BE AWARE

Bonn Agreement
Accord de Bonn

Technical Sub Report 1: Ship Traffic

Bonn Agreement
Accord de Bonn

Co-financed by the EU –
Civil Protection Financial Instrument

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The Greater North Sea and its wider approaches is one of the busiest and most highly used maritime areas in the world. With the ever-increasing competition for space comes an increased risk of accidents that could result in marine pollution.

Currently the area has no overall risk assessment for marine pollution; risk is mapped with a variety of national risk assessments which are undertaken with differing methodologies; thus reducing comparability.

The BE-AWARE project is therefore undertaking the first area-wide risk assessment of marine pollution using a common methodology that allows the risk to be mapped and compared under different scenarios.

The project outcomes will improve disaster prevention by allowing North Sea States to better focus their resources on areas of high risk.

The project is a two year initiative (2012-2014), co-financed by the European Union, with participation and support from the Bonn Agreement Secretariat, Belgium, Denmark and the Netherlands, with co-financing from Norway.

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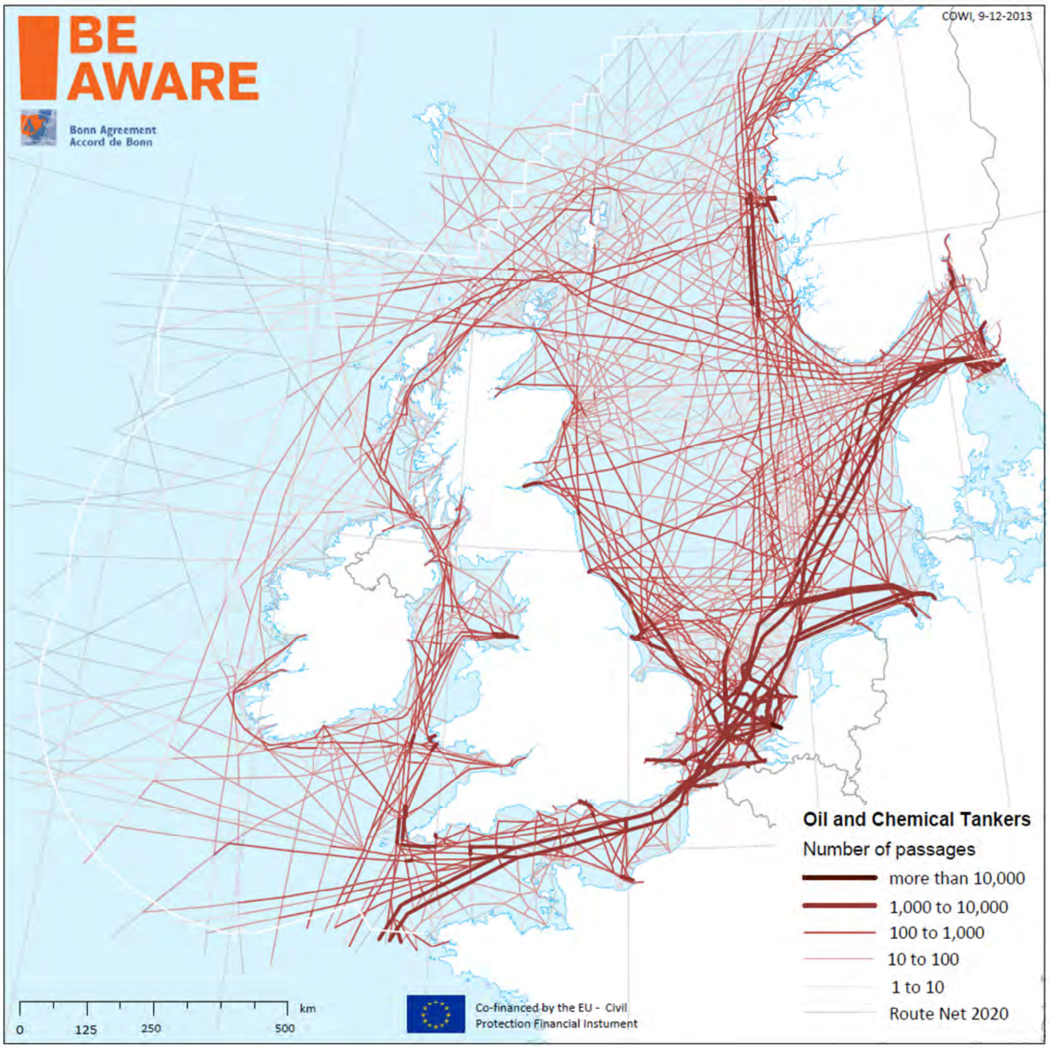
Executive Summary

This report describes the ship traffic model developed by the BE-AWARE project. The ship traffic model is based on an analysis of AIS data from the period 1 January 2011 to 31 December 2011. Based on the intensity of ship traffic, a route net is developed that describes the primary sailing routes. The movement of all vessels, received in the form of AIS data, have then been applied to calculate the number of vessels on the individual routes. By using the actual positions of each vessel the transverse distribution of the traffic on each route leg is calculated. The output database contains information about the vessels on each route leg (type, size, etc.) as well as information about the specific distribution parameters of each route leg. A graphical representation of the movement of oil and chemical tankers along the route net is given below.



The World Shipping Encyclopaedia (WSE) issued by IHS Fairplay has been used to extract information about the individual vessels' characteristics such as type, size, hull specifications etc. The traffic model database is a result of combining the vessel specific information with the movements of all vessels. This model can be used both to calculate the probability of ship-ship collisions and other accidents and as a basis for estimating the consequences of an accident based on the vessels' characteristics.

1. Introduction

1.1 Scope

This report is based on the methodology outlined in the BE-AWARE Method Note and the data collected from Bonn Agreement Contracting Parties. Its aim is to implement the chosen methodology, i.e. to process the collected data and to prepare the computational tools for use the subsequent risk assessment.

The traffic model used was developed earlier for the risk assessment of oil spills in Danish waters and later modified during the BRISK project.

The present Technical Sub-report 1 deals with the ship traffic model. As decided in the Method Note, only ships of 300 gross tonnage or more are considered in the model. Apart from the limited spill potential of smaller ships, this decision is also linked to the availability of vessel traffic data via AIS (Automatic Identification System). AIS data are only sporadically available for smaller ships which are not covered by SOLAS' requirement to carry an AIS device on board.

2. Ship traffic data

2.1 Basic

The AIS database operated by the Danish Maritime Authority (DMA) is the primary data source for establishing the traffic model. It records AIS messages from all AIS-equipped vessels in the wider Bonn Agreement area in six-minute intervals. Data are required for a 365-day period in order to eliminate seasonal differences and in order to provide statistically significant amounts of data. A period lasting from 1 January to 31 December 2011 is chosen as reference period, since 2011 was the latest complete calendar year before the BE-AWARE project was initiated in early 2012.

The World Shipping Encyclopaedia (WSE) issued by IHS Fairplay is a database containing information on a large number of parameters. Since every vessel has a unique IMO number, which is both used in WSE and for AIS, it is possible to determine relevant vessel characteristics for the vessels recorded in the AIS database (type, size, geometry, single or double hull etc.).

The WSE has earlier been known as Lloyd's Register, i.e. prior to its purchase by IHS Fairplay.

3. AIS analysis

3.1 Basics

The AIS messages sent by the vessels consist of position reports (POS) and static reports (STAT), as described in Recommendation ITU-T M. 1371-1 issued by the International Telecommunication Union (ITU).

POS reports

POS reports are sent approximately every two seconds and contain information on vessel position, course, speed etc. In these reports, the ship is identified by its MMSI number.

STAT reports

STAT reports are sent every six minutes and contain information about the ship itself, amongst others MMSI and IMO number, name, call sign, size, actual draught, category of potentially hazardous cargo and the position of the AIS transmitter relative to the ship.

It has generally been observed that AIS reports where vessels are supposed to enter data themselves are not always reliable. Information that needs to be updated by the crew (cargo, actual draught, destination etc.) is therefore not necessarily valid, whereas automatically updated information (position, course, speed) can be expected to be more reliable.

3.2 Ship identification

AIS data have been delivered by Farvandsvæsenet (Danish Maritime Safety Administration) in the form of 12 text files (345 GB). We received data as one dataset which means that POS reports have been combined with STAT reports. In general the AIS records for a particular ship should be stored at 6 minute intervals, which turned out not always to be the case. We received more than 858 million AIS records. Due to the size of the database no filtering on raw AIS was performed. We identified ships by extracting distinct MMSI numbers from AIS dataset (48,151). Following that, ship types and sizes were identified either by combining them with the IHS database using the IMO number or in cases where the information from IHS was not available, by using properties extracted directly from AIS. 19,785 MMSI numbers belonged to ships with well-defined ship type and larger than 300 GT and 4,792 MMSI numbers belonged to ships with unknown ship type but which were most probably larger than 300 GT. This identification of ships is necessary since the traffic model takes into account only ships larger than 300 GT and sailing within the BE-AWARE area (see insert in Figure 3-2). The daily variation in the number of AIS reports received from vessels larger than 300 GT is presented in Figure 3-1. The daily variation in the number of AIS reports within regions is presented in Figure 3-2.

