg and the East side of the German Bight is still relevant for scenario C.

The added areas comprise three areas within the German jurisdiction and one within the Dutch. At the time the study was in progress, there was no finalised plan for the Dutch EEZ besides Gebied 5 and its extension at the eastern side of the route. The model however assumes that should developments be decided upon for the German EEZ, the Netherlands might mirror the situation formed. Thus, an additional area was formed to the south of the three areas proposed by Germany.

The main feature of this scenario, besides the reduction in available space, will mean that the alignment of the routes as considered in the benchmark scenario will have to be adjusted to fit the space formed between the developments. In terms of planning vessels' routes, the changes will be smaller compared to the ones noted between the benchmark and scenario A1. The alignment of the routes remains largely the same, with the notable changes being the more restricted arrangement in routing vessels to SN 17 to escape to the NW of SN 10, and the change at the north, where the transfer route from the western to the eastern route and vice-versa will have to be subjected to two-course adjustments to clear the crossing between Area C3 and the areas in the Danish EEZ. Lateral distributions were selected based on the standard deviations recommended in the GL guidelines [01], [02], and the mean set for each leg in line with the projected routes presented in Figure 30.

Figure 30: Route layout for scenario C

The analysis of scenario C resulted in an annual combined allision probability within the German EEZ of 2.248, which converts to a return period of approximately 5.3 months. This constitutes a notable increase in the allision risk, however, proportional to the increase in the development area. I.e., the risk intensity (allision probability per km^2 of development area is very similar to the benchmark). The risk profile of the area of interest in the German EEZ is presented in Figure 31.

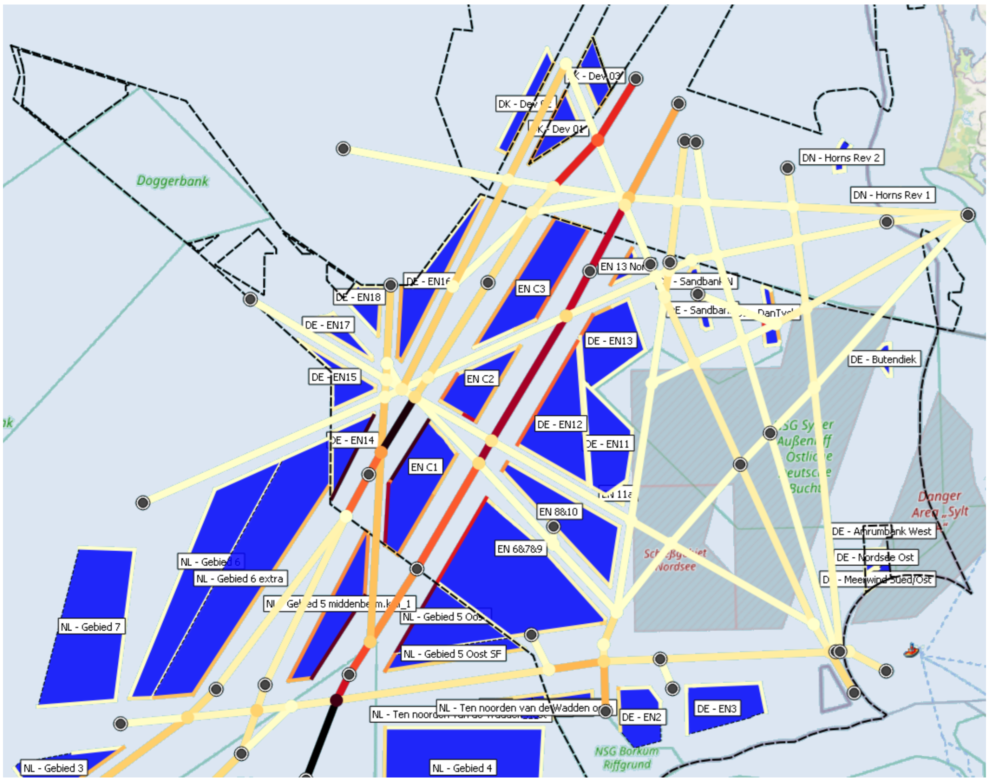
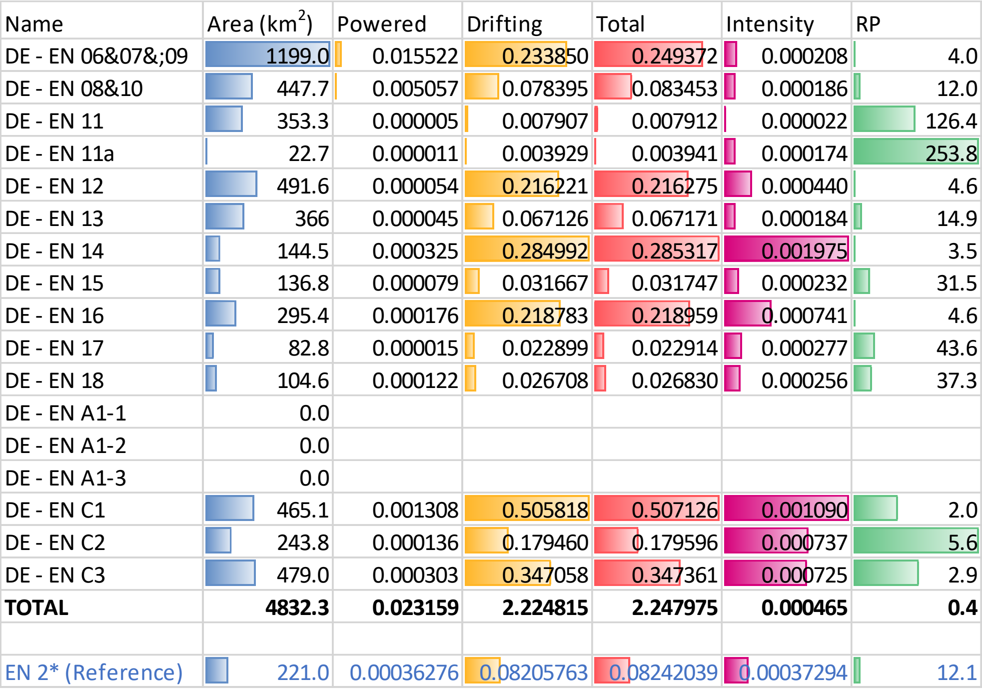


Figure 31: Risk profile of scenario C for the modelled area (percentage basis)

The calculated annual allision probabilities for the development areas in the German EEZ are presented in Table 17.

Table 17: Allision Risk of scenario C for German EEZ development areas



Name	Area (km^2)	Powered	Drifting	Total	Intensity	RP
DE - EN 06&07&;09	1199.0	0.015522	0.233850	0.249372	0.000208	4.0
DE - EN 08&10	447.7	0.005057	0.078395	0.083453	0.000186	12.0
DE - EN 11	353.3	0.000005	0.007907	0.007912	0.000022	126.4
DE - EN 11a	22.7	0.000011	0.003929	0.003941	0.000174	253.8
DE - EN 12	491.6	0.000054	0.216221	0.216275	0.000440	4.6
DE - EN 13	366	0.000045	0.067126	0.067171	0.000184	14.9
DE - EN 14	144.5	0.000325	0.284992	0.285317	0.001975	3.5
DE - EN 15	136.8	0.000079	0.031667	0.031747	0.000232	31.5
DE - EN 16	295.4	0.000176	0.218783	0.218959	0.000741	4.6
DE - EN 17	82.8	0.000015	0.022899	0.022914	0.000277	43.6
DE - EN 18	104.6	0.000122	0.026708	0.026830	0.000256	37.3
DE - EN A1-1	0.0					
DE - EN A1-2	0.0					
DE - EN A1-3	0.0					
DE - EN C1	465.1	0.001308	0.505818	0.507126	0.001090	2.0
DE - EN C2	243.8	0.000136	0.179460	0.179596	0.000737	5.6
DE - EN C3	479.0	0.000303	0.347058	0.347361	0.000725	2.9
TOTAL	**4832.3**	**0.023159**	**2.224815**	**2.247975**	**0.000465**	**0.4**
EN 2* (Reference)	221.0	0.00036276	0.08205763	0.08242039	0.00037294	12.1

As in the previous scenarios, the peak intensity is noted on area EN 14 which returns a risk per square km that is an order of magnitude higher than that of the remaining areas in the model, followed by Area C1, the southernmost of the central cluster of areas which returns risks intensities in the same order of magnitude as EN 14. All other areas in the model show milder risk, however, the risk noted on the remaining two developments of the middle cluster C2 and C3 are double that noted for SN 2, used as a measure in this assessment. This is anticipated as the new areas are exposed to high traffic on both their long sides, thus quite more susceptible than the other areas on the MSP. Area EN 16 also shows significant risk intensities as in the previous scenarios.

Drifting allisions remain dominant in terms of their contribution to the risk in the present scenario, representing 99% of the total risk noted.

For the ship-to-ship collision risk (Figure 32), the highest risk in the area of the model is noted on the West route on SN 10, between the junctions with SN 17 and SN 4. The risk intensity is similar to that noted on the route from TSS Vlieland Nord, which registers the second highest risk intensity.

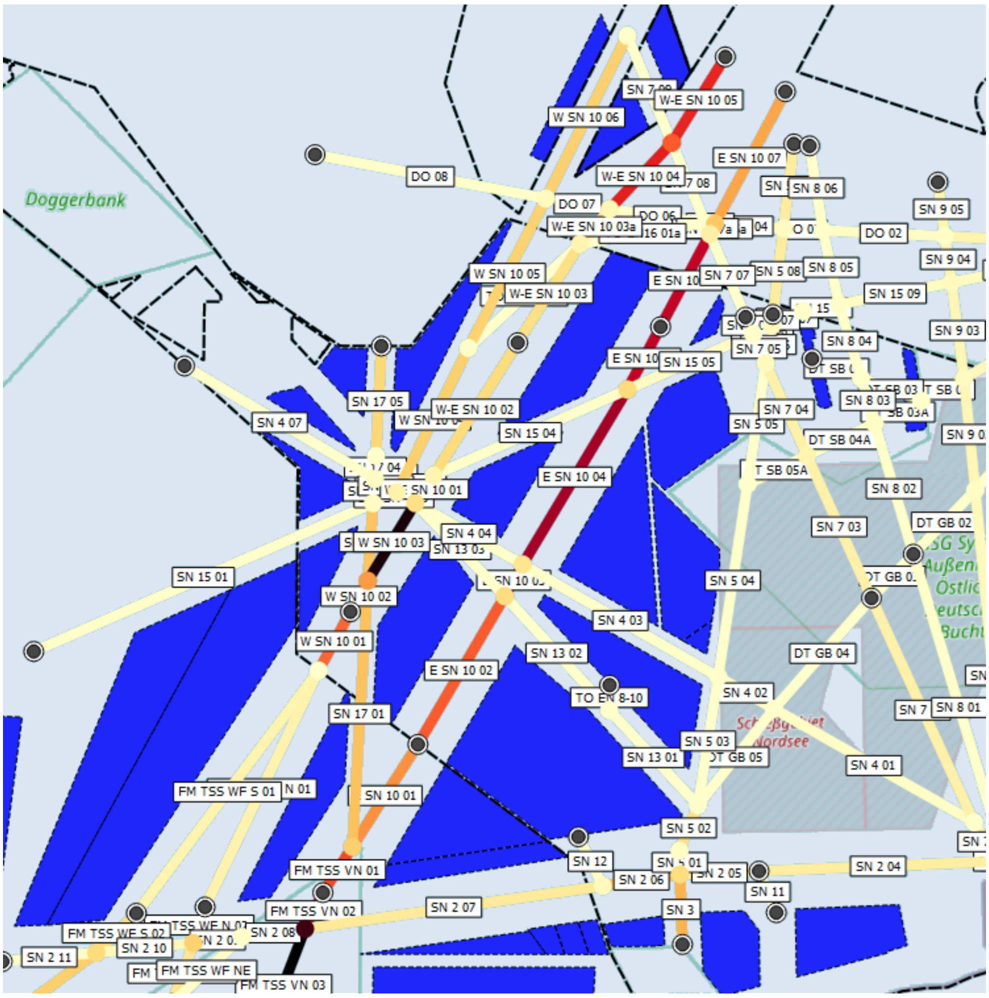


Figure 32: Ship-to-ship collision risk of scenario C for the modelled area (percentage basis)

Next in the line of large risk intensities recorded in the model are those of the East Route, especially to the north of the crossing of SN 13, followed by the West route. The peak 25 calculated annual ship-to-ship collision probabilities of the legs representing the routes in the study area are presented in Table 18.

Table 18: Ship-to-ship collision risk on model legs, scenario C

Leg Name	Dist (km)	HeadOn	Overtaking	Total Risk	RI (AP/km)	RP
FM TSS VN 03	27.2	0.000000	0.010497	0.010497	0.000386	95.3
W SN 10 03	20.8	0.007268	0.000573	0.007841	0.000378	127.5
E SN 10 03	8.1	0.001409	0.001217	0.002625	0.000323	380.9
E SN 10 04	46.6	0.007975	0.006843	0.014818	0.000318	67.5
E SN 10 06	23.9	0.003783	0.003251	0.007035	0.000294	142.2
E SN 10 06a	2.7	0.000420	0.000361	0.000780	0.000294	1281.3
E SN 10 05	16.2	0.002561	0.002200	0.004761	0.000294	210.0
FM TSS VN 02	9.2	0.000000	0.002537	0.002537	0.000276	394.2
W-E SN 10 04	20.7	0.004770	0.000511	0.005280	0.000255	189.4
W-E SN 10 05	23.1	0.005238	0.000555	0.005793	0.000251	172.6
FM TSS VN 01	12.4	0.000248	0.002517	0.002765	0.000223	361.6
E SN 10 02	39.2	0.002221	0.005954	0.008175	0.000209	122.3
W SN 10 02	8.1	0.001197	0.000404	0.001601	0.000198	624.4
W SN 10 01	15.0	0.002227	0.000752	0.002978	0.000198	335.7
E SN 10 01	27.7	0.000402	0.004194	0.004596	0.000166	217.6
E SN 10 07	34.1	0.002612	0.002203	0.004815	0.000141	207.7
SN 3	16.0	0.001479	0.000521	0.002000	0.000125	500.1
SN 2 06	17.8	0.000000	0.002162	0.002162	0.000122	462.5
SN 17 01	60.7	0.004324	0.002372	0.006696	0.000110	149.3
SN 17 02	17.7	0.001624	0.000291	0.001915	0.000108	522.3
FM TSS WF S 03	52.7	0.000065	0.004995	0.005060	0.000096	197.6
W SN 10 04	36.7	0.002972	0.000511	0.003483	0.000095	287.1
W SN 10 06	41.4	0.003369	0.000487	0.003856	0.000093	259.3
W SN 10 05	38.5	0.003117	0.000447	0.003564	0.000093	280.6
SN 17 05	25.0	0.001927	0.000217	0.002143	0.000086	466.6
...	...	...	...	...	...	...
TOTAL	**3095.4**	**0.082479**	**0.078318**	**0.160797**	**0.000052**	**6.2**

In terms of waypoint collisions between ships, the mapping of waypoints is presented on the risk profile of Figure 33 overleaf.

The highest waypoint risk for scenario C was noted at the crossing of the TSS Vlieland Nord traffic across route SN 2 which has also been the case in the benchmark scenario. The risk at Waypoint 21 is almost exclusively crossing risk. The second highest risk in the model is noted at the final adjustment of the traffic switching between the West and East routes, next to the Danish developments at the crossing with SN 7 (Waypoint 113). The risk noted at that point is mostly bend risk from the course change for a high traffic volume and to a far lesser extent crossing risk. Detailed results for the waypoints with the highest calculated risk are provided in Table 19.

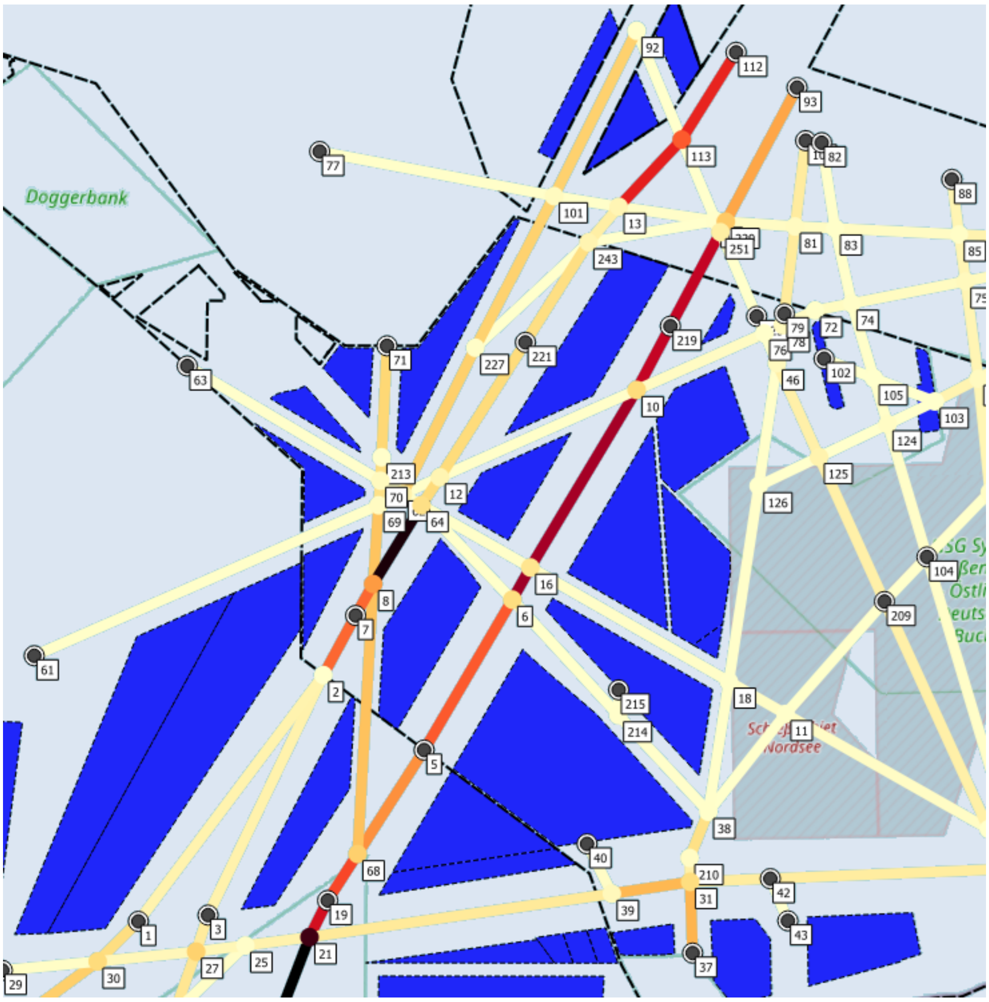


Figure 33: Waypoint collision risk of scenario C for the modelled area (percentage basis)

Within the area of the German EEZ, the waypoint with the highest risk is waypoint 8 (as in the benchmark model). Waypoint 8 is at the junction between the extension of route SN 17 and the West route of SN 10. Together with 68 in the Dutch EZZ, that is the junction of the same route with the East route, they constitute the crossing points of the traffic leaving/joining the area of SN 10 to/from the north. Waypoints with lower risk, concern the waypoints on route SN 2 and thus are not relevant to the immediate study area.

The sum of the risks for scenario C adds up to an annual probability for the occurrence of an event of any type of 2.558, which converts to a return period between incidents of slightly less than 5 months. Compared to the benchmark scenario, Scenario C results in slightly higher collision risk, and substantially higher allision risk. The increase in allision risk, however, is proportional to the increase in the development area.

Table 19: Ship-to-ship collision risk on model waypoints, scenario C

WAYPOINT	Crossing	Merging	Bend	Total	RP
21	0.029603	0.001810	0.000110	0.031524	31.7
113	0.001051	0.000000	0.015883	0.016934	59.1
8	0.009143	0.002964	0.000420	0.012528	79.8
229	0.006700	0.000000	0.001664	0.008364	119.6
68	0.002822	0.003887	0.000990	0.007698	129.9
27	0.007529	0.000055	0.000000	0.007584	131.9
30	0.006212	0.000217	0.000001	0.006430	155.5
10	0.005080	0.001249	0.000080	0.006409	156.0
6	0.006147	0.000000	0.000000	0.006147	162.7
31	0.005078	0.000903	0.000119	0.006099	164.0
64	0.005489	0.000075	0.000079	0.005643	177.2
16	0.004904	0.000000	0.000000	0.004904	203.9
32	0.003318	0.000761	0.000145	0.004224	236.7
251	0.002572	0.000000	0.000547	0.003119	320.6
62	0.000429	0.001913	0.000104	0.002446	408.8
125	0.001919	0.000000	0.000451	0.002370	422.0
243	0.001810	0.000006	0.000279	0.002096	477.2
12	0.002021	0.000000	0.000000	0.002021	494.8
13	0.001865	0.000000	0.000000	0.001865	536.2
52	0.000000	0.000000	0.001599	0.001599	625.2
39	0.000588	0.000650	0.000083	0.001321	756.9
46	0.000256	0.000174	0.000767	0.001197	835.4
75	0.001176	0.000000	0.000000	0.001176	850.5
78	0.001131	0.000000	0.000000	0.001131	884.5
101	0.001023	0.000000	0.000000	0.001023	977.3
...	...	...	...	...	...
TOTAL	**0.114372**	**0.015151**	**0.025184**	**0.154707**	**6.5**

4.1.4 Comparison between main scenarios

From a comparison of the results from the analysis of the benchmark and two main scenarios A1 and C, summarised in Table 20 below, the following can be concluded.

Table 20: Main Scenarios Risk Comparison

SCENARIO	Allision Risk	Collision	Total Risk	RP (y)
BENCHMARK	1.674485	0.302514	1.976999	0.51
SCENARIO C	2.247975	0.315504	2.563479	0.39
SCENARIO A1	1.365006	0.554936	1.919942	0.52

Scenario A1 is beneficial in terms of the allision risk, both compared to Scenario C and the benchmark scenario, as it leads to a net reduction. However, Scenario A1 leads to an almost doubling of the ship-to-ship collision risk in the model compared to both other scenarios.

Scenario C, on the other hand, leads to a very small increase in the ship-to-ship collisions compared to the benchmark, but due to the exposed perimeter of the added area to two rather than one main shipping route, allision risk to the new development areas considered within the area of route SN 10 increases by a third.

4.1.5 Mitigation considerations

From the analysis of the basic scenarios, the first point of focus, due to its presence in all scenarios considered, is the mitigation of the allision risk to development areas EN 14 and EN 16 that show unusually high-risk intensities.

Secondarily, the report will consider the potential to mitigate the risk noted in the two basic scenarios (A1 and C) to the extent possible using the measures available and suitable to each case to achieve that.

Allision risks, noted in the analyses for all scenarios, are dominated by risks from drifting vessels. These are dependent mainly on traffic volumes and the proximity of routes to the boundaries of the development areas (a point-blank effect). Therefore, these can be mitigated by the application of geometry adjustments, especially against prevailing wind/currents. These risks are also able to be partially mitigated by the provision of ETV tugs.

Ship-to-ship collision risks, on the other hand, can only be mitigated by the implementation of routing measures. For their mitigation, it will be required to orderly define navigation patterns in the waterway to the extent possible, reduce crossing routes, especially in opposite direction traffic, and limit the need and number of course adjustments.

The mitigation of allision risk is generally more realistic to achieve as it can be influenced by routing measures, geometric adjustments, as well as the provision of tugs. Ship-to-ship collisions are limited in terms of the possible interventions to the introduction of routing measures that affect the route axis and lateral distribution and are thus more elaborate to pursue.

In consideration of the relative ship-to-ship collision risk analysis outcomes of scenarios C and A1, and in particular, the complexity under which traffic will merge in scenario A1, ABL chose to focus efforts on the mitigation of Scenario C.

4.2 Allision risk mitigation for EN 14

One of the main points taken from the analysis of the main scenarios was that a high level of allision risk is noted in area EN 14 (Figure 34). The area has consistently been the most risk intensive, by some margins, and thus it is worth investigating how potential interventions at and around its boundary may reduce part of this risk.

4.2.1 Process and results

This mitigation attempt was aimed at assessing the potential of mitigation through geometric adjustments to EN 14 and the adjacent area Gebied 6 Extra within the Dutch jurisdiction.

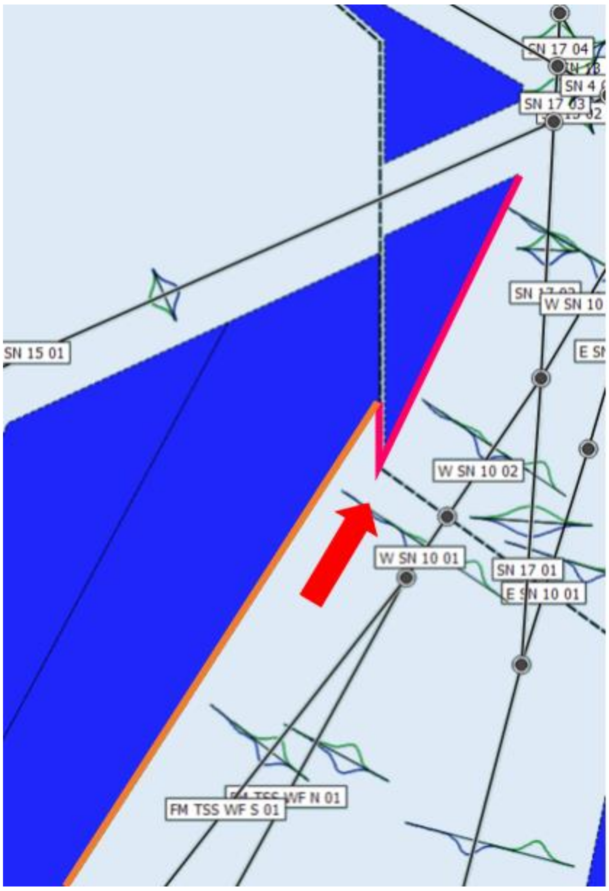


Figure 34: Close-up of EN 14 layout

Three separate mitigation attempts were made and tested for the study. These are schematically presented in Figure 35 below:

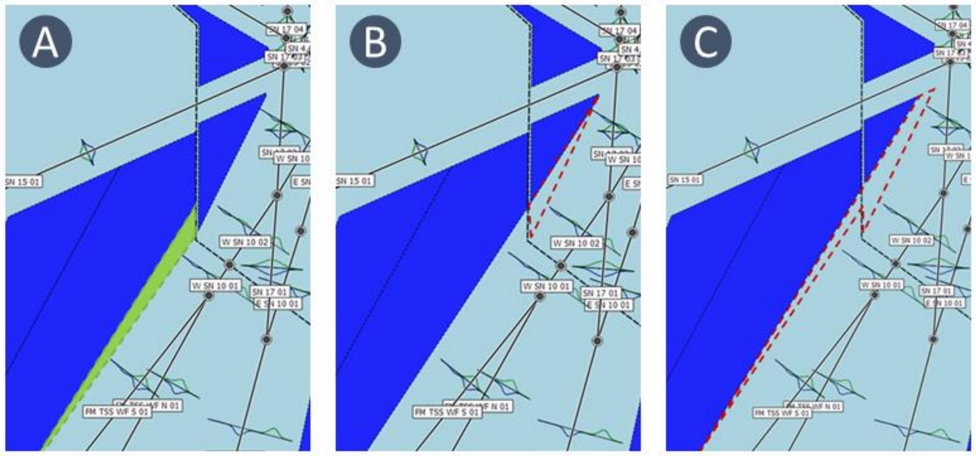


Figure 35: Summary of geometric mitigation attempts at EN 14

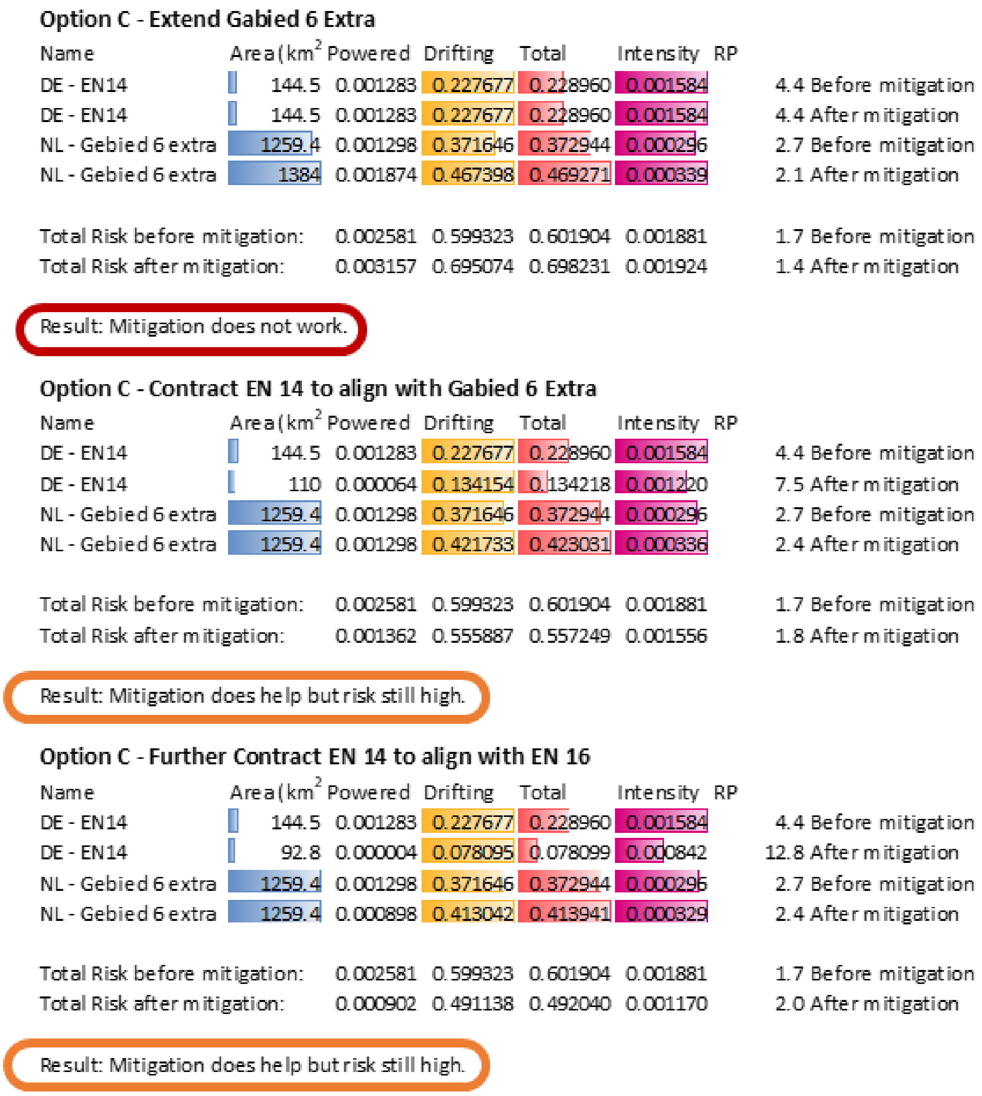
The first attempt was to investigate the effect of mitigating the protruding corner at the southern end of EN 14 (see Figure 34). This was initially done by extending the NE corner of Gebied 5 Extra to the east, to align with the southern corner of EN 14 (Figure 35A). The thought behind this attempt was to eliminate the unnecessarily exposed edge between the two developments that lies at a position subject to impact from drifters under the influence of southern winds. This attempt was not successful, as the risk intensity of EN 14 remained largely unchanged, and the pertinent risk intensity and absolute value for area Gebied 5 Extra both increased. It can thus be concluded that increasing the size of the latter to cover the exposed edge of EN 14 does not lead to risk mitigation.

The second attempt was to trim the southern corner of area EN 14 so that it aligns with the north-eastern corner of Gebied 5 Extra (Figure 35B). The logic behind this attempt was once again in terms of mitigating the protruding corner, and this moving it further away from the traffic lane in the area, securing additional time between a not under command vessel unable to steer and the time of impact, which would increase the success probability of control being restored. The outcome does offer some risk mitigation to area EN 14, however, disproportionately low compared to the reduction in development area that the intervention entailed. At the same time, it appears to raise the risk and risk intensity of Gebied 5 Extra. Based on these observations, despite the combined net benefit in terms of risk, the present arrangement does not constitute an attractive option.

The third attempt involved further moving the common as of option B edge of EN 14 and Gebied 5 Extra, to the west, to a point where it aligns with the line connecting the southern corner of Gebied 5 extra and the southern corner of EN 16 (Figure 35C). This attempt is on the same rationale as option B, however, intended to check if the additional drifting time before impact could more significantly increase the chances of repair based on the relevant Samson distribution (refer to Figure 14). This intervention proved to lower both the risk at area EN 14 as well as Gebied 5 Extra. However, same as in the case of mitigation B, the risk reduction has not been proportional to the area sacrifice required.

A summary of the iterations A to C discussed above is presented in Table 21 overleaf.

Table 21: Summary of layout mitigation attempts for area EN 14



Option C - Extend Gabied 6 Extra

Name	Area (km^2	Powered	Drifting	Total	Intensity	RP	
DE - EN14	144.5	0.001283	0.227677	0.228960	0.001584	4.4	Before mitigation
DE - EN14	144.5	0.001283	0.227677	0.228960	0.001584	4.4	After mitigation
NL - Gebied 6 extra	1259.4	0.001298	0.371646	0.372944	0.000296	2.7	Before mitigation
NL - Gebied 6 extra	1384	0.001874	0.467398	0.469271	0.000339	2.1	After mitigation
Total Risk before mitigation:		0.002581	0.599323	0.601904	0.001881	1.7	Before mitigation
Total Risk after mitigation:		0.003157	0.695074	0.698231	0.001924	1.4	After mitigation

Result: Mitigation does not work.

Option C - Contract EN 14 to align with Gabied 6 Extra

Name	Area (km^2	Powered	Drifting	Total	Intensity	RP	
DE - EN14	144.5	0.001283	0.227677	0.228960	0.001584	4.4	Before mitigation
DE - EN14	110	0.000064	0.134154	0.134218	0.001220	7.5	After mitigation
NL - Gebied 6 extra	1259.4	0.001298	0.371646	0.372944	0.000296	2.7	Before mitigation
NL - Gebied 6 extra	1259.4	0.001298	0.421733	0.423031	0.000336	2.4	After mitigation
Total Risk before mitigation:		0.002581	0.599323	0.601904	0.001881	1.7	Before mitigation
Total Risk after mitigation:		0.001362	0.555887	0.557249	0.001556	1.8	After mitigation

Result: Mitigation does help but risk still high.

Option C - Further Contract EN 14 to align with EN 16

Name	Area (km^2	Powered	Drifting	Total	Intensity	RP	
DE - EN14	144.5	0.001283	0.227677	0.228960	0.001584	4.4	Before mitigation
DE - EN14	92.8	0.000004	0.078095	0.078099	0.000842	12.8	After mitigation
NL - Gebied 6 extra	1259.4	0.001298	0.371646	0.372944	0.000296	2.7	Before mitigation
NL - Gebied 6 extra	1259.4	0.000898	0.413042	0.413941	0.000329	2.4	After mitigation
Total Risk before mitigation:		0.002581	0.599323	0.601904	0.001881	1.7	Before mitigation
Total Risk after mitigation:		0.000902	0.491138	0.492040	0.001170	2.0	After mitigation

Result: Mitigation does help but risk still high.

4.2.2 Conclusion

From the iterative process described, it can be concluded that risk mitigation based on solutions addressed to the geometry of area EN 14 is not possible, as even very large reductions in the size of the development area still leave unacceptable levels of residual allision risk.

This means that future risk mitigation at EN 14 can only be pursued via broader changes in the model, which may include routing measures, interventions in the overall geometry of the MSP, and potentially the provision of ETV tugs in a position that can influence drifting allisions to the extent that would return the risk recorded for the development to acceptable bounds. Onwards, EN 14 will be investigated as part of broader interventions to the model for Scenario C, which is the scenario that will be taken forward to be further explored and improved out of the main scenarios considered.

4.3 Risk mitigations for Scenario C

In the process of proposing means for mitigation of Scenario C, it was important to agree on the constraints in terms of applying changes to the MSP layout, in terms of the position, shape and size of elements. These were predominantly influenced by boundary conditions set at the two ends of route SN 10, within the Danish and Dutch jurisdictions.

In specific, in the Danish jurisdiction, the boundary conditions are formed by the position of the entrance to the projection of the deep-water route (Route A extending west of TSS Off Skagen) that forms the continuity of the West route within SN 10 (Note 1 in Figure 36), the tip of the area forming planning area Nordsoen II that shapes the eastern boundary of the latter and the western boundary of the extension to the East route of SN 10 (Note 2), and last, the corner of the Thor cluster on the northern side of Nordsoen I (Note 3). These are presented in Figure 36.

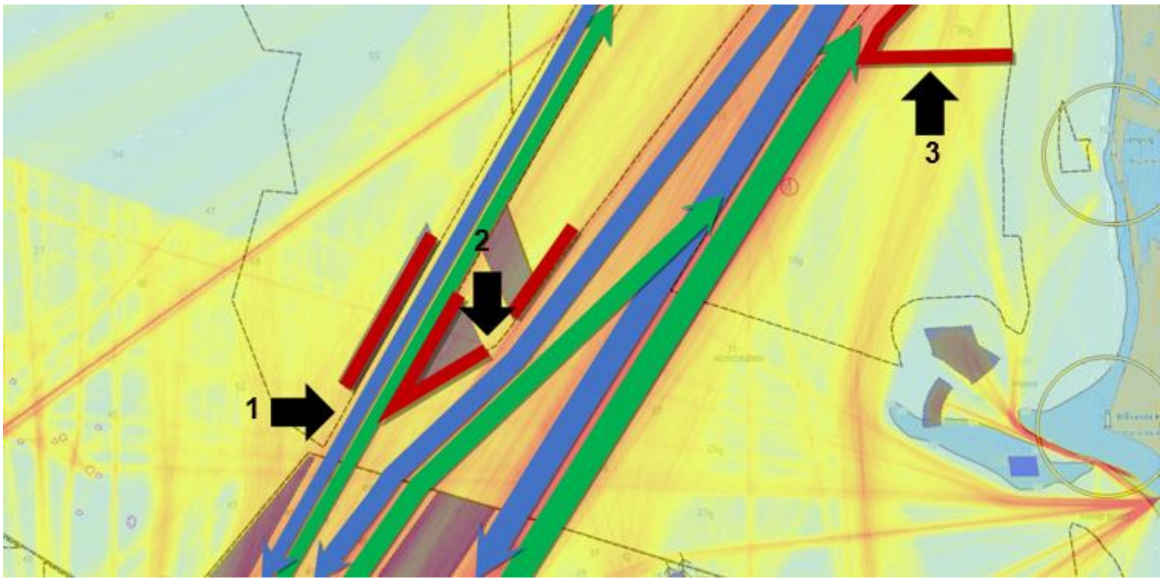


Figure 36: Elements forming the boundary conditions within the Danish jurisdiction.

In the Dutch jurisdiction, the boundary conditions are set by the existing position of the routes, as traffic from TSSs West Friesland and Vlieland Nord enters the SN 10 system. The current alignment of the northbound and southbound branches of these routes is at large determined by the positions of the relevant TSS schemes to the south of the area of interest and the position of existing offshore installations in the area. These are visible in Figure 37 overleaf.

In this case, the boundary conditions to this study are set at the circled areas in the same figure, which will generally constitute the start of the routes that will be used in the development of the model.

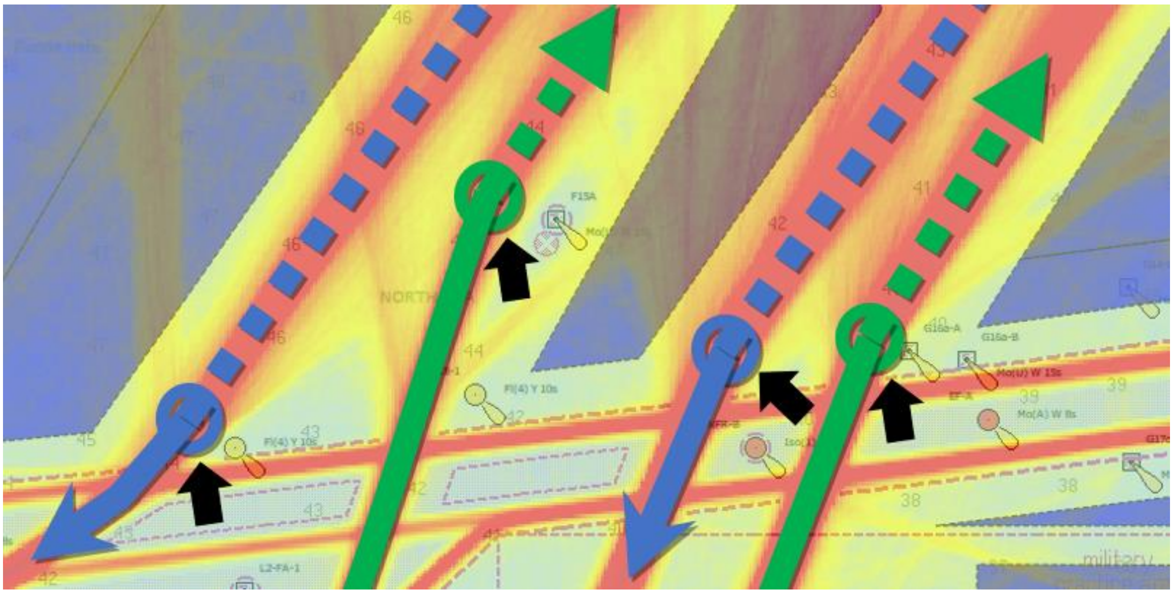


Figure 37: Elements forming the boundary conditions within the Danish jurisdiction.

Within the German jurisdiction, ABL was advised to consider the eastern edge of route SN 10 as per the current MSP fixed and was given complete freedom to alter the MSP layout within the German jurisdiction to the west.

4.3.1 Mitigation Scenario C_M1

On this basis, ABL developed the scheme of the first mitigation scenario for C, Scenario C_M1. This was based on the assumption that the West route on SN 10 would develop into a converging available corridor, from the current width of 22km at the interface with SN 2 (Friesland TSS) and to the south east of platform F3-OLT & F3-FB-1 of the Nogat Pipeline System, to a width of 7.5km at the entry point of the western route (conventionally called deep-water route onwards in this report) in the Danish EEZ. A recommended route was assumed between a point north of F15A offshore production platform and the -point of the entry to the deep-water route in the Danish jurisdiction oriented along a bearing of 027°-207°. Lateral traffic distributions would start at a similar current width in the south (SD of 926m) and would narrow down gradually along the route to 463m SD required to navigate the deep-water route. The protruding corner of area EN 14 has been removed from the shape to better define the western edge of the route.

This assumption allowed the movement of the middle-berm development areas to the west, to abut the eastern boundary of this shipping lane. This allowed for the introduction of a fourth, small development area mirroring the North side of Gebied 5 middenberm and continuing the western limit of the extension to route SN 17. A 12km-wide shipping lane was assumed for the East route of SN10, starting from the current point where vessels change course after clearing SN 2 and extending to the point vessels adjust course at the west of the Thor development area. A second recommended route was assumed between the point of intersection of this route to the extension of route SN 17 and extending into the Danish jurisdiction oriented along a course of 029°-209°

Last, the gradual crossing of traffic from the west to the east route and vice-versa at the northern end of the “middle-berm” installation, was replaced by a more direct crossing involving a neater course change. We have also considered that due to the geometry involved in the present scenario, vessels northbound with origin Off Vlieland and destined to the deep-water route in the Danish EEZ, will opt to take the SN 17 corridor in view, whilst vessels that are proceeding southbound on the eastern route and decide to proceed along the West Friesland junction, will take the course change north of the middle development. The arrangement is presented in Figure 38.

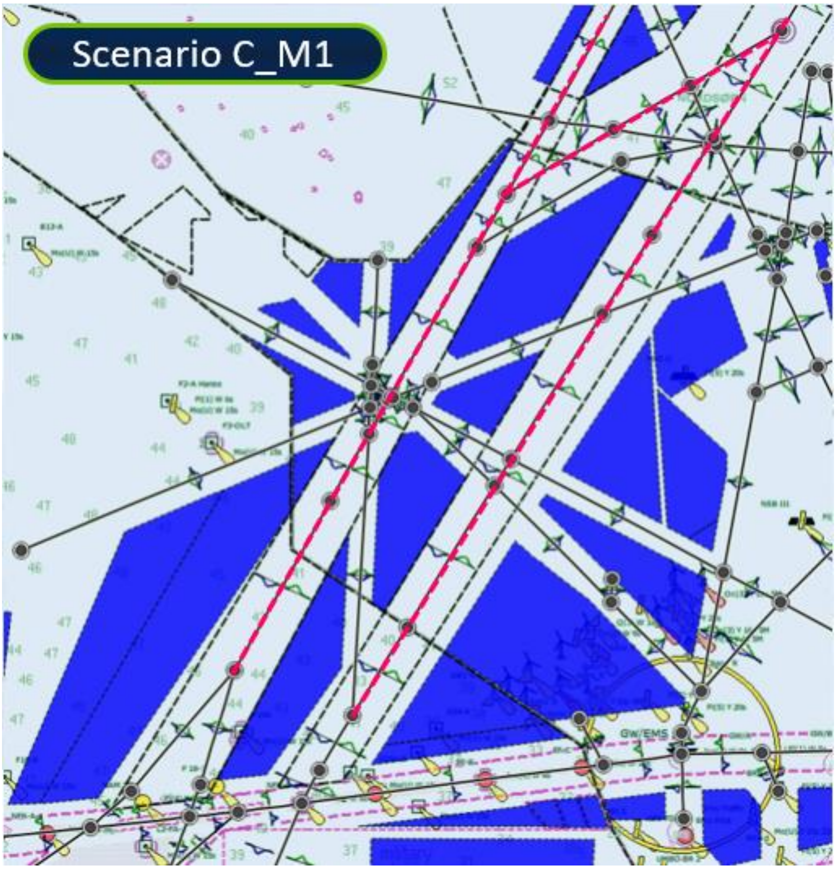


Figure 38: Proposed layout and routing measures for Scenario C_M1

It is noted that whilst the middle-berm development areas were moved to the west, the eastern edge of the development areas to the east of SN 10 was maintained. This was to provide a buffer zone against drifting vessels under the prevailing winds from the westerly sectors.

The analysis of mitigation scenario C_M1 returned an annual combined allision probability of 2.014, which converts to a return period of just under 6 months. This constitutes a 10% reduction in the allision risk, compared to that noted for Scenario C. This risk reduction is noted both as a direct reduction to the total allision risks in the area of interest, as well as in the risk intensity. The risk profile of the area of interest in the German EEZ is presented in Figure 39 overleaf.

