TRANSNAV
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 9 Number 1 March 2015

DOI: 10.12716/1001.09.01.06

Classifying Ship Encounters to Monitor Traffic Safety on the North Sea from AIS Data

W.H. van Iperen
Maritime Research Institute Netherlands (MARIN), Wageningen, The Netherlands

ABSTRACT: In studies for the Dutch Ministry of Infrastructure and the Environment, MARIN has developed methods to classify ship encounters on the North Sea from AIS data. The methods use the Distance at Closest Point of Approach (DCPA), Time to Closest Point of Approach (TCPA), and an estimate of ship domains, to determine for each crossing, head-on, and overtaking encounter, whether these follow abnormal patterns. On august 1 2013, the route structure on the North Sea, was rearranged to improve safety and efficiency. The encounter classification methods were applied to two years of AIS data. Heat maps of encounters show how the junctions have shifted. For these junctions, the numbers of encounters were compared. This paper discusses the methods to classify encounters, and the results of the comparison of the route structures. The results show a decrease of the number of exceptional head-on and crossing encounters in the new route structure.

1 INTRODUCTION

The North Sea is one of the busiest shipping traffic areas in the world. By monitoring AIS signals transmitted by ships, the Netherlands Coastguard is able to monitor the current traffic situation and assist ships. For the Dutch Ministry of Infrastructure and the Environment (I&M) it is also important to monitor any changes in the safety levels of traffic at various locations, particularly at busy junctions.

Traditionally, the safety levels of the shipping traffic and the impact of new developments and measures, can be assessed with risk models, such as the SAMSON model (Van der Tak & De Jong, 1996) that was developed at MARIN. In the SAMSON model, risk is a combination of accident probability and consequences. For the risk of collisions, the probability is modeled by estimating the number of encounters between ships with a static traffic model, and multiplying this by the probability of a collision given an encounter.

The traffic model is used to predict routes and shipping intensities in future situations, but it cannot be used to monitor the safety levels that occurred with the actual traffic.

A risk index was developed (Koldenhof et al. 2009) to apply the risk model from SAMSON to the actual real-time traffic information that is provided by AIS data. This index can be used to monitor the safety levels. In the risk index, the encounters are determined from actual ships positions instead of the static traffic model.

Both in the SAMSON model and the risk index, the probability of an encounter resulting in a collision, is still estimated from accident statistics. These statistics are, fortunately, rather scarce. The amount of detail that can be incorporated in the probability model, is therefore very limited. Moreover, for most statistics, the exact tracks of the ships are not available. Characterizations of encounters therefore only distinguish between head-on, crossing, and overtaking encounters. As a result it is still hard to estimate the probability of a collision from AIS data directly.

Instead of using the probability of a collision for monitoring the safety level, I&M therefore asked MARIN to develop methods to distinguish between normal and exceptional encounters, or even near misses, and thus get an indication of dangerous locations. The methods use the progress of the Distance at Closest Point of Approach (DCPA) and Time to Closest Point of Approach (TCPA) during encounters, as well as an estimate of the normally maintained ship domains, to determine whether an encounter follows a normal or abnormal pattern.

On august 1 2013, the route structure on the Dutch part of the North Sea, was radically changed to improve safety and efficiency regarding offshore platforms, port approach and anchorage areas, and to allocate safe areas that can be used for wind energy.

MARIN applied the classification methods for encounters to two years of AIS data for the North Sea: one year under the old route structure, and one year under the new structure. Resulting heat maps of encounter locations show the areas where many ship encounters take place. By comparing the heat maps and the traffic flows for the old and new situation, the shifting of junctions between various traffic flows was described. A number of specific areas were defined in both structures, and the types of encounters were counted and compared per month.

This paper describes the developed methods and the results of applying these to compare the old and new route structure. First, Section 2 describes the available data. The underlying principles to the methods are defined in Section 3. Section 4 gives an overview of the various criteria that are used to classify the encounters. Section 5 describes the results of the encounter comparison between the old and new route structure.

2 AVAILABLE DATA

Each month, MARIN receives AIS data from the Netherlands Coastguard for the purpose of risk and safety studies regarding shipping traffic. Not all tracks of recreational and fishing ships are available, since some ships are not yet equipped with AIS.

The AIS data has already been processed by Coastguard software upon reception at its base stations along the Dutch coastline and on various platforms in the North Sea. The processing means that for example all overlapping signals at different base stations have been merged and some tracks may have been extrapolated after signal loss. Also, where available, positions have been checked with radar tracks.

The main information that is used from the AIS signals are the recorded moments at which the signals are parsed on board of the ship ('parse times'), the positions at those moments (tracks), speed over ground, heading, course over ground, ship type, and dimensions of the ship. The track positions represent the middle of the ship.