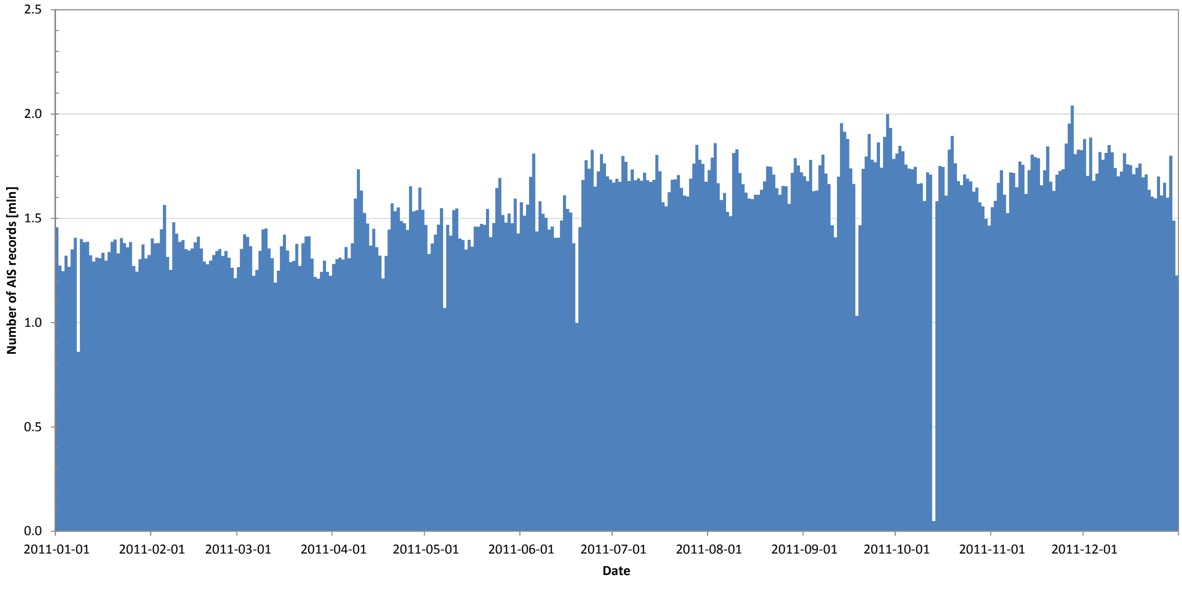


Figure 3-1 Variation in number of daily AIS reports in the period 1 January 2011-31 December 2011

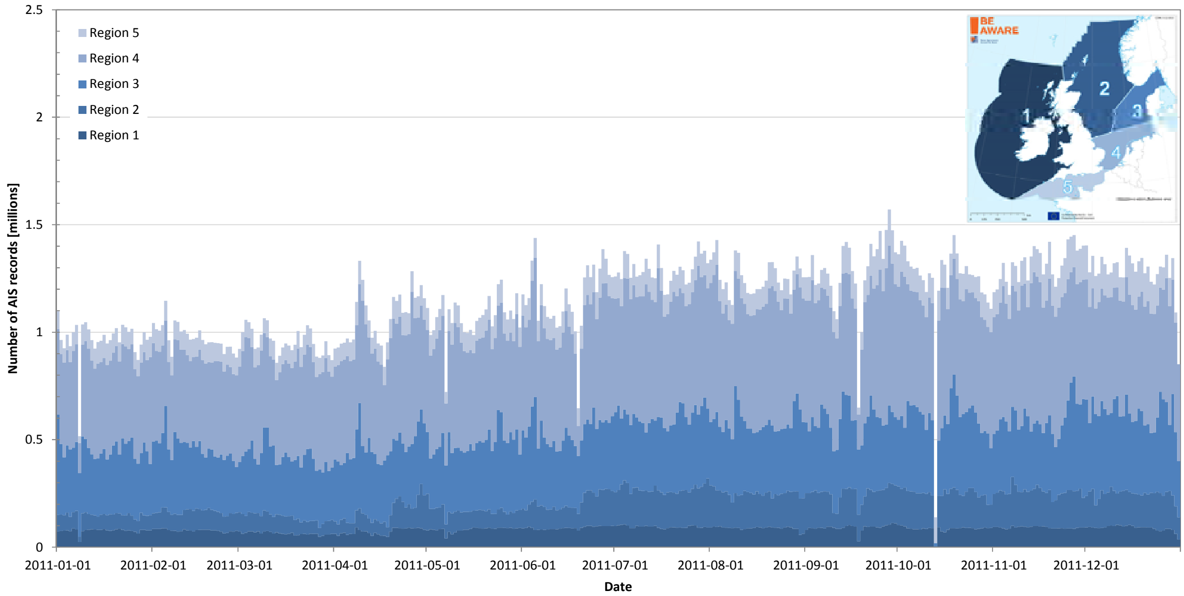


Figure 3-2 Variation in number of daily AIS reports within regions in the period 1 January 2011 – 31 December 2011

3.3 Traffic intensity

As a basis for further analysis, it is necessary to determine the resulting traffic intensity for the entire BE-AWARE project area. As well as confirming that the data processing was correct, the traffic intensity results should be suitable to serve as a decision basis for the generation of the routes and the following data analysis (Section 3.4).

The intensity is determined by following the trace of a specific vessel – longitude, latitude – and registering its path across a predefined quadratic grid. This approach is implemented by simply rounding the trace coordinates to the nearest multiples of the cell length Δlong and Δlatt in the grid net (see Figure 3-3).

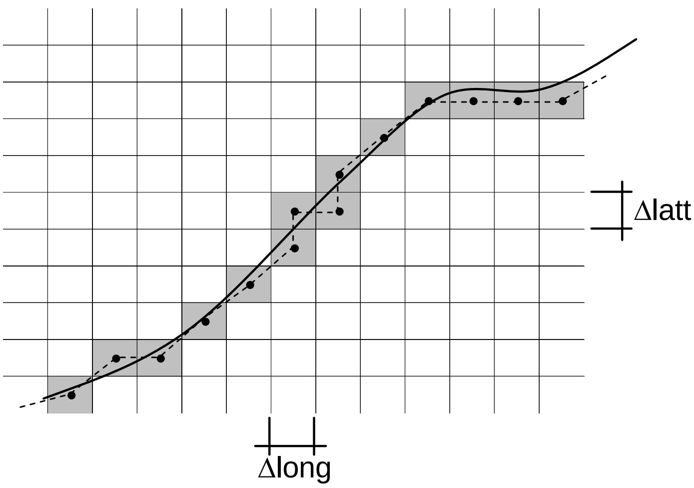


Figure 3-3 Digitalisation of a vessel's trace for determining the traffic intensity

Since the BE-AWARE project area lies between latitudes 48° N and 64° N a constant value of Δlong would mean a distorted grid of cells. Therefore, Δlong is made a function of latitude. In this way a cell size of approximately 500 m x 500 m has been achieved in the whole project area. More than 5 million cells have been defined to cover the BE-AWARE project area.

Each AIS record can be assigned to a single cell in the grid and counted afterwards. The counting of AIS records per cell has been performed, but the counts per cell cannot be directly translated into the number of passages populating the route (considering constant sampling rate and vessels with different velocities then the distance between sequential AIS records is different, therefore number of "footprints" per length is different for those vessels).

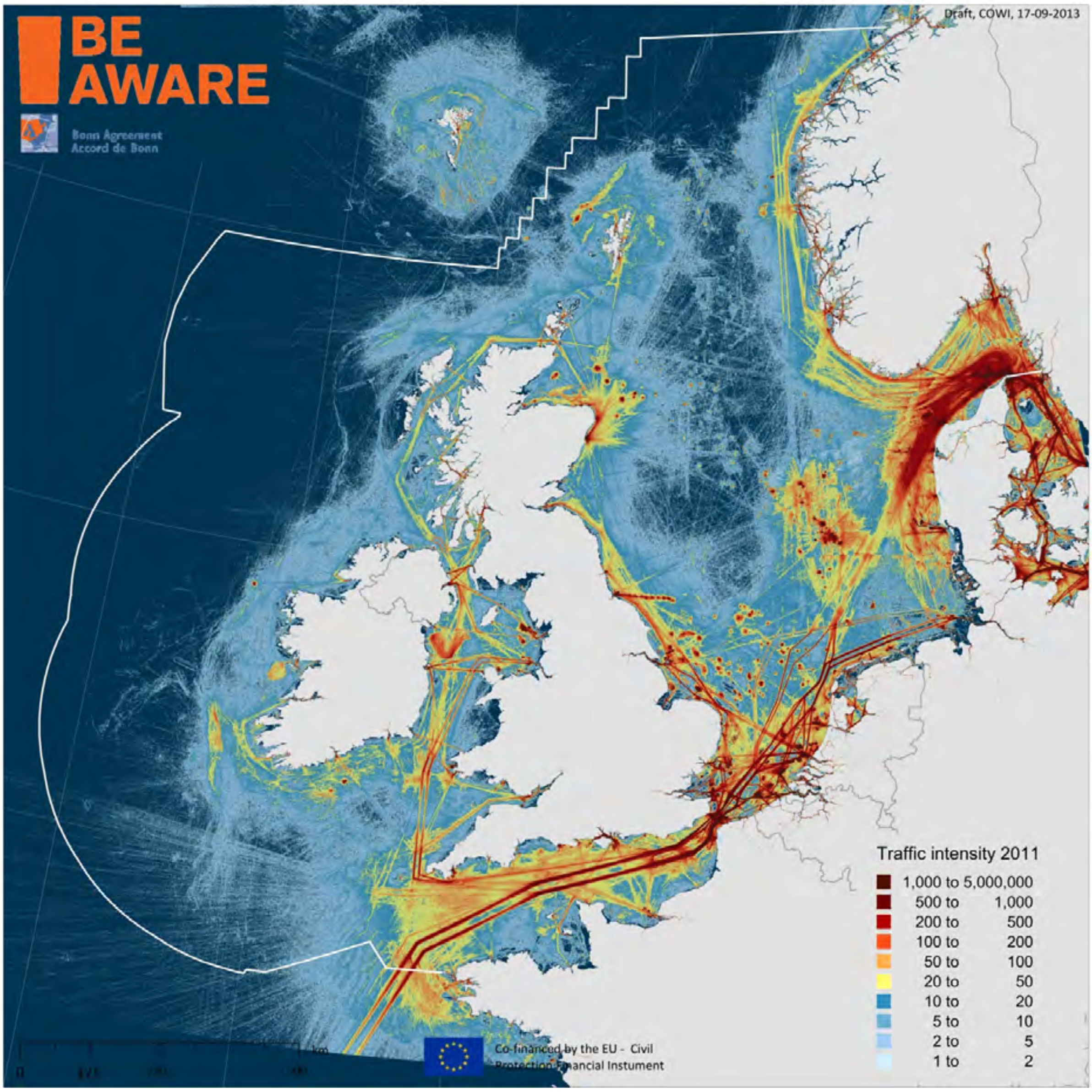


Figure 3-4 Map of traffic intensity based on counted number of AIS records per cell (due to higher sampling rate around Denmark coloured scale in that area has been adjusted to match the rest of BE-AWARE area).