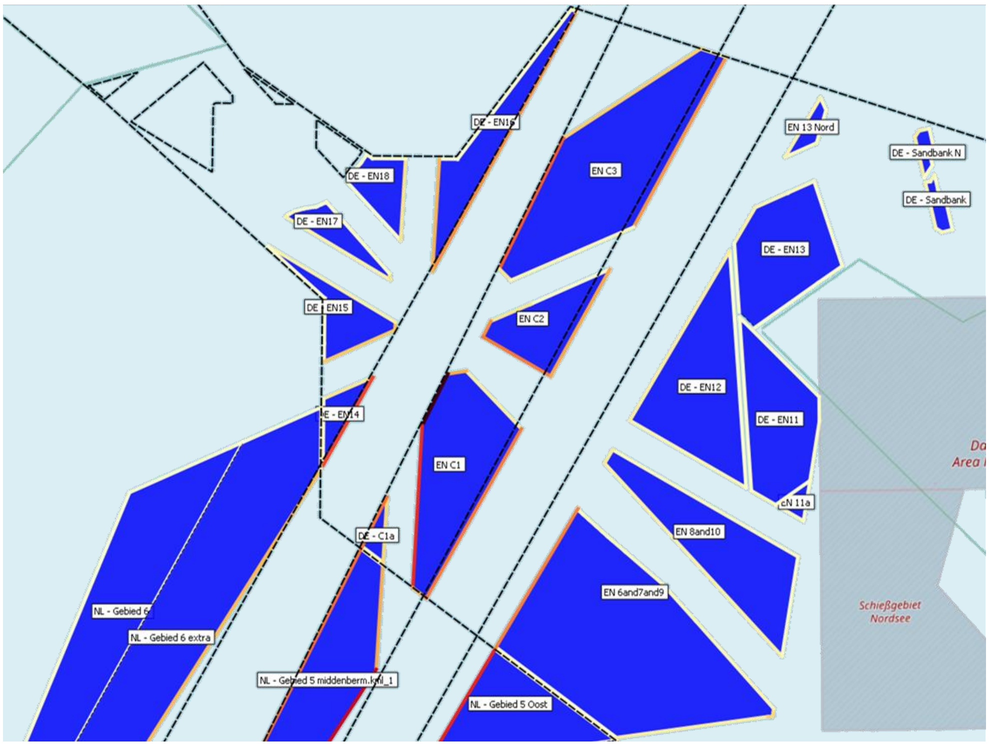
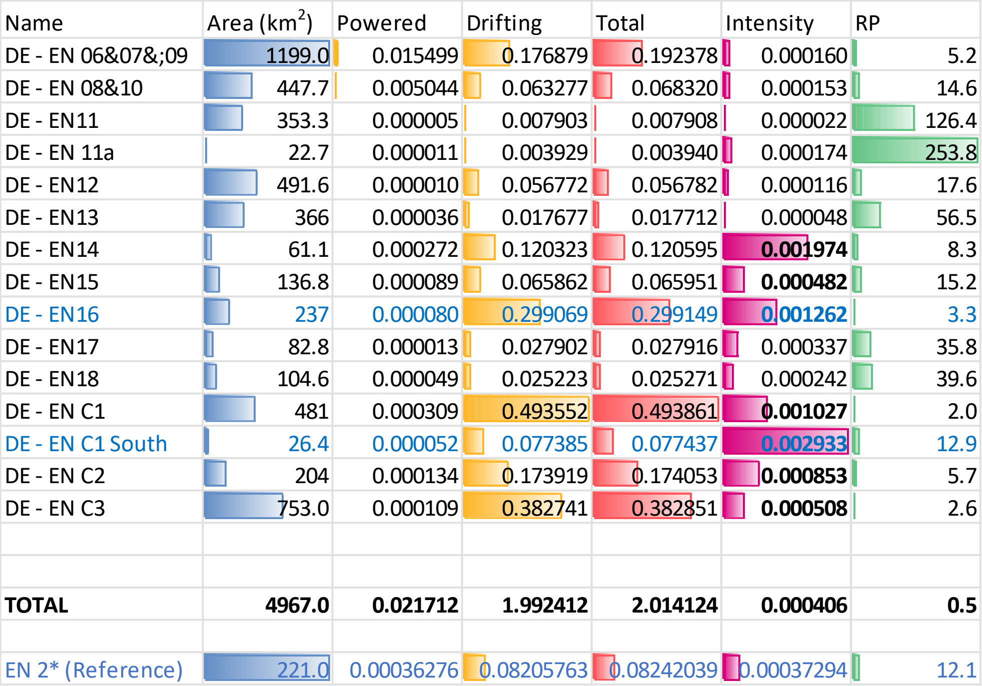


Figure 39: Allision risk profile of mitigation scenario C_M1 for the modelled area (percentage basis)

The calculated annual allision probabilities for the development areas in the German EEZ are presented in Table 22.

Table 22: Allision Risk of mitigation scenario C_M1 for German EEZ development areas



Name	Area (km^2)	Powered	Drifting	Total	Intensity	RP
DE - EN 06&07&;09	1199.0	0.015499	0.176879	0.192378	0.000160	5.2
DE - EN 08&10	447.7	0.005044	0.063277	0.068320	0.000153	14.6
DE - EN11	353.3	0.000005	0.007903	0.007908	0.000022	126.4
DE - EN 11a	22.7	0.000011	0.003929	0.003940	0.000174	253.8
DE - EN12	491.6	0.000010	0.056772	0.056782	0.000116	17.6
DE - EN13	366	0.000036	0.017677	0.017712	0.000048	56.5
DE - EN14	61.1	0.000272	0.120323	0.120595	**0.001974**	8.3
DE - EN15	136.8	0.000089	0.065862	0.065951	**0.000482**	15.2
DE - EN16	237	0.000080	0.299069	0.299149	**0.001262**	3.3
DE - EN17	82.8	0.000013	0.027902	0.027916	0.000337	35.8
DE - EN18	104.6	0.000049	0.025223	0.025271	0.000242	39.6
DE - EN C1	481	0.000309	0.493552	0.493861	**0.001027**	2.0
DE - EN C1 South	26.4	0.000052	0.077385	0.077437	**0.002933**	12.9
DE - EN C2	204	0.000134	0.173919	0.174053	**0.000853**	5.7
DE - EN C3	753.0	0.000109	0.382741	0.382851	**0.000508**	2.6
TOTAL	**4967.0**	**0.021712**	**1.992412**	**2.014124**	**0.000406**	**0.5**
EN 2* (Reference)	221.0	0.00036276	0.08205763	0.08242039	0.00037294	12.1

The model reported a very high-risk concentration on the western boundary of the new, middle-berm developments and the eastern edge of the extension to route SN 17. High concentrations of risk were also noted in areas EN 14 and EN 16, which were also the case in the basic scenarios. Peak allision risk intensity was noted in area EN C1 South, followed by that of EN 14, EN 16, and EN C1. All other areas noted an order of magnitude lower in terms of their risk intensity, however, with the newly revised middle-berm development areas EN C2 and EN C3 substantially exceeding the reference value for EN 2. Areas EN 16 and EN 12 also appear to be risk intense. In general, the highest allision risk intensities were noted in the areas that have a boundary on the West route of SN 10.

As also noted for the basic scenarios, powered allisions only constitute a small proportion of the overall allision risk noted (some 1% of the total) in this case, with the majority of the allision risk noted coming from drifting vessels.

The greatest allision reduction compared to the base scenario was noted at the developments to the East of SN 10. This demonstrates that the allowance of a buffer zone between the traffic and these areas has substantially reduced the allision risk to values substantially lower in terms of intensity than that of area EN 2. This leaves a margin for an adjustment to the alignment of the eastern route to transfer some of the risk from the areas in the middle to the areas on the east.

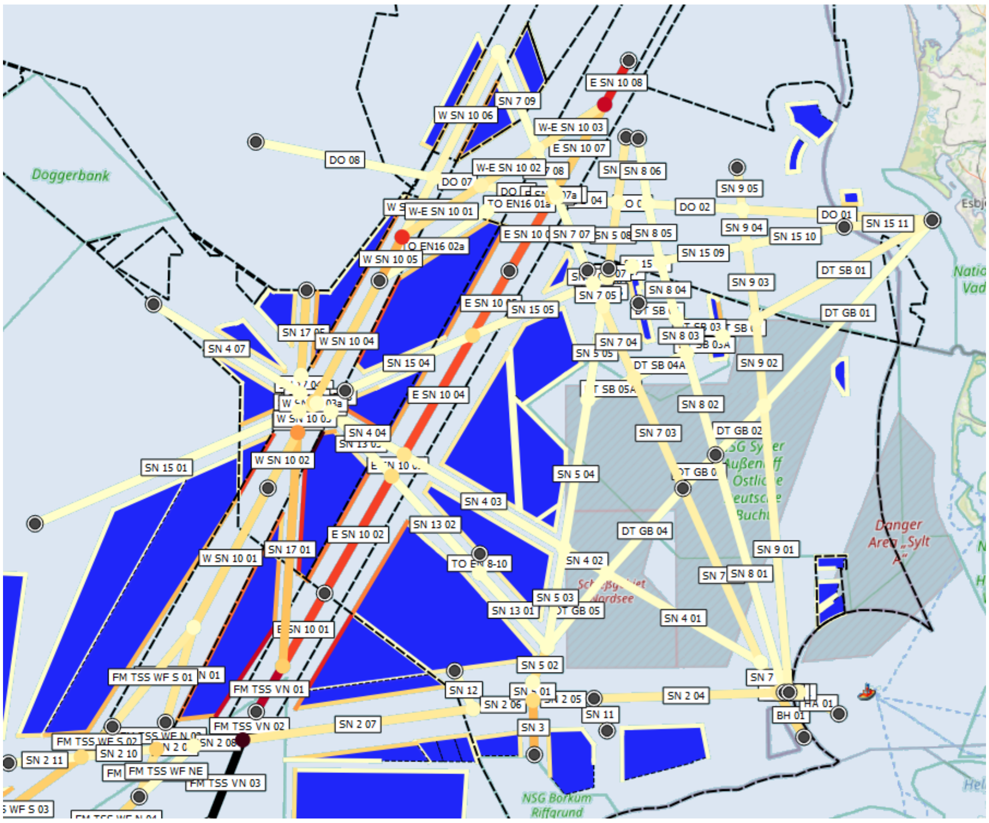
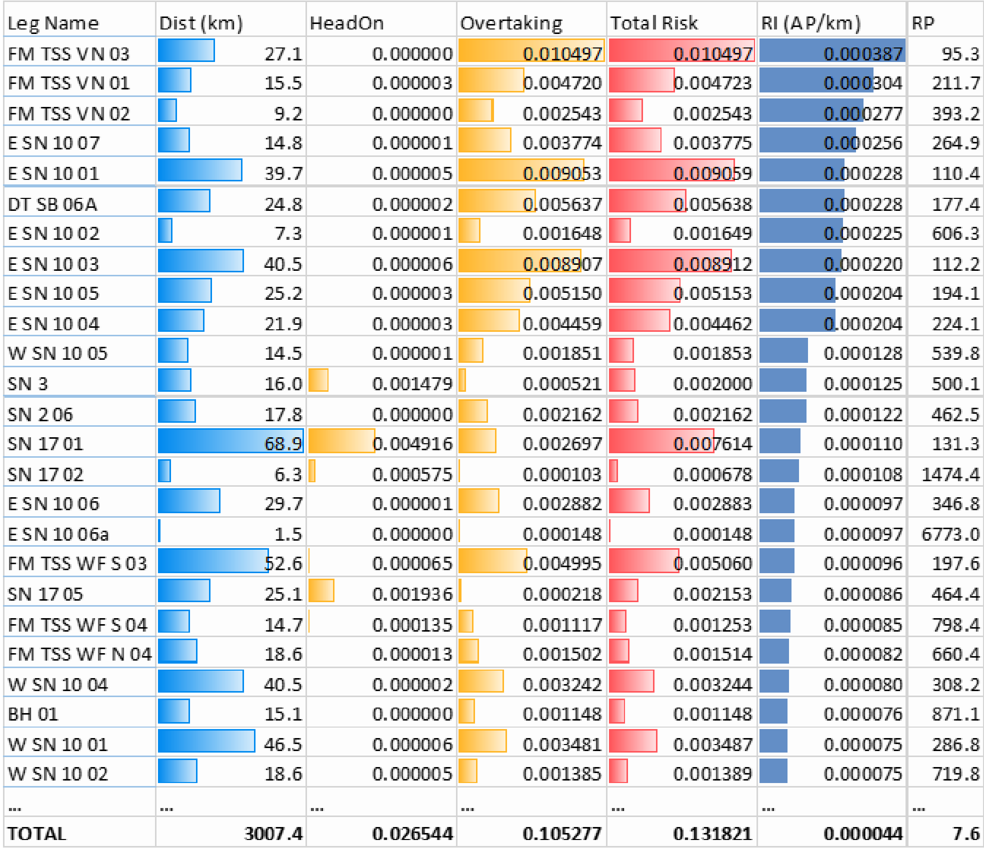


Figure 40: Ship-to-ship collision risk of mitigation scenario C_M1 for the modelled area (percentage basis)

In terms of the ship-to-ship collision risk (Figure 40), the highest risk in the model is noted at the route segment carrying traffic from/to TSS Vlieland Nord (Leg FM TSS VN 03, followed by 02 and 01). High risk intensities persist to appear along part of the East route on SN 10 to the north of the crossing of the extension to SN 17 (Leg E SN 10 01 onwards), however, at intensities notably lower than on the basic Scenario C.

The peak 25 calculated annual ship-to-ship collision probabilities of the legs representing the routes in the study area are presented in Table 23.

Table 23: Ship-to-ship collision risk on model legs, mitigation scenario C_M1



Leg Name	Dist (km)	HeadOn	Overtaking	Total Risk	RI (AP/km)	RP
FM TSS VN 03	27.1	0.000000	0.010497	0.010497	0.000387	95.3
FM TSS VN 01	15.5	0.000003	0.004720	0.004723	0.000304	211.7
FM TSS VN 02	9.2	0.000000	0.002543	0.002543	0.000277	393.2
E SN 10 07	14.8	0.000001	0.003774	0.003775	0.000256	264.9
E SN 10 01	39.7	0.000005	0.009053	0.009059	0.000228	110.4
DT SB 06A	24.8	0.000002	0.005637	0.005638	0.000228	177.4
E SN 10 02	7.3	0.000001	0.001648	0.001649	0.000225	606.3
E SN 10 03	40.5	0.000006	0.008907	0.008912	0.000220	112.2
E SN 10 05	25.2	0.000003	0.005150	0.005153	0.000204	194.1
E SN 10 04	21.9	0.000003	0.004459	0.004462	0.000204	224.1
W SN 10 05	14.5	0.000001	0.001851	0.001853	0.000128	539.8
SN 3	16.0	0.001479	0.000521	0.002000	0.000125	500.1
SN 2 06	17.8	0.000000	0.002162	0.002162	0.000122	462.5
SN 17 01	68.9	0.004916	0.002697	0.007614	0.000110	131.3
SN 17 02	6.3	0.000575	0.000103	0.000678	0.000108	1474.4
E SN 10 06	29.7	0.000001	0.002882	0.002883	0.000097	346.8
E SN 10 06a	1.5	0.000000	0.000148	0.000148	0.000097	6773.0
FM TSS WF S 03	52.6	0.000065	0.004995	0.005060	0.000096	197.6
SN 17 05	25.1	0.001936	0.000218	0.002153	0.000086	464.4
FM TSS WF S 04	14.7	0.000135	0.001117	0.001253	0.000085	798.4
FM TSS WF N 04	18.6	0.000013	0.001502	0.001514	0.000082	660.4
W SN 10 04	40.5	0.000002	0.003242	0.003244	0.000080	308.2
BH 01	15.1	0.000000	0.001148	0.001148	0.000076	871.1
W SN 10 01	46.5	0.000006	0.003481	0.003487	0.000075	286.8
W SN 10 02	18.6	0.000005	0.001385	0.001389	0.000075	719.8
...	...	...	...	...	...	...
TOTAL	**3007.4**	**0.026544**	**0.105277**	**0.131821**	**0.000044**	**7.6**

In the results, it can be seen that the lateral distribution assumed based on traffic navigating the recommended routes, which has a smaller overlap between directions compared to free navigation, has led to a reduction in the head-on collisions. The exception to this is route SN 17, where the notable traffic volumes are combined with two-directional flow assumed without directional separation, due to the limited width of the route. The model hence is dominated by overtaking risk, on which the lateral distribution of traffic (and in particular the standard deviation about the axis) becomes the key parameter.

For vessel-to-vessel allision risk at the route waypoints, which includes crossing, merging, and bend risk, refer to the risk profile presented in Figure 41 overleaf.

The peak waypoint risk is noted at the point of crossing between the traffic from/to TSS Vlieland Nord and route SN 2, at the southern boundary of route SN 10 (Waypoint 21). The risk noted is dominated by crossing risk, as a result of the high traffic volumes that crosses the junction almost at a right angle. Much lower levels of merging risk are also noted at the same waypoint. Detailed results for the waypoints with the highest calculated risk are provided in Table 24 overleaf.

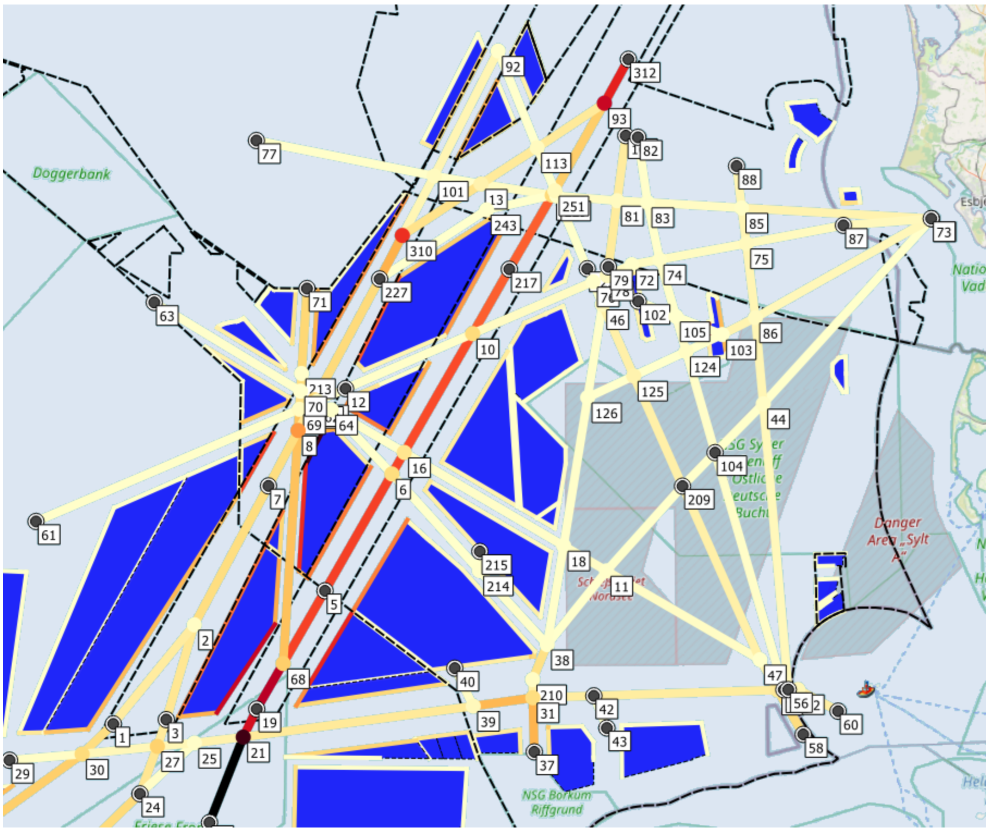


Figure 41: Waypoint collision risk of mitigation scenario C_M1 for the modelled area (percentage basis)

Within the area of the German EEZ, the waypoint with the highest risk is waypoint 310, at the north-western part of the EEZ, at the point of crossing from the western to the eastern route and vice versa. The risk noted at this point is dominated by bend risk from the turning vessels, with secondary merging and crossing risks noted. It is also noted that this behaviour is mirrored at the corresponding point on the East route, within the Danish jurisdiction.

Next in line in terms of risk are the waypoints at the junction between the extension of route SN 17 and the West and East routes of SN 10. This part of the route is taken by vessels that access the SN 10 area from TSS Vlieland Nord and want to exit the SN 10 system to the NW and vice versa. At waypoint 6, this traffic crosses the flow of the West route of SN 10. At the same point, the portion of traffic on West SN 10 from/to TSS West Friesland changes course to enter/exit the SN 10 system from/to the NW.

The sum of the risks captured and presented above adds up to a cumulative annual probability for the occurrence of an event of any type of 2.322, which converts to a return period between incidents of slightly longer than 5 months. This constitutes an improvement approaching the order of 10% compared to the basic scenario C.

Table 24: Ship-to-ship collision risk on model waypoints, mitigation scenario C_M1

WAYPOINT	Crossing	Merging	Bend	Total	RP
21	0.029601	0.001811	0.000110	0.031523	31.7
93	0.006045	0.007393	0.010176	0.023615	42.3
310	0.003088	0.005913	0.010810	0.019810	50.5
8	0.009494	0.003024	0.000427	0.012944	77.3
68	0.002865	0.003927	0.001032	0.007823	127.8
27	0.007519	0.000055	0.000000	0.007574	132.0
14	0.003813	0.002985	0.000000	0.006798	147.1
30	0.006232	0.000217	0.000001	0.006450	155.0
10	0.005082	0.001249	0.000079	0.006411	156.0
305	0.006355	0.000033	0.000013	0.006401	156.2
6	0.006151	0.000000	0.000000	0.006151	162.6
31	0.005078	0.000903	0.000119	0.006099	164.0
16	0.004901	0.000000	0.000000	0.004901	204.1
32	0.003318	0.000761	0.000145	0.004224	236.7
13	0.002087	0.000361	0.000017	0.002466	405.6
125	0.001919	0.000000	0.000451	0.002370	422.0
302	0.002036	0.000000	0.000000	0.002036	491.2
52	0.000000	0.000000	0.001599	0.001599	625.2
39	0.000588	0.000650	0.000083	0.001321	756.9
251	0.001244	0.000000	0.000000	0.001244	804.0
46	0.000256	0.000174	0.000767	0.001197	835.4
75	0.001176	0.000000	0.000000	0.001176	850.5
78	0.001131	0.000000	0.000000	0.001131	884.5
101	0.001026	0.000000	0.000000	0.001026	974.4
112	0.001015	0.000000	0.000000	0.001015	985.4
…	…	…	…	…	…
TOTAL	**0.117664**	**0.029979**	**0.028199**	**0.175842**	**5.7**

4.3.2 Mitigation Scenario C_M2

To progress into the next stage of looking into mitigation measures after scenario C_M1, the route of introducing no more than a single change on each route of the model was adopted, to be in a position to isolate and assess its impact.

For mitigation scenario C_M2, on the West route, where the main issue has been allisions, an intervention was done to the footprint of areas SN 14 and SN 16. A thin wedge formed from the northern corner of EN 16 and down to 10.5 (km S-N) to the west of the SE corner of EN 14 has been removed (Figure 42). This is to provide some additional buffer zone to the two areas, and some more space at the main junction of the routes within the German EEZ. Earlier in the report, it was shown that the risk reduction that can be achieved on EN 14 comes at a heavy reduction in its area, however, as the middle-berm areas of scenario C_M1 offer more areas than the middle-berm of the basic scenario C, this was, for the assessment, deemed a reasonable compromise.

For the East route on mitigation scenario C_M2, the axis of the recommended route was shifted by approximately 1.5 km to the east, without change in the areas surrounding it. The purpose of this shift of the 12km-wide shipping lane was to test whether the hypothesis that the provision of some buffer area to the west could alleviate some of the risk on the middle-berm developments and lead to a net benefit in risk considering the risk introduced to the development areas to the east. From a navigational perspective, the shift to the recommended route will require a slightly earlier course adjustment after crossing SN 2, however, does not influence the safe crossing to the west of G16a-A and G16a-B gas production platforms The arrangement for scenario C_M2 is presented in Figure 42.

Figure 42: Proposed layout and routing measures for Scenario C_M2

The analysis of mitigation scenario C_M2 returned an annual combined allision probability of 1.832, which converts to a return period of approximately 6.5 months. This constitutes a 9% reduction in the allision risk, compared to that noted for mitigation scenario C_M1. This risk reduction is noted both as a direct reduction to the total allision risks in the area of interest, as well as in the risk intensity, to an extent that shows that the risk reduction exceeded in proportion the reduction in the development area. The risk profile of the area of interest in the German EEZ is presented in Figure 43 overleaf.

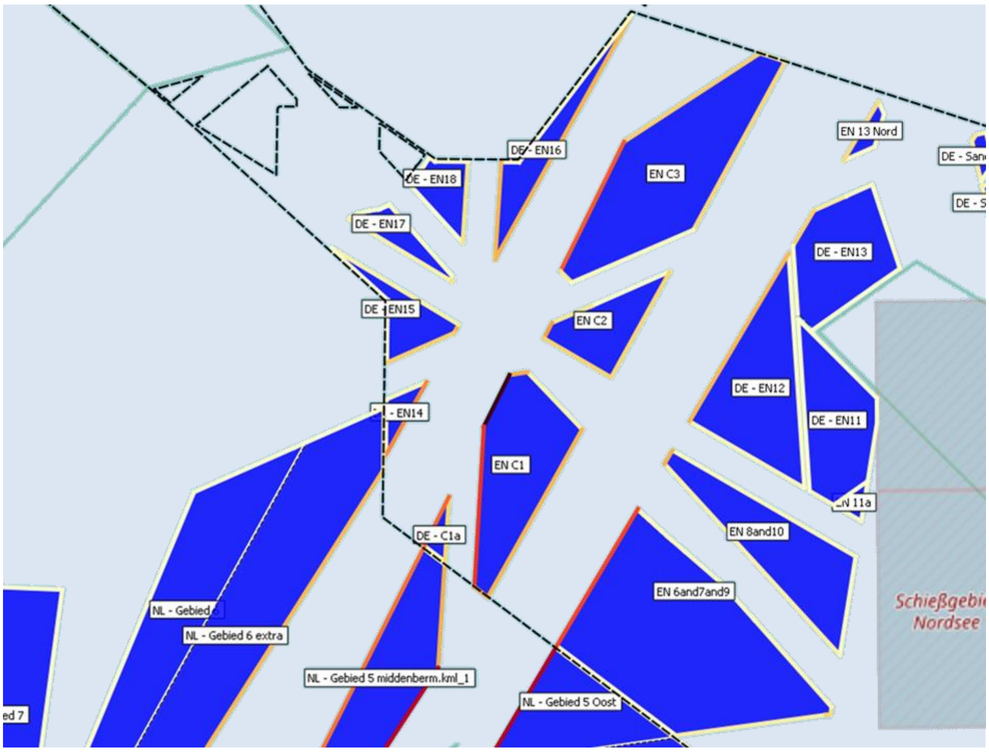
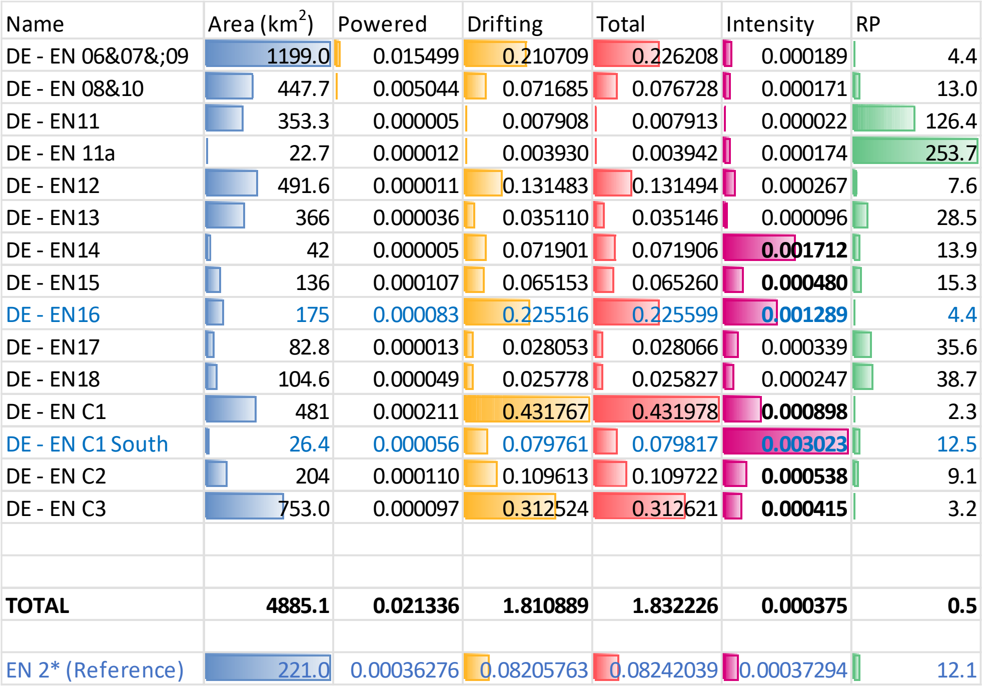


Figure 43: Allision risk profile of mitigation scenario C_M2 for the modelled area (percentage basis)

The calculated annual allision probabilities for the development areas in the German EEZ are presented in Table 25.

Table 25: Allision Risk of mitigation scenario C_M2 for German EEZ development areas



Name	Area (km^2)	Powered	Drifting	Total	Intensity	RP
DE - EN 06&07&;09	1199.0	0.015499	0.210709	0.226208	0.000189	4.4
DE - EN 08&10	447.7	0.005044	0.071685	0.076728	0.000171	13.0
DE - EN11	353.3	0.000005	0.007908	0.007913	0.000022	126.4
DE - EN 11a	22.7	0.000012	0.003930	0.003942	0.000174	253.7
DE - EN12	491.6	0.000011	0.131483	0.131494	0.000267	7.6
DE - EN13	366	0.000036	0.035110	0.035146	0.000096	28.5
DE - EN14	42	0.000005	0.071901	0.071906	**0.001712**	13.9
DE - EN15	136	0.000107	0.065153	0.065260	**0.000480**	15.3
DE - EN16	175	0.000083	0.225516	0.225599	**0.001289**	4.4
DE - EN17	82.8	0.000013	0.028053	0.028066	0.000339	35.6
DE - EN18	104.6	0.000049	0.025778	0.025827	0.000247	38.7
DE - EN C1	481	0.000211	0.431767	0.431978	**0.000898**	2.3
DE - EN C1 South	26.4	0.000056	0.079761	0.079817	**0.003023**	12.5
DE - EN C2	204	0.000110	0.109613	0.109722	**0.000538**	9.1
DE - EN C3	753.0	0.000097	0.312524	0.312621	**0.000415**	3.2
TOTAL	**4885.1**	**0.021336**	**1.810889**	**1.832226**	**0.000375**	**0.5**
EN 2* (Reference)	221.0	0.00036276	0.08205763	0.08242039	0.00037294	12.1

The model, despite the overall allision risk reduction, still reported very high-risk concentrations on the western boundary of the new, middle-berm developments and the eastern edge of the extension to route SN 17. Risk concentration in areas EN 14 and EN 16 remained high despite the slight reduction. Peak allision risk intensity was noted as in scenario C_M1 on area EN C1 South, followed by that of EN 14, EN 16. The remaining areas returned order of magnitude lower risk intensity, however, in some cases still substantially higher than the measure of EN 2. The middle-berm development areas EN C1 and EN C2 substantially exceed the reference value for EN 2. Area EN C3 returned only a slightly higher risk compared to EN 2. All other areas were within reasonable margins of risk, however, the issue with areas that have a boundary on the West route of SN 10 remained and had to be addressed in future iterations.

In terms of the risk noted to the developments to the East of SN 10, despite the increase that was noted in all areas without exception (ranging from 15% to almost doubling), the overall risk remained small and well within manageable margins. Thus, it can be concluded that the shift of the route to the east has been a successful measure.

On the contrary, the intervention to the area footprint of EN 14 and EN 16 on the West route, while it has resulted in a net benefit in risk, has not addressed the problem of allisions on that route.

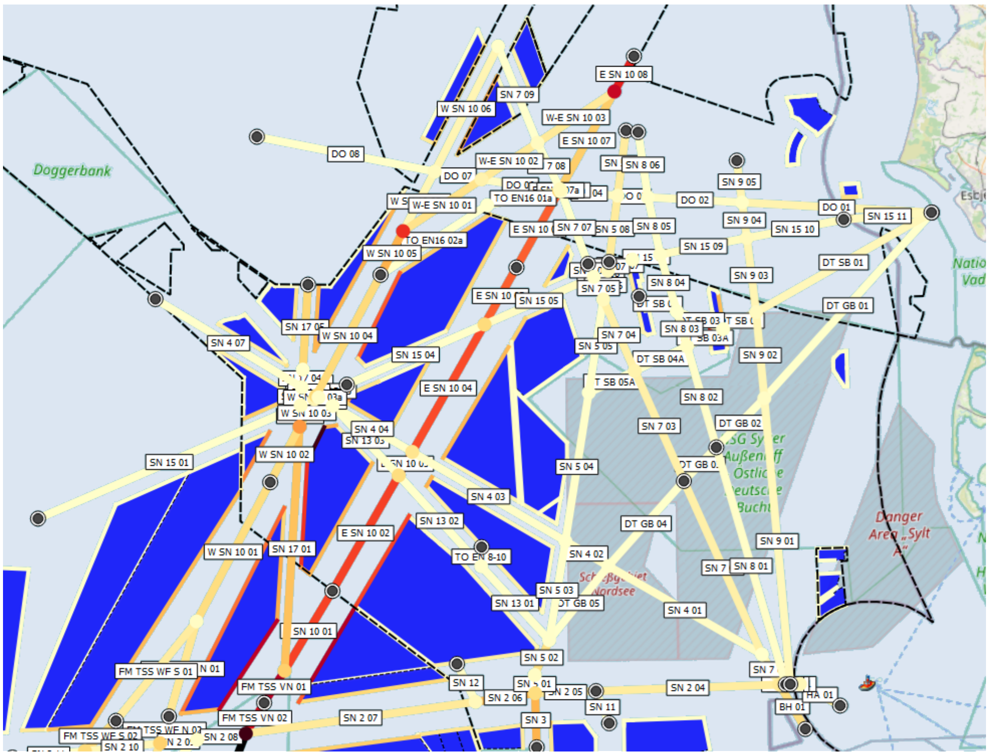
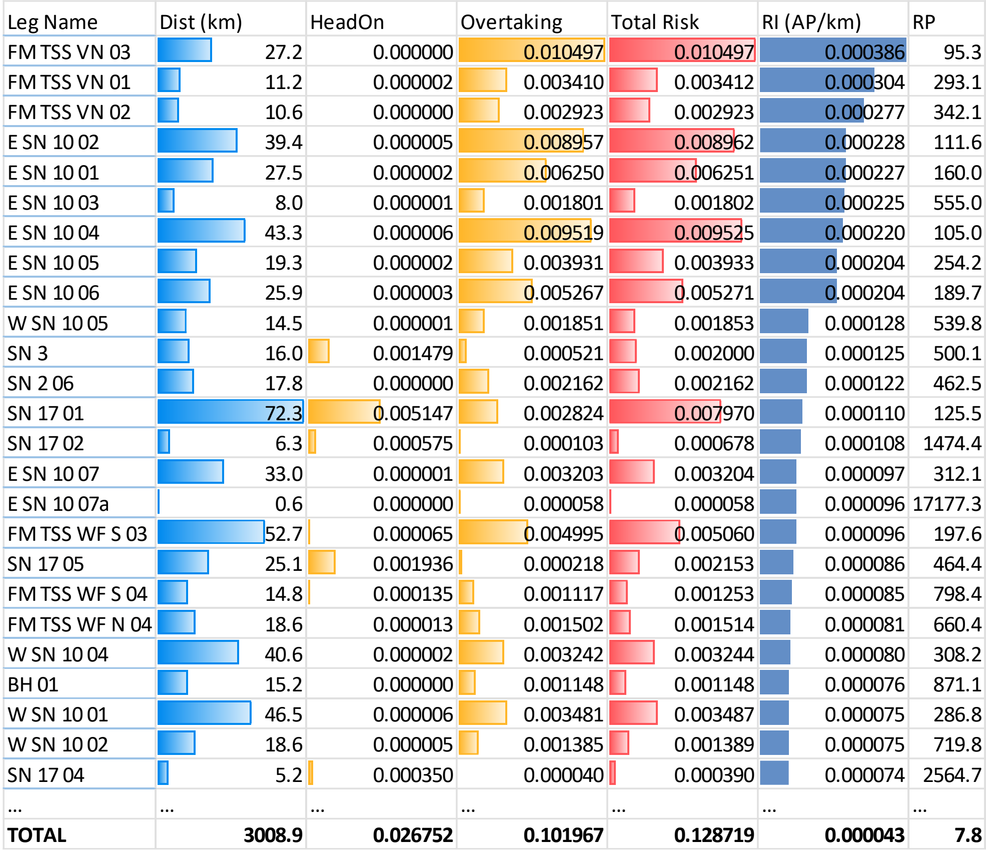


Figure 44: Ship-to-ship collision risk of mitigation scenario C_M2 for the modelled area (percentage basis)

In terms of the ship-to-ship collision risk (Figure 44), the highest risk in the model remains noted at the route segment carrying traffic from/to TSS Vlieland Nord (Leg FM TSS VN 03, followed by 01 and 02). High risk intensities persist to appear along part of the East route on SN 10 to the north of the crossing of the extension to SN 17 (Leg E SN 10 01 onwards), to the levels noted in scenario C_M1.

The peak 25 calculated annual ship-to-ship collision probabilities of the legs representing the routes in the study area are presented in Table 26.

Table 26: Ship-to-ship collision risk on model legs, mitigation scenario C_M2



Leg Name	Dist (km)	HeadOn	Overtaking	Total Risk	RI (AP/km)	RP
FM TSS VN 03	27.2	0.000000	0.010497	0.010497	0.000386	95.3
FM TSS VN 01	11.2	0.000002	0.003410	0.003412	0.000304	293.1
FM TSS VN 02	10.6	0.000000	0.002923	0.002923	0.000277	342.1
E SN 10 02	39.4	0.000005	0.008957	0.008962	0.000228	111.6
E SN 10 01	27.5	0.000002	0.006250	0.006251	0.000227	160.0
E SN 10 03	8.0	0.000001	0.001801	0.001802	0.000225	555.0
E SN 10 04	43.3	0.000006	0.009519	0.009525	0.000220	105.0
E SN 10 05	19.3	0.000002	0.003931	0.003933	0.000204	254.2
E SN 10 06	25.9	0.000003	0.005267	0.005271	0.000204	189.7
W SN 10 05	14.5	0.000001	0.001851	0.001853	0.000128	539.8
SN 3	16.0	0.001479	0.000521	0.002000	0.000125	500.1
SN 2 06	17.8	0.000000	0.002162	0.002162	0.000122	462.5
SN 17 01	72.3	0.005147	0.002824	0.007970	0.000110	125.5
SN 17 02	6.3	0.000575	0.000103	0.000678	0.000108	1474.4
E SN 10 07	33.0	0.000001	0.003203	0.003204	0.000097	312.1
E SN 10 07a	0.6	0.000000	0.000058	0.000058	0.000096	17177.3
FM TSS WF S 03	52.7	0.000065	0.004995	0.005060	0.000096	197.6
SN 17 05	25.1	0.001936	0.000218	0.002153	0.000086	464.4
FM TSS WF S 04	14.8	0.000135	0.001117	0.001253	0.000085	798.4
FM TSS WF N 04	18.6	0.000013	0.001502	0.001514	0.000081	660.4
W SN 10 04	40.6	0.000002	0.003242	0.003244	0.000080	308.2
BH 01	15.2	0.000000	0.001148	0.001148	0.000076	871.1
W SN 10 01	46.5	0.000006	0.003481	0.003487	0.000075	286.8
W SN 10 02	18.6	0.000005	0.001385	0.001389	0.000075	719.8
SN 17 04	5.2	0.000350	0.000040	0.000390	0.000074	2564.7
...	...	...	...	...	...	...
TOTAL	**3008.9**	**0.026752**	**0.101967**	**0.128719**	**0.000043**	**7.8**

Overtaking risk, remains the dominant parameter for the legs of the model, with lateral distribution being the main influencing factor.

For ship-to-ship collision risk at the route waypoints, which includes crossing, merging, and bend risk, refer to the risk profile presented in Figure 45 overleaf.

The peak waypoint risk remains at the point of crossing between the traffic from/to TSS Vlieland Nord and route SN 2, at the southern boundary of route SN 10 (Waypoint 21). Detailed results for the waypoints with the highest calculated risk are provided in Table 27.

Within the area of the German EEZ, the waypoint with the highest risk is still waypoint 310, dominated by bend risk from the turning vessels, with secondary merging and crossing risks noted. This behaviour is mirrored at the corresponding point on the East route, within the Danish jurisdiction, where the risk slightly increases (+0.25%) as a result of the shift to the axis of the East route. This reduction is negligible.

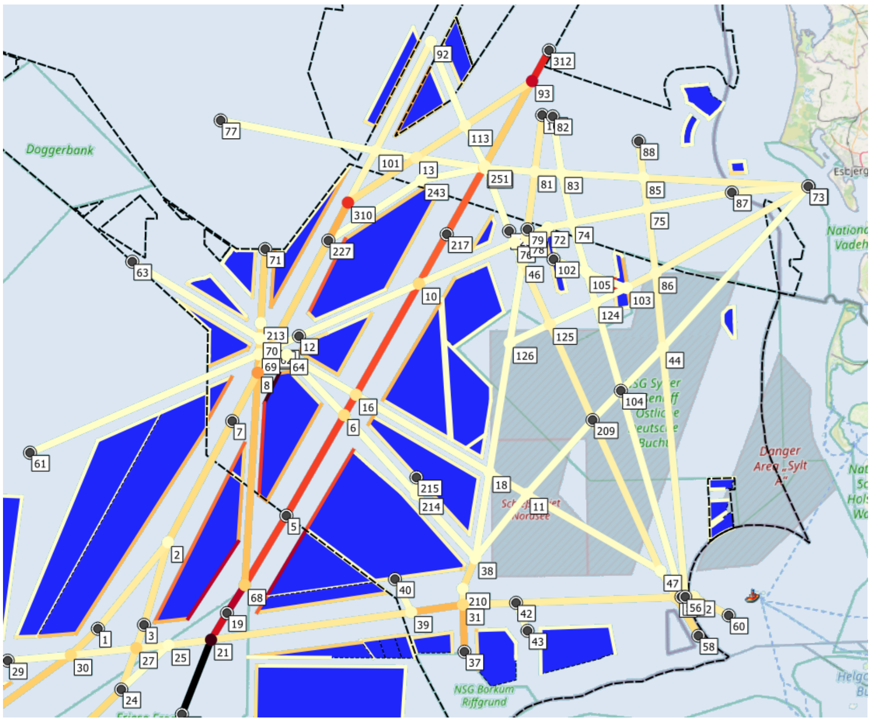
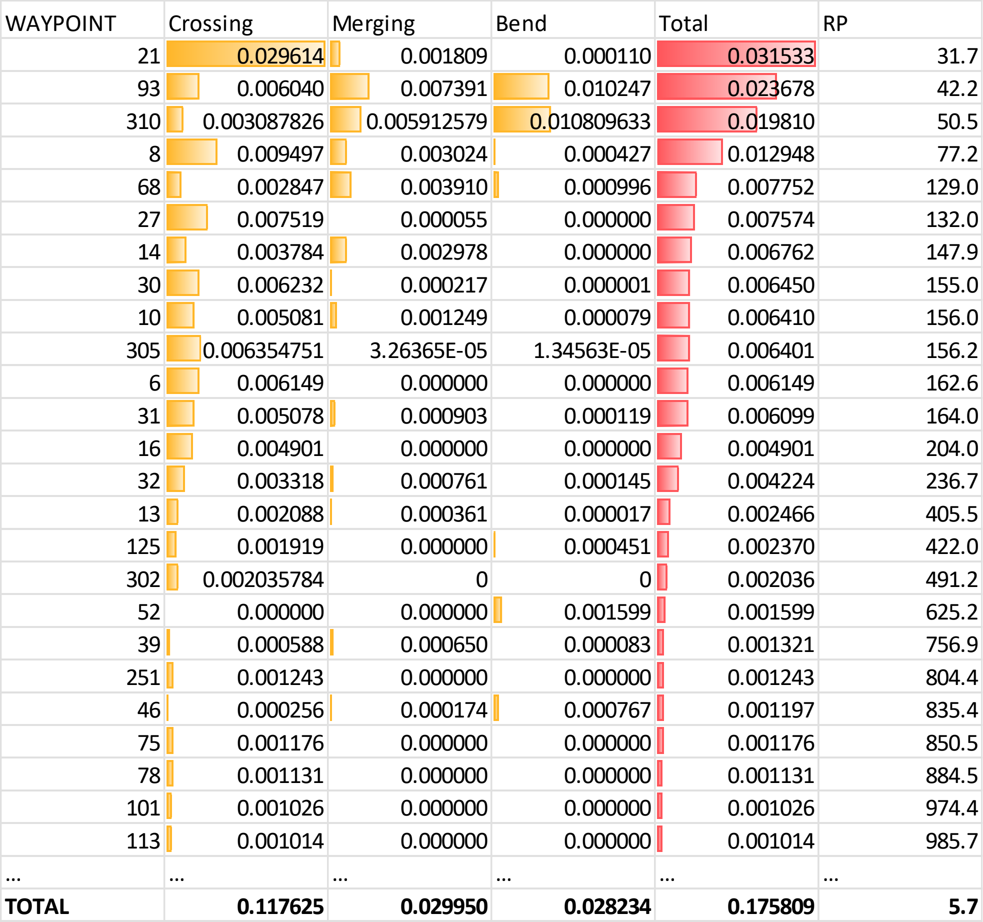


Figure 45: Waypoint collision risk of mitigation scenario C_M2 for the modelled area (percentage basis)

Next in line in terms of risk are the waypoints at the junction between the extension of route SN 17 and the West and East routes of SN 10. Risk at point 8 remains unchanged from scenario C_M1, whilst that of 68 marginally reduces (-1.00%).

The sum of the risks captured and presented above adds up to a cumulative annual probability for the occurrence of an event of any type of 2.137, which converts to a return period between incidents of slightly longer than 5.5 months. This constitutes an improvement approaching the order of 16% compared to the basic scenario C, and 8% compared to the previous mitigation scenario.