In the pre-processing of the data for this project at MARIN, information is derived and stored only for fixed intervals of 1 minute. For these 'plot times' relative positions and speeds of ships are calculated. Given the speeds, acceleration and maneuverability of most ships, the choice for 1 minute intervals is enough to avoid missing any close encounters.

The accuracy of tracks is not always optimal. The merging process with radar positions, for example, may cause some false positions in the tracks in some areas. Such positions are not taken into account in the encounter classification process. False positions are detected based on peaks in the calculated average speed between two consecutive positions.

3 DEFINITIONS

The encounter classification methods use information about relative positions between ships. It is summarized by distance, relative bearing, closest point of approach and maintained ship domains. Definitions and descriptions of these are given here.

3.1 *Encounters*

An encounter is defined as the tracks of two ships having a speed of at least 1 knot, that at certain moments during their approach, are expected to pass each other within 3 nautical miles within 20 minutes, based on their speed and course. The encounter starts at the first of such moments, and ends 20 minutes after the last of such moments. The 20 minutes extra are used to also be able to study the trajectories after the ships have passed each other.

An encounter always takes place between two ships A and B, and is studied from the perspective of both ships. If a third ship C is present, this is considered in three encounters: an encounter between A and B, between A and C, and between B and C separately.

3.2 *Distance*

The distance between ships A and B at time t is, in principle, the distance between the center points of the two ships. However, since the two ships do not necessarily parse signals at the same time, the exact distance at t cannot be calculated. The distance of ship A to ship B, denoted as d(A,B)(t), is calculated for the moments that signals are parsed at ship A by extrapolating the position of ship B at that moment. Extrapolation is based on the position, speed and course over ground at the last parse time of ship B. Given the high frequency of signals, this is sufficiently accurate for the purposes of this research.

3.3 *Absolute and relative bearing*

The position of ship B from the perspective of ship A can be uniquely described by distance and relative direction. In navigation, direction is measured in relation to a reference direction. This is called the bearing. The reference direction can be absolute (for example north) or relative (course of ship), resulting in an absolute or relative bearing. For encounters, the course over ground of the own ship is taken as reference direction.

The relative bearing of ship B as seen from ship A is defined as the angle between the line connecting the centers of ships A and B, and the course line of ship A. This is denoted as rb(B,A)(t). This angle is measured as the difference in clockwise direction, and takes values between 0° and 360°. In general, rb(B,A)(t) ≠ rb(A,B)(t), unless the ships sail in exactly the opposite direction.

3.4 *Ship directions during encounters*

The average direction of a ship during an encounter, denoted as θ, is determined as the absolute bearing of the line between the first and last position of the ship during an encounter.

The difference of direction of ship B as seen from ship A is defined as:

$$\varphi_{BA} = \theta_B - \theta_A \tag{1}$$

φ_{BA} takes values between -360° and 360°, and moreover

$$\varphi_{AB} = -\varphi_{BA} \tag{2}$$

The difference of direction of the encounter, regardless of the ship-perspective, is defined as:

$$\varphi = |\varphi_{AB}| = |\varphi_{BA}| \tag{3}$$

3.5 *Distance at closest point of approach (DCPA)*

The closest point of approach (CPA) is the position of a ship during an encounter where the distance to the other ship is minimal. The distance at that point is denoted as DCPA. During the encounter, the CPA and DCPA can be estimated from the current speed and course over ground of both ships. The prediction of DCPA therefore progresses over time and is denoted as DCPA(t), expressed in nautical miles.

There is an important difference regarding the passing distance for a give-way ship A between passing a stand-on ship B at the stern or at the bow. This can be expressed by defining a sign for DCPA:

– DCPA > 0: the give-way ship from portside passes at the bow of the stand-on ship; the relative bearing increases;
– DCPA < 0: the give-way ship from portside passes at the stern of the stand-on ship; the relative bearing decreases.

The sign of DCPA is thus determined by the change of relative bearing.

3.6 *Time till closest point of approach (TCPA)*

For each estimated DCPA-value, the time it takes to reach the CPA, is denoted as TCPA (Time till closest point of approach). TCPA also has a sign:

– TCPA > 0: the distance between the ships decreases and the CPA is still ahead;
– TCPA = 0: the CPA is reached;
– TCPA < 0: the CPA is passed; the distance between the ships increases.

3.7 *Ship coordinates and ship domains*

For safe and comfortable navigation, ships prefer to maintain a certain minimal distance to other ships. The resulting free zone around the ship is called the ship domain. The minimal distances can be expressed in miles, but also in number of ship lengths (and breadths). Depending on this, domains will be referred to here as absolute (distance) or relative (distance) ship domains respectively.