Figure 3-4 shows the map of the "raw" (all received AIS records) traffic intensity for the whole BE-AWARE area based on the number of AIS records in the cells of size approx. 500m x 500m. The colour scale is not linear and therefore all traffic routes and not just the most trafficked routes are visible. It is clearly seen in the figure that the coverage varies quite significantly over the project area. This variation has been taken into consideration in the development of the idealised traffic model.

One can easily notice that the traffic has a tendency to concentrate along routes. This is particularly noticeable in narrow navigation channels such as sounds (ex. Saint George’s Channel) or in areas with existing traffic separation schemes (ex. Dover Strait TSS). However, there is a general tendency to follow distinct routes since vessels always follow the most direct route possible between two destinations and since the number of relevant destinations is limited. One can also notice areas where the traffic intensity seems to diminish which can happen in areas a long distance from shore where some of the transmitted radio AIS reports are missing or not correctly recorded (ex. centre of North Sea). Although main routes can easily be identified in Figure 3-4, creation of a whole route net on this basis would be very difficult. Different types of ship such as merchant and offshore vessels have different sailing patterns and the contributions from different ship types cannot easily be distinguished. Therefore separated maps for merchant and offshore vessels have been prepared and are presented in Figure 3-5 and Figure 3-6 respectively. Separation between merchant and offshore traffic results in maps with much clearer traffic patterns. Also less populated routes are easily distinguishable now. One can also notice that the traffic pattern of offshore vessels differs dramatically from traffic pattern of merchant ships.

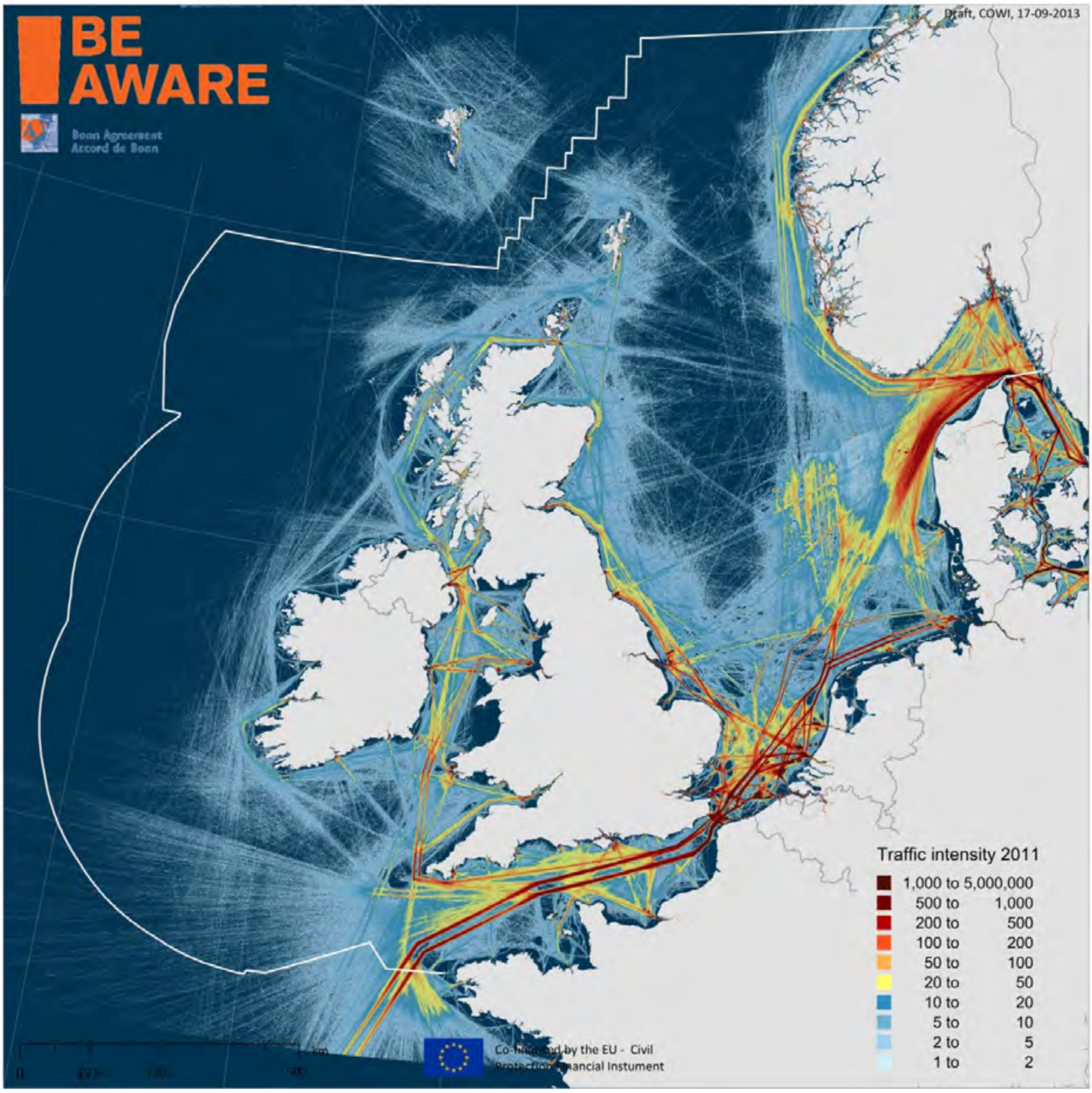


Figure 3-5 Merchant ship traffic intensity based on counted number of AIS records per cell. (Due to a higher sampling rate around Denmark the coloured scale in that area has been adjusted to match the rest of BE-AWARE area).

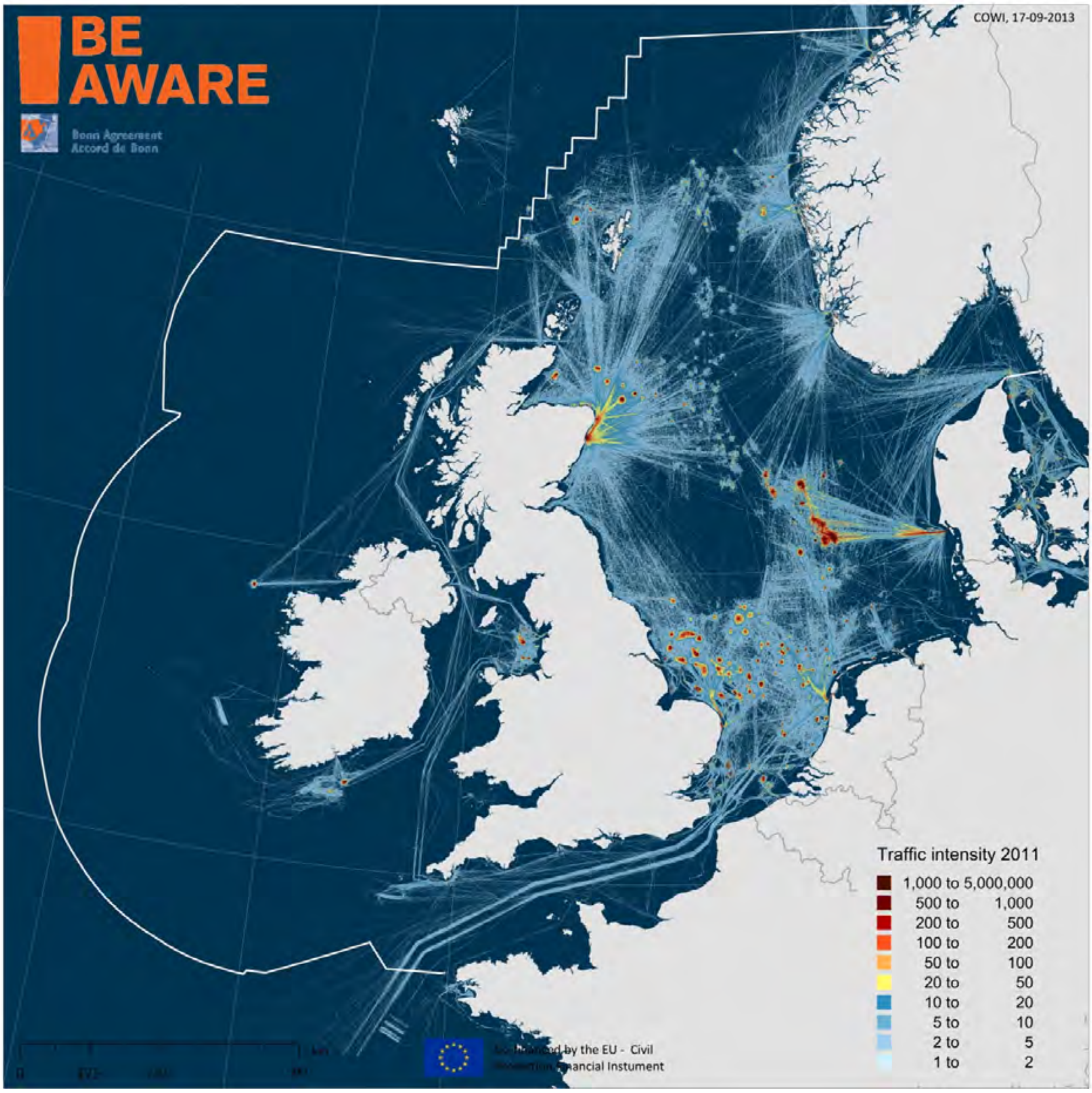


Figure 3-6 Offshore vessel traffic intensity based on counted number of AIS records per cell

It should be emphasized again that intensity maps are only serving as a background enabling creation of idealised route net that can represent the vessel traffic.