Table 27: Ship-to-ship collision risk on model waypoints, mitigation scenario C_M2



WAYPOINT	Crossing	Merging	Bend	Total	RP
21	0.029614	0.001809	0.000110	0.031533	31.7
93	0.006040	0.007391	0.010247	0.023678	42.2
310	0.003087826	0.005912579	0.010809633	0.019810	50.5
8	0.009497	0.003024	0.000427	0.012948	77.2
68	0.002847	0.003910	0.000996	0.007752	129.0
27	0.007519	0.000055	0.000000	0.007574	132.0
14	0.003784	0.002978	0.000000	0.006762	147.9
30	0.006232	0.000217	0.000001	0.006450	155.0
10	0.005081	0.001249	0.000079	0.006410	156.0
305	0.006354751	3.26365E-05	1.34563E-05	0.006401	156.2
6	0.006149	0.000000	0.000000	0.006149	162.6
31	0.005078	0.000903	0.000119	0.006099	164.0
16	0.004901	0.000000	0.000000	0.004901	204.0
32	0.003318	0.000761	0.000145	0.004224	236.7
13	0.002088	0.000361	0.000017	0.002466	405.5
125	0.001919	0.000000	0.000451	0.002370	422.0
302	0.002035784	0	0	0.002036	491.2
52	0.000000	0.000000	0.001599	0.001599	625.2
39	0.000588	0.000650	0.000083	0.001321	756.9
251	0.001243	0.000000	0.000000	0.001243	804.4
46	0.000256	0.000174	0.000767	0.001197	835.4
75	0.001176	0.000000	0.000000	0.001176	850.5
78	0.001131	0.000000	0.000000	0.001131	884.5
101	0.001026	0.000000	0.000000	0.001026	974.4
113	0.001014	0.000000	0.000000	0.001014	985.7
...	...	...	...	...	...
TOTAL	**0.117625**	**0.029950**	**0.028234**	**0.175809**	**5.7**

4.3.3 Mitigation Scenario C_M3

The third mitigation stage, scenario C_M3, is targeted to mitigate the allision risk to the development areas in the middle of route SN 10. This was pursued through the reduction in the area of the developments at the centre of SN 10, to incorporate an eastern buffer zone to the West route, where the prevailing winds are more likely to drag drifting vessels. However, contrary to C_M2, this is not combined with any routing measures or intervention to the routes.

Also, this scenario tests the impact of the removal of area C1 South. The area was found to concentrate abnormally high levels of risk, and thus in the present scenario, the impact of its removal from the development plan was investigated. The arrangement for scenario C_M3 is presented in Figure 46 overleaf.

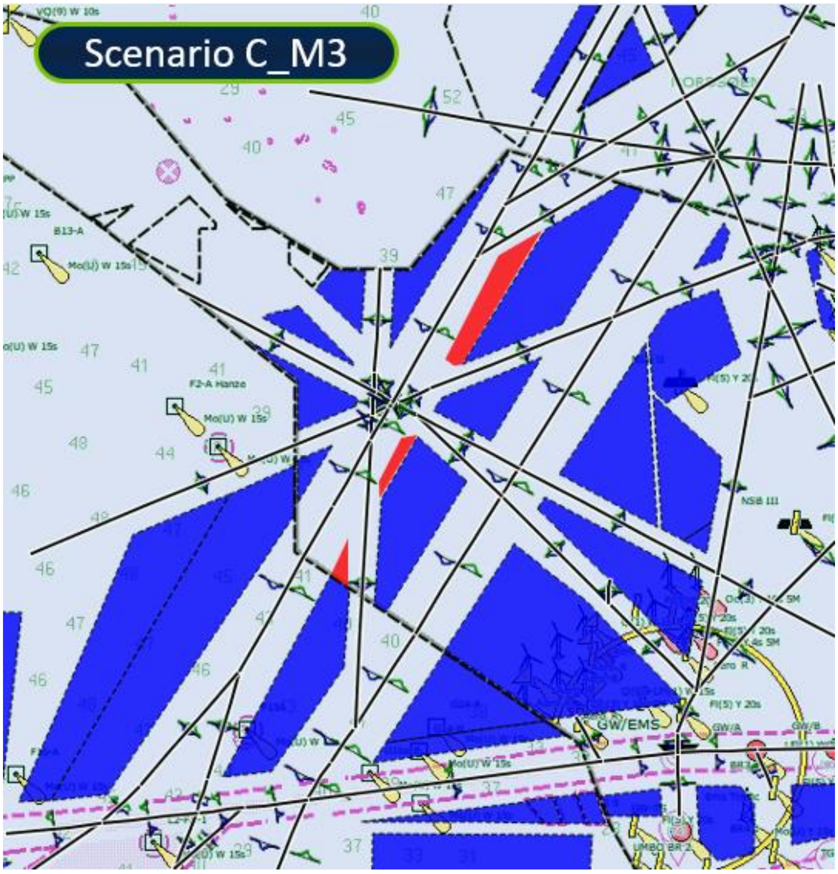


Figure 46: Proposed layout measures for Scenario C_M3

Following analysis, mitigation scenario C_M3 returned an annual combined allision probability of 1.645, which converts to a return period of approximately 7.3 months. This constitutes a 10% reduction in the allision risk, compared to that noted for mitigation scenario C_M2 and a 27% reduction compared to the basic scenario C. This risk reduction is noted both as a direct reduction to the total allision risks in the area of interest, and a reduction in the risk intensity.

However, for scenario C_M3 the reduction in intensity was lower than the overall reduction in risk, meaning that mitigation was achieved at a notable toll in terms of the development area. This reduction was of the order of 4.5% compared to C_M2, and 3.4% compared to the basic scenario C.

The risk profile of the area of interest in the German EEZ is presented in Figure 47 overleaf.

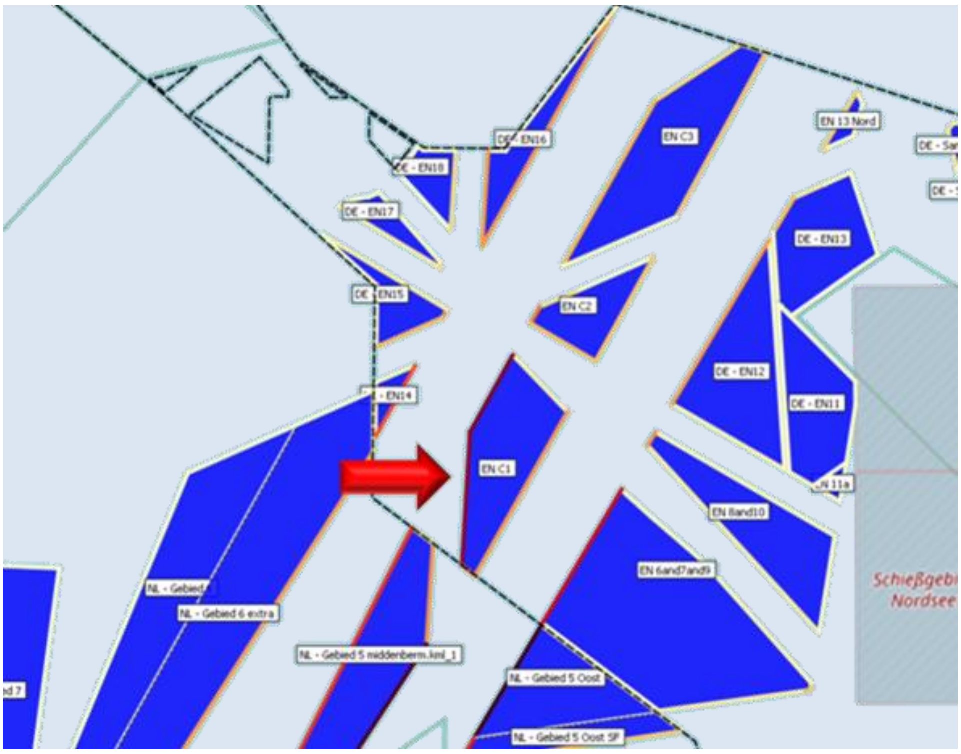
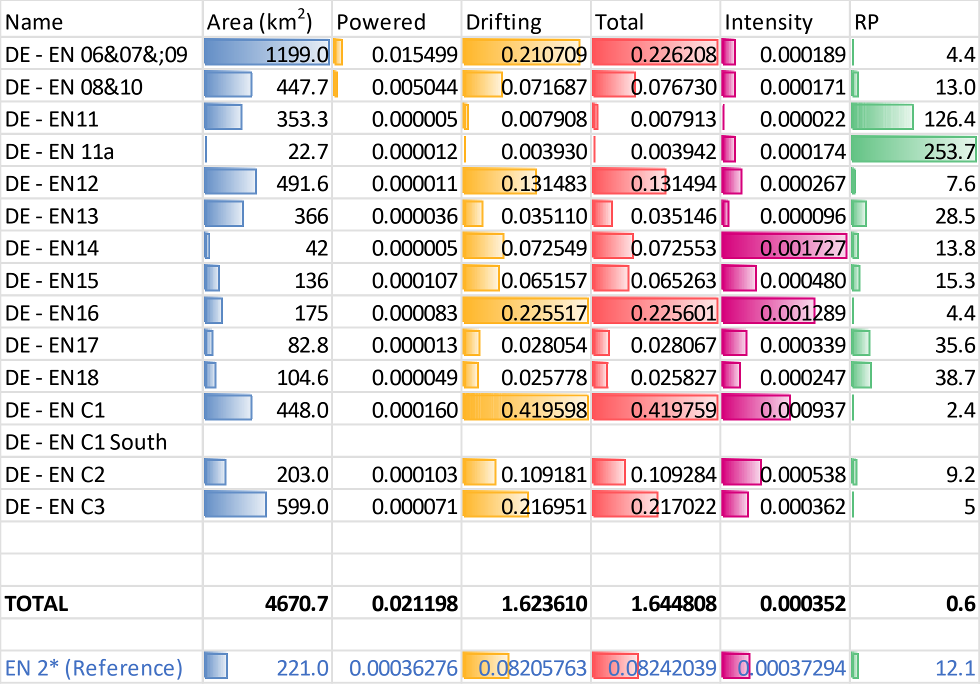


Figure 47: Allision risk profile of mitigation scenario C_M3 for the modelled area (percentage basis)

The calculated annual allision probabilities for the development areas in the German EEZ are presented in Table 28.

Table 28: Allision Risk of mitigation scenario C_M3 for German EEZ development areas



Name	Area (km^2)	Powered	Drifting	Total	Intensity	RP
DE - EN 06&07&;09	1199.0	0.015499	0.210709	0.226208	0.000189	4.4
DE - EN 08&10	447.7	0.005044	0.071687	0.076730	0.000171	13.0
DE - EN11	353.3	0.000005	0.007908	0.007913	0.000022	126.4
DE - EN 11a	22.7	0.000012	0.003930	0.003942	0.000174	253.7
DE - EN12	491.6	0.000011	0.131483	0.131494	0.000267	7.6
DE - EN13	366	0.000036	0.035110	0.035146	0.000096	28.5
DE - EN14	42	0.000005	0.072549	0.072553	0.001727	13.8
DE - EN15	136	0.000107	0.065157	0.065263	0.000480	15.3
DE - EN16	175	0.000083	0.225517	0.225601	0.001289	4.4
DE - EN17	82.8	0.000013	0.028054	0.028067	0.000339	35.6
DE - EN18	104.6	0.000049	0.025778	0.025827	0.000247	38.7
DE - EN C1	448.0	0.000160	0.419598	0.419759	0.000937	2.4
DE - EN C1 South						
DE - EN C2	203.0	0.000103	0.109181	0.109284	0.000538	9.2
DE - EN C3	599.0	0.000071	0.216951	0.217022	0.000362	5
TOTAL	**4670.7**	**0.021198**	**1.623610**	**1.644808**	**0.000352**	**0.6**
EN 2* (Reference)	221.0	0.00036276	0.08205763	0.08242039	0.00037294	12.1

The improvement in the total risk of the areas relevant to the study has been notable, however, the analysis still reported some very high-risk intensities. Whilst the provision of the buffer zone has been immediately beneficial in terms of the risk intensity at area EN C3, where it led to a reduction in allision risk (-13%), this has not been the case for EN C1, where risk rose by 4% as a result of the removal of EN C1 South. Whilst the overall risk on EN C1 has reduced, the impact in terms of the lost area was higher. The main reason is that the SW edge of the area is now exposed to drifting vessels from the West route at the south of the area, that in previous scenarios would allide with EN C1 South. The transfer of these drifting vessels into the SN 17 route, which is constrained in width, is not a forthcoming scenario and thus, area EN C1 South was reinstated in subsequent mitigation plans.

As there was no change in the form of route alignment and traffic distributions between scenarios C_M2 and C_M3, there has not been a change in the route and waypoint risk, and thus relevant output from the model is not repeated.

In summary for C_M3, the sum of the risks, which are attributable to changes in the allision risk profile only, adds up to a cumulative annual probability for the occurrence of an event of any type of 1.949, which converts to a return period between incidents of slightly longer than 6 months. This constitutes an improvement approaching the order of 24% compared to the basic scenario C, and 9% compared to the previous mitigation scenario.

4.3.4 Mitigation Scenario C_M4

The fourth mitigation scenario C_M4 is also focused on the reduction of the allision risk on either side of the Western route on SN 10. Taking away the conclusions of the previous mitigation scenario, where the risk reduction by providing buffer zones against drifting vessels was lower in rate than that of the reduction in development area as a result of allowing these zones, it was concluded that small further changes in terms of these zones would not be adequate to substantially mitigate allision risk any further. Also, the issue with the very high risk noted in areas EN 14 and EN C1 south would persist.

Thus, the next step in the mitigation process was the provision of an ETV close to the developments of interest. An ETV was thus assumed to be stationed at the SW corner of area EN C1, just outside the bounds of the West route on SN 10. The ETV in the analysis mode was assumed on the specifications of the existing tug NORDIC (refer to section 2.6.3). However, for the present assessment, and to account for the uncertainties in terms of the traffic composition in its vicinity vs that of the overall model and offshore element, the success probability of its interventions was limited from 93% to 85%. The readiness time was conservatively assumed at 30mins as for a land stationed ETV.

The only other intervention applied was the reinstatement of area C1 South in the model. The arrangement for scenario C_M4 is presented in Figure 48 overleaf.

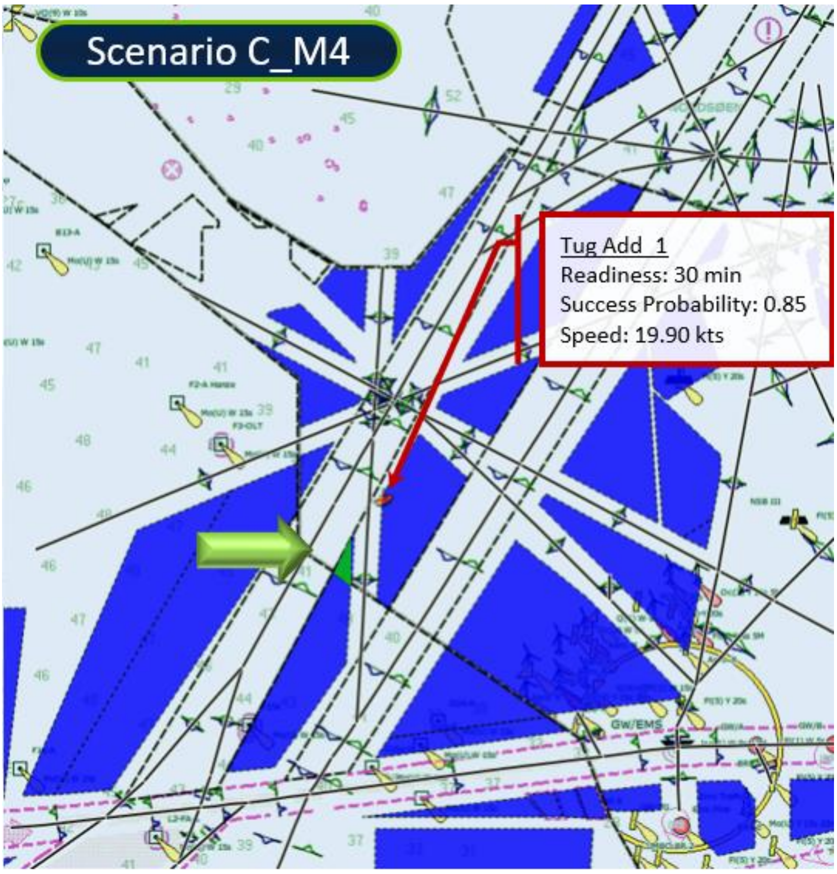


Figure 48: Proposed layout and ETV measures for Scenario C_M4

Scenario C_M4 returned an annual combined allision probability of 0.562, which converts to a return period of approximately 21.5 months. This is a 66% reduction in the allision risk, compared to that noted for mitigation scenario C_M3 and a 75% reduction compared to the base scenario C. Substantial risk reduction was achieved both in terms of direct reduction to the total allision risks in the area of interest, as well as a reduction in the risk intensity. The latter, improved on all developments relevant to the study of the German EEZ, within a range of 9% to 83%, mainly based on the proximity of each to the added ETV station.

The vast majority of the development areas in this mitigation scenario, returned risk intensities (annual allision probability per km^2) lower than those noted for area EN 2 that is currently successfully managed. The exceptions were areas EN 16, and EN C1 South. Whilst for the former, there is the option of moving the ETV station closer, thus improving its impact on EN 16 risk, there is little that can be done to mitigate risks in the case of EN C1 South. That said, it is worth noting that the return period for an allision noted on EN C1 South, which is the size of a small development was 73.7 years, and it does not deem it unfit for development as per the requirements of the applicable guidelines [01], [02].

It is important to note, that ETVs in the analysis model operate in space, and not on the model legs. Therefore, to achieve the calculated interventions on the field, provisions must be made for as-close-as direct access between the tug to the development areas. For the placement of the ETV station in the present scenario, a system of corridors such as the one presented in Figure 49 will be required within development area C1. However, taking into account the manoeuvrability of an ETV with similar arrangement as NORDIC, it should also be assumed that an ETV has the freedom to navigate across a development if safety of navigation is concerned.

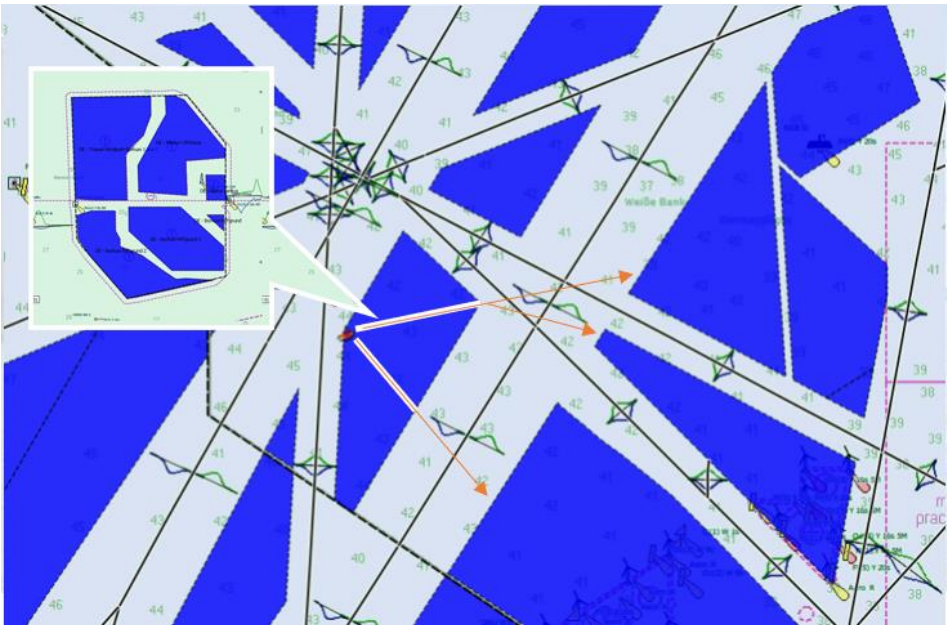


Figure 49: Indicative corridors required to ensure effective CTV intervention

The resulting risk profile for the area of interest in the German EEZ is presented in Figure 50 overleaf.

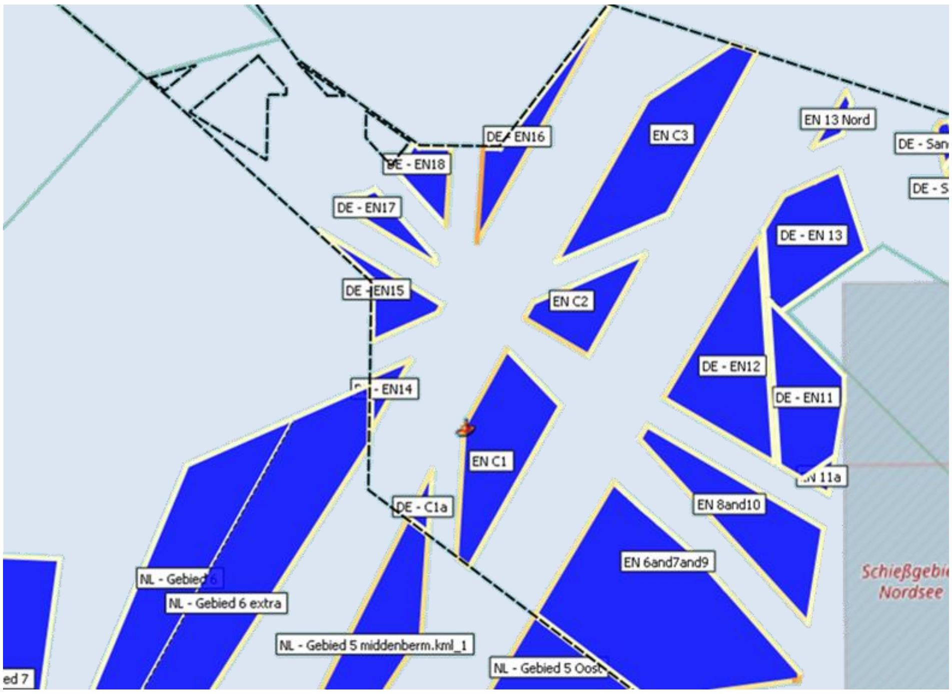
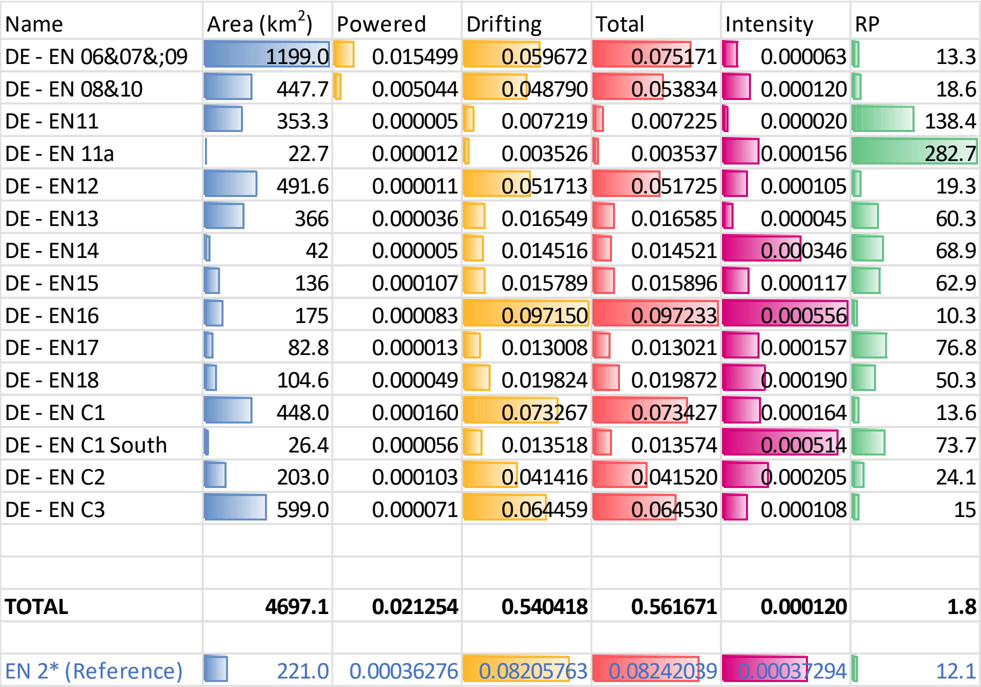


Figure 50: Allision risk profile of mitigation scenario C_M4 for the modelled area (percentage basis)

The calculated annual allision probabilities for the development areas in the German EEZ are presented in Table 29.

Table 29: Allision Risk of mitigation scenario C_M4 for German EEZ development areas



Name	Area (km^2)	Powered	Drifting	Total	Intensity	RP
DE - EN 06&07&;09	1199.0	0.015499	0.059672	0.075171	0.000063	13.3
DE - EN 08&10	447.7	0.005044	0.048790	0.053834	0.000120	18.6
DE - EN11	353.3	0.000005	0.007219	0.007225	0.000020	138.4
DE - EN 11a	22.7	0.000012	0.003526	0.003537	0.000156	282.7
DE - EN12	491.6	0.000011	0.051713	0.051725	0.000105	19.3
DE - EN13	366	0.000036	0.016549	0.016585	0.000045	60.3
DE - EN14	42	0.000005	0.014516	0.014521	0.000346	68.9
DE - EN15	136	0.000107	0.015789	0.015896	0.000117	62.9
DE - EN16	175	0.000083	0.097150	0.097233	0.000556	10.3
DE - EN17	82.8	0.000013	0.013008	0.013021	0.000157	76.8
DE - EN18	104.6	0.000049	0.019824	0.019872	0.000190	50.3
DE - EN C1	448.0	0.000160	0.073267	0.073427	0.000164	13.6
DE - EN C1 South	26.4	0.000056	0.013518	0.013574	0.000514	73.7
DE - EN C2	203.0	0.000103	0.041416	0.041520	0.000205	24.1
DE - EN C3	599.0	0.000071	0.064459	0.064530	0.000108	15
TOTAL	**4697.1**	**0.021254**	**0.540418**	**0.561671**	**0.000120**	**1.8**
EN 2* (Reference)	221.0	0.00036276	0.08205763	0.08242039	0.00037294	12.1

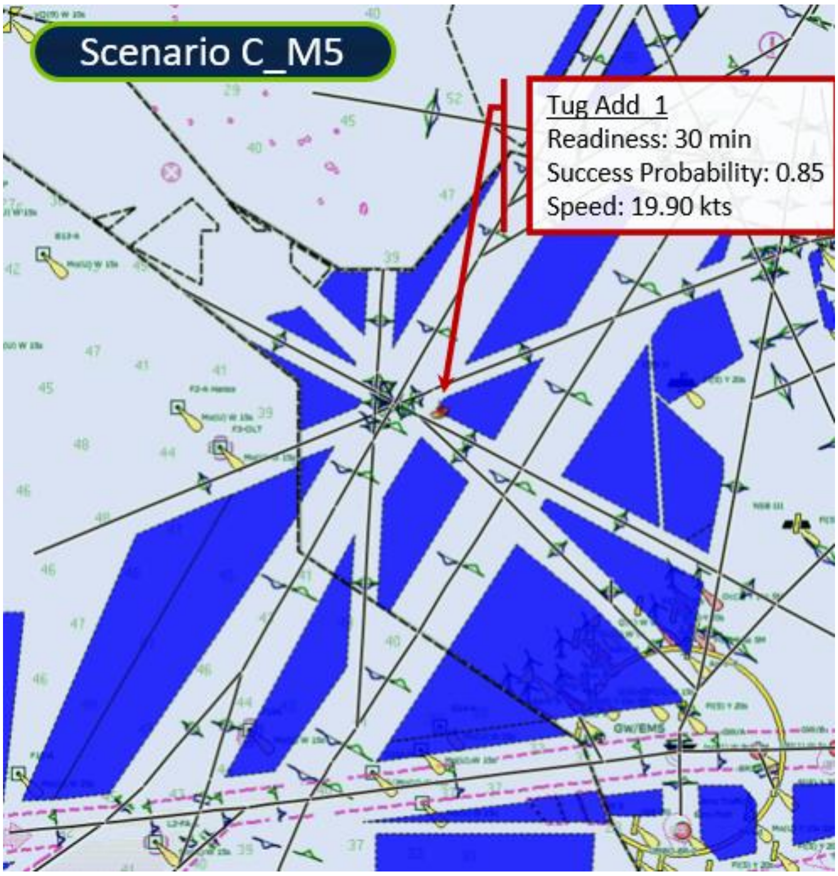
As there was no change in the form of route alignment and traffic distributions for this scenario, there has not been a change in the route and waypoint risk, and thus relevant output from the C_M2 model is still current.

In summary for C_M4, the sum of the risks due to changes in the allision risk profile only, add up to a cumulative annual probability for the occurrence of an event of any type of 0.866, which converts to a return period between incidents of almost 14 months. This constitutes an improvement of the order of 66% compared to the basic scenario C, and 56% compared to the previous mitigation scenario.

4.3.5 Mitigation Scenario C_M5

The main purpose of this mitigation scenario was to attempt to limit the risk intensity on area EN 16, without substantial detriment to the risk intensities of the remaining development areas in the German EEZ. This is attempted through the shift to the north and thus closer to EN 16 of the ETV station of mitigation scenario C_M4. All the remaining parameters and assumptions for the ETV remain unchanged.

The ETV was placed at the western corner of development area EN C2, at the centre of the main junction between routes within the German EEZ. The arrangement for scenario C_M5 is presented in Figure 51 overleaf.



Scenario C_M5

Tug Add_1
Readiness: 30 min
Success Probability: 0.85
Speed: 19.90 kts

Figure 51: Proposed ETV measures for Scenario C_M5

The relocation of the ETV station for scenario C_M5 resulted in an annual combined allision probability of 0.564, which converts to a return period of approximately 21.3 months. This is a 0.5% increase in the allision risk, compared to that noted for mitigation scenario C_M4 and a 75% reduction compared to the base scenario C. Whilst the change in the absolute value of total allision risk is negligible, there was a substantial adjustment to the risk intensities noted in the development areas of the German EEZ. At the central and northern part of the German EEZ, there was a notable reduction, whilst at the southern part as anticipated, an increase in the risk intensity.

The resulting risk profile for the area of interest in the German EEZ is presented in Figure 52 overleaf and the calculated annual allision probabilities are presented in Table 30 overleaf.

In terms of the allision risk for area EN 16, the risk intensity was reduced by 44%, thus bringing the value well within reasonable bounds. The same in terms of the acceptability of the risk intensity applies to all other areas, except for area EN C1 South. The risk intensity noted for the latter has effectively doubled compared to scenario C_M4, dropping the return period between incidents to 36.6 years, which is outside the acceptable limits for a single development. However, its presence shields the southern edge of area EN C1 and the southern-most leg of route SN 17 from drifting vessels. It was worth thus in the next mitigation scenario to test an intermediate position.

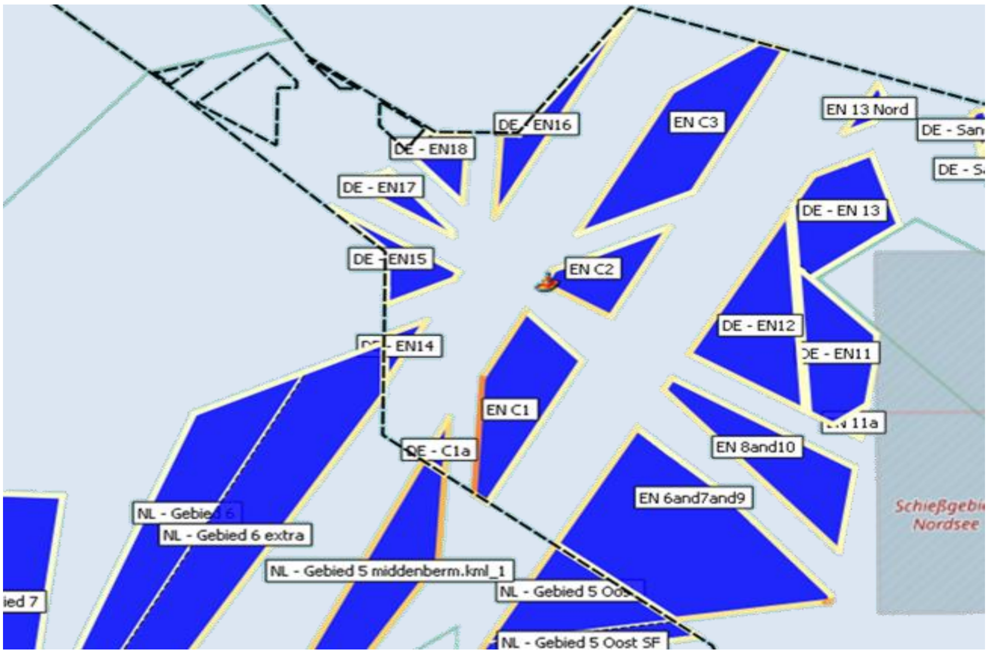


Figure 52: Allision risk profile of mitigation scenario C_M5 for the modelled area (percentage basis)

Table 30: Allision Risk of mitigation scenario C_M5 for German EEZ development areas

Name	Area (km^2)	Powered	Drifting	Total	Intensity	RP
DE - EN 06&07&;09	1199.0	0.015499	0.061904	0.077403	0.000065	12.9
DE - EN 08&10	447.7	0.005044	0.049254	0.054298	0.000121	18.4
DE - EN11	353.3	0.000005	0.006829	0.006834	0.000019	146.3
DE - EN 11a	22.7	0.000012	0.003519	0.003530	0.000156	283.3
DE - EN12	491.6	0.000011	0.050729	0.050740	0.000103	19.7
DE - EN13	366	0.000036	0.015629	0.015665	0.000043	63.8
DE - EN14	42	0.000005	0.014994	0.014999	0.000357	66.7
DE - EN15	136	0.000107	0.014461	0.014568	0.000107	68.6
DE - EN16	175	0.000083	0.054301	0.054384	0.000311	18.4
DE - EN17	82.8	0.000013	0.010910	0.010923	0.000132	91.5
DE - EN18	104.6	0.000049	0.009329	0.009377	0.000090	106.6
DE - EN C1	448.0	0.000160	0.121186	0.121346	0.000271	8.2
DE - EN C1 South	26.4	0.000056	0.027236	0.027292	0.001034	36.6
DE - EN C2	203.0	0.000103	0.038784	0.038887	0.000192	25.7
DE - EN C3	599.0	0.000071	0.064084	0.064155	0.000107	16
TOTAL	**4697.1**	**0.021254**	**0.543149**	**0.564402**	**0.000120**	**1.8**
EN 2* (Reference)	221.0	0.00036276	0.08205763	0.08242039	0.00037294	12.1

There were once again no route alignment and traffic distribution changes taking place in this scenario, thus, there has not been a change in the route and waypoint risk and relevant output from the C_M2 model is still current.

For scenario C_M5, the sum of the risks due to changes in the allision risk profile adds up to a cumulative annual probability for the occurrence of an event of any type of 0.869, which converts to a return period between incidents of almost 14 months. This constitutes an improvement of the order of 66% compared to the basic scenario C and is of marginal detriment compared to the previous mitigation scenario.

4.3.6 Mitigation Scenario C_M6

The sixth mitigation scenario was in response to a query by GDWS on what the impact on navigational safety on the routes and waypoints of the model be if the system of recommended routes for the East and West routes on SN 10 was replaced by a system of TSSs.

Whilst current knowledge is that there is a high level of directionality in the way shipping traffic navigates along recommended routes, there is always a level of overlap between the two directions at and close to the axis of the route, which can lead to an increase in the head-on collision risk. On the other hand, a TSS by definition separates the two directions of traffic, with a separation zone, generally laying at the middle axis of the scheme closed, as far as practicable, to traffic. This is understandably beneficial in terms of mitigating head-on collisions. However, another feature of TS schemes is setting an external boundary based on the width of the navigation lane for either direction of traffic within the system, thus restricting the lateral distribution away from the axis of the TSS. This generally leads to tighter distributions about the centroid axis of each traffic lane direction and may increase overtaking risk as a result. However, due to the more orderly navigation of routes that are subject to a TSS, a 15% reduction in the causation factor is applied on such routes. The aim of this scenario, therefore, was to test whether the benefit from this relief and the theoretical reduction in head-on collision risk can outweigh the likely increase in overtaking collision risk due to the more condensed traffic.

Considering the results of scenarios C_M4 and C_M5 concerning the allision risk intensity noted for area EN C1 South, this iteration also served as an opportunity to move the ETV to a position intermediate to the two aforementioned, at the NW corner of area EN C1.

In the East route of SN 10, the introduction of a TSS was fairly simple, and achievable with minimal geometric adjustments. This was not the case however for the West route, as the traffic pattern assumed, which was based on a constant rate of condensing the lateral traffic distribution between the southern end and the entrance to the deep-water route in the Danish EEZ, could not work as part of a TSS scheme. The adjustment required, therefore, was to slightly change the course of the axis of the recommended route to follow the western boundary under a constant distance up to a point shortly before the junction with the route connecting the SN 10 East and West routes. At that point, vessels are required to perform a course adjustment and head from the exit of the TSS to the centreline of the entrance to the Danish deep-water route, to join a recommended route. The arrangement for scenario C_M6 is presented in Figure 53.

Figure 53: Proposed layout and routing measures for Scenario C_M6

The analysis of mitigation scenario C_M6 returned an annual combined allision probability of 0.542, which converts to a return period of approximately 22.5 months. This constitutes a 4% reduction in the allision risk, compared to that noted for mitigation scenario C_M5. This risk reduction is noted both as a direct reduction to the total allision risks in the area of interest, as well as a small beneficial adjustment to the risk intensity. The risk profile of the area of interest in the German EEZ is presented in Figure 54 overleaf.

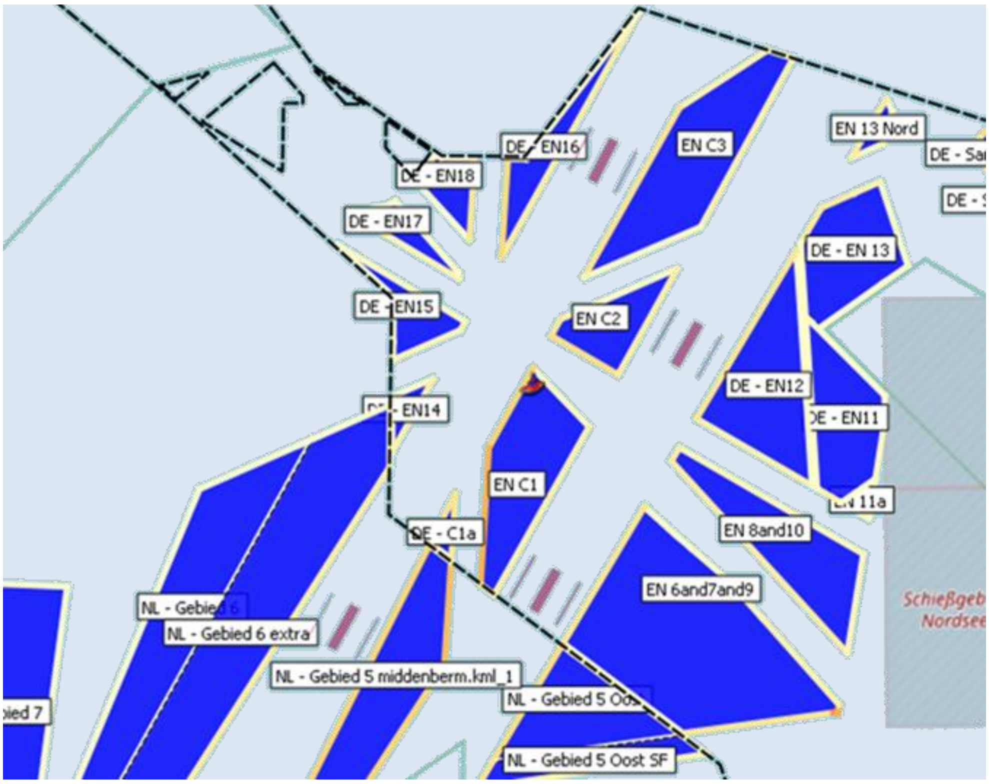
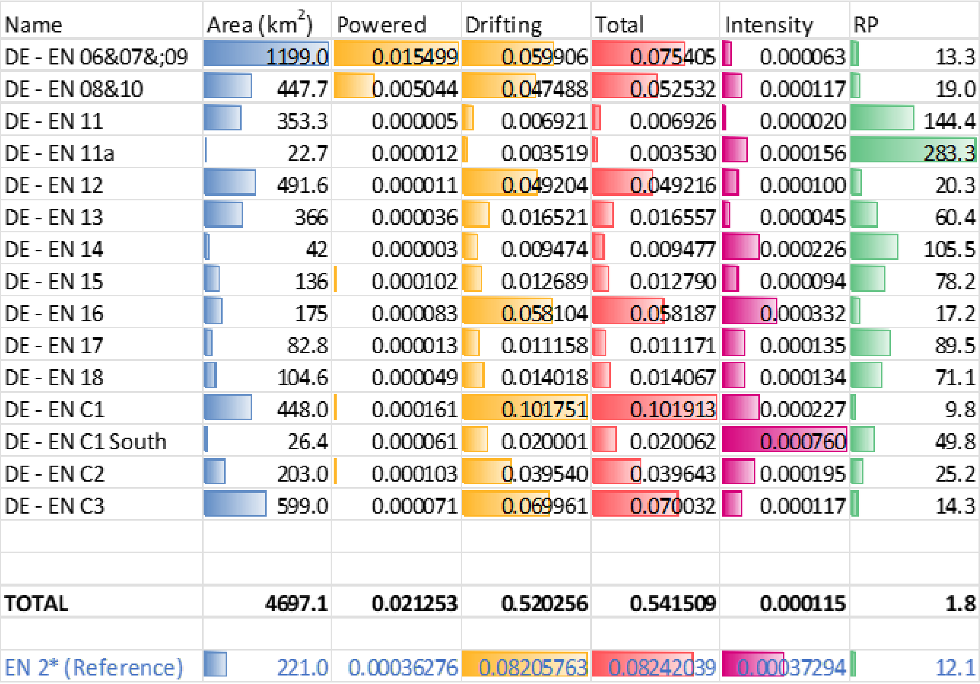


Figure 54: Allision risk profile of mitigation scenario C_M6 for the modelled area (percentage basis)

The calculated annual allision probabilities for the development areas in the German EEZ are presented in Table 31.

Table 31: Allision Risk of mitigation scenario C_M6 for German EEZ development areas



Name	Area (km^2)	Powered	Drifting	Total	Intensity	RP
DE - EN 06&07&;09	1199.0	0.015499	0.059906	0.075405	0.000063	13.3
DE - EN 08&10	447.7	0.005044	0.047488	0.052532	0.000117	19.0
DE - EN 11	353.3	0.000005	0.006921	0.006926	0.000020	144.4
DE - EN 11a	22.7	0.000012	0.003519	0.003530	0.000156	283.3
DE - EN 12	491.6	0.000011	0.049204	0.049216	0.000100	20.3
DE - EN 13	366	0.000036	0.016521	0.016557	0.000045	60.4
DE - EN 14	42	0.000003	0.009474	0.009477	0.000226	105.5
DE - EN 15	136	0.000102	0.012689	0.012790	0.000094	78.2
DE - EN 16	175	0.000083	0.058104	0.058187	0.000332	17.2
DE - EN 17	82.8	0.000013	0.011158	0.011171	0.000135	89.5
DE - EN 18	104.6	0.000049	0.014018	0.014067	0.000134	71.1
DE - EN C1	448.0	0.000161	0.101751	0.101913	0.000227	9.8
DE - EN C1 South	26.4	0.000061	0.020001	0.020062	0.000760	49.8
DE - EN C2	203.0	0.000103	0.039540	0.039643	0.000195	25.2
DE - EN C3	599.0	0.000071	0.069961	0.070032	0.000117	14.3
TOTAL	**4697.1**	**0.021253**	**0.520256**	**0.541509**	**0.000115**	**1.8**
EN 2* (Reference)	221.0	0.00036276	0.08205763	0.08242039	0.00037294	12.1

The model, except for area EN C1 South, returns manageable risk intensities, well under the ones noted for EN 2 which served as a guide in this assessment. The relocation of the ETV seems to benefit the model as it makes a more even use of its intervention potential.

Area EN C1 South returns an annual allision probability of 0.02 that converts to a return period between incidents marginally below 50 years (49.8y). 50 years is the minimum return period that can be accepted for a single development. Under the circumstances, the ability to develop this area can neither be confirmed nor categorically excluded. Thus, the most sensible approach would be to re-visit the area around this development in the future, as parts of the routing plan are developed and more factual information from the field is available, to re-evaluate the situation. It is important, however, especially in the case the intention of developing a middle-berm area in the Dutch EEZ is confirmed, for any analysis or permitting considered concerning area EN C1, to include the consideration of EN C1 South, and the shielding action it provides from drifting vessels.

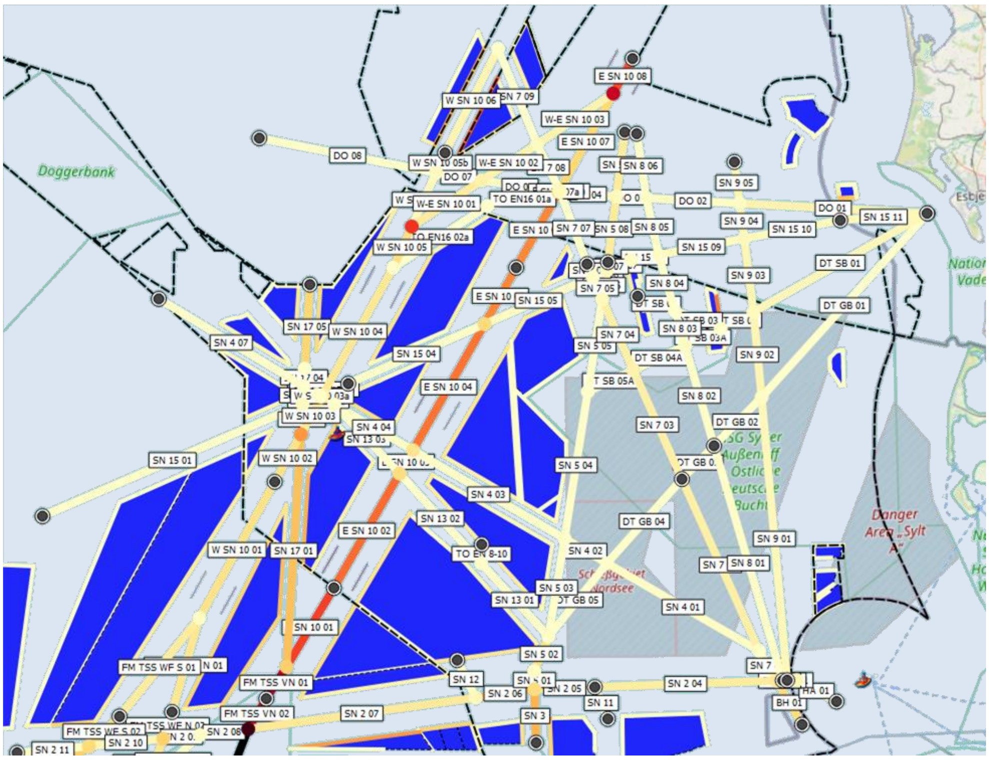


Figure 55: Ship-to-ship collision risk of mitigation scenario C_M6 for the modelled area (% basis)

In terms of the ship-to-ship collision risk (Figure 55), further to the introduction of the TSS system to the West and East routes of SN 10, the highest risk in the model remains noted at the route segment carrying traffic from/to TSS Vlieland Nord (Leg FM TSS VN 03, followed by 01 and 02). These, as in the previous cases, are followed by the legs comprising the East SN 10 route, gradually reducing by a small margin as traffic progresses to the north. To the east, where the standard deviation of the distributions does not change (the distribution is only curtailed at the boundaries of each TSS lane), the risk reduction reflects the change in the causation factor. Whilst head-on collisions are eliminated, they only account for a small fraction of the total risk, and thus the impact on the reported values is minimal.