The absolute ship domain can be observed from tracks of encounters by applying a coordinate transformation that puts each ship in the origin, after which all tracks of encountering ships can be superimposed. This transformation uses the absolute distance and relative bearing between the ships. The tracks of ship B as seen from ship A in absolute ship coordinates are calculated as:

$$\begin{aligned} x_{\mathrm{B,A}}(t) &= \mathrm{d(A,B)}(t)\sin(\mathrm{rb(B,A)}(t)) \\ y_{\mathrm{B,A}}(t) &= \mathrm{d(A,B)}(t)\cos(\mathrm{rb(B,A)}(t)) \end{aligned} \tag{4}$$

The relative ship domain can be observed by additionally scaling the absolute ship coordinates according to the length of ship A, L_A:

$$\begin{aligned} l_{\mathrm{B,A}}(t) &= x_{\mathrm{B,A}}(t) / \mathrm{L_A} \\ b_{\mathrm{B,A}}(t) &= y_{\mathrm{B,A}}(t) / \mathrm{L_A} \end{aligned} \tag{5}$$

Figure 2 shows all tracks of encounters (mainly overtaking and crossing encounters) in absolute ship coordinates that occurred during one month at the busy junction in the traffic separation scheme above Vlieland Island in the Netherlands.

The plot clearly suggests the ship domain where few ship tracks are observed, and an increased density of tracks around it. Also visible in the domain are the tracks of (two) vessels being towed by tugs. The clustered tracks above the origin represent the tug, and the clustered tracks below the origin represent the towed vessel.

The size of the ship domain (either absolute in miles, or relative in ship lengths) can be measured by determining the distribution of tracks and taking for example the 0.5% percentile. For this, a distinction is made in sectors of 11.25°, since distances in front of the ship are larger than at the side of the ship.

Figure 1 shows the 0.5%, 1% and 5% percentiles of the absolute ship coordinates in Figure 2. The 5% percentile shows a shape that is to be expected for a ship domain. It can be seen that for example for the 0° sector, only 5% of the tracks are within 1 mile of the ship. To the side of the ship, 5% of the tracks are closer than 0.5 nm of the ship.

Clearly, the towing combinations affect the shape of the 0.5% and 1% percentile. After removing these tracks, the percentile also show the expected contours.

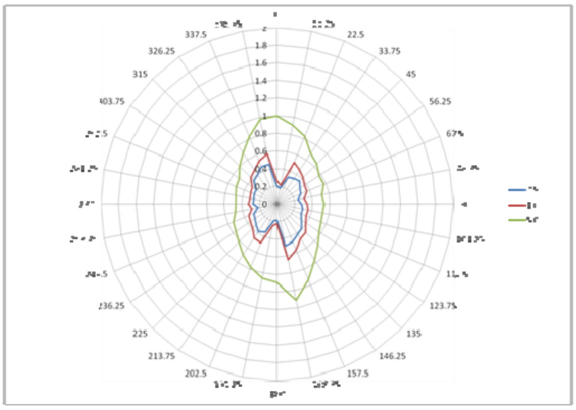

Figure 1. 0.5%, 1% and 5% domain percentiles of superimposed tracks in Figure 2, measured in nautical miles

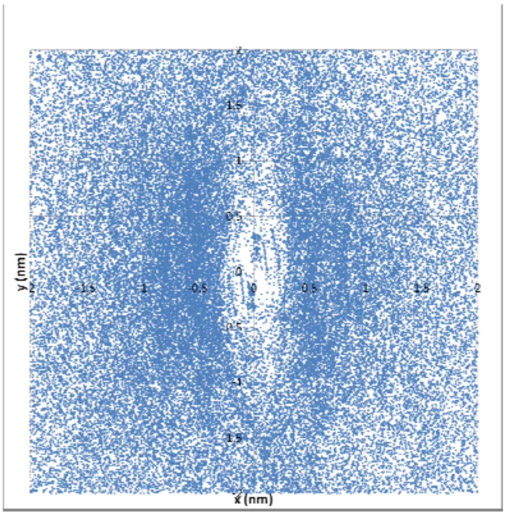

Figure 2. Superimposed tracks in absolute ship coordinates

4 ENCOUNTER CLASSIFICATION CRITERIA.

For different types of encounters, different criteria are applied to discriminate between normal and exceptional encounters.

4.1 *Types of encounters*

Three obvious types of encounters, head-on, overtaking and crossing encounters, are distinguished based on the difference of direction of the ships. The crossing encounters are further divided into two subtypes, depending on whether the give-way ship from port side crosses at the stern or at the bow. This is determined by the DCPA value at the CPA.