3.4 Route net generation and analysis

The applied method for modelling ship collision risk requires that the ship traffic is modelled in a reasonable manner. The tendency of traffic to concentrate along routes indicates that a populated route net could be a representative approximation of the sea traffic. Even the fact that the traffic on some routes is spread loosely to either side of the route axis does not present any conceptual problems.

Route generation and analysis means:

- definition of a geographic route net which can represent the vessel's movements in the BE-AWARE area with good precision;
- mathematical analysis of the route net, i.e. to determine the shortest possible paths through the net between any two locations;

- mapping of the AIS trace, i.e. to associate each AIS point with a route net segment;
- determination of various relevant statistics for each route segment, e.g. the distribution of the vessels' deviation from the route segment axis.

This work is done manually by creating a route net on a series of background maps consisting of intensity plots and sea charts. The route net has to accommodate all the traffic patterns of all ship types. This work is performed in a GIS programme (MapInfo 11.5). Once the route net has been defined, its geometry is exported to SQL and Excel for further analysis and to check its consistency (all route ends meeting at one node shall have the same coordinates).

The final route net used in the analysis is shown in Figure 3-7. The route net consists of two types of elements:

- nodes (defined by their longitude and latitude)
- route segments connecting the nodes.

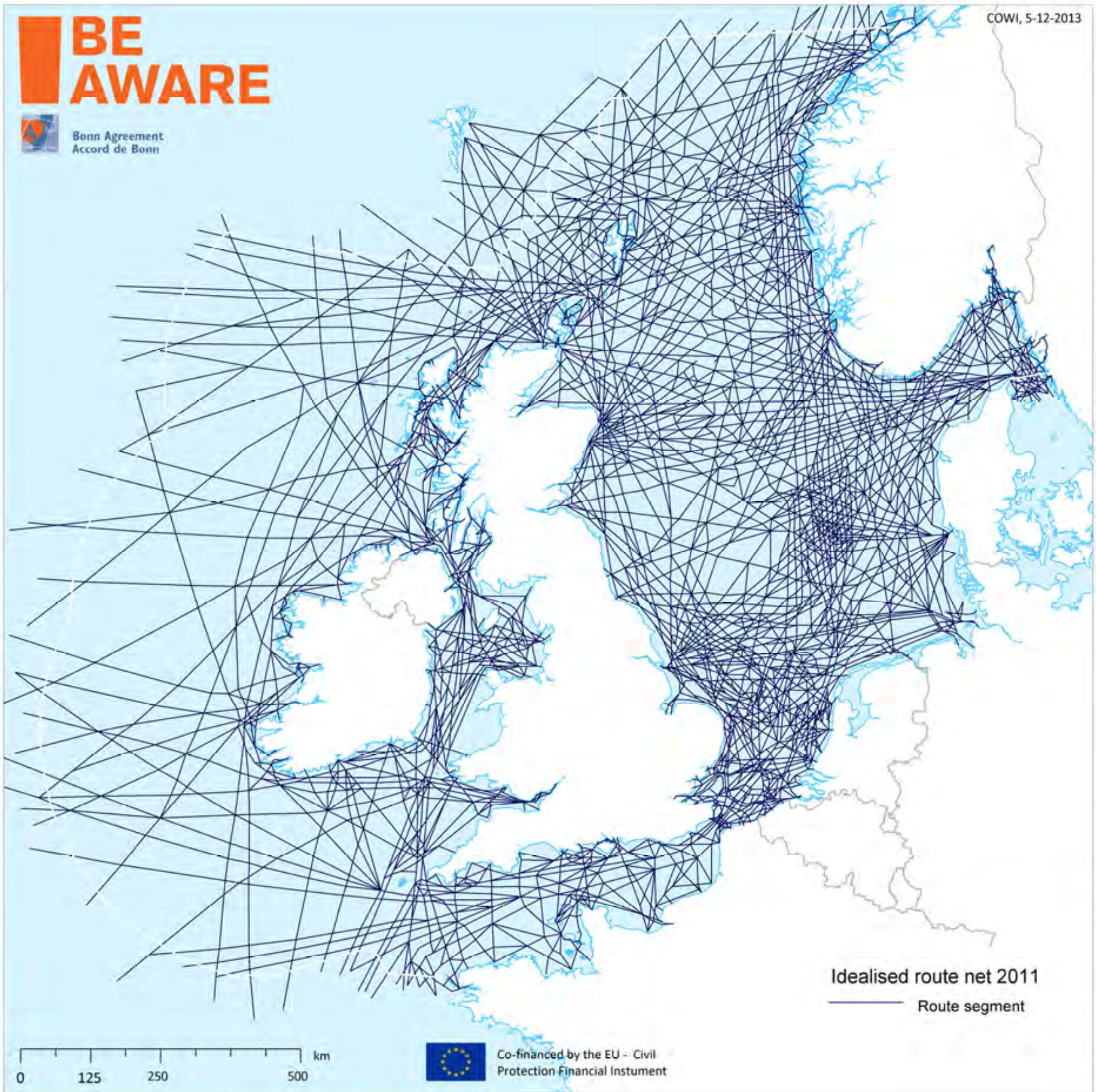


Figure 3-7 Defined route net used in the analysis of AIS records; the white line is the analysis boundary.

The route net goes beyond the geographical boundary (the white line in Figure 3-7) of the analysis area and this allows the mapping of the AIS traces to start outside the analysis area. In this way it is possible to avoid boundary problems with mapping of AIS traces inside the analysis area. The mapping therefore should be more reliable. In general, the route net is more detailed in areas with heavy traffic than in other areas.

Figure 3-8 Example of enumerated route segments and nodes; English Channel between Cotentin peninsula (France) and south coast of England (UK).

The route net defines different possible ways to travel through the sea area and the concept of "the shortest way" between two nodes in the route net is a useful support function for associating the AIS points to route segments.

The shortest way between two nodes is determined by means of a simple iterative algorithm based on Markov network logic. The results are deposited in two separate matrixes which are created for the particular route net. The two matrixes are:

- *NN(i,j)* matrix specifies that the shortest route from node *i* to node *j* starts by going from node *i* to *NN(i,j)*
- *ML(i,j)* matrix contains the length of the shortest route from node *i* to node *j*

Representation of the vessel's passage through the route net consists of a list of used route segments. Therefore representation can be stored as a table with the sequence of route segments:

TrackNo	**IMO**	**Time**	**RouteNo**
…	…	…	…
737984	9164835	2011-07-09 01:49:17	-4286
737984	9164835	2011-07-09 03:03:53	698
737984	9164835	2011-07-09 03:35:14	700
737984	9164835	2011-07-09 04:31:12	4298
737984	9164835	2011-07-09 05:10:11	694
737984	9164835	2011-07-09 06:12:27	691
…	…	…	…

Adding a sign in front of the route segment is a simple way of marking the passage direction.

Based on the description above it is possible to map the individual AIS traces systematically. As a first step, a definition needs to be drawn up of when a trace, i.e. a sequence of AIS points, can be concluded to represent a coherent journey. This definition needs to take into account the possibility of data transmission interruptions (see Figure 3-9). It would simplify the mapping procedure significantly to omit missing sequences. However, this would result in a systematic underestimation of the traffic in certain areas, if e.g. one local coastal station had been out of order for a period of time. Furthermore, information about the total journey and its origin and destination would be lost.

Therefore, the mapping procedure is refined in order to handle interrupted traces and to interpolate the missing sections. When an individual trace is identified, the following conditions are applied:

- The time difference between two successive AIS points must not exceed 12 hours;
- An approximate vessel speed (vappr) is calculated as the distance between two points divided by the time difference between the two messages. The two points are considered as part of the same trace if:

  vappr > 0 knots (the ship is not immobile)

  vappr is finite (i.e. not very large, which would indicate an unrealistic jump and therefore an error)