The peak 25 calculated annual ship-to-ship collision probabilities of the legs representing the routes in the study area are presented in Table 32.

Table 32: Ship-to-ship collision risk on model legs, mitigation scenario C_M6

Leg Name	Dist (km)	HeadOn	Overtaking	Total Risk	RI (AP/km)	RP
FM TSS VN 03	27.2	0.000000	0.010497	0.010497	0.000386	95.3
FM TSS VN 01	11.2	0.000002	0.003410	0.003412	0.000304	293.1
FM TSS VN 02	10.6	0.000000	0.002923	0.002923	0.000277	342.1
E SN 10 01	27.5	0.000002	0.006250	0.006251	0.000227	160.0
E SN 10 02	39.4	0.000000	0.007659	0.007659	0.000195	130.6
E SN 10 03	8.0	0.000000	0.001540	0.001540	0.000192	649.4
E SN 10 04	43.3	0.000000	0.008140	0.008140	0.000188	122.8
E SN 10 05	19.3	0.000000	0.003362	0.003362	0.000174	297.5
E SN 10 06	25.9	0.000000	0.004505	0.004505	0.000174	222.0
SN 3	16.0	0.001479	0.000521	0.002000	0.000125	500.1
SN 2 06	17.8	0.000000	0.002162	0.002162	0.000122	462.5
SN 17 01	69.5	0.004951	0.002716	0.007667	0.000110	130.4
SN 17 02	9.0	0.000827	0.000148	0.000976	0.000108	1025.0
FM TSS WF S 03	52.7	0.000065	0.004995	0.005060	0.000096	197.6
E SN 10 07a	0.6	0.000000	0.000057	0.000057	0.000094	17514.4
SN 17 05	25.1	0.001936	0.000218	0.002153	0.000086	464.4
FM TSS WF S 04	14.8	0.000135	0.001117	0.001253	0.000085	798.4
E SN 10 07	33.0	0.000000	0.002735	0.002735	0.000083	365.7
FM TSS WF N 04	18.6	0.000013	0.001502	0.001514	0.000081	660.4
BH 01	15.2	0.000000	0.001148	0.001148	0.000076	871.1
SN 17 04	5.2	0.000350	0.000040	0.000390	0.000074	2564.6
FM TSS WF S 02	12.8	0.000003	0.000951	0.000954	0.000074	1048.7
W SN 10 05	13.5	0.000001	0.000980	0.000981	0.000073	1019.2
SN 5 02	11.2	0.000595	0.000170	0.000765	0.000068	1307.2
SN 5 07	2.6	0.000160	0.000016	0.000176	0.000068	5675.0
...	...	...	...	...	...	...
TOTAL	**3002.2**	**0.026774**	**0.092633**	**0.119407**	**0.000040**	**8.4**

For vessel-to-vessel collision risk at the route waypoints, which includes crossing, merging, and bend risk, refer to the risk profile presented in Figure 56 overleaf.

The peak waypoint risk remains at the point of crossing between the traffic from/to TSS Vlieland Nord and route SN 2, at the southern boundary of route SN 10 (Waypoint 21). The same pattern as in previous scenarios is also repeated here, as the waypoint with the highest risk is still waypoint 310, dominated by bend risk from the vessels changing courses, with much lower merging and crossing risks noted.

The same applies to waypoint 93 in the Danish jurisdiction which is the corresponding point in the crossing route. The risk however is higher by 22%.

Next in line in terms of risk are the waypoints at the junction between the extension of route SN 17 and the West and East routes of SN 10. No change in the value of risk is noted however from scenario C_M2.

Detailed results for the waypoints with the highest calculated risk are provided in Table 33 overleaf.

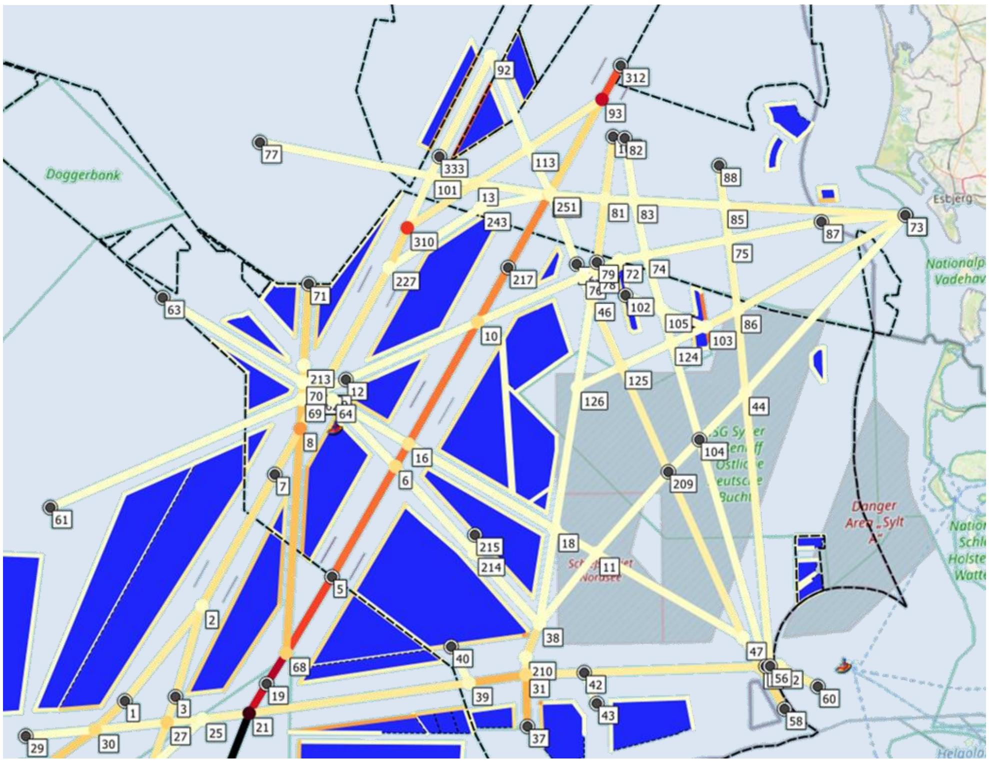
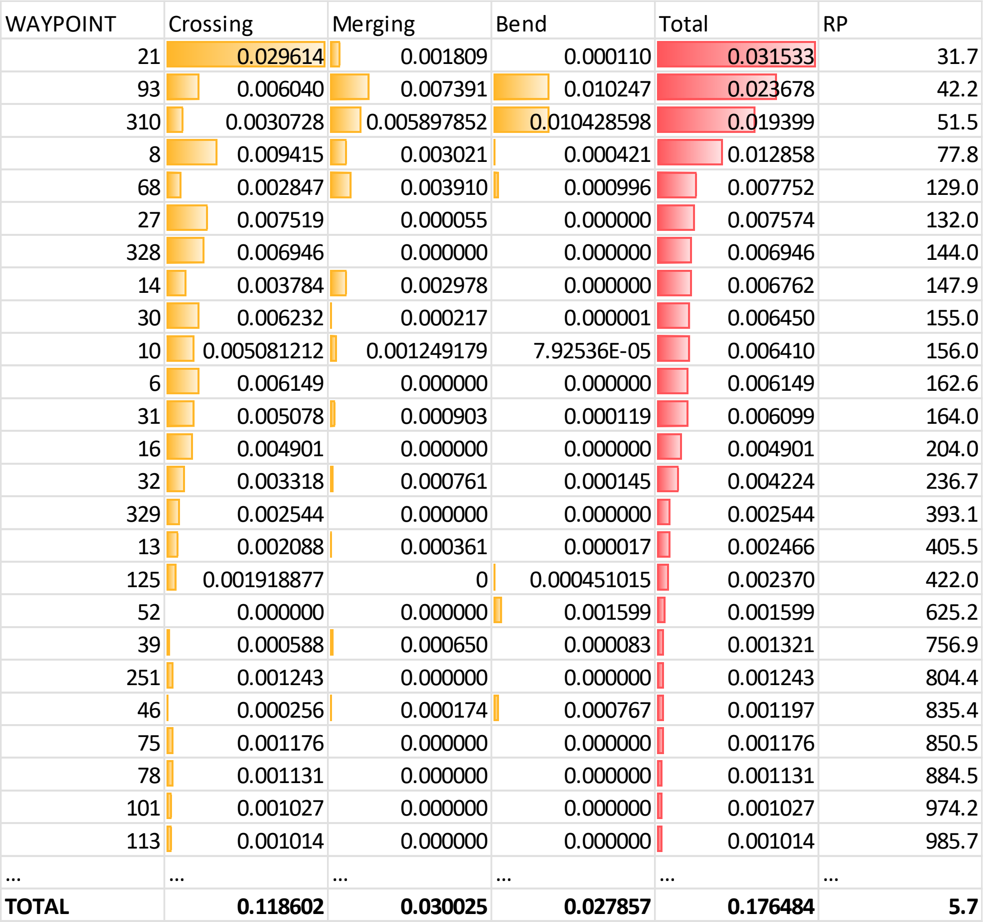


Figure 56: Waypoint collision risk of mitigation scenario C_M6 for the modelled area (% basis)

The sum of the risks captured and presented above adds up to a cumulative annual probability for the occurrence of an event of any type of 0.837, which converts to a return period between incidents of almost 14.5 months. This constitutes an improvement approaching the order of 67% compared to the basic scenario C, and 4% compared to the previous mitigation scenario.

Table 33: Ship-to-ship collision risk on model waypoints, mitigation scenario C_M6



WAYPOINT	Crossing	Merging	Bend	Total	RP
21	0.029614	0.001809	0.000110	0.031533	31.7
93	0.006040	0.007391	0.010247	0.023678	42.2
310	0.0030728	0.005897852	0.010428598	0.019399	51.5
8	0.009415	0.003021	0.000421	0.012858	77.8
68	0.002847	0.003910	0.000996	0.007752	129.0
27	0.007519	0.000055	0.000000	0.007574	132.0
328	0.006946	0.000000	0.000000	0.006946	144.0
14	0.003784	0.002978	0.000000	0.006762	147.9
30	0.006232	0.000217	0.000001	0.006450	155.0
10	0.005081212	0.001249179	7.92536E-05	0.006410	156.0
6	0.006149	0.000000	0.000000	0.006149	162.6
31	0.005078	0.000903	0.000119	0.006099	164.0
16	0.004901	0.000000	0.000000	0.004901	204.0
32	0.003318	0.000761	0.000145	0.004224	236.7
329	0.002544	0.000000	0.000000	0.002544	393.1
13	0.002088	0.000361	0.000017	0.002466	405.5
125	0.001918877	0	0.000451015	0.002370	422.0
52	0.000000	0.000000	0.001599	0.001599	625.2
39	0.000588	0.000650	0.000083	0.001321	756.9
251	0.001243	0.000000	0.000000	0.001243	804.4
46	0.000256	0.000174	0.000767	0.001197	835.4
75	0.001176	0.000000	0.000000	0.001176	850.5
78	0.001131	0.000000	0.000000	0.001131	884.5
101	0.001027	0.000000	0.000000	0.001027	974.2
113	0.001014	0.000000	0.000000	0.001014	985.7
…	…	…	…	…	…
TOTAL	**0.118602**	**0.030025**	**0.027857**	**0.176484**	**5.7**

4.3.7 Mitigation Scenario C_M7

The seventh and final mitigation scenario was a follow-up run relevant to a discussion with the GDWS and addressed the requirement of providing additional safety zone to the developments exposed to high traffic volumes, in a way that geometrically preserves the request for a 3.7km (2nm) + 500m allowance between the development areas and the shipping lanes of SN 10. This included some further adjustment to the geometries of the development areas, as well as the realignment of the East route to match the heading of the boundary of the development areas to the East. Some areas increased in size and others shrank. Scenario C_M7 resulted to a net decrease in development area of 60.5 km^2 across the German EEZ. Also, although the analysis does not reliably cover areas outside the German EEZ, the geometric system of the West route was extended to the south within the Dutch jurisdiction to ensure consistency in the spatial allowances.

The arrangement for scenario C_M7 is presented in Figure 57 overleaf.

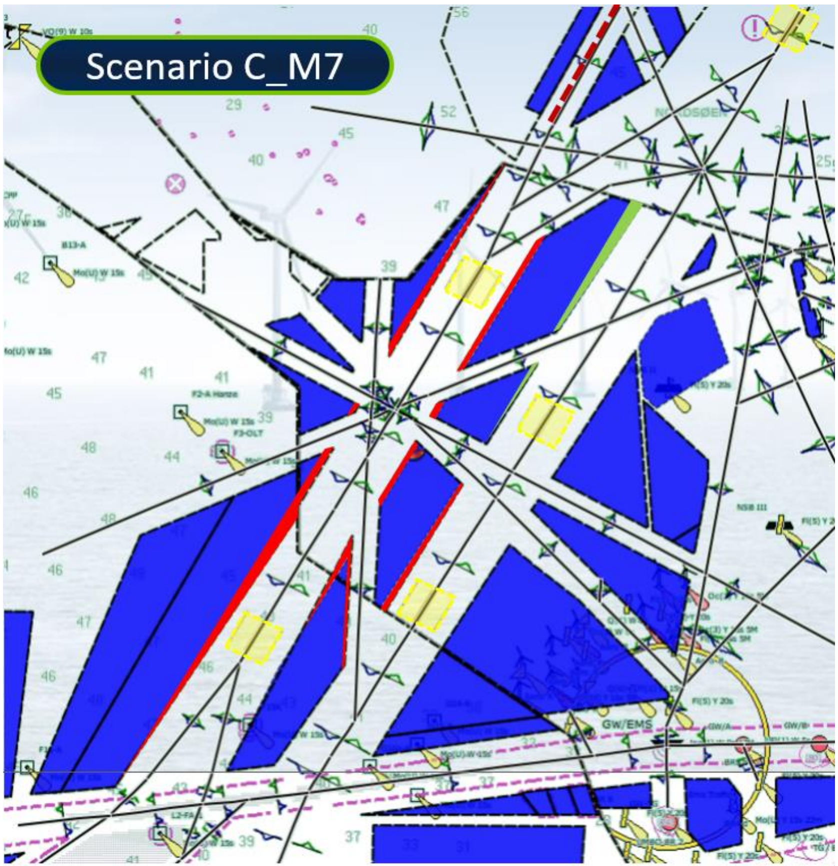


Figure 57: Proposed layout and routing measures for Scenario C_M7

The analysis of mitigation scenario C_M7 returned an annual combined allision probability of 0.502, which converts to a return period of approximately 23.9 months. This constitutes a 7% reduction in the allision risk, compared to that noted for mitigation scenario C_M6. This risk reduction is noted as a direct reduction to the total allision risks in the area of interest, whilst the risk remains almost constant. The risk profile of the area of interest in the German EEZ is presented in Figure 58 overleaf.

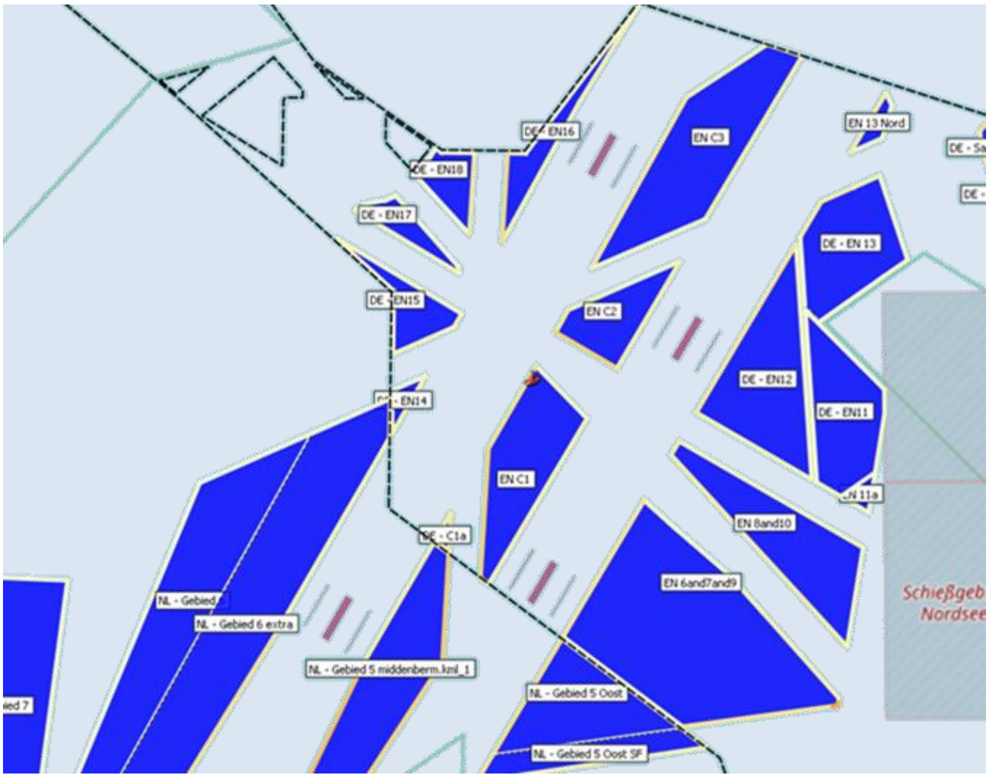
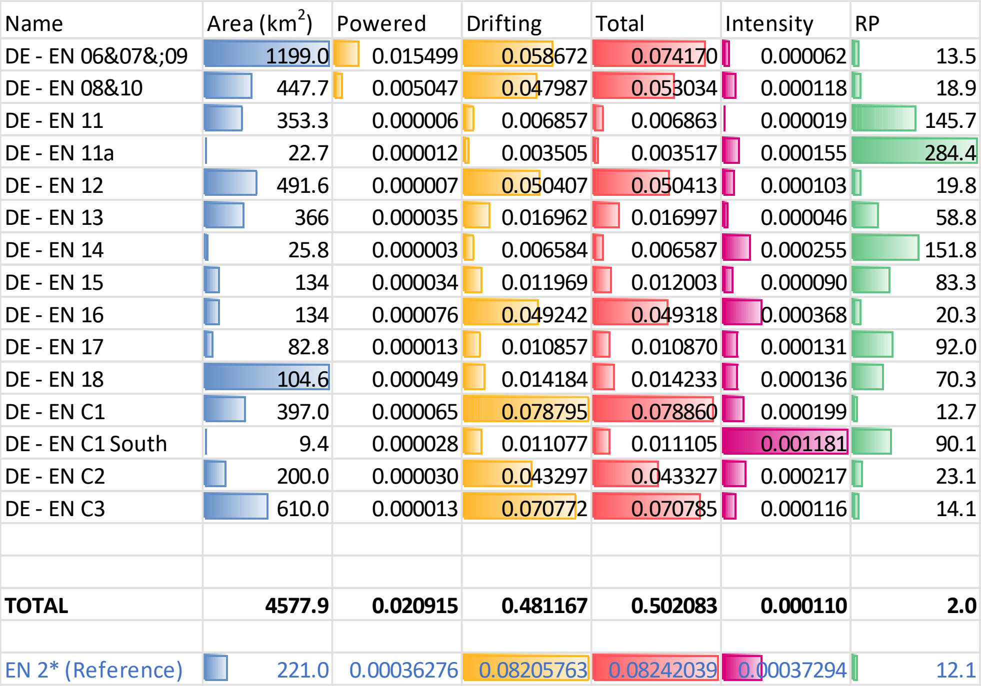


Figure 58: Allision risk profile of mitigation scenario C_M7 for the modelled area (percentage basis)

The calculated annual allision probabilities for the development areas in the German EEZ are presented in Table 34.

Table 34: Allision Risk of mitigation scenario C_M7 for German EEZ development areas



Name	Area (km^2)	Powered	Drifting	Total	Intensity	RP
DE - EN 06&07&;09	1199.0	0.015499	0.058672	0.074170	0.000062	13.5
DE - EN 08&10	447.7	0.005047	0.047987	0.053034	0.000118	18.9
DE - EN 11	353.3	0.000006	0.006857	0.006863	0.000019	145.7
DE - EN 11a	22.7	0.000012	0.003505	0.003517	0.000155	284.4
DE - EN 12	491.6	0.000007	0.050407	0.050413	0.000103	19.8
DE - EN 13	366	0.000035	0.016962	0.016997	0.000046	58.8
DE - EN 14	25.8	0.000003	0.006584	0.006587	0.000255	151.8
DE - EN 15	134	0.000034	0.011969	0.012003	0.000090	83.3
DE - EN 16	134	0.000076	0.049242	0.049318	0.000368	20.3
DE - EN 17	82.8	0.000013	0.010857	0.010870	0.000131	92.0
DE - EN 18	104.6	0.000049	0.014184	0.014233	0.000136	70.3
DE - EN C1	397.0	0.000065	0.078795	0.078860	0.000199	12.7
DE - EN C1 South	9.4	0.000028	0.011077	0.011105	0.001181	90.1
DE - EN C2	200.0	0.000030	0.043297	0.043327	0.000217	23.1
DE - EN C3	610.0	0.000013	0.070772	0.070785	0.000116	14.1
TOTAL	**4577.9**	**0.020915**	**0.481167**	**0.502083**	**0.000110**	**2.0**
EN 2* (Reference)	221.0	0.00036276	0.08205763	0.08242039	0.00037294	12.1

The model, except for area EN C1 South, returns manageable risk intensities, well under the ones noted for EN 2 which served as a guide in this assessment. The introduction of additional safety distances further benefits the model in terms of allision risks, however, to a small degree.

The most notable change is at Area EN C1 South returns an annual allision probability of 0.011 that converts to a return period between incidents of 90 years, a substantial improvement from the previous scenario. This is a result of the substantially reduced size of the area, as the risk intensity remains high. However, based on the new size, the area would most likely be approved for development based on the requirements of the current guideline.

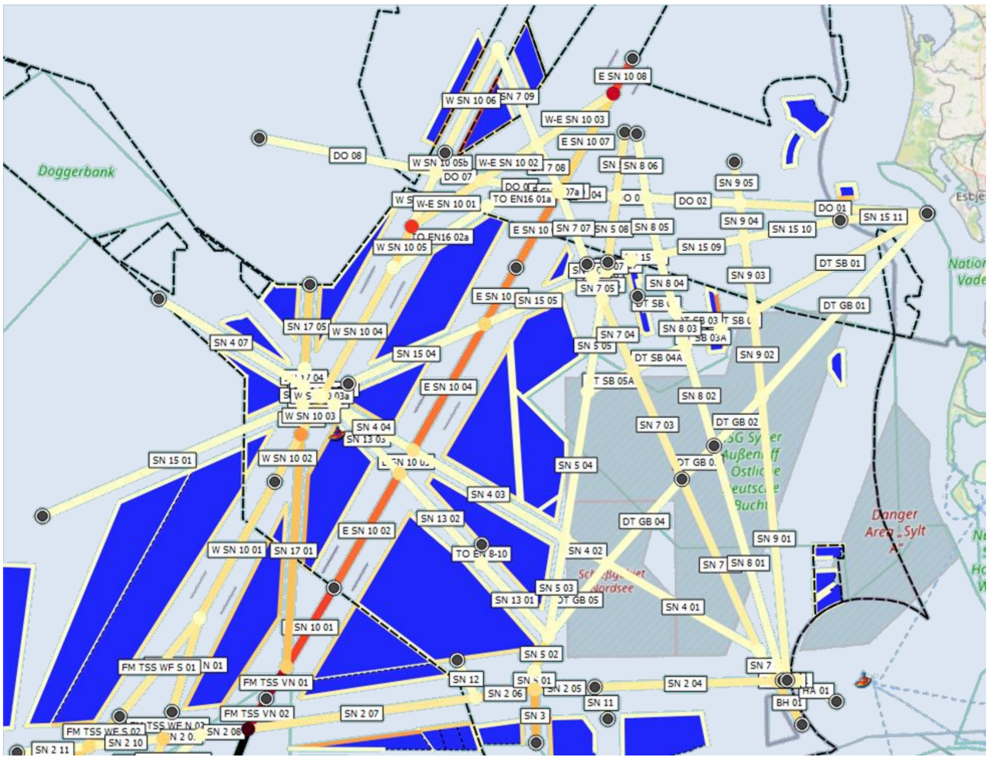
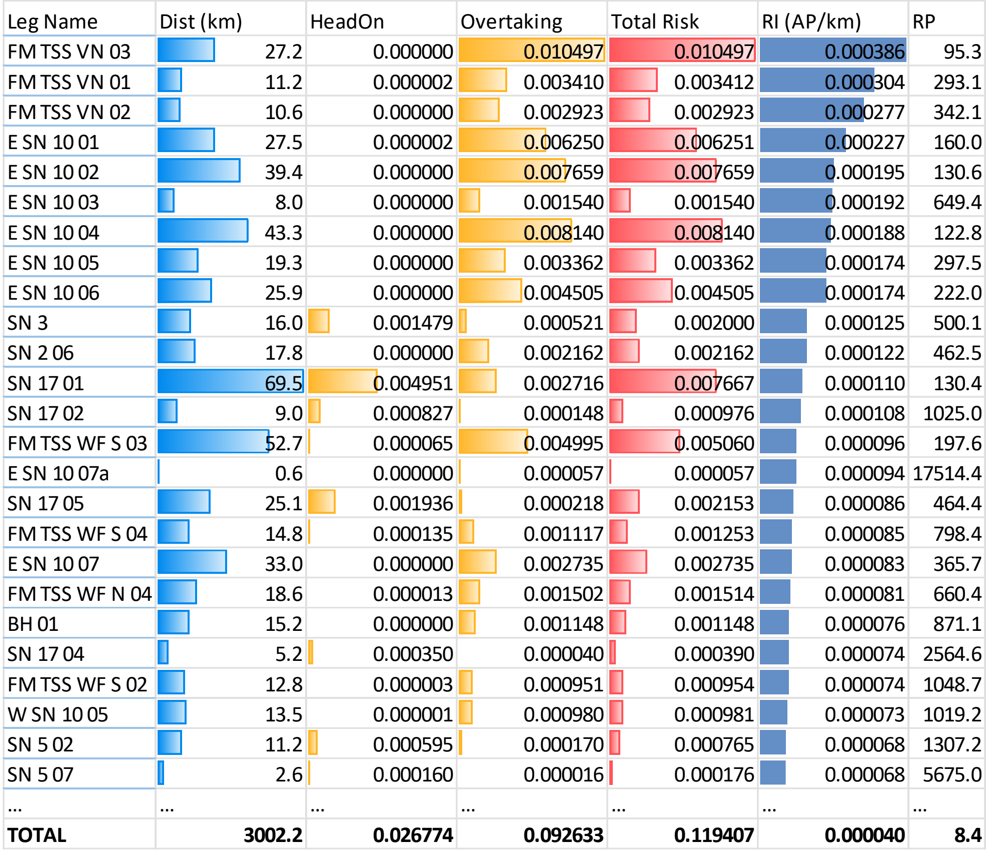


Figure 59: Ship-to-ship collision risk of mitigation scenario C_M7 for the modelled area (% basis)

In terms of the vessel-to-vessel collision risk (Figure 59), further to the introduction of the TSS system to the West and East SN 10 routes, the highest risk in the model remains noted at the route segment carrying traffic from/to TSS Vlieland Nord (Leg FM TSS VN 03, followed by 01 and 02). These as in the previous cases are followed by the legs comprising the East SN 10 route, gradually reducing by a small margin as traffic progresses to the north.

The peak 25 calculated annual ship-to-ship collision probabilities of the legs representing the routes in the study area are presented in Table 35.

Table 35: Ship-to-ship collision risk on model legs, mitigation scenario C_M7



Leg Name	Dist (km)	HeadOn	Overtaking	Total Risk	RI (AP/km)	RP
FM TSS VN 03	27.2	0.000000	0.010497	0.010497	0.000386	95.3
FM TSS VN 01	11.2	0.000002	0.003410	0.003412	0.000304	293.1
FM TSS VN 02	10.6	0.000000	0.002923	0.002923	0.000277	342.1
E SN 10 01	27.5	0.000002	0.006250	0.006251	0.000227	160.0
E SN 10 02	39.4	0.000000	0.007659	0.007659	0.000195	130.6
E SN 10 03	8.0	0.000000	0.001540	0.001540	0.000192	649.4
E SN 10 04	43.3	0.000000	0.008140	0.008140	0.000188	122.8
E SN 10 05	19.3	0.000000	0.003362	0.003362	0.000174	297.5
E SN 10 06	25.9	0.000000	0.004505	0.004505	0.000174	222.0
SN 3	16.0	0.001479	0.000521	0.002000	0.000125	500.1
SN 2 06	17.8	0.000000	0.002162	0.002162	0.000122	462.5
SN 17 01	69.5	0.004951	0.002716	0.007667	0.000110	130.4
SN 17 02	9.0	0.000827	0.000148	0.000976	0.000108	1025.0
FM TSS WF S 03	52.7	0.000065	0.004995	0.005060	0.000096	197.6
E SN 10 07a	0.6	0.000000	0.000057	0.000057	0.000094	17514.4
SN 17 05	25.1	0.001936	0.000218	0.002153	0.000086	464.4
FM TSS WF S 04	14.8	0.000135	0.001117	0.001253	0.000085	798.4
E SN 10 07	33.0	0.000000	0.002735	0.002735	0.000083	365.7
FM TSS WF N 04	18.6	0.000013	0.001502	0.001514	0.000081	660.4
BH 01	15.2	0.000000	0.001148	0.001148	0.000076	871.1
SN 17 04	5.2	0.000350	0.000040	0.000390	0.000074	2564.6
FM TSS WF S 02	12.8	0.000003	0.000951	0.000954	0.000074	1048.7
W SN 10 05	13.5	0.000001	0.000980	0.000981	0.000073	1019.2
SN 5 02	11.2	0.000595	0.000170	0.000765	0.000068	1307.2
SN 5 07	2.6	0.000160	0.000016	0.000176	0.000068	5675.0
...	...	...	...	...	...	...
TOTAL	**3002.2**	**0.026774**	**0.092633**	**0.119407**	**0.000040**	**8.4**

For ship-to-ship collision risk at the route waypoints, which includes crossing, merging, and bend risk, refer to the risk profile presented in Figure 60 overleaf.

The peak waypoint risk remains at the point of crossing between the traffic from/to TSS Vlieland Nord and route SN 2, at the southern boundary of route SN 10 (Waypoint 21). The same pattern as in previous scenarios is also repeated here, as the waypoint with the highest risk is still waypoint 310, dominated by bend risk, with much lower merging and crossing risks noted.

The same applies to waypoint 93 in the Danish jurisdiction which is the corresponding point in the crossing route.

Detailed results for the waypoints with the highest calculated risk are provided in Table 36.

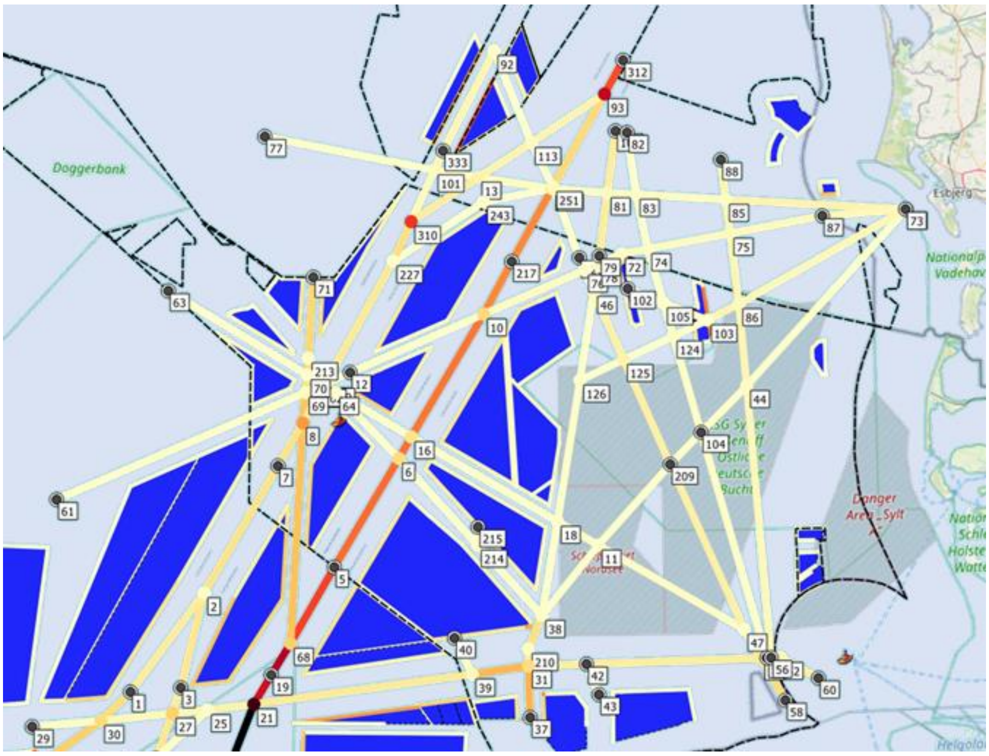


Figure 60: Waypoint collision risk of mitigation scenario C_M7 for the modelled area (% basis)

The sum of the risks captured and presented above adds up to a cumulative annual probability for the occurrence of an event of any type of 0.8008, which converts to a return period between incidents of almost 15 months. This constitutes an improvement approaching the order of 69% compared to the basic scenario C, and 4% compared to the previous mitigation scenario C_M6.

Table 36: Ship-to-ship collision risk on model waypoints, mitigation scenario C_M7

WAYPOINT	Crossing	Merging	Bend	Total	RP
21	0.029614	0.001809	0.000110	0.031533	31.7
93	0.006040	0.007391	0.010247	0.023678	42.2
310	0.0030728	0.005897852	0.010428598	0.019399	51.5
8	0.009415	0.003021	0.000421	0.012858	77.8
68	0.002847	0.003910	0.000996	0.007752	129.0
27	0.007519	0.000055	0.000000	0.007574	132.0
328	0.006946	0.000000	0.000000	0.006946	144.0
14	0.003784	0.002978	0.000000	0.006762	147.9
30	0.006232	0.000217	0.000001	0.006450	155.0
10	0.005081212	0.001249179	7.92536E-05	0.006410	156.0
6	0.006149	0.000000	0.000000	0.006149	162.6
31	0.005078	0.000903	0.000119	0.006099	164.0
16	0.004901	0.000000	0.000000	0.004901	204.0
32	0.003318	0.000761	0.000145	0.004224	236.7
329	0.002544	0.000000	0.000000	0.002544	393.1
13	0.002088	0.000361	0.000017	0.002466	405.5
125	0.001918877	0	0.000451015	0.002370	422.0
52	0.000000	0.000000	0.001599	0.001599	625.2
39	0.000588	0.000650	0.000083	0.001321	756.9
251	0.001243	0.000000	0.000000	0.001243	804.4
46	0.000256	0.000174	0.000767	0.001197	835.4
75	0.001176	0.000000	0.000000	0.001176	850.5
78	0.001131	0.000000	0.000000	0.001131	884.5
101	0.001027	0.000000	0.000000	0.001027	974.2
113	0.001014	0.000000	0.000000	0.001014	985.7
...	...	...	...	...	...
TOTAL	**0.118602**	**0.030025**	**0.027857**	**0.176484**	**5.7**

4.3.8 Summary of mitigation

The mitigation scenarios analysed and presented, relied on the qualitative assessment of the environment and route system in the area of SN 10. Each mitigation measure introduced and tested has educated the selection of the subsequent steps. It is thus not unexpected that the majority of scenarios modelled and tested in sequence resulted in a net benefit in terms of the risks noted. A summary of the iterations is presented in Table 37.

Table 37:Summary of the mitigation process

SCENARIO	Allision Risk	Collision	Total Risk	RP (y)
BENCHMARK	1.684569	0.302514	1.987084	0.50
SCENARIO C	2.242629	0.315504	2.558133	0.39
SCENARIO C_M1	2.014124	0.307662	2.321786	0.43
SCENARIO C_M2	1.832226	0.304528	2.136754	0.47
SCENARIO C_M3	1.644808	0.304528	1.949336	0.51
SCENARIO C_M4	0.561671	0.304528	0.866199	1.15
SCENARIO C_M5	0.564402	0.304528	0.868930	1.15
SCENARIO C_M6	0.541509	0.295891	0.837400	1.19
SCENARIO C_M7_	0.502083	0.298801	0.800883	1.25

That is except for mitigation scenario C_M5, where a small net increase in the allision risk was noted.

What is evident from the analyses is the necessity for the provision of an ETV next to the middle-berm development areas as a means of allision risk mitigation. Based on the assumed parameters for the ETV, its placement near the centre of the main route junction proved very effective in mitigating allision risk within the German EEZ.

5 NAVIGATIONAL RISK ASSESSMENT, WP 3 – AREA EN 13 NORD

In commissioning the study, the BSH was interested to investigate the impact on the risk profile of the SN 10 system of developing an area to the north of area EN 13, and whether its development is in line with the safety and efficiency of shipping.

5.1 The system around area EN 13 – North

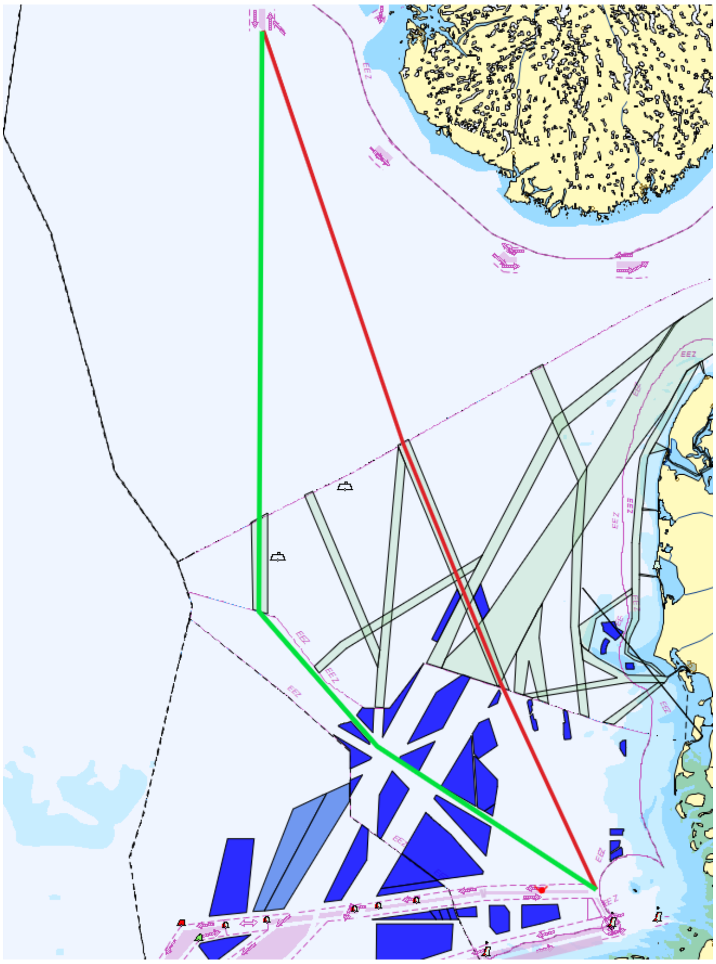


Figure 61: Routing from Hamburg to the Arctic

The assessment becomes of significance in the case of future ice-free arctic waters, which have the potential to introduce additional traffic to the local shipping corridors directed to the Northern Sea Route.

This traffic will predominantly be originating from Hamburg and will comprise mainly larger vessels on trans-continental voyages.

The two alternative routes for such vessels are marked by the lines in Figure 61. Due to it being the shortest route, unless it is blocked by further development plans on the Danish side, the red route using SN 7 as the main access to the Arctic is expected to be the preferred route for such traffic.

The green route can act as an alternative route, however, adding 35 nautical miles to the sea passage requiring several additional narrow transits and alteration of courses. The latter is expected to be attractive to vessels heading towards the northern shipping hubs of the East coast of the Great Britain or offshore installations.

Area EN 13-North in the benchmark scenario is at the junction between routes SN 10, SN 15, SN 5, and SN 7, as presented in Figure 62 overleaf.

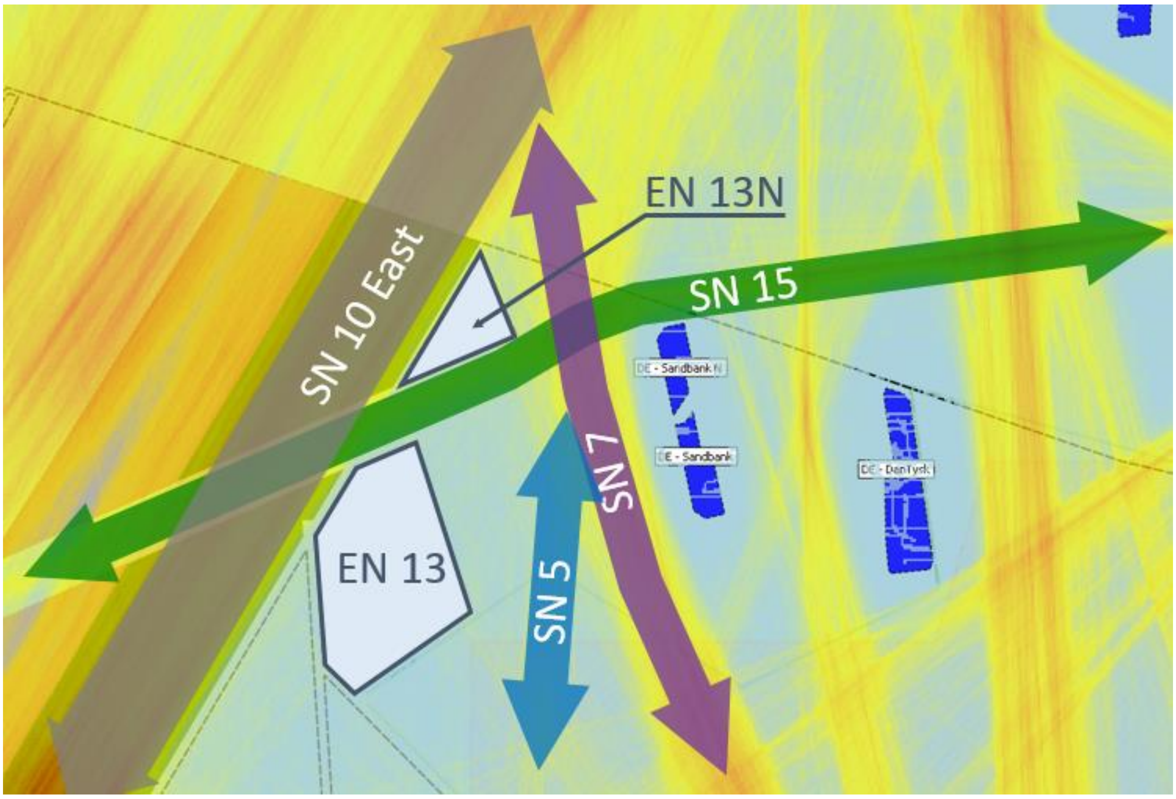
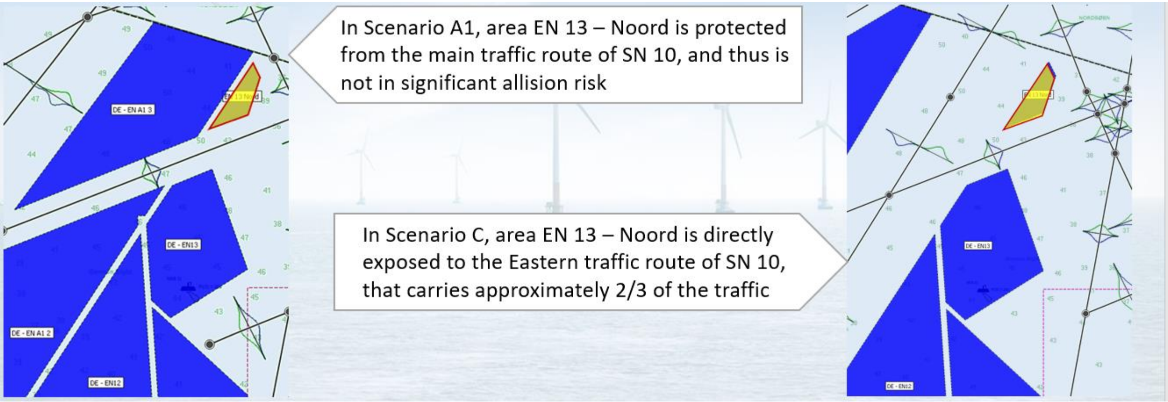


Figure 62: Traffic around development areas EN 13 and EN 13-North

Whilst the main traffic volume in its vicinity comes from route SN 10, this varies between the considered scenarios as demonstrated in Figure 63.



In Scenario A1, area EN 13 – Noord is protected from the main traffic route of SN 10, and thus is not in significant allision risk

In Scenario C, area EN 13 – Noord is directly exposed to the Eastern traffic route of SN 10, that carries approximately 2/3 of the traffic

Figure 63: Area EN 13 – North in the two main scenarios of the study.

In terms of the remaining traffic contributors, route SN 15 carries small amounts of traffic between the western areas of the Bight and Esbjerg, as well as diverted traffic from the blocked route SN 6. The combined eastbound traffic noted in the risk model is of the order of 576 annual crossings and, westbound, 544 annual crossings. The route is mainly used by General Cargo and Ro-Ro Cargo vessels in both directions.

Routes SN 5 and SN 7, cross to the east of the area of interest and merge into SN 10 just north of area EN 13-N. Out of the two routes, SN 7 carries the most traffic, with SN 5 carrying approximately a quarter of the traffic volume of SN 7. For route SN 7 the analysis at the point of EN 13-N recorded 139 annual Northbound crossings and 149 annual southbound crossings. The primary users of route SN 7 are noted to be Tankers and Bulk Carriers. Route SN 5 carries traffic from/to the ports of Emden and Leer to the north, through the northern part of route SN 10. This route in the future scenarios receives the largest part of the current traffic of SN 7 out of Hamburg. Since this route is on the east and in the vicinity of EN 13 – N, it is relevant to the allision risk profile around the latter. SN 5 to the east of the area of interest is expected to carry 1,165 annual northbound crossings, and 1,293 annual southbound crossings.

5.2 Risk Assessment for Area EN 13 – North

As the development of area EN 13 – North is considered to follow other developments in and around route SN 10, it has not been considered as part of the benchmark scenario for the risk assessment.

The area was taken into account, however, in both development scenarios A1 and C that were tested in the study for additional developments in the SN 10 system.

For Scenario A1, with the additional developments introduced on the eastern edge of the footprint of SN 10, area EN 13 – North is fully sheltered from the high volumes of traffic transiting on route SN 10 and thus the annual probability of allision to the area was noted to be very small. The development of area EN 13 – North as part of this scenario would introduce one allision incident every 2,211 years which exceeds the limits set in the guideline [01] for a single development by a factor of more than 20.

The situation changes considerably in the case of the base Scenario C, where the longest edge of the development area is exposed directly to the high volumes of traffic on East route SN 10 (Figure 64) and thus is prone to allisions from drifting vessels on the route.