Figure 3 shows the distribution of the differences in direction for over half a million encounters between merchant vessels on the Dutch part of the North Sea in the first three months of 2011. The graph is more or less symmetrical, given (2).The graph shows three peaks. The center peak indicates the overtaking encounters, having $\varphi \approx 0°$. The left and right peak indicate the head-on encounters, having $\varphi \approx 180°$. Between and around the peaks are the two types of crossing encounters.

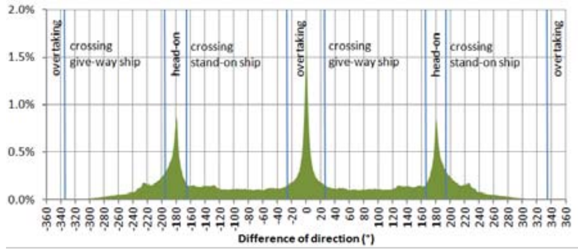

Figure 3. Distribution of observed differences in direction between encountering ships

Table 1 summarizes how the encounter types are categorized.

Table 1. Overview of distinguished types of encounters

Encounter type	Criteria
Overtaking	$\varphi < 25º$
Head-on	$165º < \varphi < 195º$
Crossing, give-way ship passes at stern	$(25º < \varphi < 165º$ or $195º < \varphi < 335º)$ and DCPA < 0 at TCPA = 0
Crossing, give-way ship passes at bow	$(25º < \varphi < 165º$ or $195º < \varphi < 335º)$ and DCPA > 0 at TCPA = 0

Besides these types of encounters, there are a number of intentional encounter types. These include towing combinations (either the one ship towing another, or two tugs towing a third ship), navy convoys, and encounters between ships and pilot vessels. Distinction is based on relative positions, average speeds, maximum distances during encounter, ship types, etc.

The intentional encounters are left out of consideration when defining criteria for exceptional and unintentional encounters, since the maintained distances are often much smaller. An example of an intentional encounter was shown in Figure 2, where a towing combination can be seen in the center. Its effect on the ship domain can be seen in Figure 3.

4.2 *Criteria for exceptional encounters*

In preliminary discussions about detection of near misses and hazardous encounters from AIS with representatives of I&M and the Netherlands Coastguard, it became clear that any definition of a near miss will always be subject to exceptions. Therefore a broad bottom-up approach was chosen in which normal encounters are excluded, leaving a selection of 'relevant' encounters.

Out of 3152 encounters on the busy junction above Vlieland Island in May 2010, initially 371 encounters were selected for which the expected DCPA was less than 0.5 nm at some point within 9 minutes of reaching the CPA. The relevance of many of these encounters was discussed with experts by studying animations of the encounters. The expert panel consisted of members of the Shipping Advisory Board of the North Sea (under whom representatives of captains, pilots, port authorities and of the Coastguard). The animations led to discussions about the causes of the situations and possible other criteria that could be investigated. It was agreed that ship domains needed to be determined from AIS, in order to judge whether some ships were uncomfortably close from the other ship's perspective.

A resulting set of encounters, the top of a ranking that was based on both DCPA values and ship domain entrees, were classified into three categories: 'safe and irrelevant', 'exceptional and relevant', and a category in between. The encounter tracks served as a training set of negative (-), neutral (+/-), and positive (+) instances to determine classification criteria for relevant cases.

4.2.1 *Give-way ships crossing at the stern*

Figure 4 shows the 14 DCPA-TCPA graphs for the positive, neutral and negative instances of the crossing encounters where the give-way ship crosses at the stern. An interesting area in the graph is the area where 0 < TCPA < 0.05 and -0.2 < DCPA < 0. None of the graphs of the irrelevant instances cross this area, whereas the neutral and positive instances do have observed values in this area. Some of the neutral instances pass very close to the origin, but have a constant graph in the last 3 minutes (0.05 hours) before reaching CPA, indicating that although the ship passes very close at the stern, it happens in a controlled manner. The two positive instances initially have positive DCPA values, but only just before reaching CPA (TCPA ≈ 0.05 = 3 minutes), the course is changed. In the end the ships pass at 0.2 nm, but the maneuver is far more abrupt than for the neutral cases.

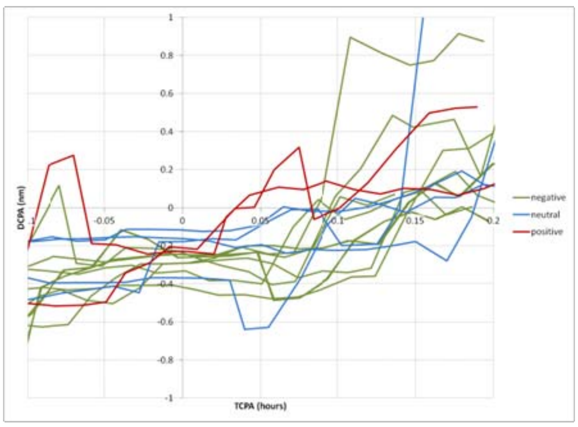

Figure 4. DCPA-TCPA graph of the training set where the give-way ship from port side passes at the stern

Based on these observations, the relevant encounters were defined as encounters that have -0.2 < DCPA < 0 at some moments where 0 < TCPA < 0.05.