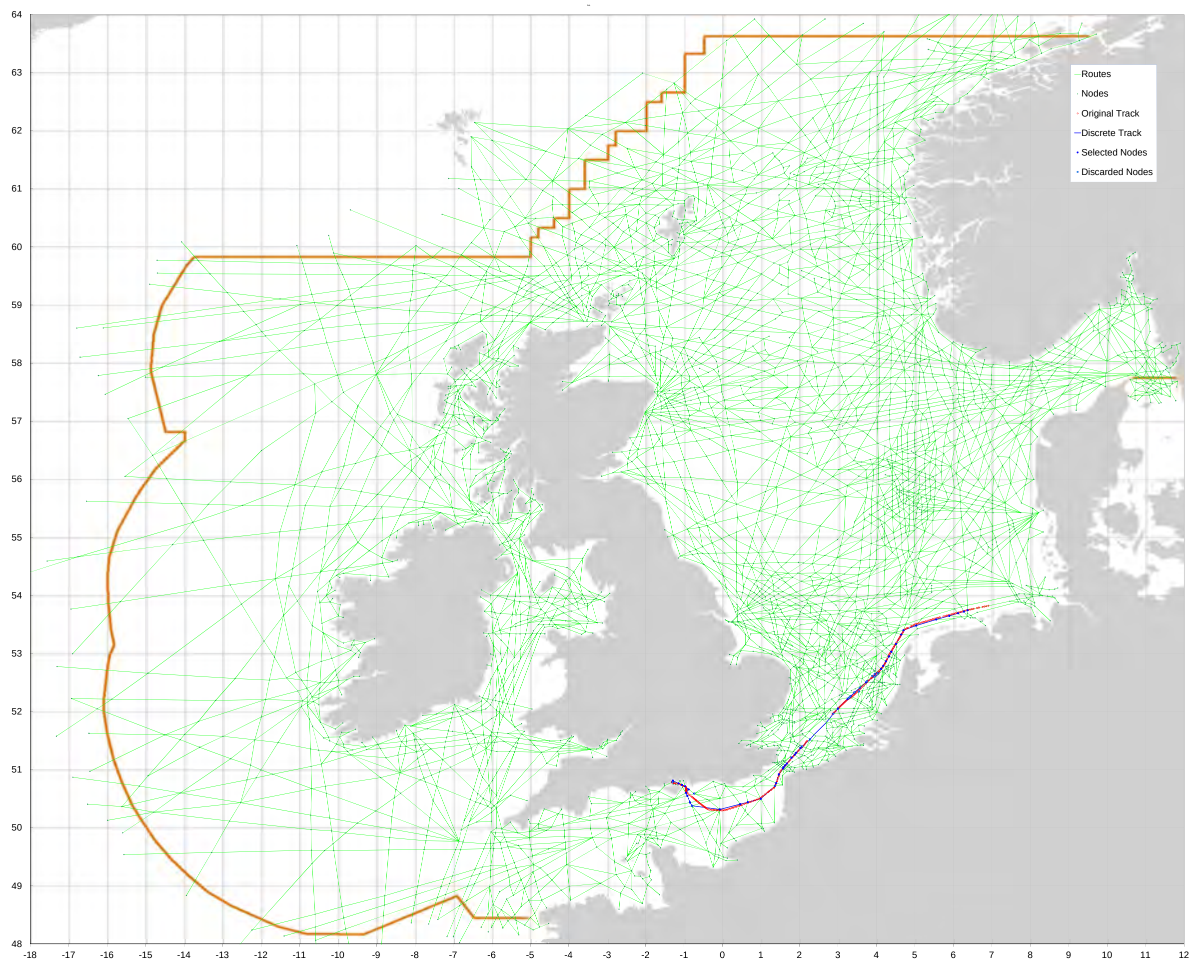


Figure 3-9 Example of the AIS points with clear dropout of AIS reports together with identified track.

With these conditions, the most significant errors are filtered away and the trace is interrupted if the vessel stops. The latter is chosen in order to obtain two separate traces for a vessel lying in a port or at anchor.

When a sequence of AIS points has been recognized as a continuous trace (as shown in Figure 3-9), an algorithm regards the point sequence and determines which nodes are passed at the closest distance (see Figure 3-10).

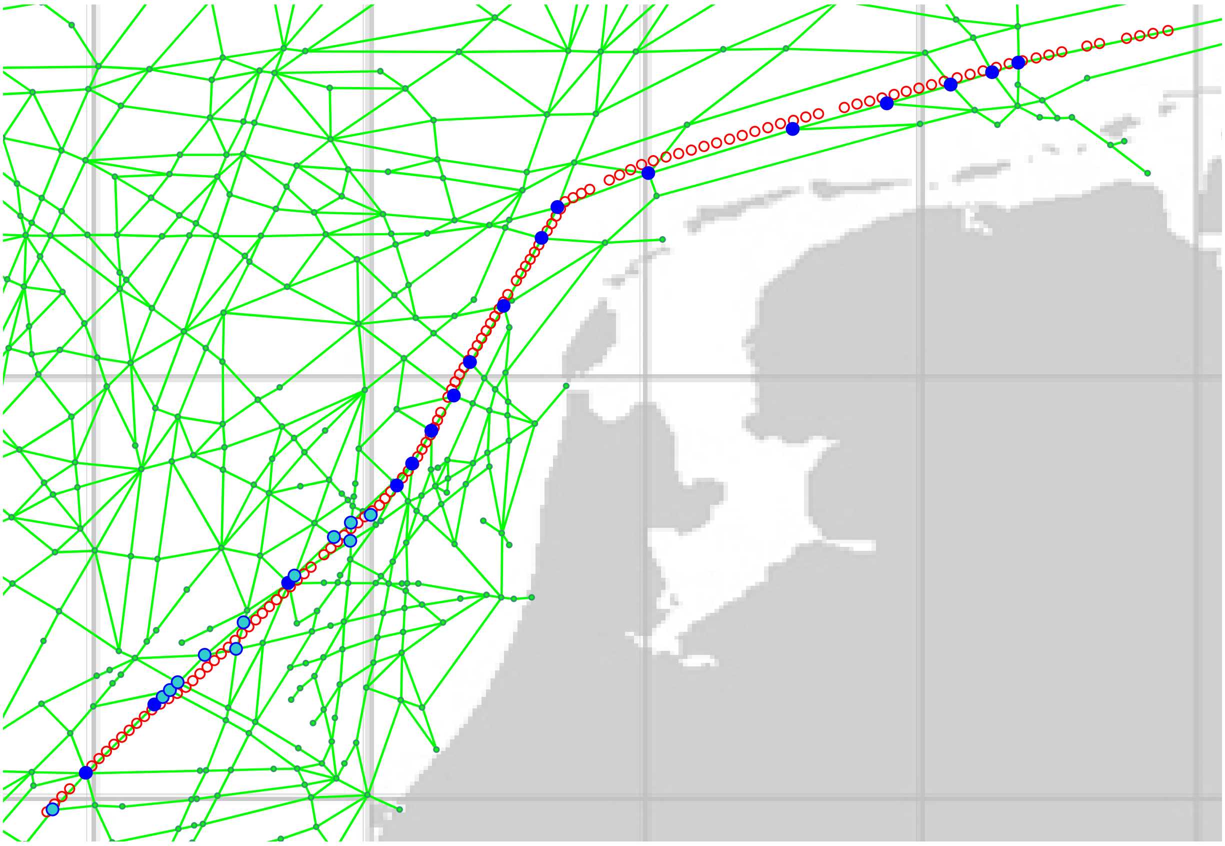


Figure 3-10 Determination which nodes are closest to the AIS trace.

To limit the number of analysis iterations it has been necessary to simplify and optimize this determination of the closest nodes to the trace. It is done by, among others, determination of the closest node once for a number of points evenly distributed in the area of analysis and storing the results in the table. For this purpose the same cells used to create the traffic density mapping are used. In the analysis of AIS points the cell to which the AIS point belongs is first determined and using the above mentioned reference table the closest route net node is then established. This discrete grid used in this approximation method has sufficiently good resolution (500m in both directions) to assure that no major errors occur while determining the node closest to the AIS trace.

Once the sequence of route net nodes has been determined, another recursive algorithm determines which nodes are essential for achieving the best possible track representation. Algorithm starts with first and last track nodes and finds the node that lies closest to the centre of the track between the start and end nodes. Here, the sequence of nodes is split into two and each of the two sequences is treated with this recursive method. The quality of the track mapping onto the route net including this centre node is checked after each new subdivision of node sequences. If the quality improves or stays unchanged, the centre node is taken into account. If the quality deteriorates it means that including the new node gives inconsistency in tracks and the logic of the route net. Evaluation of track representation quality is carried out by comparison of the route track length with the real track length (calculated via numerical integration). This quality check is robust and fast to apply in the main algorithm.

This additional procedure is necessary because systematic determination of sequences of the closest nodes often gives nodes that distort the mapping algorithm (see Figure 3-11).

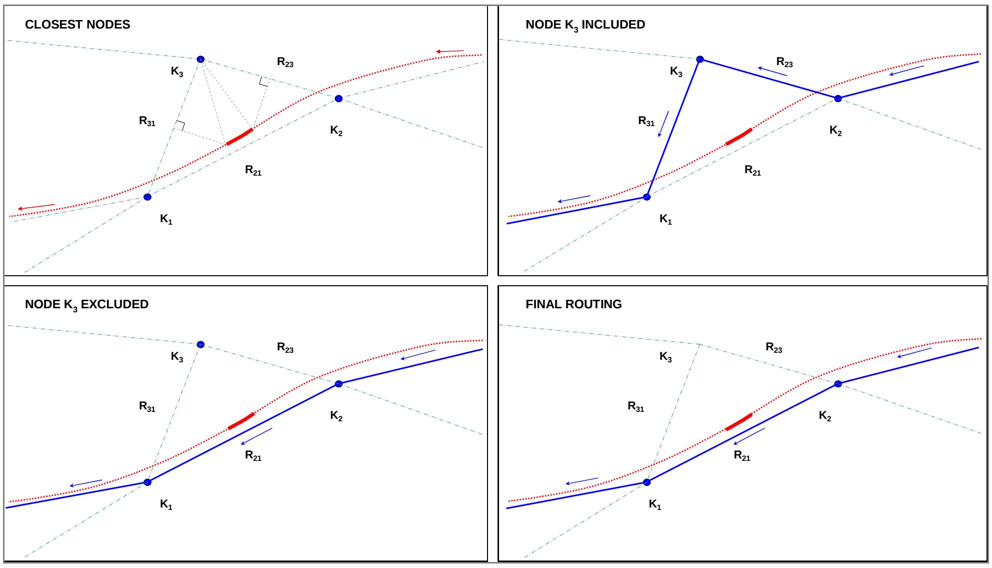


Figure 3-11 Example showing how the closest node (K3) can mislead the mapping algorithm.