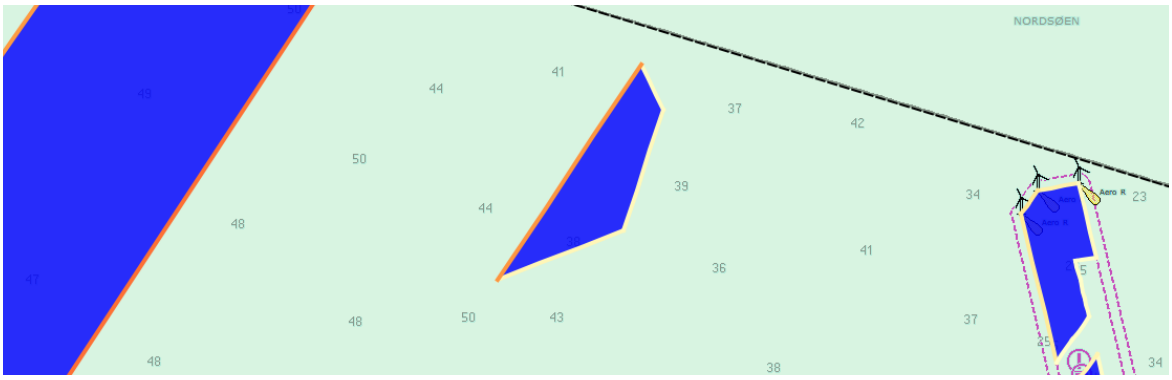
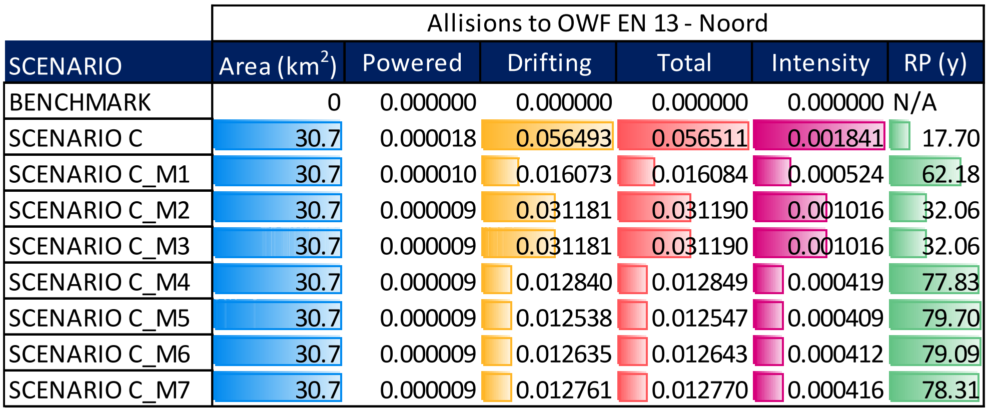


Figure 64: Allision risk on area EN 13 - North under the basic Scenario C

The analysis of the basic Scenario C produces a return period between allision incidents of 18 years, which is well out of the acceptable range for a single development.

As part of the study, a plethora of mitigation scenarios has been tested to pursue incremental gains in navigation risk and allision risk reduction in the area around route SN 10. These and their overall effect on the model have been thoroughly described earlier in the report (section 4.3). Whilst the introduction of these mitigation measures was not focused on improving the allision risk profile of area EN 13 – North, most proved beneficial in terms of reducing risk in the area. The results of each mitigation scenario on the development area of interest are summarised in Table 38.

Table 38: Summary of mitigation process on area EN 13 - North



	Allisions to OWF EN 13 - Noord					
SCENARIO	Area (km^2)	Powered	Drifting	Total	Intensity	RP (y)
BENCHMARK	0	0.000000	0.000000	0.000000	0.000000	N/A
SCENARIO C	30.7	0.000018	0.056493	0.056511	0.001841	17.70
SCENARIO C_M1	30.7	0.000010	0.016073	0.016084	0.000524	62.18
SCENARIO C_M2	30.7	0.000009	0.031181	0.031190	0.001016	32.06
SCENARIO C_M3	30.7	0.000009	0.031181	0.031190	0.001016	32.06
SCENARIO C_M4	30.7	0.000009	0.012840	0.012849	0.000419	77.83
SCENARIO C_M5	30.7	0.000009	0.012538	0.012547	0.000409	79.70
SCENARIO C_M6	30.7	0.000009	0.012635	0.012643	0.000412	79.09
SCENARIO C_M7	30.7	0.000009	0.012761	0.012770	0.000416	78.31

The main summary of the impact of the tested mitigation scenarios on area EN 13 – North is that:

- The risk profile of EN 13 – North benefits from the introduction of the recommended route in Scenario C_M1, however, the subsequent shift of the route to the East under mitigation Scenario C_M2, offset most of the benefit gained with the former.

- The interventions to the geometry of the middle-berm development areas C1 to C3 in mitigation Scenario C_M3 do not influence the annual allision probability for area EN 13 – North.

- Area EN 13 – North was found to benefit from the introduction of an ETV. Although this was not to the extent that areas close to the tug station have benefited, the introduction of an ETV resulted in a significantly higher return period between allision incidents.

- The introduction of a traffic separation scheme in the constituent routes of SN 10 as part of mitigation Scenario C_M6 has marginally benefited area EN 13 – North from an allision risk perspective. The opposite applied from the adjustment of the TSS layout in Scenario C_M7.

The analysis results show that under the implementation of a version of Scenario C, where area EN 13 – North is directly exposed to SN 10 traffic, its development is not viable from an allision risk perspective without the provision of an ETV stationed at the central part of the route.

With the provision of an ETV, the annual probability of allisions to area EN 13 – North appears to reduce substantially for all tested positions of the ETV station. It is noted that the return period between allision incidents in the area under the scenarios that consider ETV stationed in the system range between 77.7 and 79.7 years. Whilst this is not as high as the 100-year return period that is considered desirable by guideline [01] for a single development, it is well above the limit of categorical rejection of an application that is set in the same references at 50 years. This, places development area EN 13 – North at the risk range where “this alone does not necessarily lead to a refusal to authorise the project”, however, approval requires a more intensive examination, which must be based in particular on the suitability for traffic and the expected environmental effects.

Because the development of this area is expected to be one of the last in the MSP, its consideration for implementation is quite distant in time, and the fact that the current study is based on assumptions to project a future scenario, ABL recommends that the assessment and final decision on the development of area EN 13 – North is deferred to the future. This will enable the assessment that will inform the final decision, to be made with a large part of the new environment in and around route SN 10 formed and the use of contemporary traffic volume and consistency data.

6 CONCLUSION AND RECOMMENDATIONS

The purpose of the study for the North Sea was to analyse from a navigational and risk perspective the area of Route SN 10 in and around the German EEZ and test possible scenarios for new offshore wind development areas. The study was focused on the implications to the traffic system of SN 10 of introducing additional development areas within the current footprint of route SN 10, to inform the development of the German MSP for the North Sea. In addition, the fact that the system around route SN10 has been modelled provided the opportunity to test and assess the impact of introducing small, additional areas on or outside the boundary, but in the vicinity of route SN 10.

6.1 Analysis of SN10

A challenge for the study was that the benchmark scenario on which the impact of additional developments was evaluated does not reflect the current situation in and around route SN 10, but a future arrangement with developments on either side of the existing route that is expected to materialise around 2031. This involved a large number of assumptions to be made in terms of the potential developments, traffic volume, patterns, and consistency. The study was performed on the best current knowledge, with input from the Dutch and Danish authorities.

The model for the benchmark scenario considered full implementation of the current German MSP to the east of route SN 10. Also, the development of area Gebied 5 East in the Dutch jurisdiction, and thus, the blocking of and subsequent elimination of route SN 6. To the west of route SN 10, the study considered the development of Gebied 6 and Gebied 6 Extra, based on the shapefiles provided by the Dutch authorities. Despite these developments not having yet been conclusively approved, their presence would prevent the free flow of traffic in and out of the southern part of SN 10 to/from the WNW, and thus forms a more onerous scenario for the study, as the relevant traffic will have to navigate within the SN 10 system and leave it through route SN 17. For the same reason, the benchmark scenario assumes the development of areas EN 14 to EN 18 on the western edge of the route. Within the Danish jurisdiction, the model assumes the presence of developments at the southern end of Nordsoen II and Nordsoen West planning areas, which define the projection of the Off Skagen deep-water route and the point of its separation from the east route. Also, the extension to route SN 7.

Following the establishment of the benchmark scenario, two main scenarios were considered in terms of additional development areas in the footprint of route SN 10. Scenario A1, introduces three additional development areas on the east edge of route SN 10, adjoining the boundaries of the areas in the present MSP. Traffic is condensed to the remaining space to the west of these developments. Scenario C also introduces three additional areas, however, in the middle of route SN 10, separating the East and West routes.

The analysis of the benchmark scenario model identified an annual combined allision probability of 1.684, which converts to a return period of just over 7 months. Considering the ship-to-ship collisions noted in the analysis of the benchmark scenario model, the collective collision and allision risk was found to add up to a cumulative annual probability for the occurrence of an event of any type of 1.987, which converts to a return period between incidents of 6 months.

Looking at the two basic development scenarios in comparison to the benchmark, Scenario A1 is beneficial in terms of the allision risk, both compared to Scenario C and the benchmark scenario, as it returns an annual allision probability of 1.361 that constitutes a 19% reduction compared to the benchmark. This converts to a return period between allision incidents of just under 9 months. However, Scenario A1 leads to an almost doubling of the ship-to-ship collision risk in the model compared to both other scenarios. This almost completely offsets the benefit of the reduction in allisions, as the combined annual probability for the occurrence of an event of any type was noted to be 1.916, which converts to a return period between incidents of just over 6 months.

Scenario C on the contrary leads to a very small increase in the ship-to-ship collisions compared to the benchmark, but due to the exposed perimeter of the added area to two rather than one main shipping route, allision risk increases by a third. The analysis returns an annual probability of an allision incident of 2.243, which converts to a return period between events of slightly less than 5.5 months. Considering ship-to-ship collisions, the model for Scenario C returns quite similar results to the benchmark scenario. The combined annual probability for an incident of any type was calculated to be 2.558, which corresponds to a return period between incidents of just over 4.5 months.

The preferred scenario for further development out of the two basic scenarios was Scenario C. It was selected considering the relative ship-to-ship collision risk outcomes of scenarios C and A1, and in particular, the complexity under which traffic will need to merge and navigate route SN 10 in scenario A1. Whilst Scenario A1 offers a benefit to C in terms of allision risk, mitigation of the latter is more likely to be achieved as it can be influenced by routing measures, geometric adjustments, as well as the provision of ETV tugs. Ship-to-ship collisions on the other hand are limited in terms of possible interventions to the introduction of routing measures that affect the route axis and lateral distribution and are thus more elaborate to pursue.

The allision risks noted are dominated by risks from drifting vessels. These were found to be dependent mainly on traffic volumes and the proximity of routes to the boundaries of the development areas.

Mitigation Scenario C_M1, the first mitigation scenario that was considered, was based on the fact that the width of the West route on SN 10 would have to reduce to the width of the route in the Danish jurisdiction. That would require an adjustment from the current width of 22km at the interface with SN 2 and clear to the West of the Netra Nogat Pipeline System installation to a width of 7.5km at the entry point of the deep-water route in the Danish waters. Assuming a gradual adjustment, this allowed for the movement of the middle-berm development areas to the West, to match the eastern boundary of this shipping lane. At the same time, a 12km-wide shipping lane was assumed for the East route of SN10. Two recommended routes were added to match the axis of the two routes, West, and East. The gradual crossing of traffic from the West to the East route and vice-versa was replaced by a more direct crossing involving a more proclaimed course change.

The analysis returned an annual combined allision probability of 2.014, which converts to a return period of just under 6 months. This constitutes a 10% reduction in the allision risk, compared to that noted for Scenario C. The sum of the total risks, including vessel-to-vessel collision risks, add up to a cumulative annual probability for the occurrence of an event of any type of 2.322, which converts to a return period between incidents of slightly longer than 5 months. This constitutes an improvement approaching the order of 10% compared to the basic scenario C.

Mitigation Scenario C_M2 was aimed at addressing allision risk on either side of the west route, and the western edge of the East route. A thin wedge formed from the northern corner of area EN 16 and down to 10.5 (km S-N) to the west of the SE corner of area EN 14 was removed to provide an additional buffer zone to the two areas, and more space at the main junction of routes at the centre of SN 10 in the German EEZ. For the East route, the axis of the recommended route was shifted by approximately 1.5 km to the East, without change in the areas surrounding it, to test whether the provision of a buffer area to the west would mitigate some of the risk on the middle-berm developments that could lead to a net benefit in risk considering the risk introduced to the development areas on the east.

The analysis returned an annual combined allision probability of 1.832, i.e., a return period of approximately 6.5 months. This constitutes a 9% reduction in the allision risk, compared to that noted for mitigation scenario C_M1. The sum of the total risks, including ship-to-ship collision risks, add up to a cumulative annual probability for the occurrence of an event of any type of 2.137, which converts to a return period between incidents of slightly longer than 5.5 months. This constitutes an improvement approaching the order of 17% compared to the basic scenario C, and 8% compared to the previous mitigation scenario.

Mitigation Scenario C_M3 was targeted to mitigate the allision risk to the development areas in the middle-berm via the reduction in the area of the developments at the centre of SN 10, to incorporate a buffer zone at the east of the West route, towards where the prevailing winds are more likely to drag vessels adrift. Also, this scenario tested the impact of the removal of area C1 South which was found to concentrate unusually high levels of risk for its size.

The analysis returned an annual combined allision probability of 1.644, which converts to a return period of approximately 7.3 months. This constitutes a 10% reduction in the allision risk, compared to that noted for mitigation scenario C_M2 and a 27% reduction compared to the basic scenario C. No change was noted in ship-to-ship collisions compared to the previous scenario. On this basis, the combined annual probability for the occurrence of an event of any type was found to be 1.949, which converts to a return period between incidents of slightly longer than 6 months. This constitutes an improvement approaching the order of 24% compared to the basic scenario C, and 9% compared to the previous mitigation scenario.

Mitigation Scenario C_M4 was also focused on the reduction of the allision risk on either side of the Western route, however, this time with the provision of an ETV near the developments of interest. An ETV was thus assumed to be stationed at the SW corner of area EN C1, just outside the bounds of the West route on SN 10. Also, area C1 South has been reinstated, as the risk-benefit from its removal was offset by the risk increase on area C1.

The analysis returned an annual combined allision probability of 0.561, which converts to a return period of approximately 21.5 months. This is a 56% reduction in the allision risk, compared to that noted for mitigation scenario C_M3 and a 75% reduction compared to the base scenario C. In consideration of ship-to-ship collisions, the cumulative sum of the risks (due to changes in the allision risk profile only), added up to an annual probability for the occurrence of an incident of any type of 0.866, which converts to a return period between incidents of almost 14 months. This constitutes an improvement of the order of 66% compared to the basic scenario C, and 56% compared to the previous mitigation scenario.

Mitigation Scenario C_M5 was considered as a means of limitation to the risk intensity on area EN 16, without causing substantial detriment to the risk intensities of the remaining development areas in the German EEZ. This is attempted through the shift to the north and placement of the ETV at the western corner of development area EN C2, closer to EN 16.

The relocation of the ETV station resulted in an annual combined allision probability of 0.564, which converts to a return period of approximately 21.3 months. This is a 0.6% increase in the allision risk, compared to that noted for mitigation scenario C_M4, but albeit, a 75% reduction compared to the base scenario C. The cumulative sum of the risks due to changes in the allision risk profile resulted in an annual probability for the occurrence of an event of any type of 0.8689, which converts to a return period between incidents of almost 14 months. This constitutes an improvement of the order of 66% compared to the basic scenario C and is of marginal detriment compared to the previous mitigation scenario.

Mitigation Scenario C_M6 was analysed in response to a query by GDWS on the impact to navigational safety on the routes and waypoints of the model if the system of recommended routes for the East and West routes on SN 10 was replaced by a system of TSSs. In analysis terms, the model was given a final run to investigate whether the benefit from the 15% causation factor reduction for routes under a TS Scheme and the theoretical reduction in head-on collision risk can outweigh the likely increase in overtaking collision risk due to the more condensed traffic in the narrower space where navigation is permissible. This iteration also served as an opportunity to move the ETV to a position intermediate to the two scenarios C_M4 and C_M5, at the NW corner of area EN C1.

The analysis returned an annual combined allision probability of 0.542, which converts to a return period of approximately 22.5 months. This constitutes a 4% reduction in the allision risk, compared to that noted for mitigation scenario C_M5. The sum of the risks captured and presented above adds up to a cumulative annual probability for the occurrence of an event of any type of 0.8374, which converts to a return period between incidents of almost 14.5 months. This constitutes an improvement approaching the order of 67% compared to the basic scenario C, and 4% compared to the previous mitigation scenario.

Mitigation Scenario C_M7 was also analysed as a follow-up case relevant to a discussion with the GDWS and addressed the issue of providing additional safety zone to the developments exposed to high traffic volumes, in a way that geometrically preserves the request for a 2nm +500m allowance between the development areas and the main traffic routes of SN 10. This included some further adjustment to the geometries of the development areas, as well as the realignment of the East route to match the heading of the boundary of the development areas to the east.

The analysis returned an annual combined allision probability of 0.502, which converts to a return period of approximately 23.9 months. This constitutes a further 4% reduction in the allision risk, compared to that noted for mitigation scenario C_M6. The sum of the risks captured and presented above adds up to a cumulative annual probability for the occurrence of an event of any type of 0.8008, which converts to a return period between incidents of almost 15 months. This constitutes an improvement approaching the order of 67% compared to the basic scenario C, and 4% compared to the previous mitigation scenario. It is thus safe to assume that under the assumptions of the study, this scenario produced the most favourable outcome in terms of allision and total risk.

Overall, except for mitigation scenario C_M5, where a small net increase in the allision risk was noted, all mitigations scenarios attempted generated a net benefit in risk compared to the preceding. The main point from the study is that the provision of an ETV next to the middle-berm development areas as a means of allision risk mitigation is necessary to manage the relevant risks. Based on the assumed parameters for the ETV, its placement near the centre of the main route junction proved very effective in mitigating allision risk within the German EEZ.

6.2 Analysis of EN 13 – North

The study examined the impact on the risk profile of the SN 10 system of developing an area to the north of area EN 13, to comment on whether its development is in line with the safety and efficiency of shipping.

The development of area EN 13 – North is expected to follow other developments in and around route SN 10 and on this basis, it was not considered in the benchmark scenario for the risk assessment. For Scenario A1, area EN 13 – North is fully sheltered from the high volumes of traffic transiting on route SN 10 and thus the annual probability of allision to the area was found to be very small. It was found to introduce one allision incident every 2,211 years which exceeds the limits set in guideline [01] for a single development by a factor over 20. This changes for Scenario C, where the longest edge of the development area is exposed directly to the high volumes of traffic on route SN 10 East. The area was found to be prone to allisions from drifting vessels on the route. The analysis of Scenario C produces a return period between allision incidents of 18 years, which is well out of the acceptable range for a single development.

Area EN 13 – North benefited in terms of the allision risks noted in most of the mitigation scenarios presented earlier. This covers the introduction of the recommended route in Scenario C_M1, but not the subsequent shift of the route to the east under mitigation Scenario C_M2 or the area footprint interventions of Scenario C_M3. The introduction of an ETV in the model was beneficial in terms of the risk on EN 13 – North, however, not to the extent that areas close to the tug station have benefited. The introduction of a traffic separation scheme in the constituent routes of SN 10 as part of mitigation Scenario C_M6 was marginally beneficial to area EN 13 – North.

The analysis results show that the development is not viable from an allision risk perspective without the provision of an ETV within Route SN 10. With the provision of an ETV, the annual probability of allisions appeared to reduce substantially for all tested positions of the ETV station. Whilst the return periods of allision incidents noted in the analyses with ETV presence are lower than the 100-year return period considered desirable by guideline [01] for a single development, they were found well above the limit of categorical rejection of an application that is set in the same references at 50 years. The development was found to be at the risk range where referencing guideline [01] “this alone does not necessarily lead to a refusal to authorise the project”, however, approval requires a more intensive examination, which must be based in particular on the suitability for traffic and the expected environmental effects.

Because the development of this area is expected to be one of the last in the implementation of the MSP, ABL recommends that the assessment and final decision on the development of area EN 13 – North be deferred to the future. This will enable the assessment that will inform the final decision, to be made with a large part of the new environment in and around route SN 10 already implemented and the use of contemporary traffic volume and consistency data.

It is noted that the content of this report is advisory, and the final decisions rest with the German authorities and stakeholders.

7 ADDITIONAL TOPICS

7.1 WP 5: Request to study the effects of a potential future traffic intervention in the German Bight

Further to the work conducted for work packages 1 and 2, an additional inquiry for an ad-hoc analysis was raised as part of work package 5. The inquiry pertained to the effects of a potential future traffic intervention in the German Bight, by shifting traffic from TSS Terschelling-German Bight to TSS German Bight Western Approach.

Four scenarios of interest have been provided by the German Authorities to be considered in terms of the likely intervention:

1. Diversion of all vessels with the following parameters: length >295m and beam >32m and a draft of more than 12m.
2. Diversion of all Container vessels with a length >200m and all other vessels with a draft more than 12m.
3. Diversion of all Container vessels with a length >200m or a beam >32m.
4. TSS Terschelling-German Bight will be closed, and all vessels will have to use TSS German Bight Western Approach.

ABL requested clarifications concerning the potential implementation of the above scenarios, and scenario 4 in specific, as the full closure of the TSS Terschelling-German Bight and diversion of the traffic on route SN 02 through TSS East Friesland and TSS German Bight Western Approach would evidently exceed the capacity of the latter and obstruct traffic to the ports of the Ems River and estuary. It was clarified that the measures were intended for traffic from TSS Off Vlieland to Hamburg / Bremerhaven, which constitutes the majority of the traffic on route SN 01. Subsequently, ABL performed the exercise by diverting the vessel traffic that fits the size criteria associated with the different scenarios, which follow the full length of route SN 01.

It is also noted that scenario SC 04 is not seen as a plausible scenario for implementation, as early in the analysis it was evident that it results in notably higher risk intensity than that currently managed in the model, both on the route from TSS Vlieland North to SN 02, as well as on route SN 02 itself where the risk increases by an order of magnitude. SC 04 also came with a very high net increase in the overall allision risk of the model as traffic on SN 01 which is exposed to developments only on the north side, is re-directed to SN 02 which is exposed to developments both to the north and south. On these grounds, it has been eliminated from the assessment.

These three scenarios to be examined in further detail, are onwards referred to as SC 01, SC 02, and SC 03, respectively.

German authorities required ABL’s opinion and commentary on the following topics:

A. The effects of implementing each of the scenarios in terms of the collision risks (ship-to-ship) and allision risks (ship-to-windmill).

B. If the present dimensions (navigational width) of the TSS German Bight Western Approach would be sufficient to handle the additional diverted traffic from scenarios 01 to 03.

C. Whether safe navigation is possible within TSS German Bight Western Approach following the introduction of the additional diverted traffic.

ABL constructed a partial model of the area of interest and performed a traffic analysis based on the list of vessels relevant to a risk assessment (SOLAS vessels + cargo vessels >100 GT), the results of which in terms of traffic volumes in the routes of interest are summarised in Figure 65.

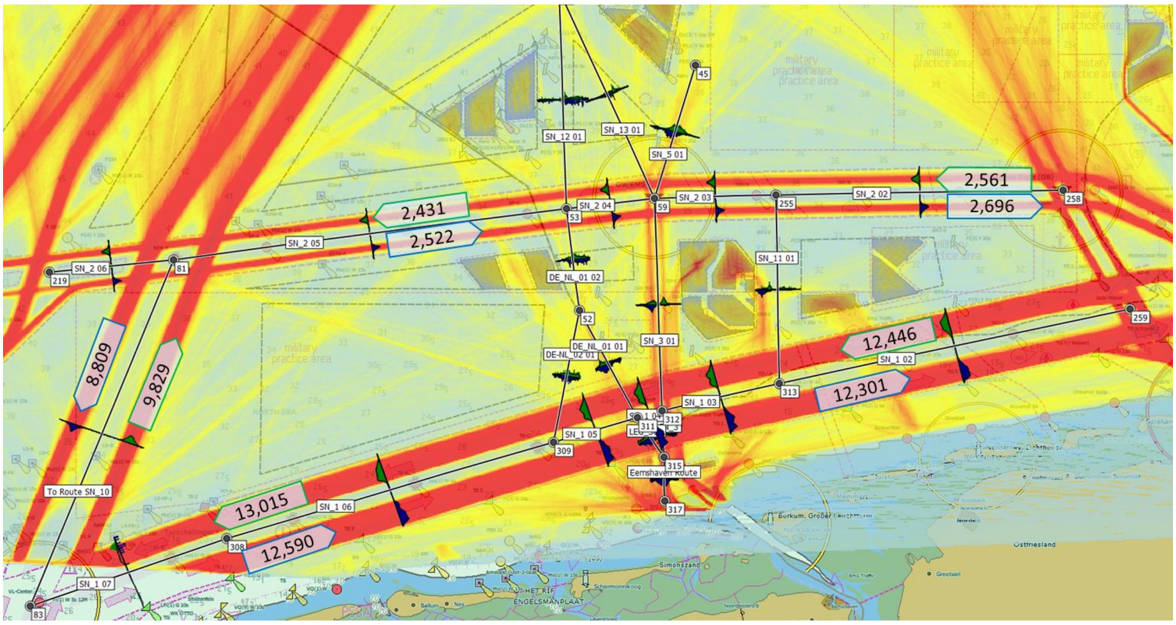


Figure 65:Traffic volumes for the analysis of the diversion scenarios

Subsequently, counting lines (gates) were set up to record crossings on either end of route SN 01, and an algorithm was used to identify and extract the crossings in either direction (westbound / eastbound) that appear on both gates as part of the same trip, denoting through traffic to/from Hamburg and Bremerhaven. The relevant traffic to each diversion scheme was hence quantified in terms of annual passage numbers and vessel type/length group. The diversion scenarios were subsequently constructed based on this information. A summary is provided in Table 39.

Table 39: Diverted annual traffic count per scenario

Scenario	Description	Westbound	Eastbound
SC 01	Diversion of all vessels with the following parameters: length >295m and beam >32m and a draft of more than 12m.	847	607
SC 02	Diversion of all container vessels with a length >200m and all other vessels with a draft more than 12m.	1766	1473
SC 03	Diversion of all container vessels with a length >200m or a beam >32m.	1552	1239

Out of the three scenarios, SC 01 is the one with the smallest number of diverted vessels, however, also the one with the largest vessels in the set. Scenarios SC 02 and SC 03 are similar in terms of the number of diverted vessels, with the main difference being that the latter is limited to Container vessels only.

The analysis of the scenarios with the diverted traffic will require adjustments to the lateral distribution of traffic on the routes that will be influenced by the diverted traffic, in line with the requirements of the GL guideline. On route SN 01 and the leg from TSS Vlieland North to TSS North Friesland and route SN 02, where the space for the implementation of the parameters for traffic-separated lanes is adequate, the latter were applied (standard deviation SD = 0.5 nm). On route SN 02, where the width of the route is limited, a SD = 0.30 nm has been used instead.

The benchmark case BM, with the traffic volumes and lateral distributions extracted from the AIS dataset was calculated first, to set the risk baseline. A second, fictitious case (SC 00) was subsequently run using the same traffic volumes and the new lateral distributions as reported above. The results of the latter are presented together with the results of the three scenarios considered, to provide a basis for comparison of the impact of altering the lateral traffic distribution parameters in the model. The risk profile from the analysis of the BM scenario is presented in Figure 66.

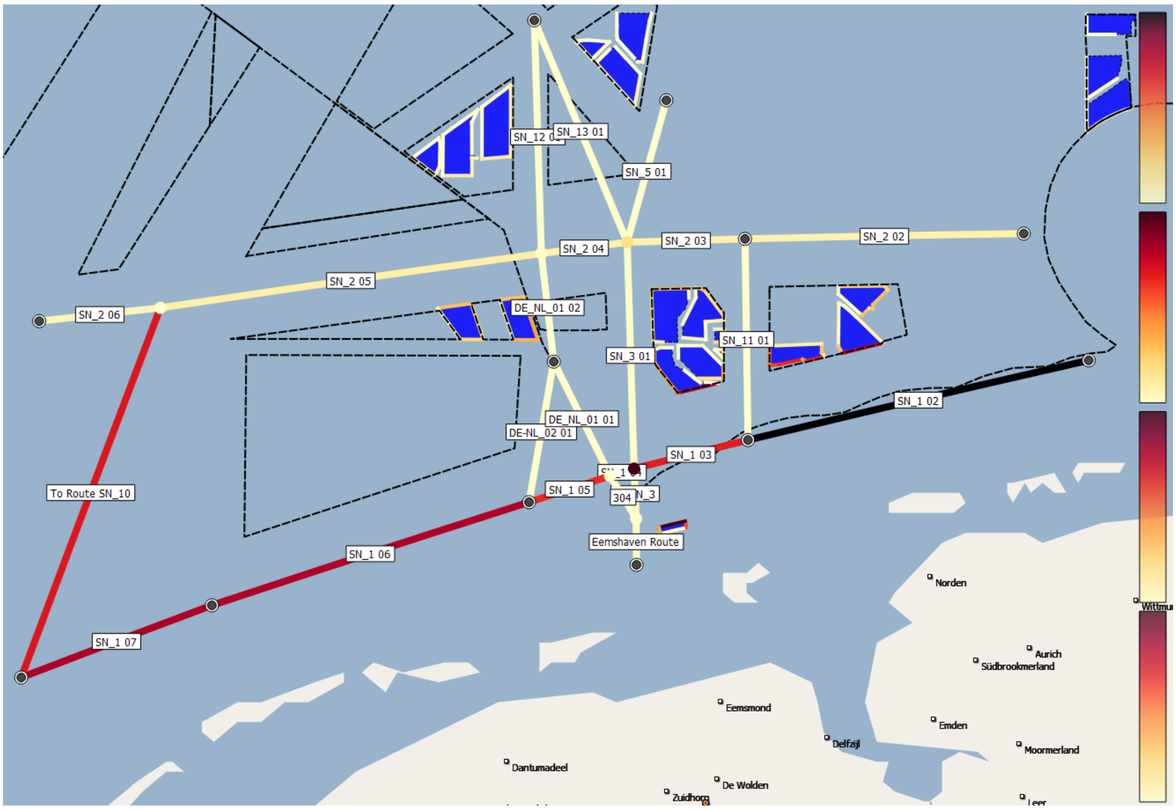


Figure 66: Current (BM) risk profile

The figure shows that the risk is concentrated on route SN 01 and the leg from TSS Vlieland North to TSS North Friesland and SN 02. This is expected, as SN 01 carries five-fold the traffic of SN 2. The largest risk concentration is noted at the easternmost leg of SN 01, where the lateral distribution of traffic condenses as it lines up for the approach of the pilotage area. The risk profile for the fictitious scenario SC 00, remains similar, however, as the lateral distribution is now identical on all legs of each route, the risk becomes volume-driven, and thus is distributed more uniformly along SN 01 as presented in Figure 67.

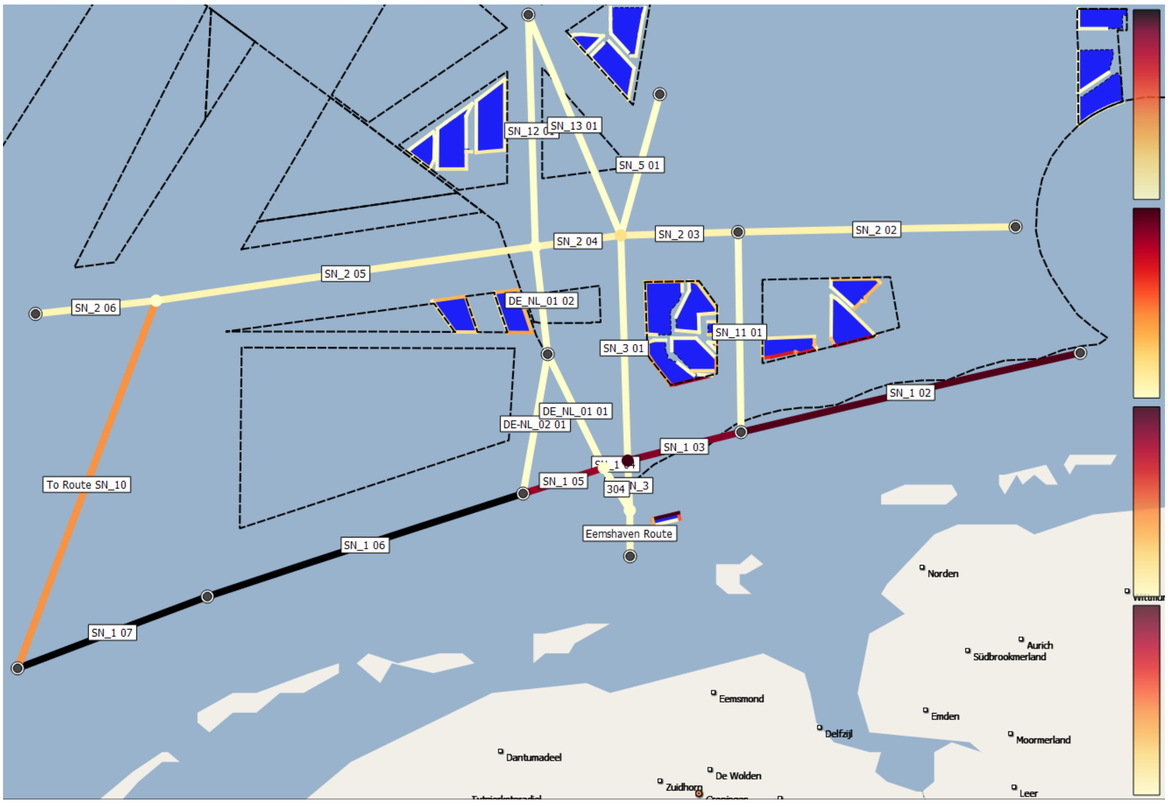


Figure 67: SC 00 risk profile

The risk profile remains the same for scenario SC 01, as the traffic volume that is redirected is rather small. The only notable difference is a small risk shift towards the leg from TSS Vlieland North to TSS North Friesland and SN 02.

Scenarios SC 02 and SC 03 also share a very similar risk profile. A more substantial portion of the traffic is diverted away from SN 01 and into SN 02, via the leg from TSS Vlieland North to TSS North Friesland and SN 02. This is evident in how the risk profile is shaped, with risk moving away from route SN 01, and increasing on routes SN 02, and predominantly on the leg from TSS Vlieland North to SN 02. The latter returns the highest risk per unit length in the model. This denotes that under scenarios SC 02 and SC 03, the latter route is brought closer to reaching safe navigation capacity compared to route SN 02. The risk profile associated with scenarios SC 02 and SC 03 is presented in Figure 68.

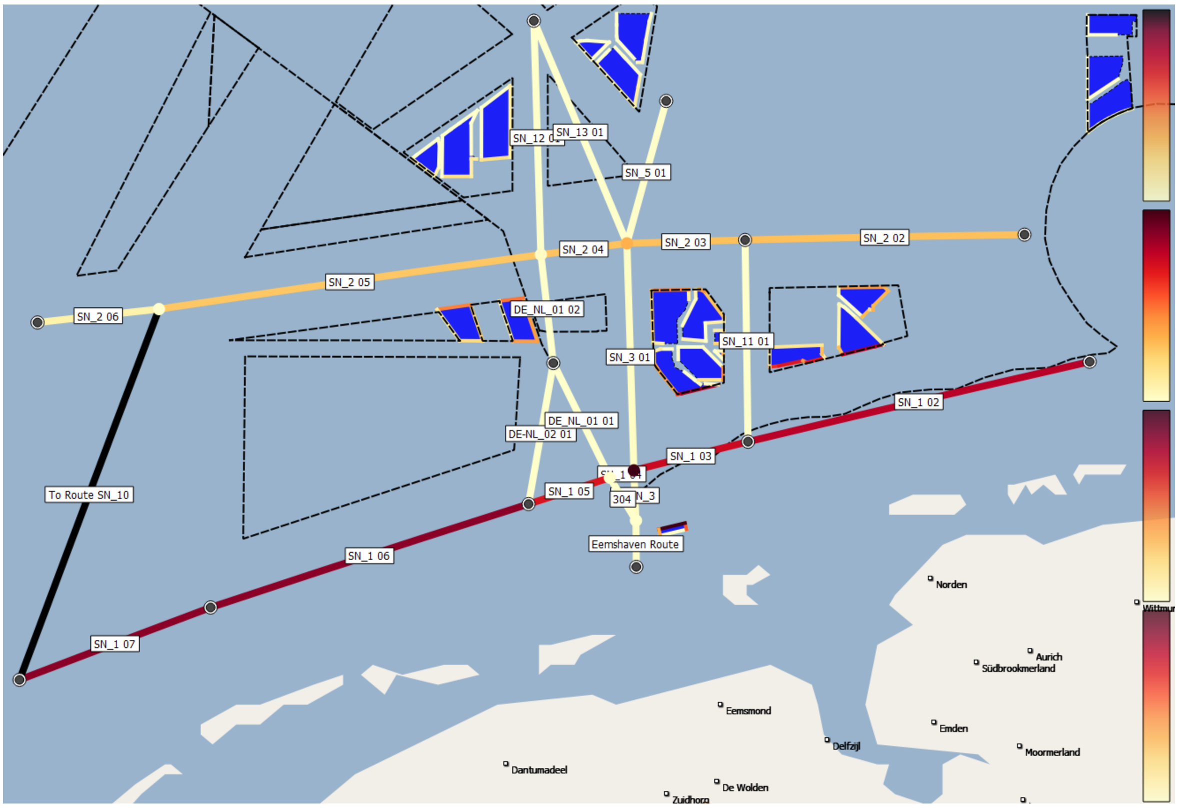


Figure 68: Risk profile for scenarios SC 02 and SC 03

7.1.1 Effects of implementing each of the scenarios in terms of the collision risks (ship-to-ship) and allision risks (ship-to-windmill).

There are two elements to consider in looking at the risk associated with the implementation of each scenario. The total risk in the system and how the latter constitutes a change from the current (benchmark BM and adjusted SC 00), and the risk intensity on each route. Results for the former, that correspond to the total risk in the system, will be presented and discussed below. Risk is expressed in the form of annual collision/allision probability.

From the results of the analysis of the scenarios outlined earlier in the report, it can be seen that the total annual collision probability in the system under the current traffic volumes and lateral distribution across the routes, is almost identical to the one post-adjustment of the lateral distributions to those of the GL guideline. However, it is noted that following the adjustment of the lateral distributions, the risk on SN 01 appears to increase, whilst that on SN 02 and the leg from TSS Vlieland North to TSS North Friesland decrease, respectively. This suggests that the theoretical distributions on the latter are wider than the actual and thus induce higher risk, and the opposite applies for route SN 01. Also, it is worth noting that the three main routes considered, concentrate almost all the risk recorded in the model. The annual collision probabilities for all scenarios are presented in Figure 69.

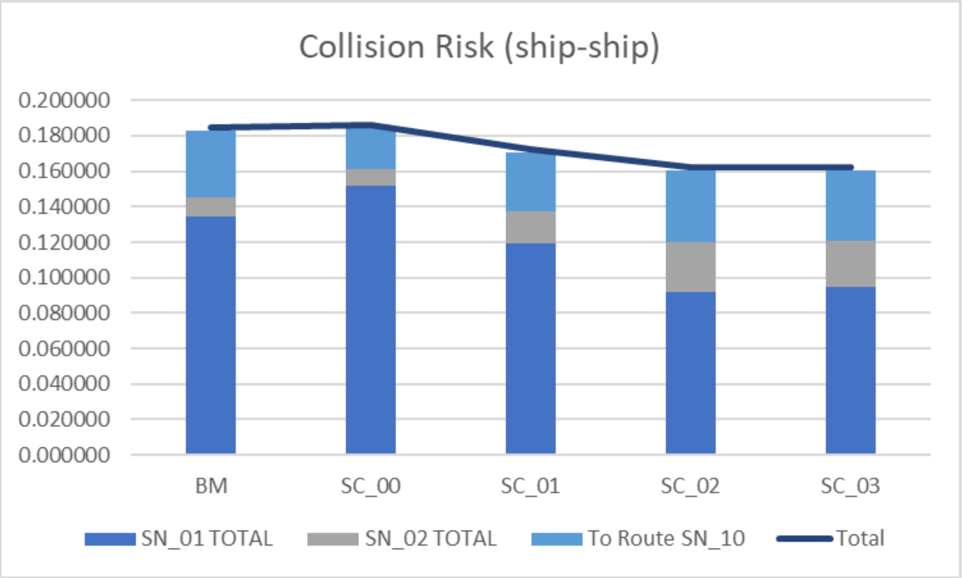


Figure 69: Ship-to-ship annual collision probability in the model

For each of the three scenarios SC 01, SC 02, and SC 03, the overall collision risk appears to reduce compared to the current risk levels. In all cases, risk on SC 02 and the leg from TSS Vlieland North to TSS North Friesland appears to increase, whilst the risk on SN 01 decreases as traffic is moved away from the route. Combined with the fact that the overall risk reduces whilst the length of the track of the diverted traffic increases, suggests that SN 01 at present operates closer to capacity compared to route SN 2. Each onward scenario from SC 01 to SC 03, appears to reduce the overall collision risk, and thus, SC 03 appears to be the most attractive scenario when looking at ship-to-ship collisions.

Looking at ship-to-windmill allisions, it is noted that the allision risk associated with the leg from TSS Vlieland North to TSS North Friesland and SN 02 is marginal, and almost lost in the relevant chart of Figure 70. Also, the three focus routes represent the vast majority of allision risk recorded in the model, however not to the extent noted in the case of collision risk. The main allision risk contributors in the model are these routes SN 01 and SN 02. Looking at the results for scenarios BM and SC 00, it can be seen that the adjustment of the lateral traffic distribution from the actuals based on the AIS dataset to the theoretical in the GL recommendation, leads to a reduction of the annual allision probability for both routes SN 01 and SN 02. This corresponds to an overall reduction in risk of 4% compared to the present situation.

Scenario SC 01, with the smallest proportion of diverted traffic, appears to be the only one of the three considered scenarios that results in a net decrease in annual allision probability. That is noted to be of the order of 2%. The remaining two scenarios (SC 02 and SC 03) result in an overall allision risk increase compared to the current, of 2% and 1% respectively. It is noted that most of the variation occurs in the form of a risk increase on route SN 02, with mild decreases of risk on route SN 01 in all three scenarios.

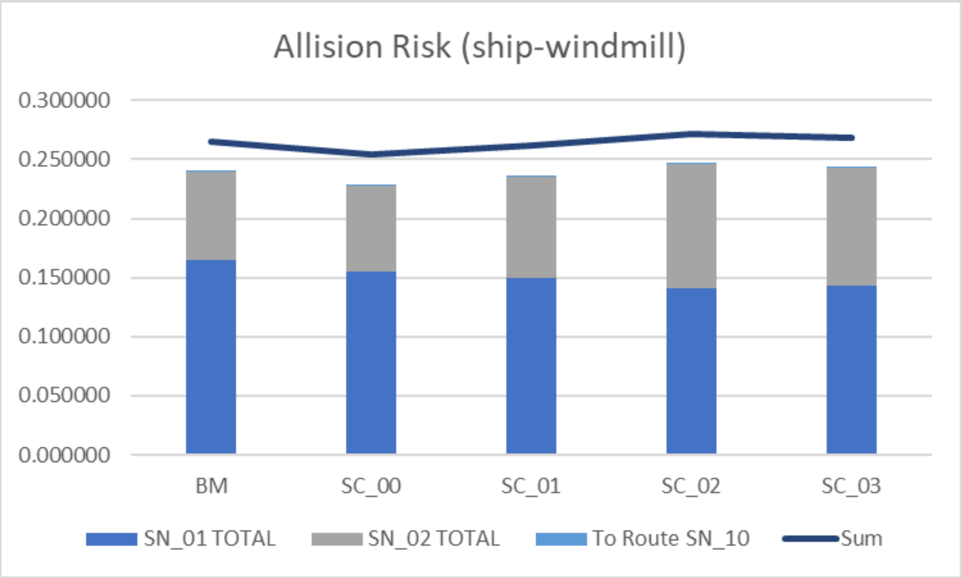


Figure 70: Ship-to-windmill annual allision probability in the model

A combined chart of the collision and allision risk associated with each scenario is presented in Figure 71.

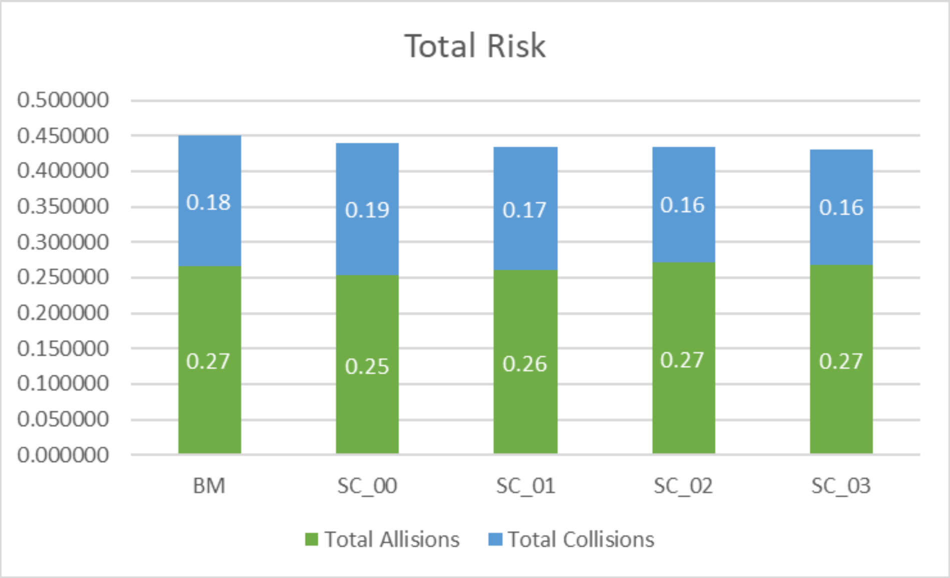


Figure 71: Total risk summary

The combined results demonstrate that there is very little difference in the overall risk noted between the three scenarios (SC 01, SC 02, and SC 03). Scenario SC 03 marginally provides the lowest combined risk of the three.

Scenario SC 01 is the one with the lowest allision risk of the three, whilst SC 02 and SC 03 provide the lowest collision risk. Based on absolute risk, none of the three stands out, and they all appear to constitute viable propositions.

Looking at the collision risk intensity that is noted on the three main routes considered in the analysis (Figure 72), i.e., the annual collision probability per nm-length of each route, we can gain insight into the impact of each of the main scenarios on the safety of each route. Scenarios SC 02 and SC 03 produce very similar, almost identical results. Scenario SC 01 appears to be introducing notably less risk to the route from TSS Vlieland Nord to TSS North Friesland and SN 2, mainly due to the substantially lower volume of diverted traffic. The same applies to the SC 02 for the same reasons.