Since 14 encounters only give a very rough impression of attained DCPA values during the encounters,

Figure 5 shows the accumulated DCPA-TCPA graphs of 164646 crossing encounters on the Dutch part of the North Sea during the last three months of 2011 where the give-way ship crosses at the stern. Encounters with special craft (tugs, pilot vessels, etc) have been left out in this graph. In the graph, lines indicate percentiles for the DCPA values for each TCPA value. For a given TCPA value, the 50% line indicates that 50% of all DCPA values are below that line at the given TCPA value.

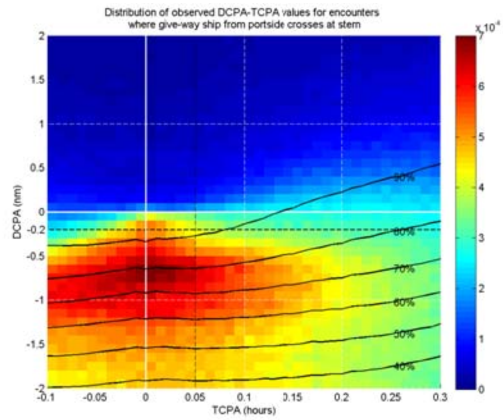

Figure 5. Accumulated DCPA-TCPA values of 164646 crossing encounters where the give-way ship from port side passes at the stern

The graph shows that for each value 0 < TCPA < 0.05 the 90% DCPA percentile is clearly below -0.2 nm, therefore less than 10% of the DCPA values in the last 3 minutes before reaching the CPA are within 0.2 nm. The graph further shows that around 10% of the actual passing distances of the encounters was less than 0.3 nm. A major part of the encounters takes place between 0.3 and 1.2 nm (the red spot between the 60% and 90% percentiles). 60% of the encounters had passing distances larger than 1.2 nm.

4.2.2 *Give-way ships crossing at the bow*

The training set contained 17 encounters where the give-way ship crosses at the bow: 1 positive (relevant) instance was found, next to 6 neutral instances and 10 negative instances.

For all 17 encounters the number of positions of ships in the other ships domain were counted, but both for the absolute and relative domain these counts did not seem to discriminate between positive, neutral and negative instances. The domains were therefore not used to formulate additional criteria for this encounter type.

Figure 6 shows the DCPA-TCPA graph for the set of 17 encounters. The graphs for the negative instances (the safe and normal encounters) have positive DCPA values during the entire approach, whereas the positive instance and all but one of the neutral instances initially have negative DCPA values. This means that for these encounters the initial intention of the give-way ship was to pass at the stern, but that it later decided to pass at the bow (possibly because of other traffic).

For these encounters, the actual CPA is not yet reached when the ship passes exactly before the bow, but somewhat later. The actual CPA is therefore not the critical domain point that the give-way ship uses to anticipate. This means that, in terms of TCPA, anticipation is normally done earlier than for the crossings of give-way ships at the stern.

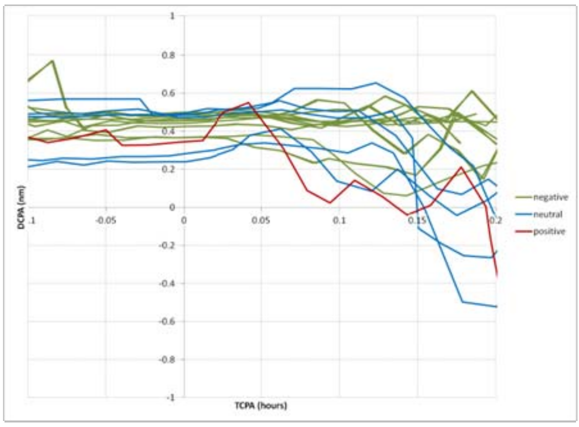

Figure 6. DCPA-TCPA graph of the training set where the give-way ship from port side passes at the bow

The graphs show that neither the negative nor the neutral graphs take on DCPA-values less than 0.2 nm for 0 < TCPA < 0.1 (except one value just at the border). For the positive encounter the graph does cross this area. The DCPA-TCPA criterion that is applied for these types of encounters, is that an instance is dismissed if there are no DCPA-values less than 0.2 nm for all TCPA-values 0 < TCPA < 0.1 (= 6 minutes).