The example above shows identified nodes closest to the track as nodes $\mathbf{K_1}$, $\mathbf{K_2}$ and $\mathbf{K_3}$. While taking into account the centre node $\mathbf{K_3}$ makes the route length too large ($\mathbf{R_{23}+R_{31}}$) in comparison with the actual track length, omitting node $\mathbf{K_3}$ gives good approximation ($\mathbf{R_{21}}$) of the track length. The situation would be even worse if route segment $\mathbf{R_{21}}$ did not exist – see Figure 3-12. In such a case the inclusion of node $\mathbf{K_3}$ leads to a "dead end" and an even larger increase of route length. Applying a quality check algorithm removes those types of errors.

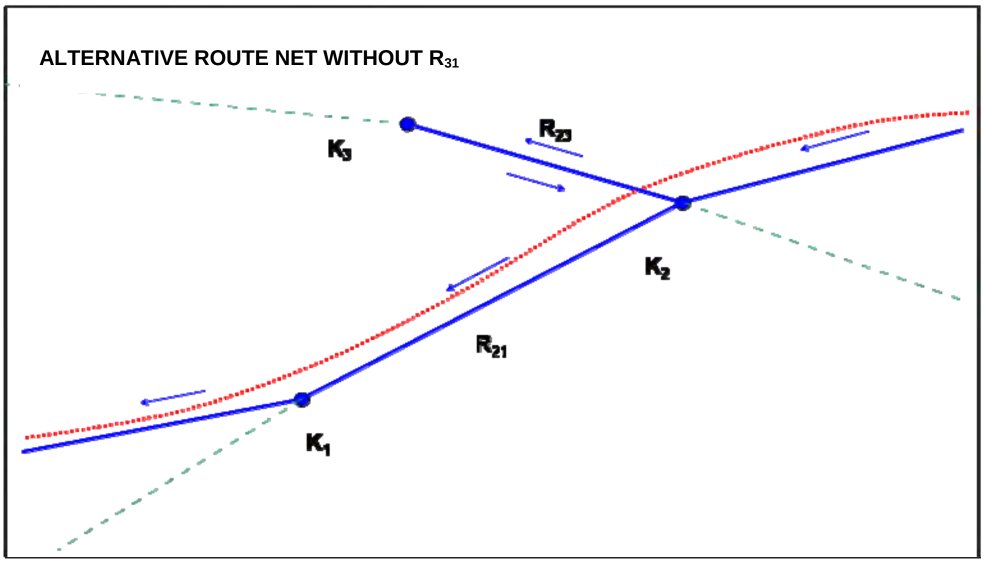


Figure 3-12 Example of misleading track mapping.

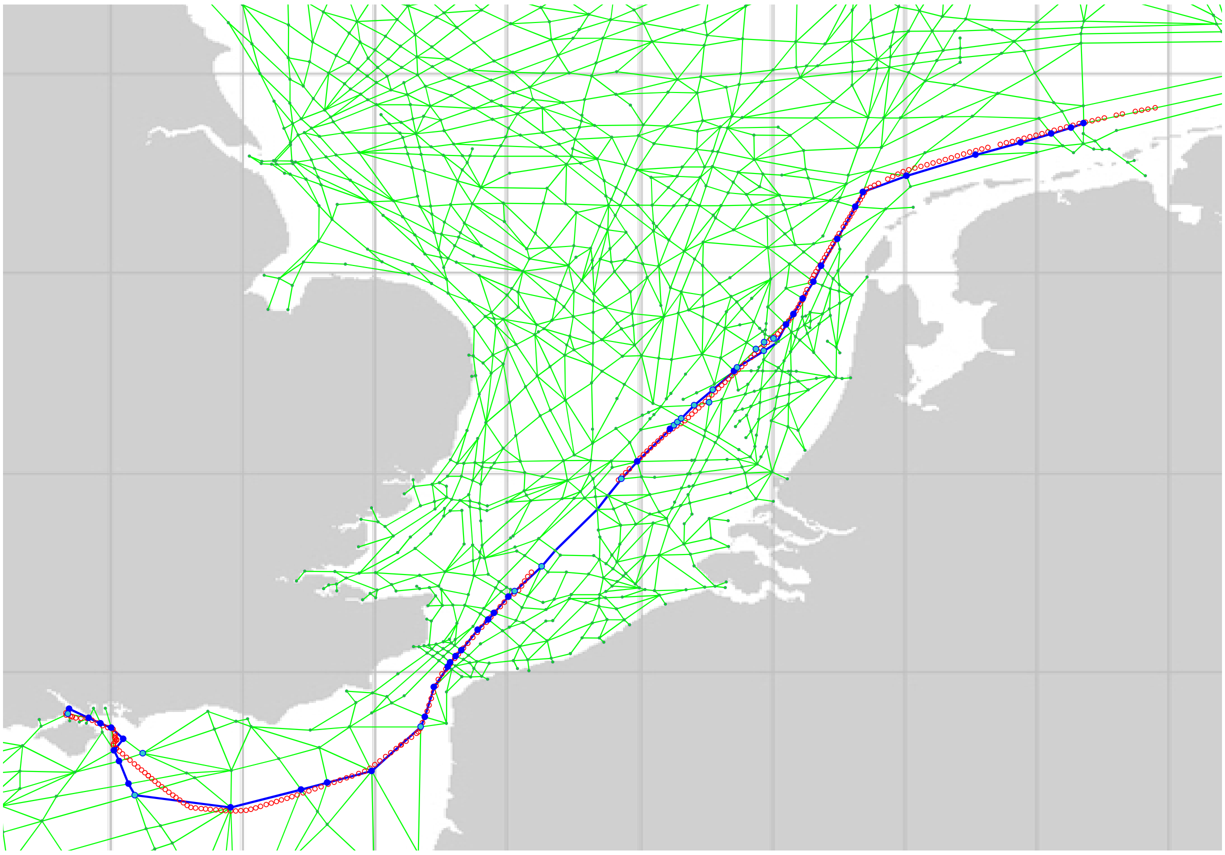


Figure 3-13 Example of the mapping of the AIS trace with clear AIS report's dropout.

Described procedures enable reliable route mapping even for tracks with AIS reports' dropout. Results of algorithm calculations are presented in Figure 3-13.

After the track has been determined, note is taken of which AIS points have actively contributed to the track mapping and which route segments are included in this track.

Key results for track mapping usage of AIS reports

Total number of AIS reports	858,018,209
Number of AIS reports from ships larger than 300 GT	525,719,501
Number of AIS reports from ships most probably larger than 300 GT	42,681,088
AIS reports with identified track	206,272,630
Identified route passages	14,284,881

During the route mapping procedure it is determined which AIS points can be associated with which route segment passages. This information is subsequently used for determining the mean value and allocating the average geometrical distance between the points and the ideal line in the route net. These statistics are required for the calculation of the collision frequency of vessels sailing along the same route segment (see Technical Sub-report 8 “Maritime oil spill risk analysis”).

It has been found that a 12h dropout time correction is not enough. Therefore, an additional “gap closing” algorithm has been prepared and all gaps up to 36h have been closed by finding the shortest way through the route net, see Figure 3-14. In this way an additional 527,604 route segment passages have been found.