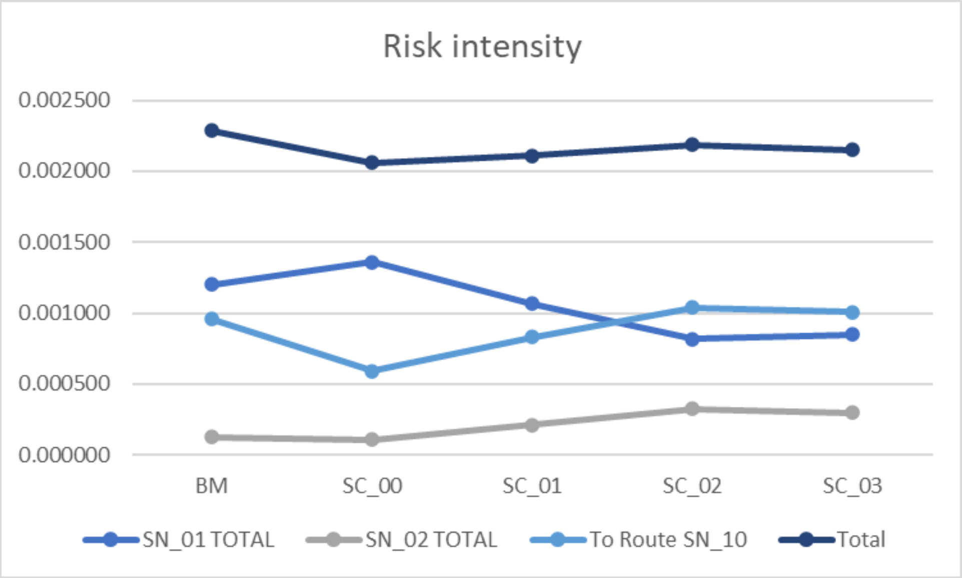


Figure 72: Risk intensity (annual collision probability per nm length)

Considering the high volume of traffic already on the TSS Vlieland North to SN 02 route, as well as the fact that the latter route runs exclusively within the Dutch jurisdiction, scenario SC 01 may be the most attractive one to agree and enforce, as it entails the minimum amount of risk transfer between the two jurisdictions.

Considering that further OW developments will appear in the area of the model in the future, it should be expected that the risk will increase accordingly. Although the differences in the risk weighting between collision and allision risk are small, the fact that route SN 02 is exposed to developments on both sides vs the exposure of SN 01 predominantly to developments in the north, selecting an option with the least possible diversion of traffic is expected to benefit the overall safety of the system. On this basis, SC 01 may prove to be the most attractive scenario to implement looking into the future.

7.1.2 Are the present dimensions (navigational breadth) of the TSS German Bight Western Approach sufficient to handle the additional diverted traffic from scenarios 01 to 03?

From the results of the analysis of the three relevant scenarios, there is no evidence suggesting that the current width of the TSS German Bight Western Approach would not be in the position to safely accommodate the relevant traffic from scenarios SC 01 to SC 03, however, the smaller the traffic volume adjustment, the easiest it will be to accommodate. This is of particular importance as the diverted route is longer than the original, thus providing more opportunities for risk to materialise. Moreover, the available studies to date assessing the width of a navigational corridor against the density of the shipping traffic transiting the same corridor indicate that the TSS German Bight Wester Approach is safe to accommodate such increment of traffic as described above.

7.1.3 Whether safe navigation is possible within TSS German Bight Western Approach following the introduction of the additional diverted traffic.

Whilst the annual collision probability noted on route SN 02 post-introduction of the additional traffic of scenarios SC 01 to SC 03 increases in the model, it does not exceed the values noted elsewhere in the model (SN 02). This stands both in terms of absolute value, and in terms of risk intensity. Therefore, it is reasonable to say that the risk increase noted as a result of traffic diversion to the requirements of scenarios SC 01 to SC 03 does not deem navigation on route SN 02 unsafe.

7.2 Commentary on area EN 11a

7.2.1 Safety of navigation related to the presence of EN11a

ABL was asked to comment about the concerns that the presence of EN 11a development would lead to the safety of navigation in the immediate area for the shipping traffic. More specifically, the issue was related to the available manoeuvrable room a vessel would have heading south along route SN 05 encountering on her starboard a vessel bounding towards the Elbe River on SN 04. The following Figure 73 graphically depicts the assumed situation of concern.

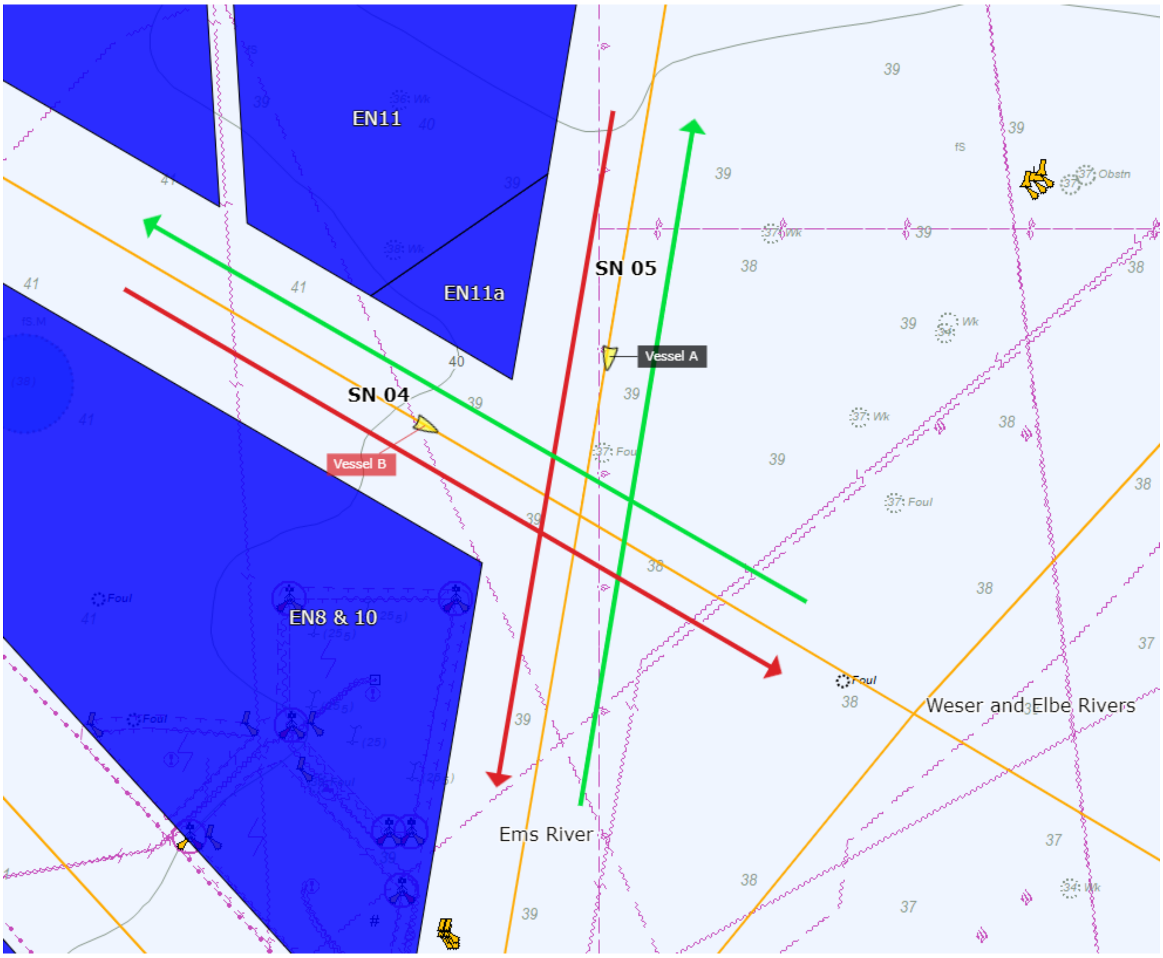


Figure 73: Crossing situation south of EN 11a

According to Rule 15 of Colreg, when a risk of collision arises between two power-driven vessels crossing each other route, the vessel which has the other on her starboard side shal keep out of the way and avoid, if possible, crossing ahead. Therefore Vessel A (in Figure 73) should keep out of the way, by altering her course to starboard passing astern of Vessel B.

By doing so Vessel A would reduce the room between her original track and the installation of deevelopement EN 11a.

There are some assumptions necessary to make in advance:

- A vessel's Closest Point of Approach is generally 5 cables (0.5nm) in good weather and visibility conditions
- A reasonable officer of the watch would not proceed at distances closer to 1.8nm to the installations
- Vessels proceeding along SN 04 would maintain the central axis of the corridor

- An average speed of 15 knots is assumed for both vessels.

The two vessels should be able to visually spot each other, namely be clear from the visual obstruction of the wind generators, when at approximately 4.2nm of distance with a TCPA (time of closest point of approach) of approximately 15 minutes.

Hence, vessel A will assume a bow passage of vessel B in the order of 0.6nm and she will initiate her course alteration at a distance of about 4.0 from each other. As required Vessel B will maintain her course and speed.

A TCPA of 15 minutes is enough for the officer of the watch (OOW) to take appropriate actions, considering also the number of vessels that might be navigating at the same time in the area, as explained in the following paragraphs, the OOW should have enough time to assess the situation and plan an avoidance manoeuvre.

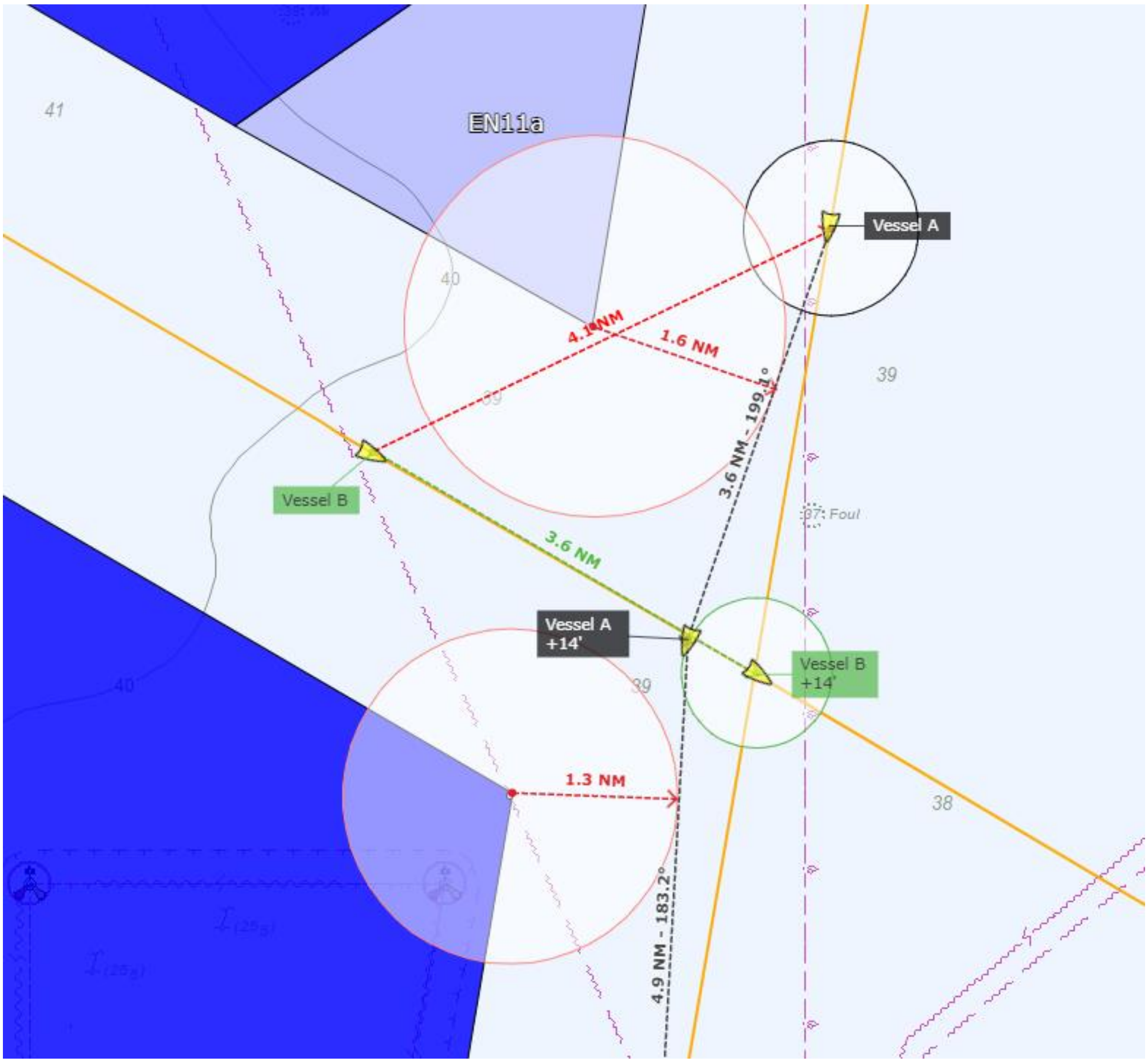


Figure 74: Avoidance manoeuvre of Vessel A southbound on SN 05.

As illustrated, if Vessel A would take a 10 degrees to starboard alteration at T0, she would have passed Vessel B on her stern at T+14 with a CPA of 0.6nm.

Vessel A closest transit to EN 11a would have been 1.6nm and, as it is evident in the reconstruction, the closest passage to installation would be 1.3nm with the southern development of EN 8 & 10.

The current geometry of the crossing routes shows how the issue for a southbound vessel on SN 05 is not EN 11a directly but the southern installation of EN 8 & 10.

It is of course agreed that the entire absence or reshape of the boundary of EN 11a would increase the available room for manoeuvring of vessels in transit however this would be beneficial for some of them only.

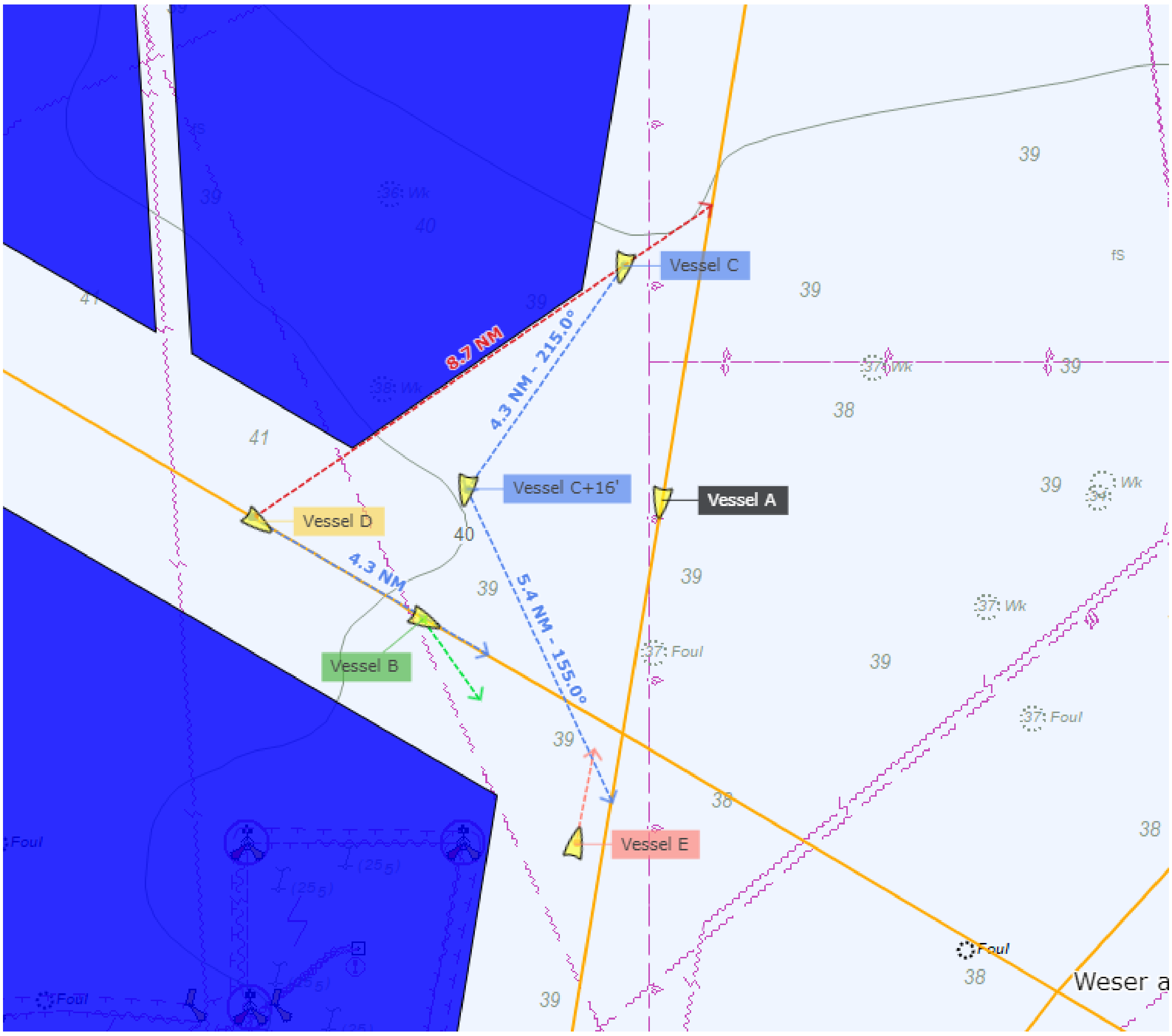


Figure 75: EN 11a removed

Figure 75 shows the situations that might arise from the area EN 11a completely removed. This would allow traffic to utilise the room of water north of the eastern corner of EN 8 & 10. Assuming Vessel C navigating near the boundaries of the OW installations, and therefore not as good seamanship would suggest, she might use the space previously occupied by EN 11a to avoid the collision with eastbound traffic of SN 04 (i.e., Vessel D), however she would end up in a position where a sharp course alteration would be required (about 60°) to re-join the original track and avoid allision with the EN 8 & 10.

Similarly, assuming an additional Vessel E northbound on SN 05 which based on the analysed data it is quite unlikely if not impossible that a similar concentration of vessels could occur in the area, Vessel B should be required to alter her course to starboard without having much available room to manoeuvre due to the presence of EN 8 & 10.

In summary, EN 11a, as it stands, does not constitute an actual issue for the safety of navigation of the vessel in the area more than what EN 8 & 10 already does for SN 04 eastbound traffic. Although, additional maritime space would be utilised by the vessels for ship-to ship manoeuvre, the allowance given by the area occupied by EN 11a would result in an asymmetric additional space which might be counterproductive to other traffic heading on specific routes in the area.

A possible solution to mitigate the risk of situations where vessels have to manoeuvre near installations EN 11 and EN 8 & 10, with sharp angle of course alterations, is to shift the axis of SN 05 easterly. The distance at which this mitigation might be considered is based on an imaginary central axis of the corridor made by Sandbank and EN 11 installations. The converging channel would allow an axis with over 3.0nm distances on both sides, and 3.3nm in correspondence of EN 11a (see Figure 76). This shifting would allow much more manoeuvrable room to the vessels transiting both routes SN 04 and SN 05 and would refrain OOW from getting too close to the boundaries of the installations.

The mitigation might be performed by way of the introduction of a recommended route and/or by deploying aids to navigation to assist the OOW in maintaining the appropriate course in the area.

Figure 76: Shifting of SN 05 easterly.

Additional considertation is worth to be given to the volume of traffic analysed in this study for the reference route SN 05 and SN 04. The current study identified an annual transit along SN 04 westabound of 387 vessels and eastbound of 328 vessel with the majority of vessels in the range of 200-250 m of length over all.

SN 05, instead, recorded 226 northbound transits and 200 southbound, where the majority (more than 50%) of the fleet is comprised of vessels with length over all between 75-125m.

This would bring down to rare the probability of two vessels to encounter in a situation where the alteration of course is required in a collsion avoidance manouevre, considering that the two routes, SN 04 and SN 05, experiences transit of vessels per day in the order of 1 vessel or less in a 24 hour period.

7.3 Wartsila Simulations supplementing the analysis of SN 10

7.3.1 Overview

7.3.1.1 Objectives and setup

The objective was to run a navigation simulation of the selected option (Option C_M7) from the original study, inclusive of mitigation proposals in the area of the German North Sea surrounding route SN10. The simulation is also aimed to gain insights on the post-development environment, and at the same time identify if the available room of maritime space resulted from the introduction of offshore installations is enough to allow traffic navigating safely.

In this regard two main risk hotspots were identified in the study, one where the traffic diverts between the eastern and western branches of SN 10 near the boundary between the Danish and German EEZs (North Scenario); and a second one at the crossing of SN10 with the western routes of SN04, SN 15, and SN 17 (West Scenario) – see Figure 77 overleaf.

The simulation model was populated with third-party vessels based on the AIS data, extracted for the busiest period noted in the available 2-year dataset. This corresponds to the 3-hour window of 17 June 2020 08:00-11:00 UTC. A close-quarter encounter scenario was superimposed to the heaviest traffic noted and therefore the overall scenario represents a highly adverse circumstance during a busy period. Furthermore, environmental conditions for wind, wave and current were added based on the predominance of the data obtained from the metocean assessment.

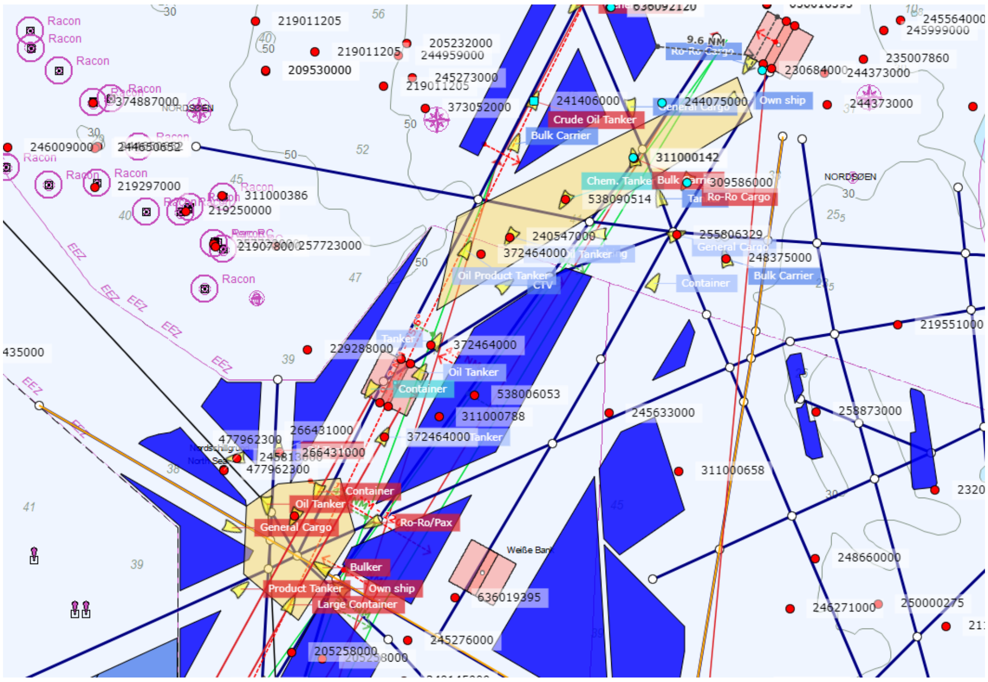


Figure 77: North and West Scenario areas depicted in yellow

To evaluate whether the available maritime space that resulted from the modification of the maritime spatial plan surrounding SN 10 as part of scenario C_M7 is safe for the ships to navigate, the following assumptions were made:

The scenario was built up using the most representative vessels present in the area, based on the analysis of the AIS dataset.

The scenario required the vessels to make several avoidance manoeuvres towards both the port and starboard sides accordingly.

The environmental conditions were adapted to represent the predominant weather in the area.

Simulations were conducted whilst controlling a Feeder and a Large Container ship.

Sections 7.3.1.3 to 7.3.4 below describe the Wartsila simulation model development, the AIS data analysis used for the simulations (the AIS data scenario), the additional close-quarters encounter scenario and the metocean environmental conditions.

7.3.1.2 Simulation software

The simulator used for this study was a Wartsila NTPro5000 (previously called Transas NTPro5000) desktop version which is a DNV-approved ship simulator. It simulates the integration of ship hydrodynamics and one of its functions is to be used as a tool to assist with vessel and scenario simulation.

The mathematical vessel models, including the physical forces and effects acting on them, have been based on results from research studies. Each vessel model has been designed to include the propulsion and manoeuvrability characteristics of the vessel based on six degrees of freedom (surge, heave, sway, pitch, yaw and roll) caused by the effects of wind, waves, currents and water depths.

The simulator also has the capability of being able to model all forces, movements, closest point of approach to fixed structures or other vessels, vessel engine/rudder movements and numerous other parameters.

ABL use this software in-house, and it is understood that BSH also operate the same Wartsila software in their simulation lab. The models prepared in this study will be passed onto BSH for future use following this simulation study.

7.3.1.3 Wartsila simulation model development

A database file for local marine charts (up to date at the time of modelling) was provided by BSH for use as a basis before any modifications. These charts were received in the form of a *.cab* filetype, recognisable by Wartsila Model Wizard software used to prepare the simulation models.

Modifications made to the charts database were focussed on the simulation focus areas – that is, the northeast TSS in the eastern branch of SN10 and the central western crossing of SN 10 with SN 13, 15 and 17. The modifications implemented were the following:

- The input of the locations of the windfarms with GPS coordinates used to define all boundaries. Turbine locations were also added; however, these were at estimated positions and were not based on GPS coordinates for the specific turbine locations. Visual wind turbines were also added to the simulation graphics for the bridge view within the simulation software.
- A 500m-wide safety zone, together with a restricted area marking around that offset from the perimeter of the wind farm boundaries.
- Cardinal buoys located at the relevant corners of the 500m restricted area zone to mark the delimitation of such area (Note: cardinal buoys were not added to other windfarms as these were outside of the simulation focus area).

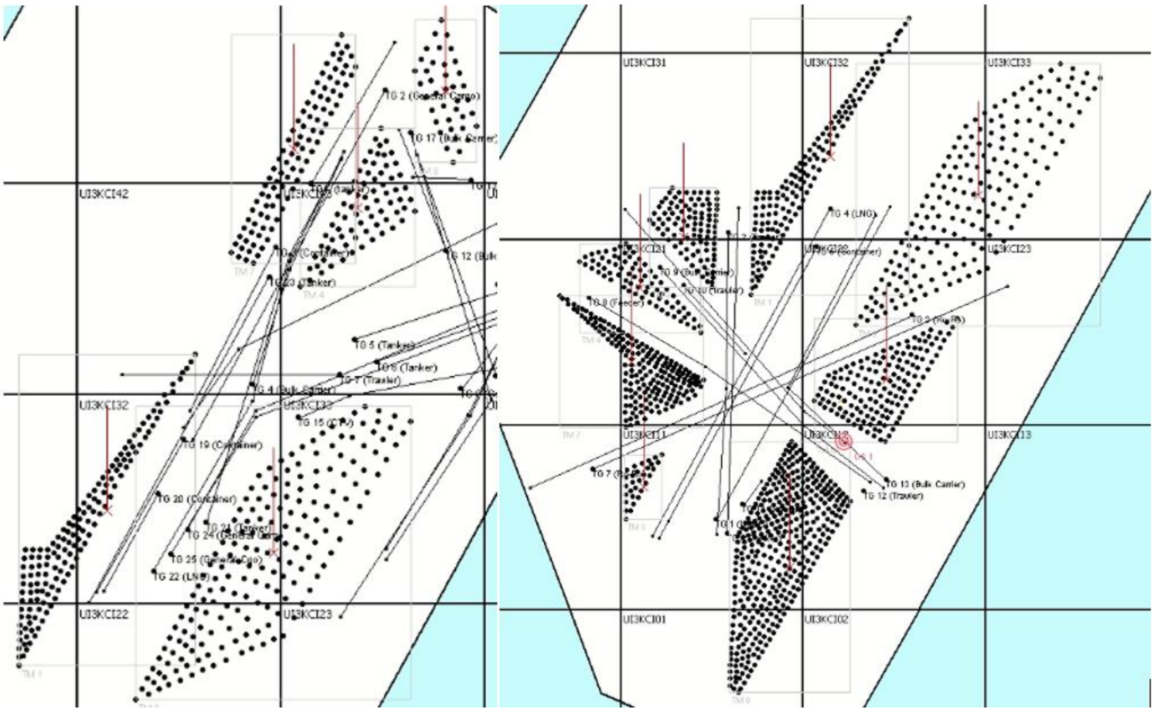


Figure 78: Modifications made to charts for the North (left) and West (right) Scenarios

7.3.2 AIS data scenario

7.3.2.1 Vessels

Third-party ships were added to the model to populate the scenario, and these were extracted from the AIS data. These are called “Target” ships, generally fitting into one of the 9 categories listed below. To reduce the number of separate vessel models used in the simulation, the following vessels were used as third-party vessels in the simulations:

- Ro-Ro Pax Ferries – represented by ~ 190m Ro-Pax Ferry model
- Car Carriers – represented by ~ 230 and 195m Car Carrier models
- Tankers – represented by ~ 250m VLCC Tanker model
- LNG Tankers – represented by ~299 and 315m LNG Tanker models
- Container vessels – represented by ~ 170, 220, 300 and 430m Container models
- Bulk Carriers – represented by 320, 235 and 75m Bulk Carrier models
- Cruise ships – represented by ~ 215m Cruise Ship model
- Ro-Ro vessels – represented by ~ 240m Car Carrier model

- Fishing vessels – represented by ~50m Trawler model.

7.3.2.2 Vessel tracks

Tracks from the AIS data were simplified to only include major changes of course. Being in open water, speeds were typically observed to be maintained at a constant speed with only minor variations for most of the vessels. The speed used in simulations for all vessels was therefore set at the average speed of the vessel over the 3-hour AIS data recorded.

Tracks were redirected when the actual AIS data showed a crossing through the boundaries of new windfarm areas. This was done in line with the assumptions of the risk study that preceded the simulation. Where practicable, these modified tracks were re-aligned to the new recommended routes. Tracks extending beyond the model extents were clipped at the boundary and therefore any vessel entering the boundary was set to “enter” the simulation at the time it crossed the boundary in real life. This was to maintain consistency with the situation recorded by the AIS data, but which did not affect the close-quarters scenario tested in the runs.

Refer to Appendix D for a visual representation of the third-party vessel tracks based on AIS data.

7.3.3 Additional close-quarters encounter scenario

7.3.3.1 Vessels

Additional vessels were added to the scenario to create the fictional close quarters encounter and subsequent evasive manoeuvre. All vessels used in the close-quarters encounter were based on the vessels observed in the AIS dataset. Ships operated in the scenario, called “Own Ship” (OS) were a Feeder and a large Container Vessel. The details of the Own Ship vessels are as presented in Figure 79 and Figure 80:

Type of engine	Slow Speed Diesel (1 x 12640 kW)
Type of propeller	CPP
Thruster bow	Yes
Thruster stern	Yes

General information

Vessel type	Feeder container ship 1 (1610
Displacement	24080.0 t
Max speed	20.5 knt

Dimensions

Length	169.0 m
Breadth	27.2 m
Bow draft	8.5 m
Stern draft	9.5 m
Height of eye	31 m

Figure 79: Feeder Container Object Information

View

Type of engine	Slow Speed Diesel (1 x 54719 kW)
Type of propeller	FPP
Thruster bow	Yes
Thruster stern	None

General information

Vessel type	Container ship 36 (22600 TEL
Displacement	286053.8 t
Max speed	22.0 knt

Dimensions

Length	430.0 m
Breadth	59.0 m
Bow draft	16.0 m
Stern draft	16.0 m
Height of eye	50 m

Figure 80: Large Container Object Information

7.3.3.2 Vessel tracks

The “Target” ships followed pre-defined tracks and at speeds designed to interact, where reasonable, with OS tracks and utilise the maritime space available for avoidance manoeuvre when required.

Own Ships were also set to follow a pre-defined track dictated by the intended transit according to the scenario. The track and speed were followed using autopilot recreating the usual condition on the bridge of a vessel whilst sailing in open waters. When manoeuvring was necessary, the operator then took manual control, similar to what would occur on the wheelhouse of the ship and navigated as required.

See Appendix D for a visual representation of the vessel tracks used in this scenario.

7.3.4 Metocean environmental (metocean) conditions

Metocean conditions were chosen to simulate the predominant conditions as taken from the metocean assessment completed based on data available to ABL from the main risk study. Details for wind, waves and currents are presented in the table below.

Table 40: Simulation metocean conditions

Parameter	Magnitude	Direction
Wind	20 knots (steady)	From 225° (to 045°)
Wave	1.5m (significant height)	From 330° (to 150°)
Current	0.4 knots (steady)	From 030° (to 210°)

7.3.5 Scenario simulations

7.3.5.1 North Scenario

The North Scenario considered at the northern edge of the German EEZ is depicted in Figure 81, and it is based on, as described above, AIS data improved by additional vessels distributed to increase the frequency of traffic transiting the area.

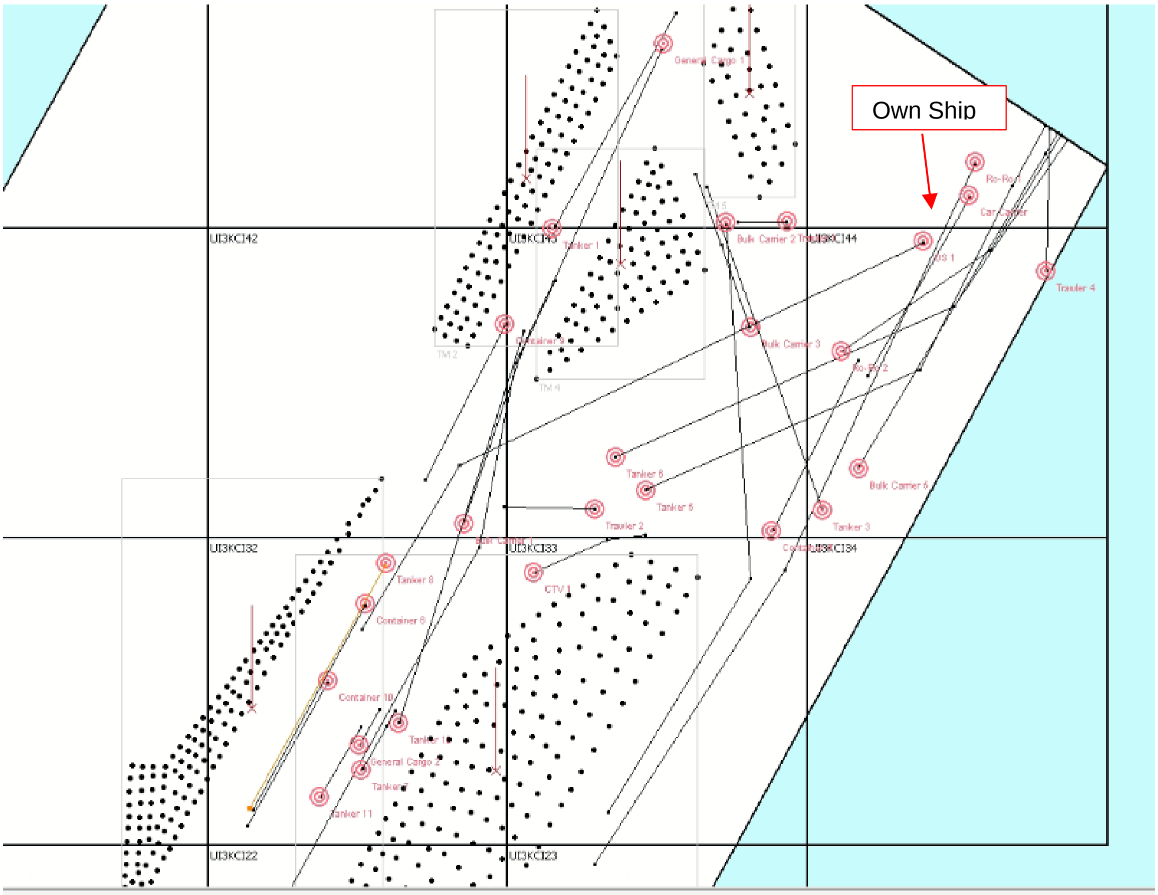
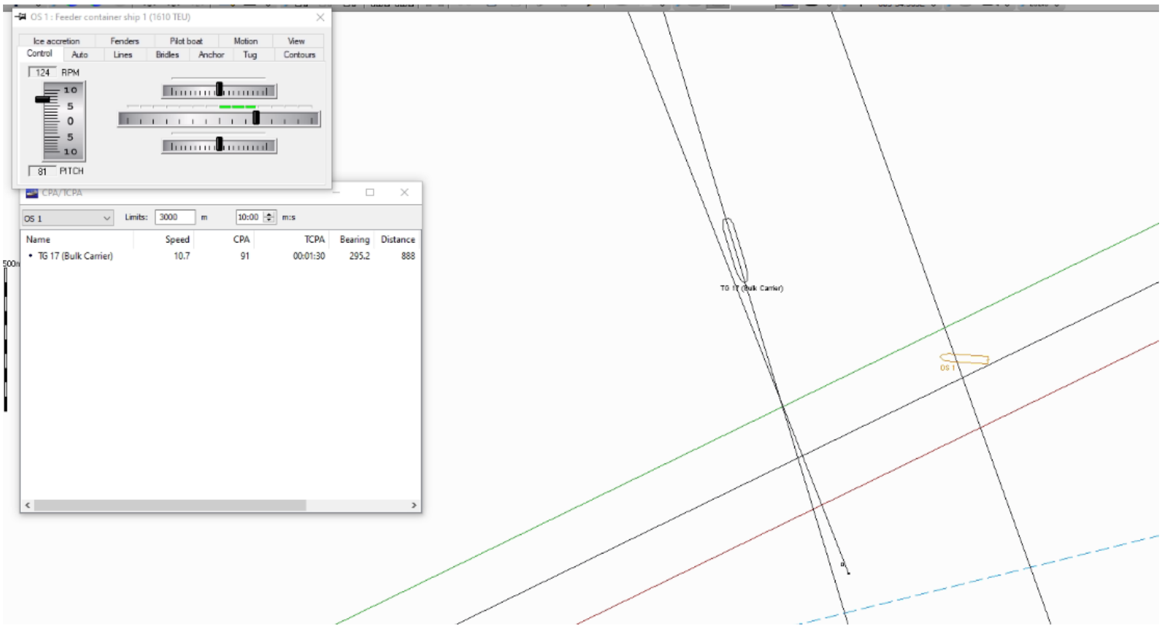


Figure 81: Depiction of the scenario at the northern part of the EEZ

The scenario as an overall extension of over 100km and the Own Ship (OS) vessel selected to run the simulation was a Feeder Container Vessel exiting the TSS, southbound, at the eastern branch of SN10 proceeding south-westerly, along a track of 241° bearing with a speed over ground of approximately 15 knots, towards the west to then alter her course to port to 215° to align with the TSS located at the western branch of SN10 so that she has to divert from the eastern to the western traffic flows.

The OS vessel utilised to run this part of the simulation is a feeder container vessel as described in Figure 79, as it detaches from the NE TSS and proceeds on course 241°, the first crossing situation is encountered with the vessels proceeding along SN 07 (Figure 82). However, this occurs when the distance to offshore installations in the Danish EEZ is over 6 km whilst the southern area is free of obstructions. This results in a lot of room for OS to manoeuvre and even to take a wide alteration of course using more space for collision avoidance.



124 RPM

81 PITCH

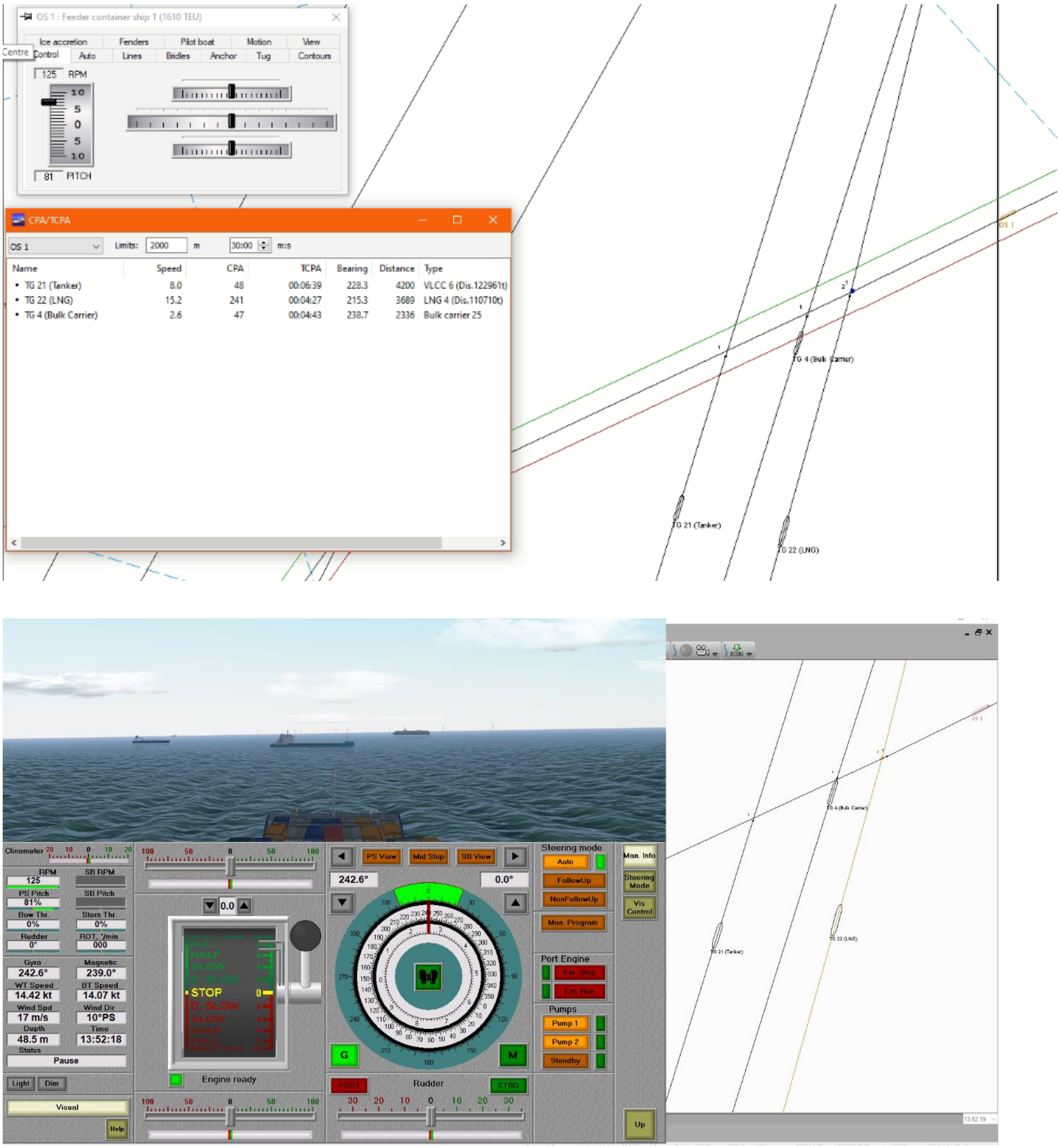
OS 1 Limits: 3000 m 10:00 m:s

Name	Speed	CPA	TCPA	Bearing	Distance
• TG 17 (Bulk Carrier)	10.7	91	00:01:30	295.2	888

Figure 82: OS altering to starboard to clear TG17 southbound on SN 07

The track then proceeds almost parallel to the offshore installations on the starboard for approximately 25km until OS encounter northbound vessels transiting the SN 10 western branch directed towards the projection of the Danish Route A off Skagen TSS at the north.

Also, this crossing situation takes place far from the offshore developments, approximately 7km from the southernmost tip of the Danish installations and 11km from EN 16 to the west, resulting in a wide space that can be used for collision avoidance.



CPA/TCPA

OS 1 Limits: 2000 m 30:00 m:s

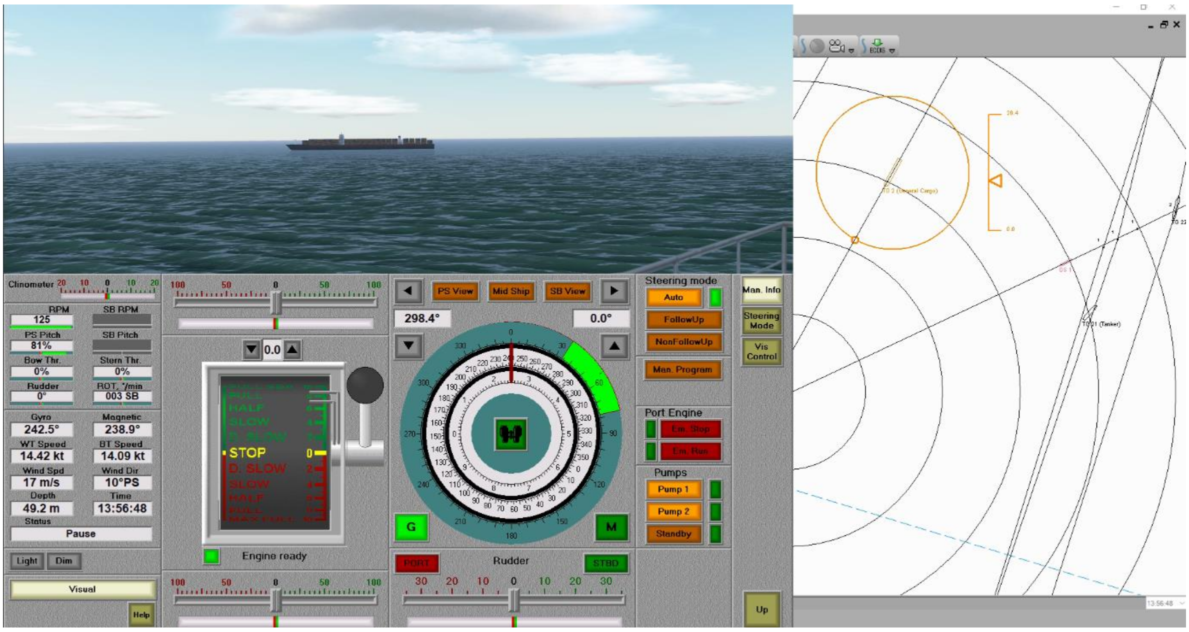
Name	Speed	CPA	TCPA	Bearing	Distance	Type
• TG 21 (Tanker)	8.0	48	00:06:39	228.3	4200	VLCC 6 (Dis.122961t)
• TG 22 (LNG)	15.2	241	00:04:27	215.3	3689	LNG 4 (Dis.110710t)
• TG 4 (Bulk Carrier)	2.6	47	00:04:43	238.7	2336	Bulk carrier 25

RPM 125
PS Pitch 81%
Bow Thr. 0%
Stern Thr. 0%
Rudder 0°
ROT °/min 000
Gyro 242.6°
Magnetic 239.0°
WT Speed 14.42 kt
BT Speed 14.07 kt
Wind Spd 17 m/s
Wind Dir 10°PS
Depth 48.5 m
Time 13:52:18
Status Pause

Figure 83: OS encountering northbound traffic to Route A

As illustrated in Figure 83, three northbound vessels meet OS in a close-quarters situation. Having the three northbound vessels on her port quarter, OS is required to maintain her course and speed. The targets' speed over ground and their actual position were adjusted to recreate a hazardous scenario (conservatively, despite this not being realistic under normal navigation circumstances).