As an indication, Figure 7 shows the accumulated DCPA-TCPA graphs of 123736 crossing encounters on the entire Dutch part of the North Sea during October – December 2011 where the give-way ship from port side passes at the bow.

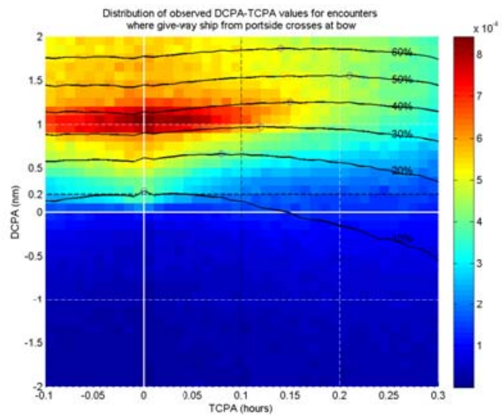

Figure 7. Accumulated DCPA-TCPA values of 123736 encounters where the give-way ship from port side passes at the bow

This graph shows that the distance at which ships pass at the bow, is much more fixed than the distance at which ships pass at the stern.

4.2.3 *Overtaking encounters*

Because of the relatively slow and long approach of ships in overtaking encounters, a DCPA-TCPA criterion did not really discriminate between relevant and irrelevant overtaking encounters. Two relevant overtaking encounters in the training set could not be distinguished based on the DCPA values. The ship domains were more discriminating.

As training set therefore all overtaking encounters were studied that had at least one domain entrance of the other ship, either for the relative or absolute domain. Of the encounters, 3 were judged as relevant, 5 were neutral, and the remaining 35 were irrelevant. For the training set the count of positions inside the relative domain of the other ship seemed to be reasonably discriminating factor between irrelevant and relevant or neutral encounters. No clear additional criterion was formulated other than having entered the relative domain of the other ship and having a minimal passing distance smaller than 0.35 nm.

For overtaking encounters, the applied criterion for a relevant encounter is therefore that for at least one moment during the encounter, the other ship is within the relative domain. The relative domain is defined as the 0.5% percentile contour based on 3204 overtaking encounters (excluding intentional encounters) in a diverse traffic area in the Dutch part of the North Sea in May 2010. This domain is shown as the inner contour in Figure 8. The figure shows that the domain is about 6 or 7 ship lengths in front of the ship, and around 3 to 4 ship lengths at the side.

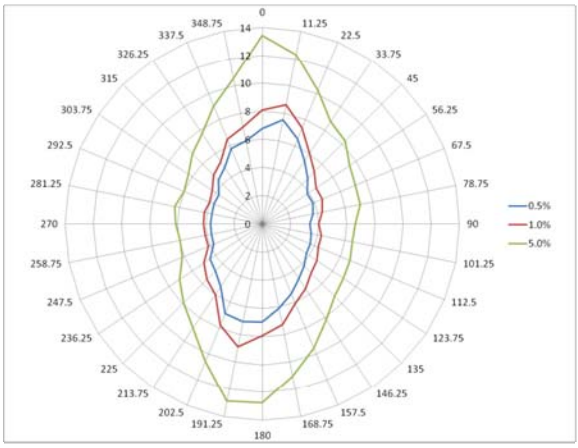

Figure 8. 0.5%, 1% and 5% percentiles of the relative distances for 3204 overtaking encounters in May 2010 in a diverse traffic area in the Dutch part of the North Sea

4.2.4 *Head-on encounters*

Criteria for exceptional head-on encounters are similar to those for overtaking: at least one moment where the other ship is inside the relative domain, and a minimal passing distance of at least 0.35 nm.

The relative domain that is used in this case, is based on 1960 head-on encounters in May 2010 in the same diverse traffic area in the Dutch part of the North Sea. The domain is shown in Figure 9.

The figure shows that, as is to be expected, the domain stretches much more forward (around 20 ship lengths) than in the case of overtaking encounters.

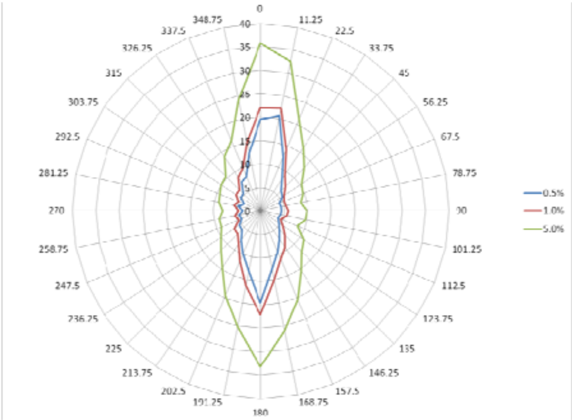

Figure 9. 0.5%, 1% and 5% percentiles of the relative distances for 1960 head-on encounters in May 2010 in a diverse traffic area in the Dutch part of the North Sea

The number of lengths at the side of the ship is comparable to that for the overtaking encounters.