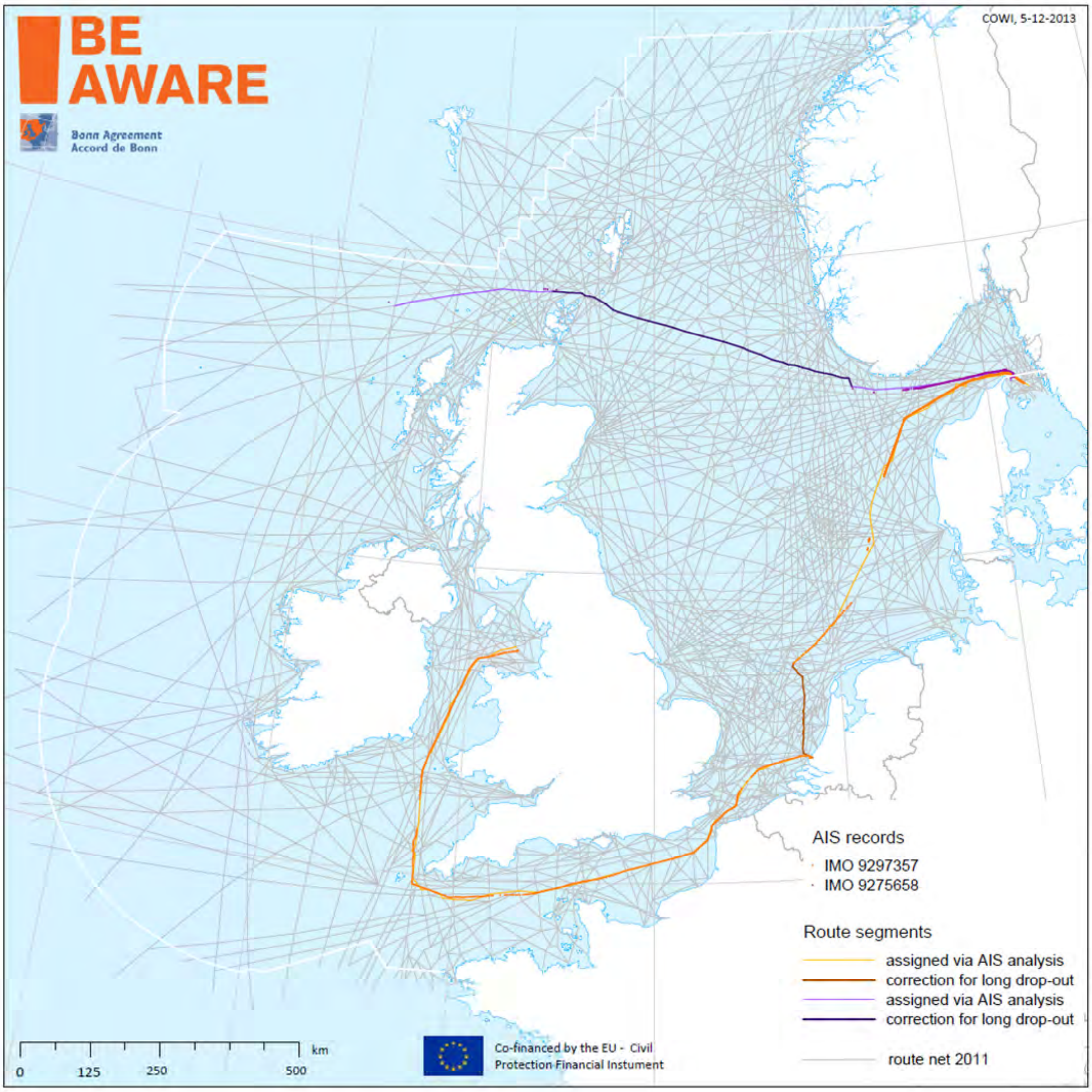


Figure 3-14 **Example of additional gap closing due to AIS dropout exceeding 12h. Maximum time gap of 36h has been corrected.**

During analysis it became apparent that parts of the German Bight have lower AIS data coverage than the rest of the BE-AWARE project area, see Figure 3-15. When the AIS reports were mapped onto the route net it became even clearer that the AIS traces stop far from the German destination harbour. Therefore, the number of passages on route segments in Helgoland Bight has been multiplied by factors 2 to 9 to account for the missing AIS data. Correction factors have been obtained by comparing harbour data with the number of passages obtained from AIS mapping. Additionally, results from ACCSEAS project have been used (ACCSEAS). The passage line statistics used are shown in Figure 3-16. The transverse distribution of the vessels along the routes and the size distribution of the vessels in the German Bight have been taken directly from the AIS data available at the time of the analysis.

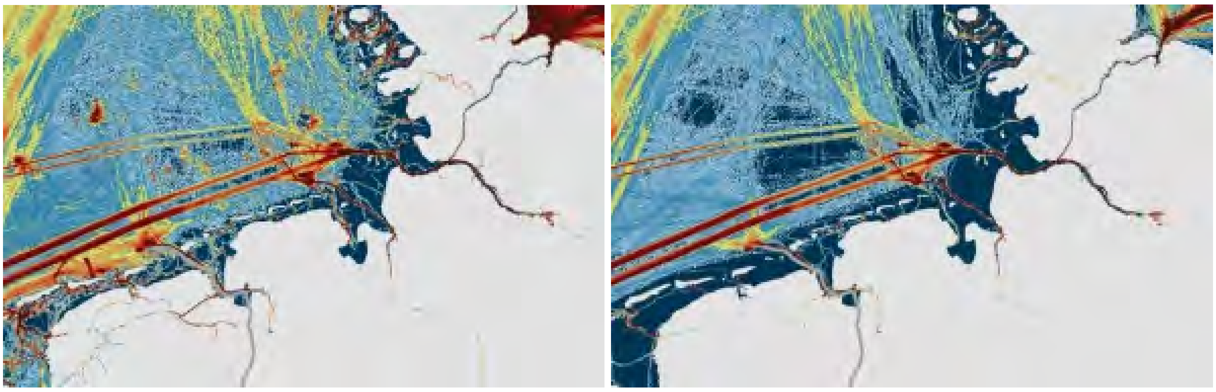


Figure 3-15 Ship traffic intensity in Helgoland Bight for all vessels (left) and merchant vessels (right) based on the counted number of AIS records per cell. Intensity loss in the raw AIS data along main traffic routes is clearly visible.

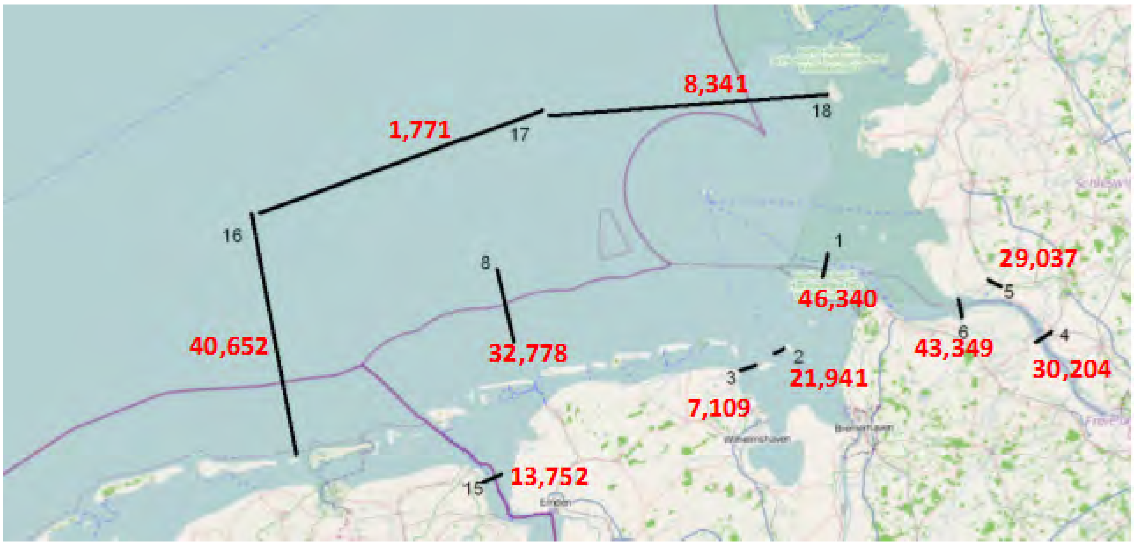


Figure 3-16 Passage line statistics in the from the ACCSEAS project, (ACCSEAS), applied to correct the number of vessels in the German Bight

3.5 The resulting traffic model

The resulting traffic model is essentially described as a database table containing all identified route passages (events, where a vessel passes a route segment) combined with information about passage direction and vessel characteristics from IHS database and a corresponding table containing the calibration factor F. Each vessel is allocated to the nearest route leg based on the AIS signal. Each route leg comprises traffic in two directions. The distances between the vessels and the route leg are described statistically in terms of normal distributions (one in each direction) by means of offset and standard deviation. Hence, the traffic characteristics are represented for each specific route leg and route direction. This means i.e. that traffic on route legs that comprise complicated traffic characteristics, such as TSS regulated traffic as well as more general ship traffic, will be represented in the traffic model according to the statistics of the AIS signals and no artificial risks are introduced in the model.

Using this detailed model has the following advantages:

- traffic surveys can be performed very flexibly based on the detailed ship characteristics from the IHS database;

- the actual journeys of the respective vessels are contained in the description, since sequences of route passages are tied together by a common track number and the date information;
- the passage of the vessels through the respective nodes in the route net – i.e. on which route segment a vessel arrives at a node and on which route segment it continues – are contained in the description and can be used in the ship collision model.

The database provides traffic data for the calculation of accident and spill frequencies which are directly dependent upon the traffic, its volume and composition.

In order to display the content of the traffic model, different tables can be extracted: the aggregated transport activity (sailed nautical miles) and the distribution of the traffic on specific routes to different ship types and sizes.

The information on the identified vessels that can be found in the IHS database is more detailed than what is meaningful in the context of the risk analysis. This broad classification is reduced to 24 different types as shown in Table 3-1. Type 25 “unknown” is not used in the final traffic model but is used in order to classify the remaining group that cannot be identified during the model establishment.

Table 3-1 Ship types used in the model (left) and general groups of types used for preparing statistics and results (right)

Type ID	Type description
1	Work vessel
2	Car transport
3	Bulk
4	Bulk/Oil
5	Container
6	Fishing vessel
7	Ferry
8	Ferry/Ro-Ro
9	Cruise ship
10	Reefer
11	Nuclear fuel
12	Offshore
13	Ro-Ro
14	Tug
15	General cargo
16	Navy
17	Tanker, food
18	Tanker, gas
19	Tanker, chemical/products
20	Tanker, chemical
21	Tanker, product
22	Tanker, crude oil
23	Tanker, others
24	Others
25	Unknown

Vessel group	Type description
Tankers	Bulk/oil
	Tanker, food
	Tanker, gas
	Tanker, chemical/prod.
	Tanker, chemical
	Tanker, product
	Tanker, crude oil
	Tanker, others
Bulk carriers	Bulk
General cargo	General cargo
Packed cargo	Car transport
	Container
	Reefer
	Nuclear fuel
	Offshore
	Ro-Ro
Ferry and passenger traffic	Ferry
	Ferry/Ro-Ro
	Cruise ship
Others	Work vessel
	Fishing vessel
	Tug
	Navy
	Others
	Unknown

With a GIS system, traffic can be illustrated graphically for individual traffic segments. Examples of this kind of data presentation are in Figure 3-17.

Figure 3-17 Map of the total traffic intensity on route segments of oil and chemical tankers larger than 300GT in 2011

4. Flow of goods

Information about the cargo on board the respective ships is of vital importance for predicting which substances could be released into the maritime environment in an accident. Traffic information contained in the recorded AIS data (STAT messages) can in the best case comprise information about the classification of the cargo of a vessel, but those data are not sufficiently detailed and reliable in order to be applied in the risk analysis. Therefore, the transported cargo is investigated in a more detailed way based on data from other sources. The corresponding model is referred to as transport model and is handled in Technical Sub-report 2: Oil Cargo Model.