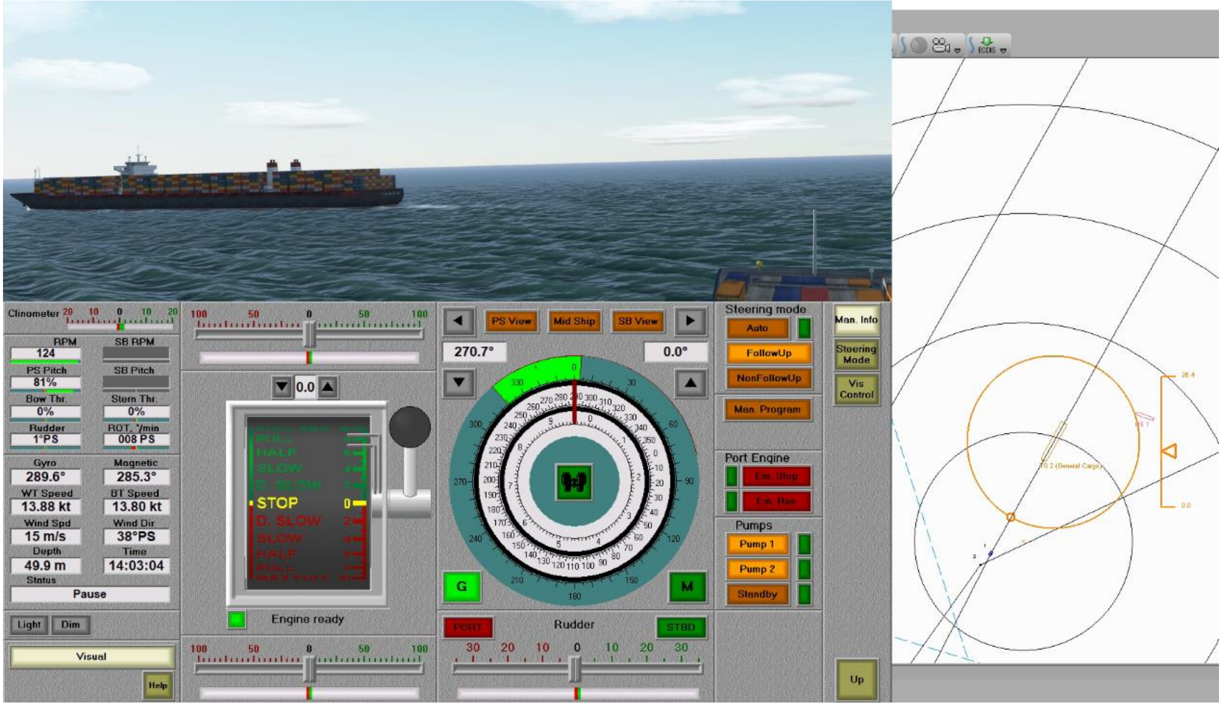
Whilst the "target" dead ahead increased her speed to improve the clearance of the passage at the bow of OS, the two targets on the port side altered their course to starboard to transit astern OS as required by the Rules of the Road. Again, the 'open water' condition allows the vessels to safely manoeuvre without jeopardising their track and position.



RPM: 125
SB RPM:
PS Pitch: 81%
SB Pitch:
Bow Thr.: 0%
Stern Thr.: 0%
Rudder: 0°
ROT, °/min: 003 SB
Gyro: 242.5°
Magnetic: 238.9°
WT Speed: 14.42 kt
BT Speed: 14.09 kt
Wind Spd: 17 m/s
Wind Dir: 10°PS
Depth: 49.2 m
Time: 13:56:48
Status: Pause

Figure 84: Southbound traffic originated from Route A

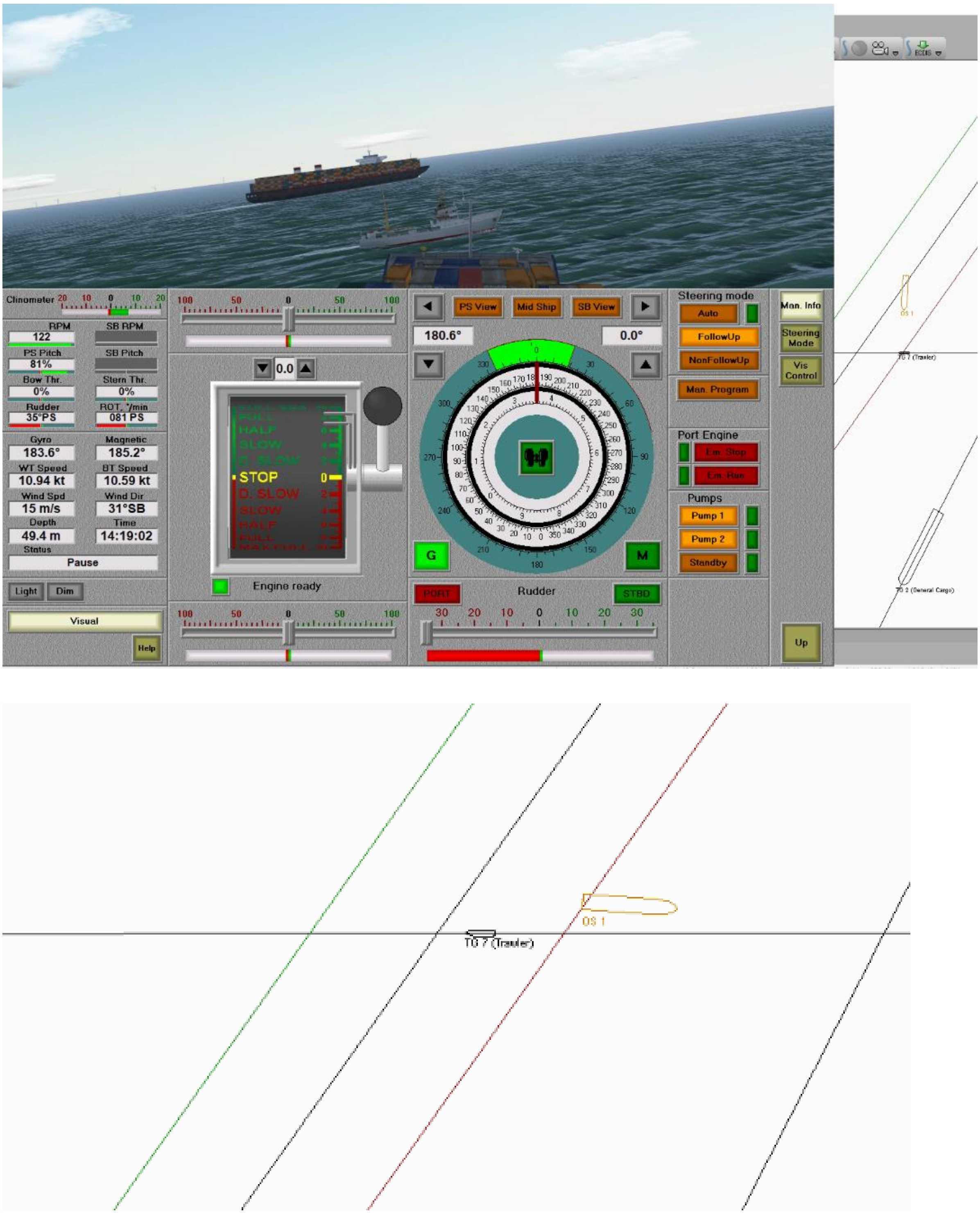
Following the crossing of the northbound traffic, OS starts encountering vessels proceeding towards the TSS southbound on the SN 10 west branch. Figure 84 illustrates the crossing of a large container vessel proceeding south, requiring OS to manoeuvre and pass astern of the container ship (Figure 85).



RPM: 124
SB RPM:
PS Pitch: 81%
SB Pitch:
Bow Thr.: 0%
Stern Thr.: 0%
Rudder: 1°PS
ROT, °/min: 008 PS
Gyro: 289.6°
Magnetic: 285.3°
WT Speed: 13.88 kt
BT Speed: 13.80 kt
Wind Spd: 15 m/s
Wind Dir: 38°PS
Depth: 49.9 m
Time: 14:03:04
Status: Pause

Figure 85: OS passing astern of southbound container vessel

Then a Trawler was added to recreate a dangerous close-quarter situation where OS needs to take a sharp alteration to the port side to avoid a collision with the fishing vessel proceeding westward (Figure 86).



RPM: 122
PS Pitch: 81%
Bow Thr.: 0%
Stern Thr.: 0%
Rudder: 35°PS
ROT, °/min: 081 PS
Gyro: 183.6°
Magnetic: 185.2°
WT Speed: 10.94 kt
BT Speed: 10.59 kt
Wind Spd: 15 m/s
Wind Dir: 31°SB
Depth: 49.4 m
Time: 14:19:02
Status: Pause

Figure 86: OS altering hard to port to avoid a fishing trawler proceeding almost parallel to the trawler’s tail to avoid possible fishing arrangements.

This last-minute manoeuvre also considered the need to not cross the ‘tail’ of the trawler to avoid consequences to the vessel’s rudder and propeller entangled with the fishing gear. Hence, OS proceeded parallel to the Trawler direction up to 900m before starting to realign with its original track.

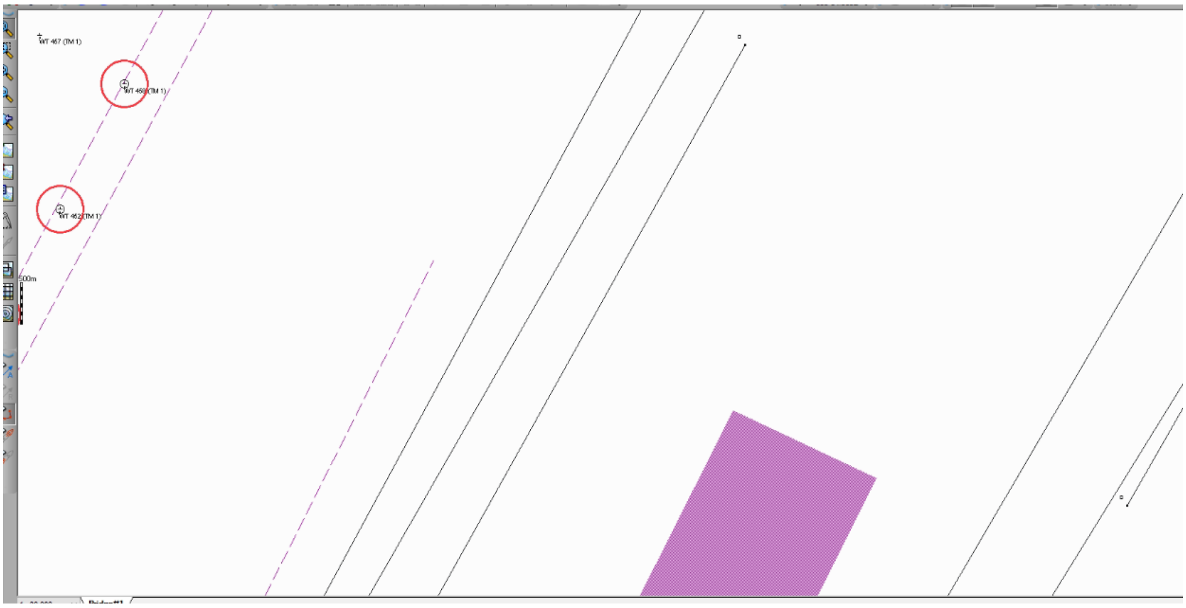


Figure 87: OS alignment with TSS on SN 10 west branch.

The exercise terminated with OS aligned on bearing 210 towards the southbound traffic lane of the TSS on the west branch of SN 10 (Figure 87).

7.3.5.2 West Scenario

The West Scenario, as depicted in Figure 88, considered a large container vessel with a capacity of over 22,000 TEUs (Own Ship) leaving the port of Hamburg and proceeding along SN 04 on bearing 308° and speed over ground 20 knots towards the Northern Sea Route passing westward of the Gorm Oilfield installations.

The Scenario also included several ships (targets) proceeding along the routeing system formed in the area based on Scenario C_M7 of the main study, and therefore on SN 04, SN 13, SN 15 and SN 17.

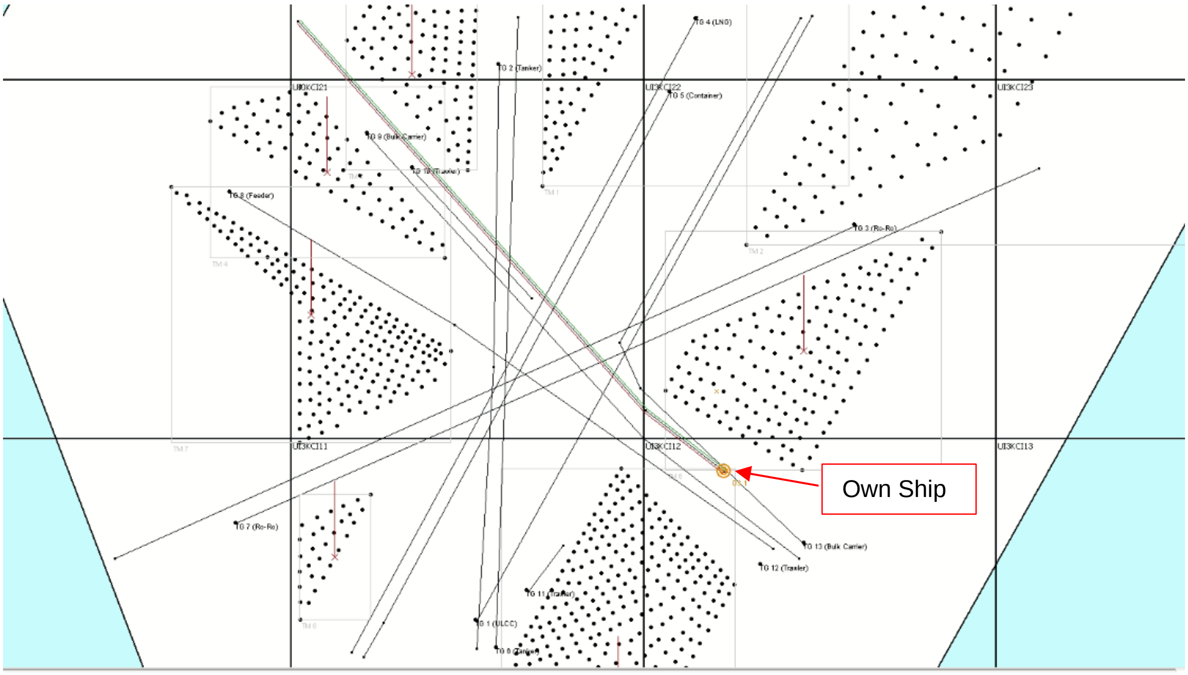


Figure 88: Depiction of West Scenario

The first crossing situation occurred with the northbound traffic proceeding along SN 10 East, immediately followed by the ships on route SN 15 to which OS needs to pay attention as they are coming from her starboard.

Figure 89 shows the large container carrier proceeding northbound on the west branch of SN 10 which takes an evasive manoeuvre to transit astern of OS.

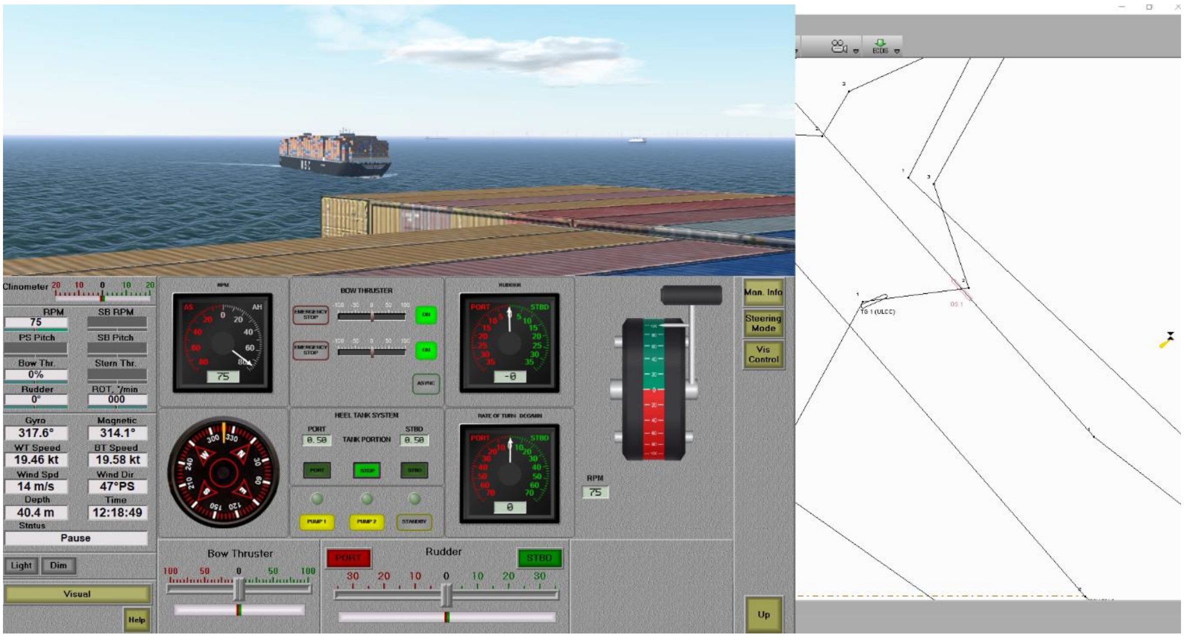


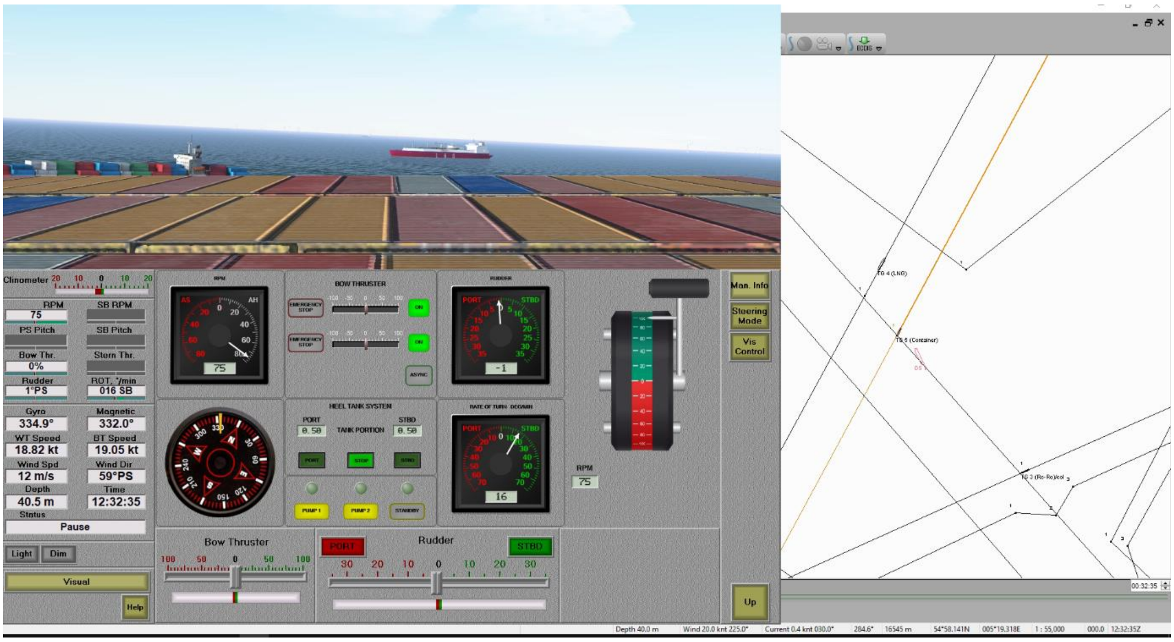
Figure 89: Northbound ULCC on SN 10

Similarly, an eastbound ship on SN 15 (TG 7) crossing OS's track, alters her course to starboard letting OS pass ahead of her bow. At the same time on SN 15, a Ro-Ro ship (TG 3) is proceeding westbound and requires OS to alter her course to starboard in a collision avoidance manoeuvre (Figure 90).

Figure 90: OS crossing SN 15

Subsequently, OS encounters southbound traffic on SN 10 west branch and she manoeuvres accordingly with over 8 km of available room in the surroundings.

The scenario represented two vessels, a container (TG 5) and an LNG tanker (TG 4) proceeding south-westerly with OS on their port quarters (Figure 91).

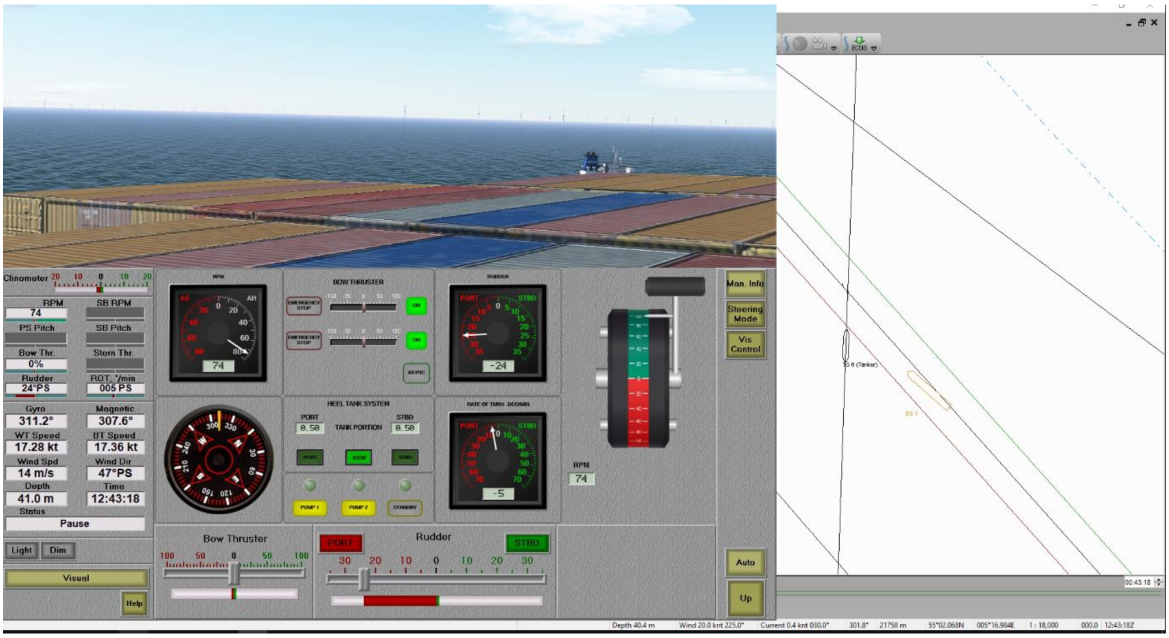


RPM 75
Bow Thr. 0%
Rudder 1°PS
ROT. °/min 016 SB
Gyro 334.9°
Magnetic 332.0°
WT Speed 18.82 kt
BT Speed 19.05 kt
Wind Spd 12 m/s
Wind Dir 59°PS
Depth 40.5 m
Time 12:32:35
Status Pause

Depth 40.0 m Wind 20.0 knt 225.0° Current 0.4 knt 030.0° 284.6° 16545 m 54°58.141N 005°19.318E 1 : 55,000 000.0 12:32:35Z

Figure 91: OS crossing the southbound lane of SN 10

The scenario continued with OS proceeding towards the lane of SN 17 (Figure 92), where a tanker (TG 8) is navigating northbound, and she should give way to OS. However, the scenario considered the tanker did not comply with the collision regulations, therefore forcing OS to take an alteration of course to port to avoid the impact with the tanker and her converging track.



RPM 74
Bow Thr. 0%
Rudder 24°PS
ROT. °/min 005 PS
Gyro 311.2°
Magnetic 307.6°
WT Speed 17.28 kt
BT Speed 17.36 kt
Wind Spd 14 m/s
Wind Dir 47°PS
Depth 41.0 m
Time 12:43:18
Status Pause

Depth 40.4 m Wind 20.0 knt 225.0° Current 0.4 knt 030.0° 301.8° 21758 m 55°02.068N 005°16.984E 1 : 18,000 000.0 12:43:18Z

Figure 92: OS crossing SN 17

A close-quarters situation occurred, with OS avoiding the collision. Whilst OS is realigning with her original course, another tanker (TG 2) proceeding southbound on SN 17 is in a close approach situation with OS, and a bulk carrier (TG 9) is also navigating on a head-on situation, despite “clear on the port” after OS is on her initial bearing (Figure 93).

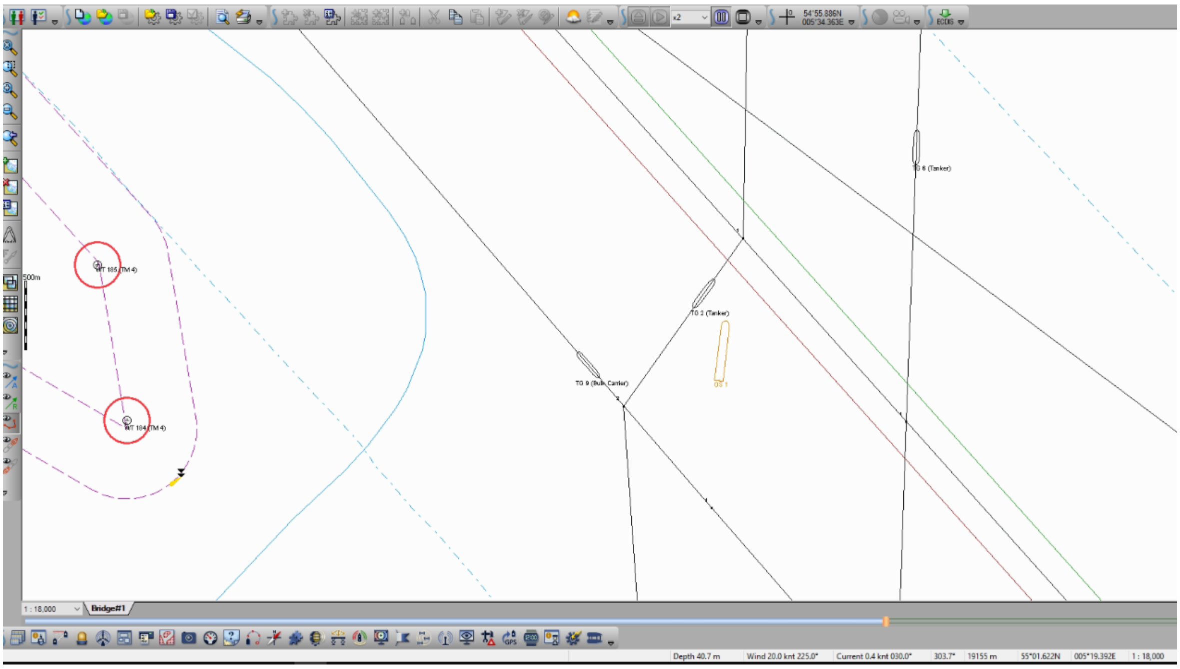
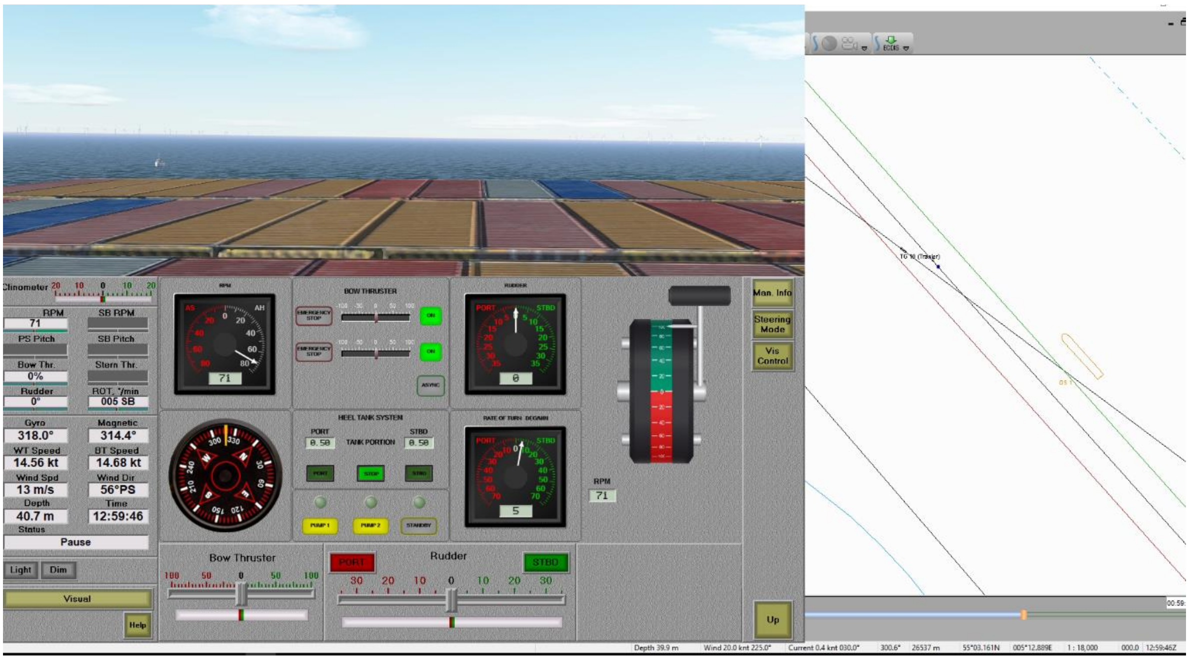


Figure 93: OS encountering southbound vessel SN 17

OS thus had to take a hard-to-starboard manoeuvre whilst TG 2 also altered her course to starboard to avoid a collision with TG 9. Manoeuvring took place at a distance of 3.7km from the nearest offshore installation.

When OS is almost back on her track, the scenario included a fishing trawler proceeding south-easterly and requiring OS to adjust her heading towards starboard to pass clear of the fishing vessel bow (Figure 94).



RPM: 71
Bow Thr.: 0%
Rudder: 0°
ROT, °/min: 005 SB
Gyro: 318.0°
Magnetic: 314.4°
WT Speed: 14.56 kt
BT Speed: 14.68 kt
Wind Spd: 13 m/s
Wind Dir: 56°PS
Depth: 40.7 m
Time: 12:59:46
Status: Pause

Figure 94: OS and fishing trawler

Subsequently, OS realigns on her track and proceeds to the Northern Sea Route.

7.3.6 Conclusions

The assumptions made for the simulations intended to exaggerate the number of vessels and the crossing situation of both scenarios to verify the capacity of vessels in the simulation to take evasive manoeuvres without being jeopardised by the limited availability of navigating waters.

In reality, it is difficult to recreate and even imagine situations where a ship is required to take evasive action so often as considered in the scenarios, in what can be considered open waters, apart from cases where transit occurs within OW installations on the corridors of the West Scenario, where crossings should not normally occur. The simulated thus, constitute very conservative scenarios.

In summary, given the current traffic volume and the future expected growth of the shipping traffic in the area, the maritime space appears to be sufficient for the safe navigation of the vessels in the area of SN 10 and its immediate surroundings.

From the simulation, it appears that the most hazardous area, or the area which would require particular attention to the navigation, is the junction between SN 17 and the SN 10 system. A ship can be required to take several evasive manoeuvres and be in an unfavourable position when the maritime space reduces between the installations.

Of course, an attentive Officer of the Watch would plan their action in advance and attempt to manoeuvre to be where they want to be in terms of navigating through the system.

Nevertheless, external factors such as inclement weather, low visibility, and poor communication, might lead to situations where the same Officer of the Watch would not have opted to find themselves in.

To obtain a real benefit from the Wartsila simulation machine, more specific scenarios might need to be built up to stress and focus on particular conditions in specific areas of SN 10. This should take place as a series of studies and in sequence as the new OW developments begin to appear in the maritime space. This will allow issues to be addressed as they arise from the incremental changes imposed to the traffic system as formed at the time of development and be targeted on the main issues picked up in navigational hazard identification studies as well as on particular concerns raised by stakeholders.

8 REFERENCES

[01] Federal Ministry of Transport, Building and Housing Division, LS 23, 6231.1/3- Wind – Approval-relevant guideline values for offshore wind farms - Report of a working group, Bonn, 14.3.2005.

[02] Federal Maritime and Hydrographic Agency, Order No. 4500015637 of 16.04.2010 – Report No. SO-ER2010.095 Offshore wind farms - parameters for risk analyses in the approval procedure and effectiveness of collision prevention measures, Version 1.0/2010-07-29

[03] International Transport Forum (2021), ITF Transport Outlook 2021, OECD Publishing, Paris, https://doi.org/10.1787/16826a30-en.

[04] Fujii, Y. and Mizuki, N.: “Design of VTS systems for water with bridges”. Proc. of the International Symposium on Advances in Ship Collision Analysis. Gluver & Olsen eds. Copenhagen, Denmark, 10-13 May 1998. pp. 177-190

[05] MacDuff, T.: “The Probability of Vessel Collisions”. Ocean Industry, September 1974. pp. 144-148.

[06] Lefebvre, C and Rosenhagen, G.: “The Climate in the North and Baltic Sea Region”, Die Küste, 74 ICCE (2008), 45-59

[07] The BACC Author Team: “Assessment of Climate Change for The Baltic Sea Basin” Berlin, 2008. Pp 3-7

[08] Jan, Jędrasik Kowalewski, Marek: “Mean annual and seasonal circulation patterns and long-term variability of currents in the Baltic Sea” Journal of Marine Systems Vol. 193, 10.1016/2018.12.011.

[09] Capt. P. Zahalka: “Bollard Pull” Association of Hanseatic Marine Underwriters, Hamburg, 2008 pp 1-10.

[10] Eloot, K.; Delefortrie, G.; Mostaert, F: “Manoeuvring characteristics”. Flanders State of the Art 16 023 07, FHR Report.

[11] S. Kristiansen, “Maritime Transportation, Safety Management and Risk Analysis”, Elsevier, 2005.

[12] European Maritime Safety Agency, European Environment Agency, “European Maritime Transport Environmental Report”, 2021.

[13] HELCOM Maritime Assessment Report, “Maritime Activities in the Baltic Sea”, 2018.

[14] Baltic Lines, “Exploring the future of shipping in the Baltic Sea”, 2018.

[15] Hindcast dataset, www.worldweatheronline.com, 2008-2021.

[16] MCA and QinetiQ, “Results of the electromagnetic investigations and assessments of marine radar, communications and positioning systems undertaken at the North Hoyle wind farm by QinetiQ and the Maritime and Coastguard Agency”, 2004.

[17] MCA, MGN 371 (M+F), “Offshore Renewable Energy Installations (OREIs) - Guidance on UK Navigational Practice, Safety and Emergency Response Issues”, 2008.

[18] Steamship Mutual Risk Alerts (https://www.steamshipmutual.com/Risk-alerts/RA02NavigationOREI.pdf)

[19] BWEA, “Investigation of Technical and Operational Effects on Marine Radar Close to Kentish Flats Offshore Windfarm”, 2007

[20] Erweiterter Vorentwurf Flächenentwicklungsplan, BSH, Hamburg, 14 April 2022

[21] National Academies of Sciences, Engineering, and Medicine 2022. Wind Turbine Generator Impacts to Marine Vessel Radar. Washington, DC: The National Academies Press. https://doi.org/10.17226/26430

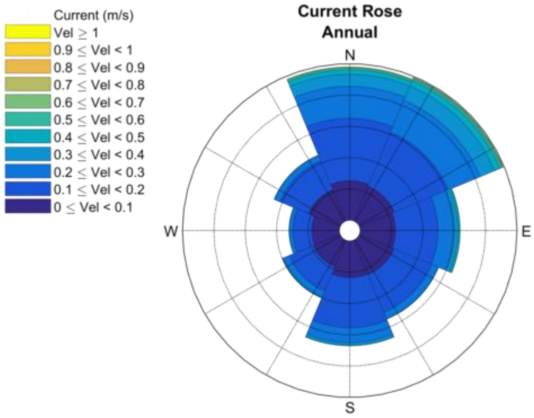
APPENDIX A

Metocean Data, South Baltic Sea

Metocean Data, North Sea

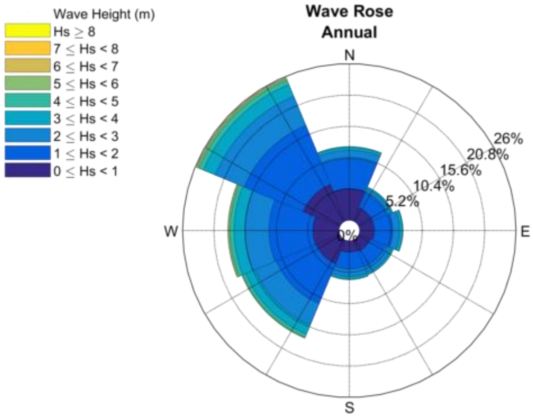
Dir (°N)	Current (m/s) - Annual											
	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	>2.0	TOT.
0	8.85	3.85	0.49	0.06	0.01							13.25
30	8.86	5.14	0.98	0.15	0.03	0.01	*					15.17
60	7.44	3.27	0.46	0.04	0.01	*						11.22
90	6.53	1.69	0.17	0.01								8.40
120	6.42	0.70	0.01	*								7.13
150	7.01	0.72	0.01									7.74
180	7.57	1.66	0.05									9.27
210	5.55	1.00	0.03	*								6.58
240	4.05	0.43	0.01									4.49
270	3.88	0.33	0.01									4.22
300	4.67	0.29	0.01									4.96
330	6.56	0.97	0.04									7.56
TOT.	77.39	20.03	2.27	0.27	0.04	0.01	0.00	0.00	0.00	0.00		100.00

* Value lower than 0.01 %



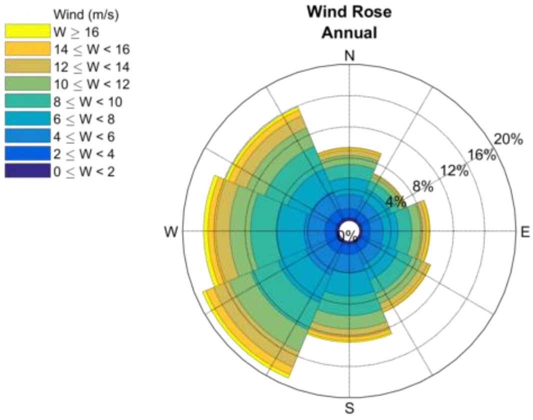
Dir (°N)	Hs (m) - Annual													
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	>6.0	TOT.
0	0.78	2.62	1.85	1.02	0.48	0.25	0.13	0.06	0.03	0.01	0.01	*	*	7.24
30	0.43	1.39	1.04	0.58	0.31	0.16	0.09	0.04	0.02	0.01	*	*		4.07
60	0.33	1.14	1.01	0.71	0.39	0.19	0.12	0.08	0.04	0.02	0.01	0.01	*	4.04
90	0.36	1.31	1.25	0.80	0.45	0.31	0.20	0.11	0.06	0.02	*	*		4.87
120	0.33	1.19	1.21	0.84	0.50	0.34	0.20	0.10	0.04	0.01	0.01	*		4.76
150	0.26	0.96	1.01	0.63	0.36	0.21	0.11	0.05	0.02	0.01	*			3.62
180	0.21	0.98	1.05	0.73	0.48	0.29	0.16	0.08	0.04	0.02	0.01	*	*	4.04
210	0.34	1.92	2.22	1.70	1.20	0.80	0.53	0.30	0.17	0.09	0.04	0.02	0.02	9.32
240	0.56	2.62	2.89	2.23	1.69	1.21	0.77	0.49	0.29	0.15	0.07	0.04	0.04	13.04
270	0.56	2.30	2.59	2.23	1.61	1.10	0.74	0.47	0.28	0.17	0.10	0.07	0.08	12.29
300	0.63	2.76	3.09	2.38	1.59	1.05	0.69	0.44	0.28	0.16	0.09	0.06	0.08	13.31
330	0.90	4.50	4.63	3.36	2.26	1.46	0.92	0.56	0.34	0.21	0.13	0.07	0.07	19.41
TOT.	5.67	23.70	23.84	17.21	11.30	7.36	4.65	2.78	1.59	0.87	0.47	0.27	0.29	100.00

* Value lower than 0.01 %



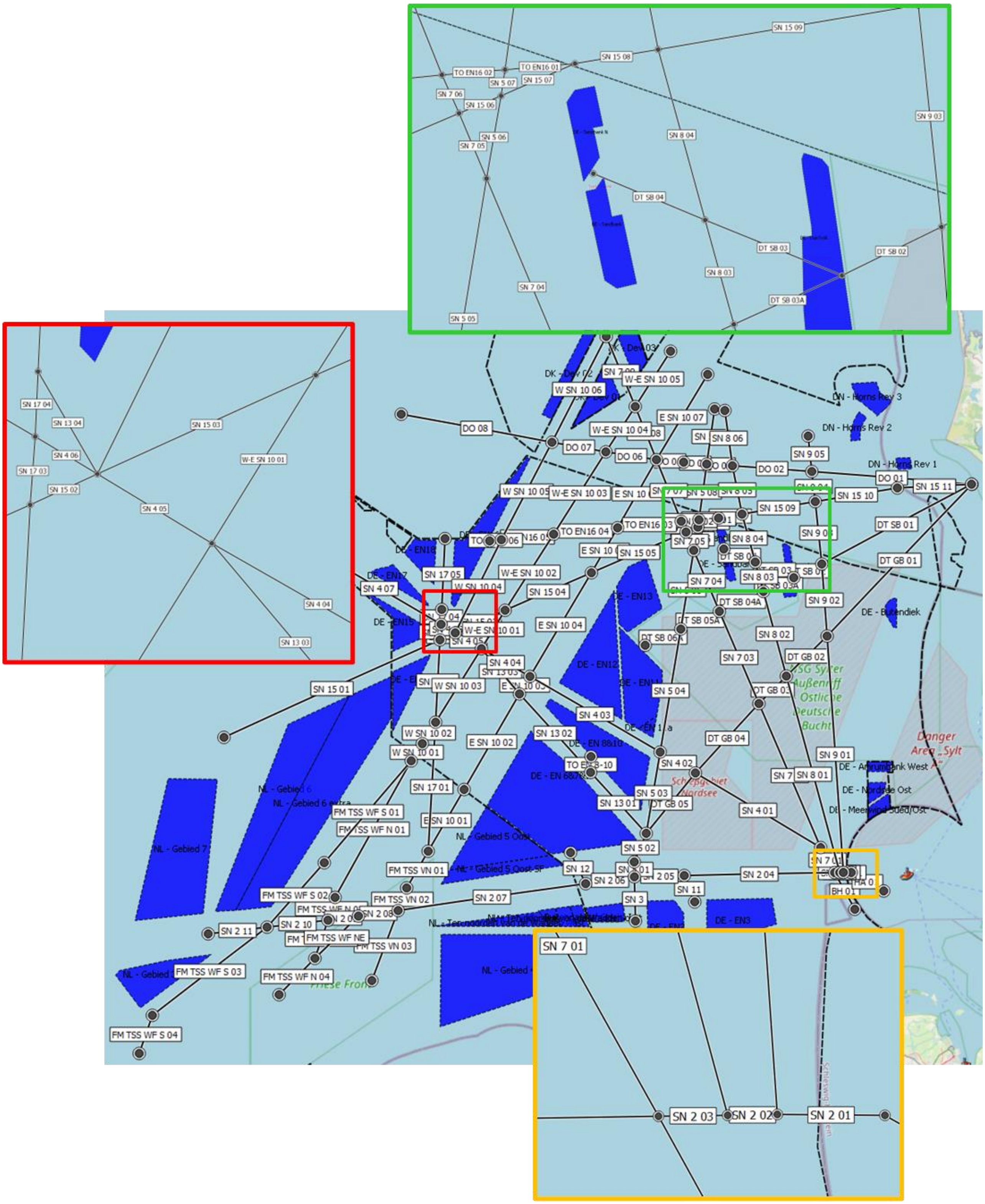
Dir (°N)	W (m/s) - Annual											
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	>20.0	TOT.
0	0.38	1.22	1.87	2.08	1.68	1.13	0.61	0.27	0.07	0.01	*	9.34
45	0.37	1.09	1.54	1.52	1.10	0.62	0.28	0.11	0.03	0.01		6.66
90	0.35	1.07	1.67	1.90	1.75	1.11	0.69	0.37	0.09	0.01	*	8.99
135	0.37	1.17	1.85	2.12	1.93	1.35	0.76	0.31	0.07	0.01	*	9.94
180	0.37	1.36	2.40	2.97	2.48	1.67	1.00	0.46	0.15	0.04	0.01	12.90
225	0.41	1.54	2.95	3.85	3.76	2.98	2.06	1.02	0.35	0.07	0.02	19.01
270	0.42	1.49	2.69	3.49	3.35	2.61	1.75	0.96	0.40	0.12	0.04	17.31
315	0.41	1.38	2.46	3.13	3.18	2.48	1.59	0.82	0.30	0.08	0.02	15.85
TOT.	3.07	10.33	17.41	21.06	19.22	13.97	8.74	4.32	1.46	0.34	0.09	100.00