5 COMPARISON OF ENCOUNTERS IN THE OLD AND NEW ROUTE STRUCTURE

5.1 *The old and new route structure*

An important measure in the new route structure to improve safety and efficiency, is by reducing the variety of routes that ships take, and creating clear and confined areas for encounters.

Figure 10 shows the shifts of the routes in this new route structure, by comparing the traffic densities (the average number of ships present per square unit. The black line demarcates the area that contains the changes in the route structure. The number of routes to and from the north has been reduced in particular.

Figure 11 shows a map of all crossing encounters in the area for the first year that the new route structure was in effect. The green dots indicate locations of exceptional encounters.

Figure 12 shows the shift of junctions by comparing the number of crossing encounters per gridcell of 1 x 1 km. The map also shows the junction areas that were defined to compare changes in the number of encounters between specific traffic flows. Areas 5, 6 and 7 particularly show how the area where encounters take place, is more compact in the new situation.

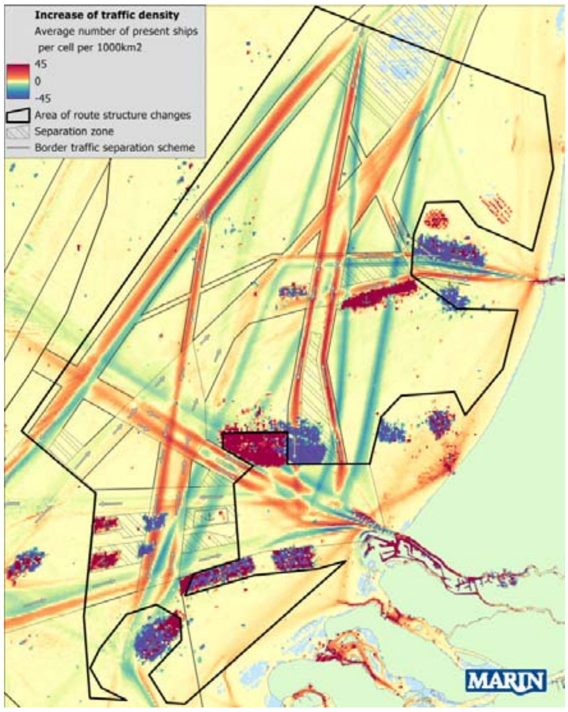

Figure 10. Shifts of the main traffic flows due to the new route structure, based on two years of AIS data

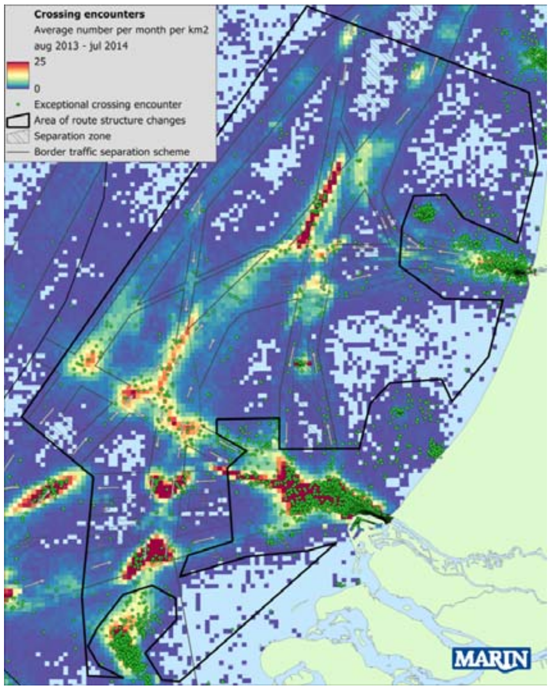

Figure 11. Heat map of crossing encounters in the new route structure

5.2 *Results of classification and comparison*

During August 2013 – July 2014, an average decrease of the various traffic intensities in the area was observed of 10.6%. Due to these lower intensities, a decrease of the number of crossing encounters can be expected of $100\% \times (1 - (1 - 0.106)^2) = 20\%$.

Table 2 contains the numbers of crossing encounters per area for 2011 (the old route structure) and the first year under the new route structure. The table shows that in the entire area where the routes have changed, the encounters have decreased by 31.1%. On the specific junction areas, the reduction was 20.0%, the reduction that could be expected due to the decreased intensities. Outside the junctions, the reduction was 47.9%, showing that the encounters take place more in designated junction areas.