5. Future scenario

In addition to analysing the present traffic situation, the future development needs to be taken into account in order to provide a sound basis for sustainable decision-making.

Therefore, the situation in 2020 will be modelled as a scenario in addition to the present-day scenario. This requires a realistic prognosis of the traffic development in the meantime. The corresponding prognosis model is handled in Technical Sub-report 3: Future Traffic Model 2020.

Due to the growing offshore wind farms sector, the route net for year 2020 had to be modified. Additionally, the Netherlands have introduced a new TSS scheme in their waters. The modified route net is presented in Figure 5-1.

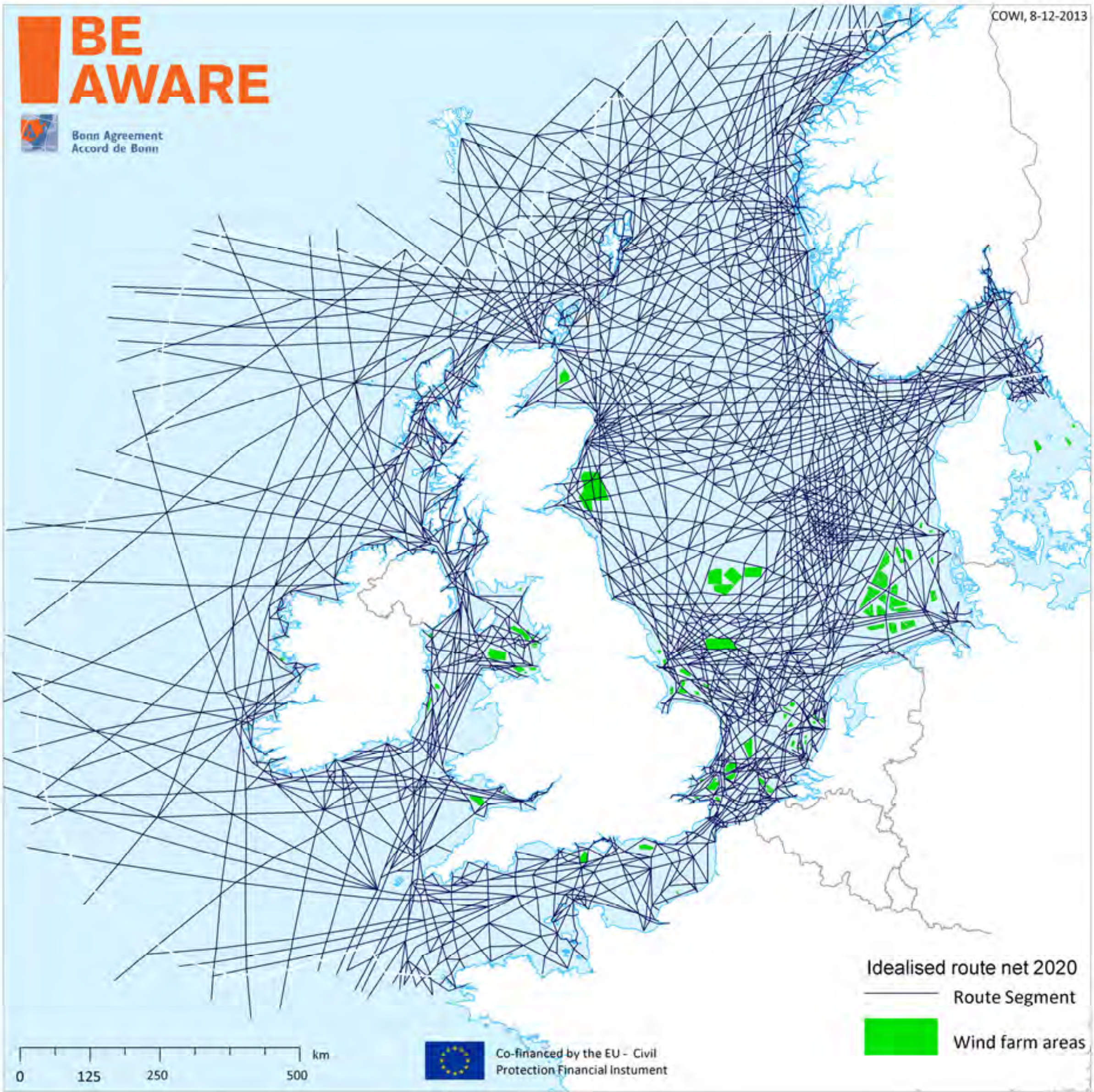


Figure 5-1 Modified route net used in scenario 2020. The white line is the analysis boundary, green areas represent wind farms.

Modification of the route net implied necessary rerouting of vessels on routes valid only in scenario 2011 to the route segments available in 2020. This has been done by finding all route segment sequences that are not available in 2020 and identification of start and end node of rerouting. Afterwards, the shortest way between the identified nodes through the route net 2020 is found.

Route passages valid only in Scenario 2011	747,862
Route passages rerouted on route net 2020	825,679
Identified route passages in Scenario 2020	14,890,302

Traffic intensity mapped on route net 2020 is presented in Figure 5-2.

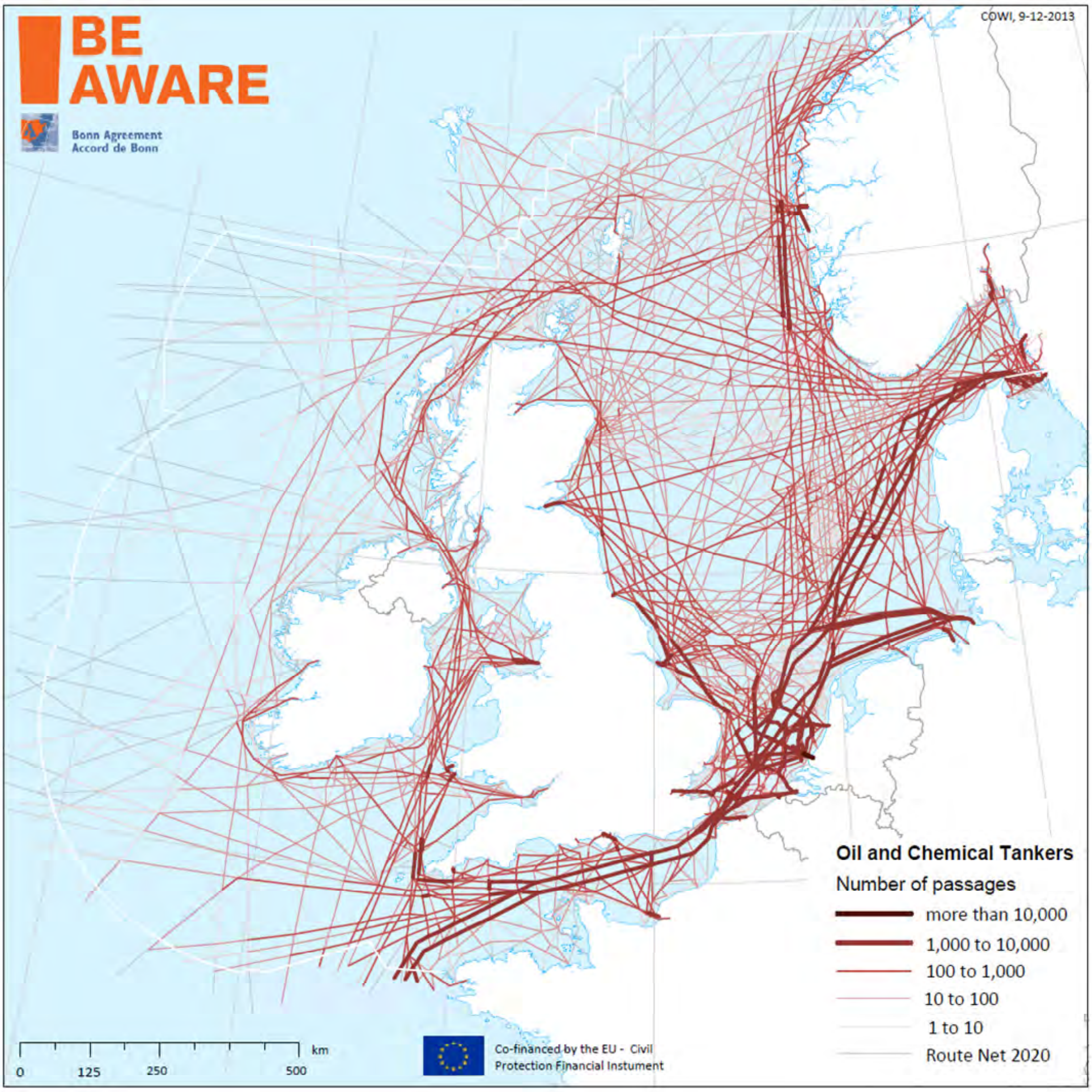


Figure 5-2 **Map of the total traffic intensity on route segments of oil and chemical tankers larger than 300GT in 2020.**

6. Abbreviations

AIS	Automatic Identification System
DMA	Danish Maritime Authority
WSE	World Shipping Encyclopaedia
IMO	International Maritime Organisation
MMSI	Maritime Mobile Service Identity
SOLAS	International Convention for Safety of Life at Sea
TSS	Traffic Separation Scheme
VTS	Vessel traffic service
BRISK	Project on sub-regional risk of spill of oil and hazardous substances in the Baltic Sea
HELCOM	Baltic Marine Environment Protection Commission (also: Helsinki Commission)

7. References

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