* Value lower than 0.01 %

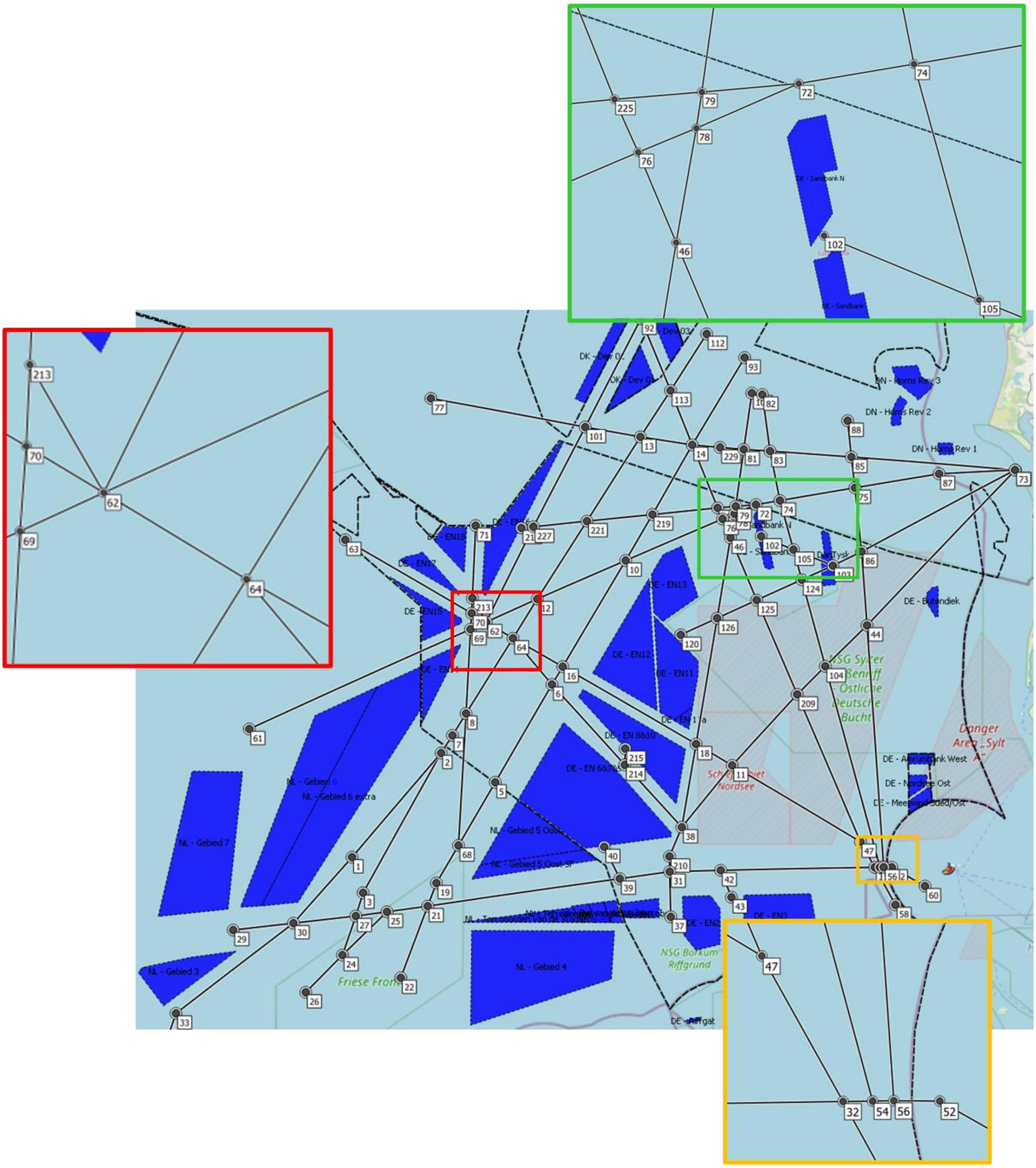


APPENDIX B

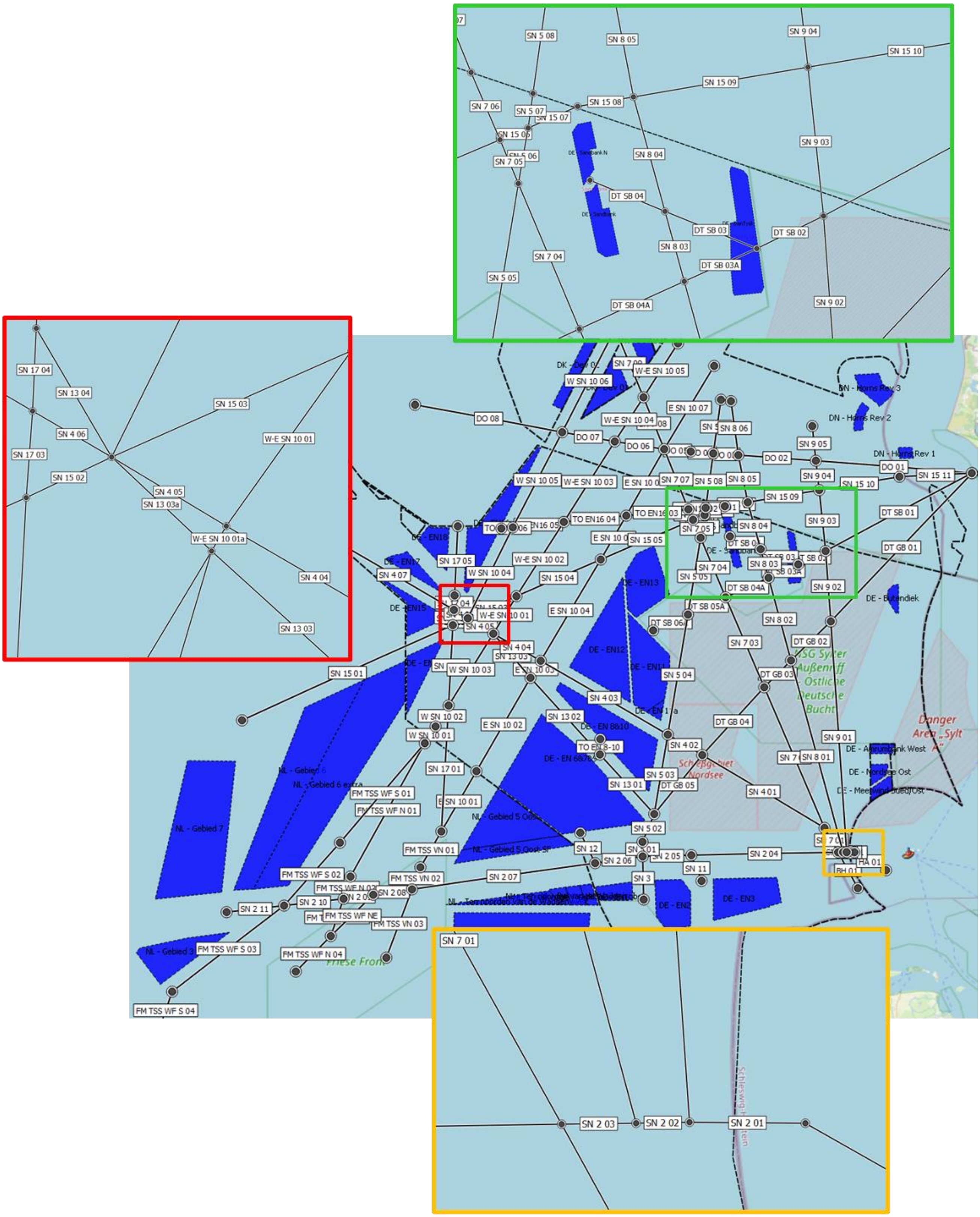
Map of model legs and waypoints



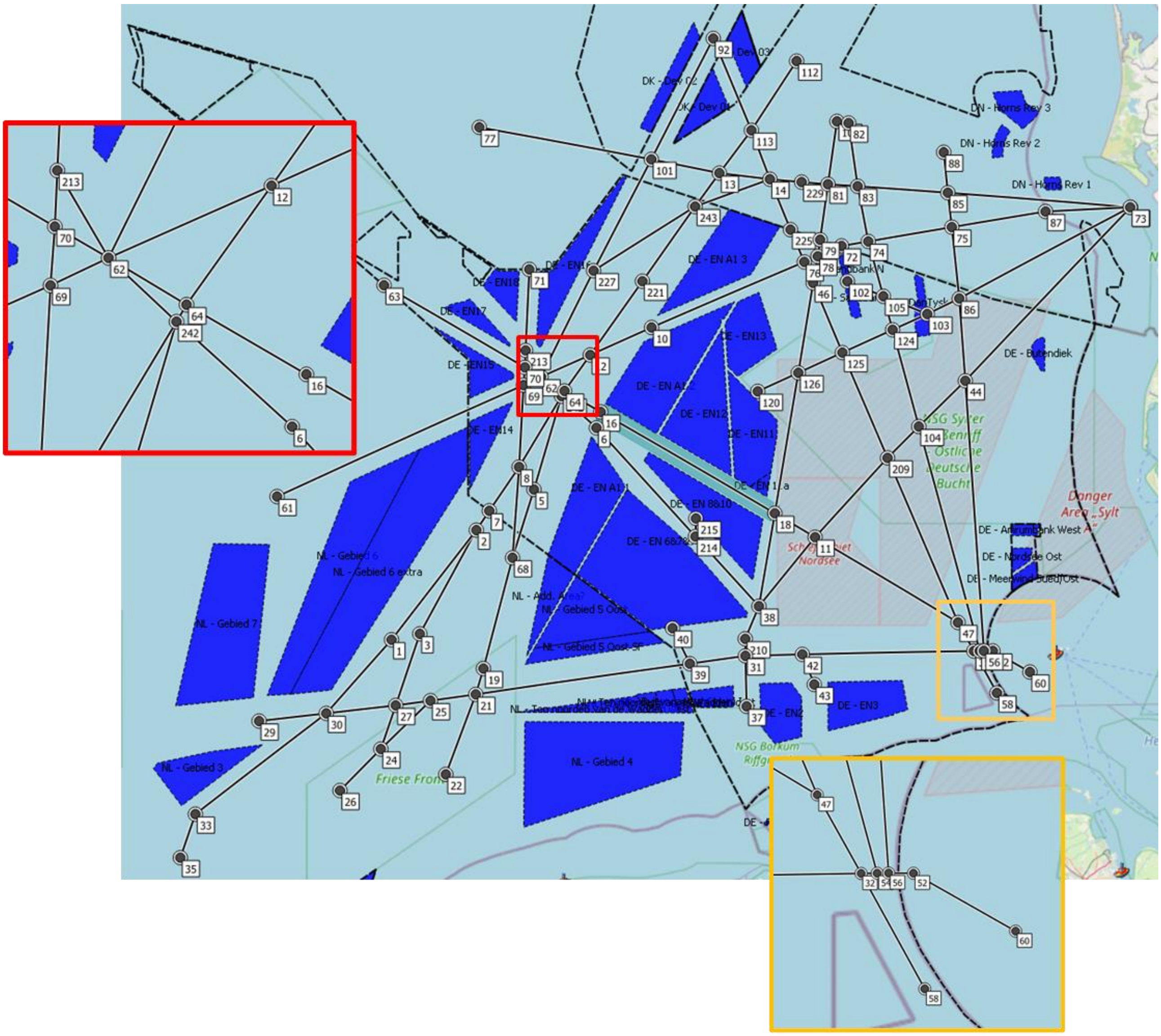
Map of model legs benchmark scenario



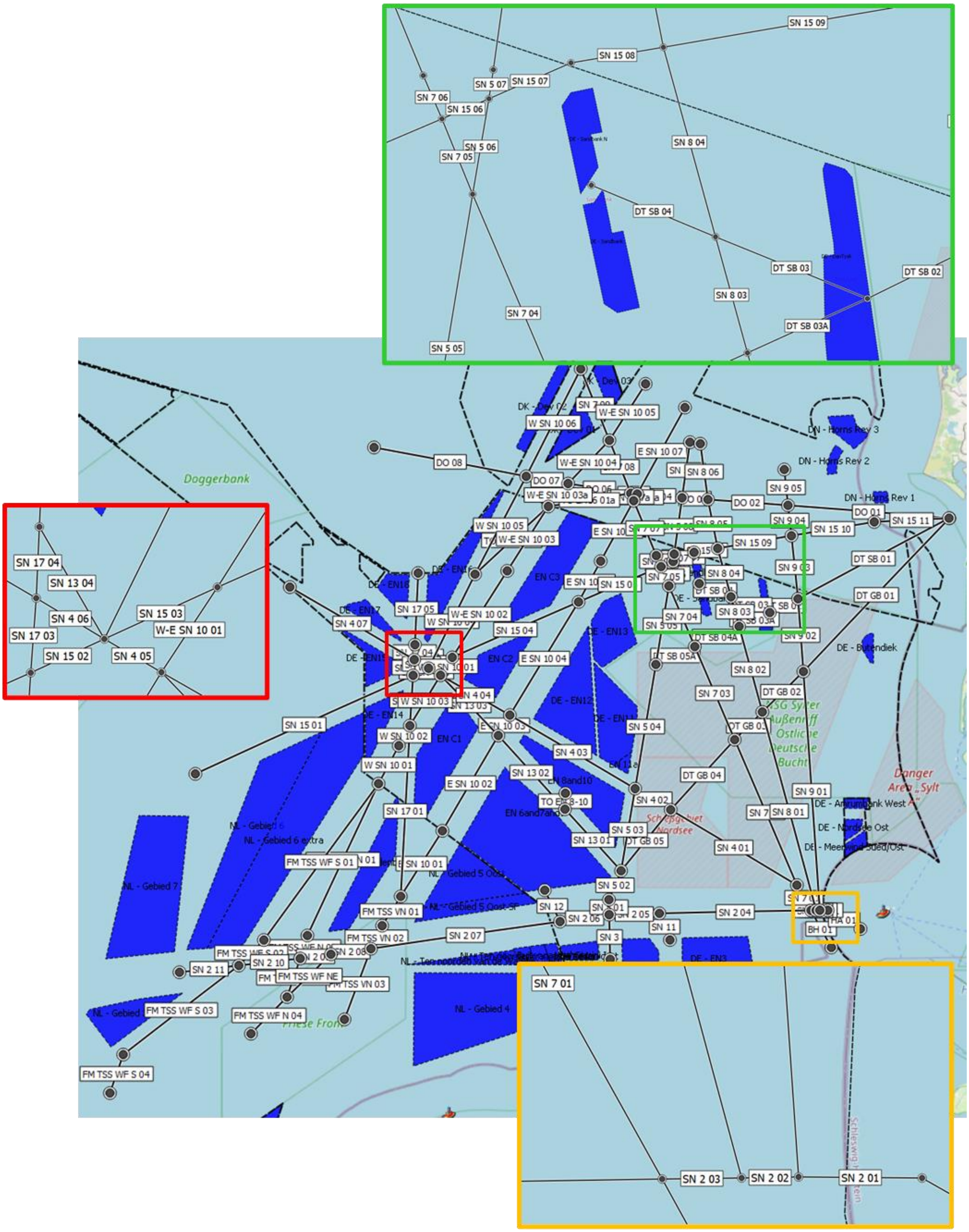
Map of model waypoints benchmark scenario



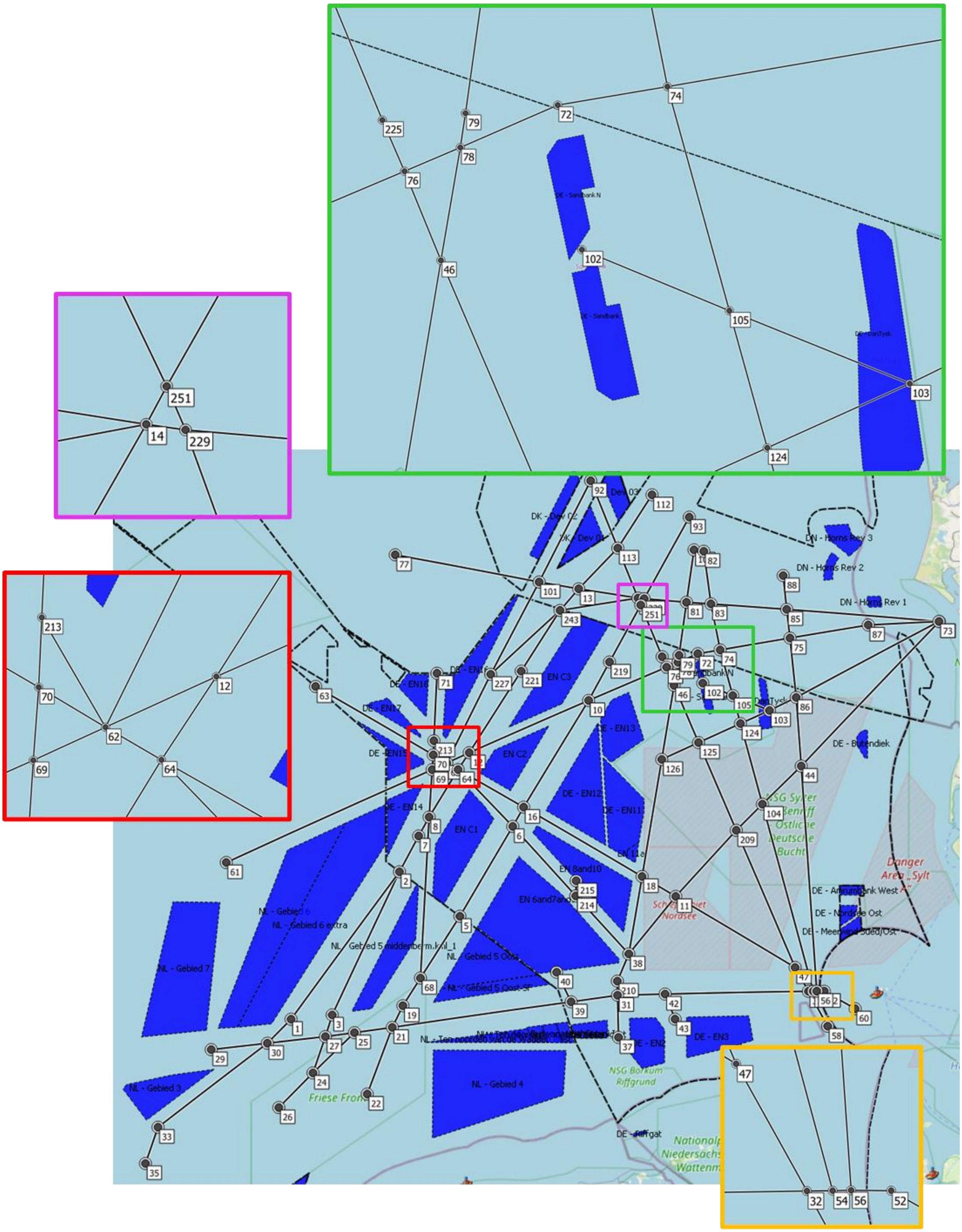
Map of model legs Scenario A1



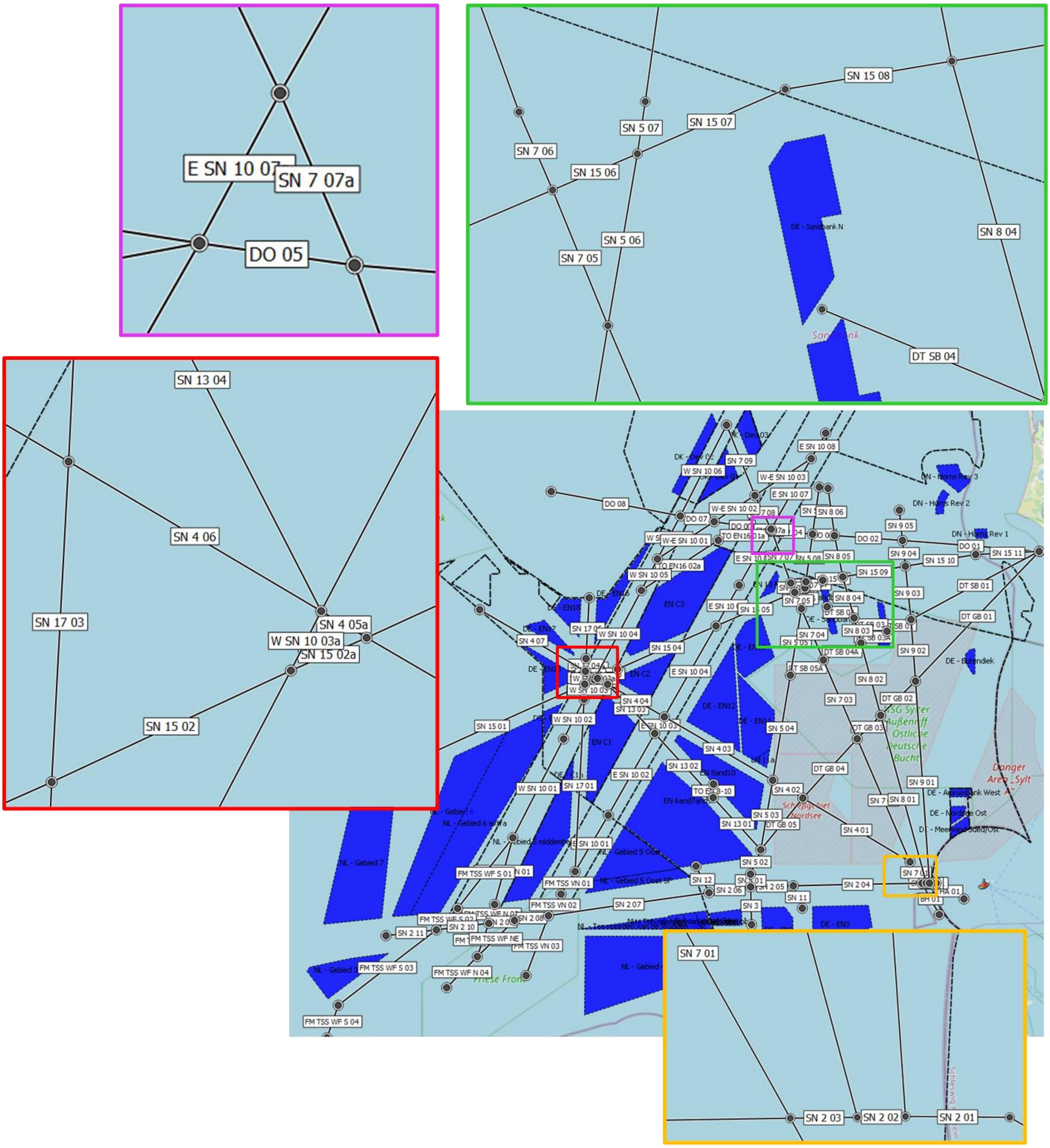
Map of model waypoints Scenario A1



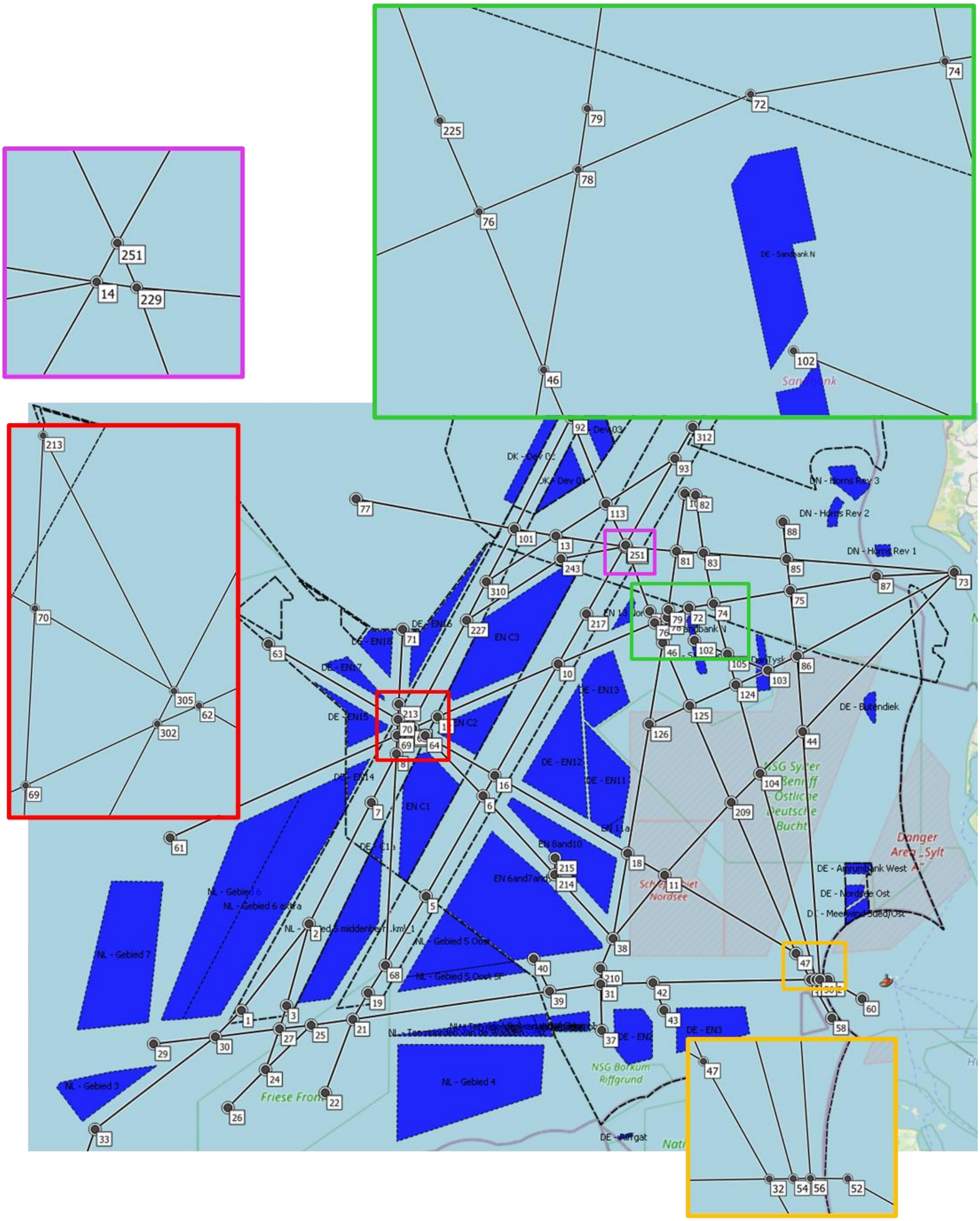
Map of model legs Scenario C



Map of model waypoints Scenario C



Map of model legs Scenario C_M2 and onward models

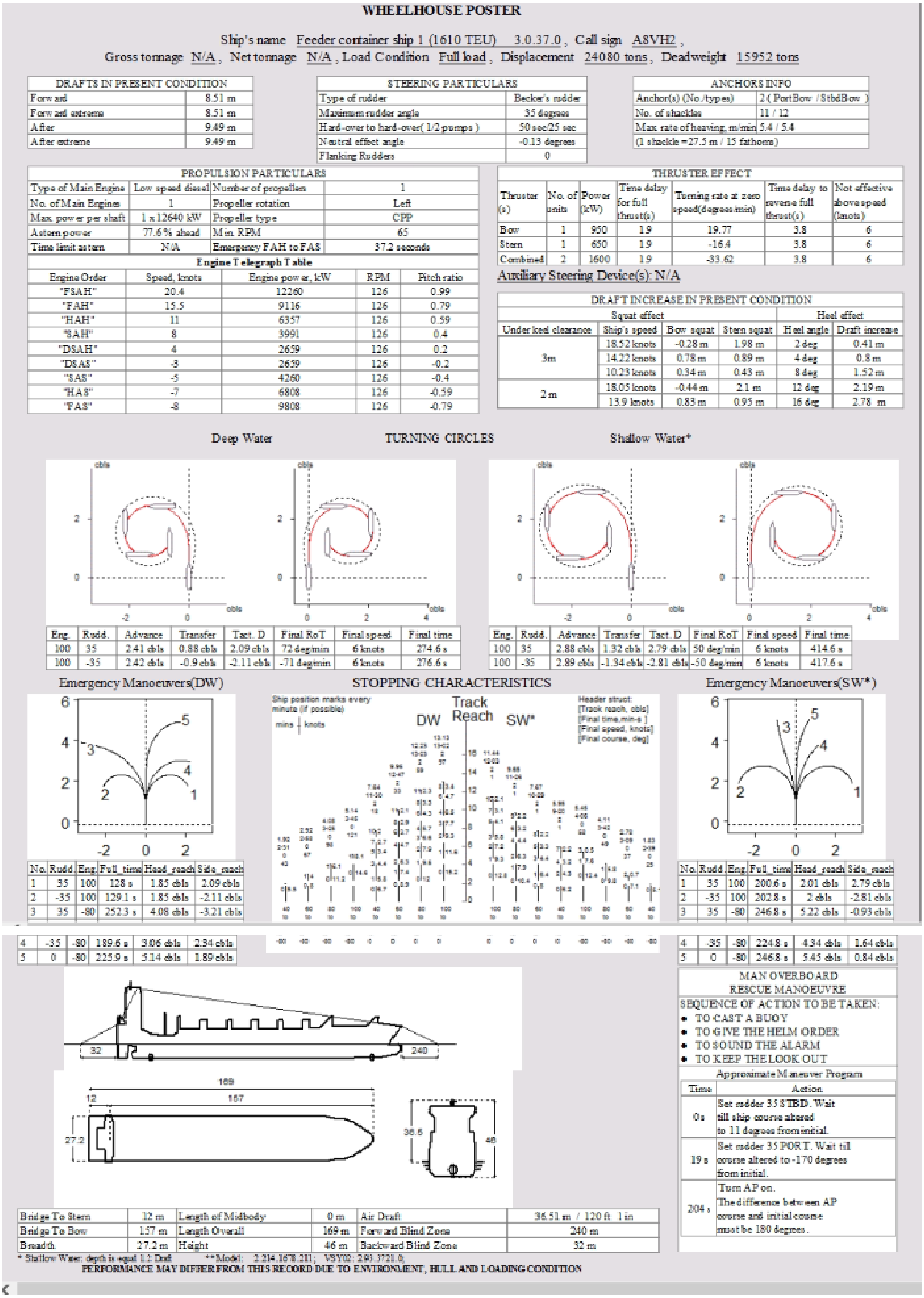


Map of model waypoints Scenario C_M2 and onward models

APPENDIX C

Wartsila Simulation – Own Ship Wheelhouse Posters

FEEDER CONTAINER SHIP (NORTH SCENARIO OS)



WHEELHOUSE POSTER

Ship's name Feeder container ship 1 (1610 TEU) 3.0.37.0 , Call sign A8VH2 ,
Gross tonnage N/A , Net tonnage N/A , Load Condition Full load , Displacement 24080 tons , Deadweight 15952 tons

DRAFTS IN PRESENT CONDITION	
Forward	8.51 m
Forward extreme	8.51 m
After	9.49 m
After extreme	9.49 m

STEERING PARTICULARS	
Type of rudder	Becker's rudder
Maximum rudder angle	35 degrees
Hard-over to hard-over(1/2 pumps)	50 sec/25 sec
Neutral effect angle	-0.13 degrees
Flanking Rudders	0

ANCHORS INFO	
Anchor(s) (No./types)	2 (PortBow / StbdBow)
No. of shackles	11 / 12
Max. rate of heaving, m/min	5.4 / 5.4
(1 shackle = 27.5 m / 15 fathoms)	

PROPULSION PARTICULARS			
Type of Main Engine	Low speed diesel	Number of propellers	1
No. of Main Engines	1	Propeller rotation	Left
Max. power per shaft	1 x 12640 kW	Propeller type	CPP
Astern power	77.6% ahead	Min. RPM	65
Time limit astern	N/A	Emergency FAH to FAS	37.2 seconds

Engine Telegraph Table

Engine Order	Speed, knots	Engine power, kW	RPM	Pitch ratio
"FSAH"	20.4	12260	126	0.99
"FAH"	15.5	9116	126	0.79
"HAH"	11	6357	126	0.59
"SAH"	8	3991	126	0.4
"DSAH"	4	2659	126	0.2
"DSAS"	-3	2659	126	-0.2
"SAS"	-5	4260	126	-0.4
"HAS"	-7	6808	126	-0.59
"FAS"	-8	9808	126	-0.79

THRUSTER EFFECT

Thruster (s)	No. of units	Power (kW)	Time delay for full thrust(s)	Turning rate at zero speed(degrees/min)	Time delay to reverse full thrust(s)	Not effective above speed (knots)
Bow	1	950	19	19.77	3.8	6
Stern	1	650	19	-16.4	3.8	6
Combined	2	1600	19	-33.62	3.8	6

Auxiliary Steering Device(s): N/A

DRAFT INCREASE IN PRESENT CONDITION

	Squat effect			Heel effect	
Under keel clearance	Ship's speed	Bow squat	Stern squat	Heel angle	Draft increase
3m	18.52 knots	-0.28 m	1.98 m	2 deg	0.41 m
	14.22 knots	0.78 m	0.89 m	4 deg	0.8 m
	10.23 knots	0.34 m	0.43 m	8 deg	1.52 m
2 m	18.05 knots	-0.44 m	2.1 m	12 deg	2.19 m
	13.9 knots	0.83 m	0.95 m	16 deg	2.78 m

Deep Water TURNING CIRCLES Shallow Water*

Eng.	Rudd.	Advance	Transfer	Tact. D	Final RoT	Final speed	Final time
100	35	2.41 cbls	0.88 cbls	2.09 cbls	72 deg/min	6 knots	274.6 s
100	-35	2.42 cbls	-0.9 cbls	-2.11 cbls	-71 deg/min	6 knots	276.6 s

Eng.	Rudd.	Advance	Transfer	Tact. D	Final RoT	Final speed	Final time
100	35	2.88 cbls	1.32 cbls	2.79 cbls	50 deg/min	6 knots	414.6 s
100	-35	2.89 cbls	-1.34 cbls	-2.81 cbls	-50 deg/min	6 knots	417.6 s

Emergency Manoeuvers(DW) STOPPING CHARACTERISTICS Emergency Manoeuvers(SW*)

No.	Rudd.	Eng.	Full_time	Head_reach	Side_reach
1	35	100	128 s	1.85 cbls	2.09 cbls
2	-35	100	129.1 s	1.85 cbls	-2.11 cbls
3	35	-80	252.3 s	4.08 cbls	-3.21 cbls
4	-35	-80	189.6 s	3.06 cbls	2.34 cbls
5	0	-80	225.9 s	5.14 cbls	1.89 cbls

No.	Rudd.	Eng.	Full_time	Head_reach	Side_reach
1	35	100	200.6 s	2.01 cbls	2.79 cbls
2	-35	100	202.8 s	2 cbls	-2.81 cbls
3	35	-80	246.8 s	5.22 cbls	-0.93 cbls
4	-35	-80	224.8 s	4.34 cbls	1.64 cbls
5	0	-80	246.8 s	5.45 cbls	0.84 cbls

MAN OVERBOARD
RESCUE MANOEUVRE

SEQUENCE OF ACTION TO BE TAKEN:
- TO CAST A BUOY
- TO GIVE THE HELM ORDER
- TO SOUND THE ALARM
- TO KEEP THE LOOK OUT

Approximate Maneuver Program

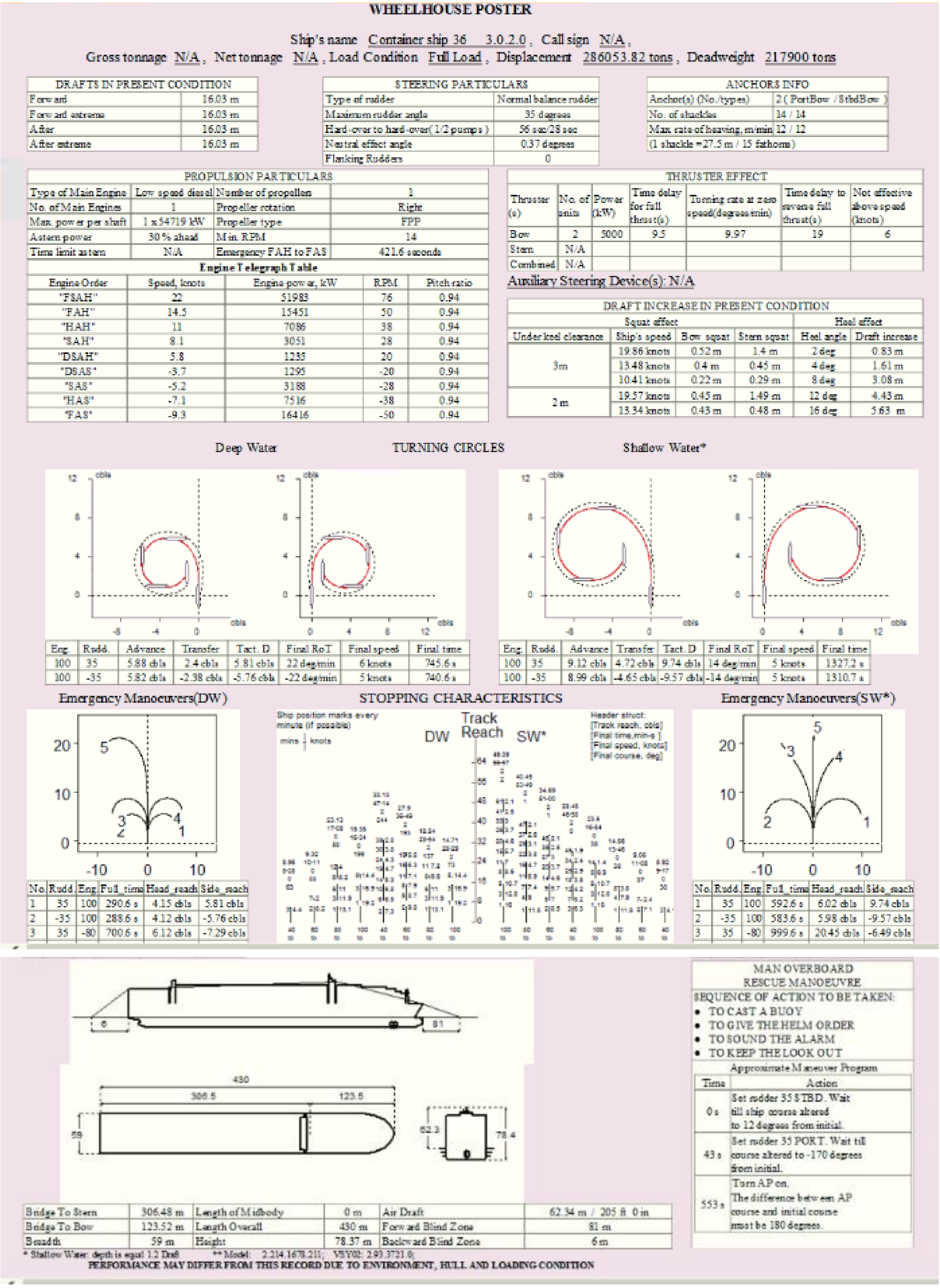
Time	Action
0 s	Set rudder 35 STBD. Wait till ship course altered to 11 degrees from initial.
19 s	Set rudder 35 PORT. Wait till course altered to -170 degrees from initial.
204 s	Turn AP on. The difference between AP course and initial course must be 180 degrees.

Bridge To Stern	12 m	Length of Midbody	0 m	Air Draft	36.51 m / 120 ft 1 in
Bridge To Bow	157 m	Length Overall	169 m	Forward Blind Zone	240 m
Breadth	27.2 m	Height	46 m	Backward Blind Zone	32 m

* Shallow Water: depth is equal 1.2 Draft ** Model: 2.214.1678.211; VSY02: 2.93.3721.0;

PERFORMANCE MAY DIFFER FROM THIS RECORD DUE TO ENVIRONMENT, HULL AND LOADING CONDITION

ULTRA LARGE CONTAINER CARRIER (WEST SCENARIO OS)



WHEELHOUSE POSTER

Ship's name Container ship 36 3.0.2.0, Call sign N/A,
Gross tonnage N/A, Net tonnage N/A, Load Condition Full Load, Displacement 286053.82 tons, Deadweight 217900 tons

DRAFTS IN PRESENT CONDITION	
Forward	16.03 m
Forward extreme	16.03 m
After	16.03 m
After extreme	16.03 m

STEERING PARTICULARS	
Type of rudder	Normal balance rudder
Maximum rudder angle	35 degrees
Hard-over to hard-over(1/2 pumps)	56 sec/28 sec
Neutral effect angle	0.37 degrees
Flanking Rudders	0

ANCHORS INFO	
Anchor(s) (No./types)	2 (PortBow / StbdBow)
No. of shackles	14 / 14
Max rate of heaving, m/min	12 / 12
(1 shackle =27.5 m / 15 fathoms)	

PROPULSION PARTICULARS			
Type of Main Engine	Low speed diesel	Number of propellers	1
No. of Main Engines	1	Propeller rotation	Right
Max. power per shaft	1 x 54719 kW	Propeller type	FPP
Astern power	30 % ahead	Min. RPM	14
Time limit astern	N/A	Emergency FAH to FAS	421.6 seconds

Engine Telegraph Table

Engine Order	Speed, knots	Engine power, kW	RPM	Pitch ratio
"FSAH"	22	51983	76	0.94
"FAH"	14.5	15451	50	0.94
"HAH"	11	7086	38	0.94
"SAH"	8.1	3051	28	0.94
"DSAH"	5.8	1235	20	0.94
"DSAS"	-3.7	1295	-20	0.94
"SAS"	-5.2	3188	-28	0.94
"HAS"	-7.1	7516	-38	0.94
"FAS"	-9.3	16416	-50	0.94

THRUSTER EFFECT						
Thruster (s)	No. of units	Power (kW)	Time delay for full thrust(s)	Turning rate at zero speed(degrees/min)	Time delay to reverse full thrust(s)	Not effective above speed (knots)
Bow	2	5000	9.5	9.97	19	6
Stern	N/A					
Combined	N/A					

Auxiliary Steering Device(s): N/A

DRAFT INCREASE IN PRESENT CONDITION					
Squat effect				Heel effect	
Under keel clearance	Ship's speed	Bow squat	Stern squat	Heel angle	Draft increase
3m	19.86 knots	0.52 m	1.4 m	2 deg	0.83 m
	13.48 knots	0.4 m	0.45 m	4 deg	1.61 m
	10.41 knots	0.22 m	0.29 m	8 deg	3.08 m
2 m	19.57 knots	0.45 m	1.49 m	12 deg	4.43 m
	13.34 knots	0.43 m	0.48 m	16 deg	5.63 m

Deep Water TURNING CIRCLES Shallow Water*

Deep Water:

Eng.	Rudd.	Advance	Transfer	Tact. D	Final RoT	Final speed	Final time
100	35	5.88 cbls	2.4 cbls	5.81 cbls	22 deg/min	6 knots	745.6 s
100	-35	5.82 cbls	-2.38 cbls	-5.76 cbls	-22 deg/min	5 knots	740.6 s

Shallow Water*:

Eng.	Rudd.	Advance	Transfer	Tact. D	Final RoT	Final speed	Final time
100	35	9.12 cbls	4.72 cbls	9.74 cbls	14 deg/min	5 knots	1327.2 s
100	-35	8.99 cbls	-4.65 cbls	-9.57 cbls	-14 deg/min	5 knots	1310.7 s

Emergency Manoeuvers(DW) STOPPING CHARACTERISTICS Emergency Manoeuvers(SW*)

Emergency Manoeuvers(DW):

No.	Rudd.	Eng.	Full_time	Head_reach	Side_reach
1	35	100	290.6 s	4.15 cbls	5.81 cbls
2	-35	100	288.6 s	4.12 cbls	-5.76 cbls
3	35	-80	700.6 s	6.12 cbls	-7.29 cbls

Emergency Manoeuvers(SW*):

No.	Rudd.	Eng.	Full_time	Head_reach	Side_reach
1	35	100	592.6 s	6.02 cbls	9.74 cbls
2	-35	100	583.6 s	5.98 cbls	-9.57 cbls
3	35	-80	999.6 s	20.45 cbls	-6.49 cbls

MAN OVERBOARD
RESCUE MANOEUVRE

SEQUENCE OF ACTION TO BE TAKEN:

- TO CAST A BUOY
- TO GIVE THE HELM ORDER
- TO SOUND THE ALARM
- TO KEEP THE LOOK OUT

Approximate Maneuver Program

Time	Action
0 s	Set rudder 35 STBD. Wait till ship course altered to 12 degrees from initial.
43 s	Set rudder 35 PORT. Wait till course altered to -170 degrees from initial.
553 s	Turn AP on. The difference between AP course and initial course must be 180 degrees.

Bridge To Stern	306.48 m	Length of Midbody	0 m	Air Draft	62.34 m / 205 ft 0 in
Bridge To Bow	123.52 m	Length Overall	430 m	Forward Blind Zone	81 m
Breadth	59 m	Height	78.37 m	Backward Blind Zone	6 m

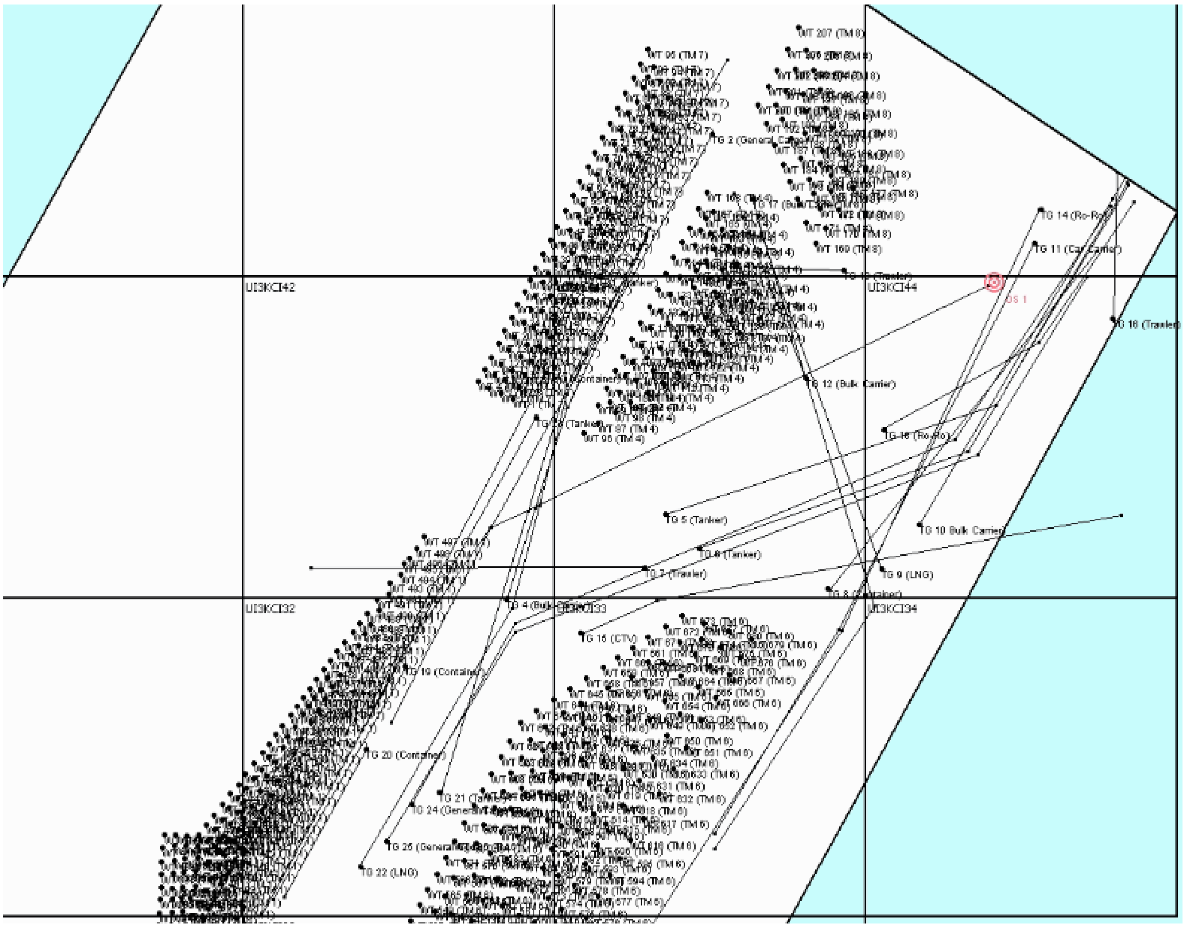
* Shallow Water: depth is equal 1.2 Draft ** Model: 2.214.1678.211; VSY02: 2.93.3721.0;

PERFORMANCE MAY DIFFER FROM THIS RECORD DUE TO ENVIRONMENT, HULL AND LOADING CONDITION

APPENDIX D

Wartsila Simulation – Vessel Tracks

North Scenario tracks



West Scenario tracks