The fraction of crossing encounters that are classified as exceptional, has decreased in the new route structure, in the junction areas (0.2% instead of 0.4%), but even more outside the junction areas (0.4% instead of 0.9%). This can be seen in Table 3. This is attributed to the reduction of the diversity of routes. In the new route structure, traffic is better able to anticipate other traffic.

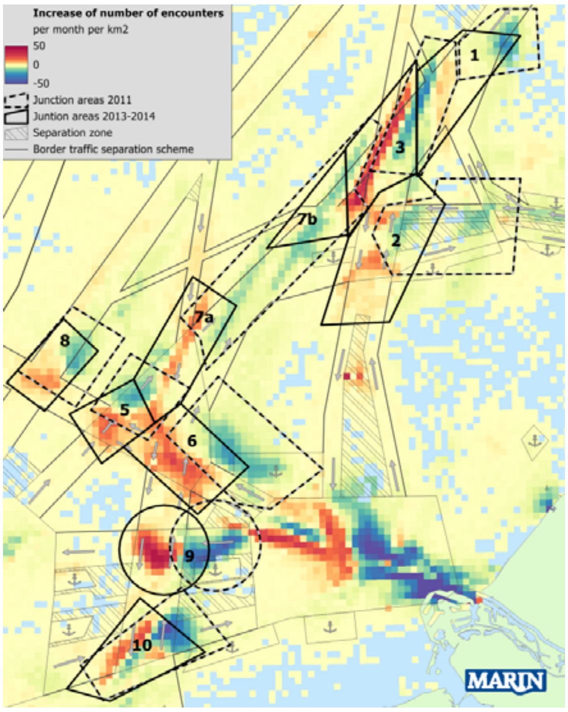

Figure 12. Shifts of the main junctions of traffic flows due to the new route structure, based on difference of number of crossing encounters per cell in two years of AIS data

Table 2. Numbers of crossing encounters in 2011 (old route structure) and August 2013 – July 2014 (new route structure)

Area	2011	2013-2014	Increase
1	8607	7202	-16.3%
2	14074	12047	-14.4%
3	17378	20597	18.5%
5	13263	10865	-18.1%
6	21727	16410	-24.5%
7	30109	20877	-30.7%
8	12156	9073	-25.4%
9	20862	16030	-23.2%
10	34716	25129	-27.6%
Total junction areas	172892	138230	-20.0%
Outside junction areas	114008	59451	-47.9%
Route change area	286900	197681	-31.1%

For overtaking encounters, the fraction of exceptional encounters is higher, and increased from 5.7% to 6.4% in the new situation. This is due to the fact that ships sail on less and slightly narrower routes.

Head-on encounters also have a somewhat higher fraction of exceptional encounters, but it decreased from 2.2% to 1.4% in the new situation. This is owing to the traffic separation zones, especially in area 2 because of the separation of the fairway.

Table 3. Numbers of exceptional crossing encounters in 2011 and in August 2013 – July 2014.

Area	2011	2013 -2014	Increase	Percentage exceptional encounters 2011	2013-2014
1	48	12	-75.0%	0.6%	0.2%
2	59	40	-32.2%	0.4%	0.3%
3	47	39	-17.0%	0.3%	0.2%
5	38	16	-57.9%	0.3%	0.1%
6	89	44	-50.6%	0.4%	0.3%
7	150	37	-75.3%	0.5%	0.2%
8	41	18	-56.1%	0.3%	0.2%
9	95	41	-56.8%	0.5%	0.3%
10	162	45	-72.2%	0.5%	0.2%
Total junction areas	729	292	-59.9%	0.4%	0.2%
Outside junction areas	1056	248	-76.5%	0.9%	0.4%
Route change area	1785	540	-69.7%	0.6%	0.3%

6 CONCLUSIONS

The numbers of normal and exceptional crossing, head-on and overtaking encounters, are in line with the objectives of the new route structure. There are relatively less exceptional crossing and head-on encounters, and encounters take place in designated junction areas. The overtaking encounters, however, seem to be tighter due to more dense traffic on the somewhat narrower traffic routes.

Overtaking encounters may still need additional criteria to determine really exceptional encounters, as a the domain criteria still returns a relatively large fraction of encounters as exceptional. Also, the used criteria do not seem to apply for approach areas, as these areas contain many exceptional encounters.

ACKNOWLEDGEMENT

The major part of the work was commissioned by the Dutch Ministry of Infrastructure and the Environment.

REFERENCES

Koldenhof, Y., Tak, C. van der & Glansdorp, C.C. 2009. Risk Awareness; a model to calculate the risk of a ship dynamically. Proceedings of "XIII International Scientific and Technical Conference on Marine Traffic Engineering", 112-119.

Tak, C. van der & Jong, J.H. de. 1996. Safety Management Assessment Ranking Tool (SMART). 8th International Symposium on Vessel Traffic Services.