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Examination of ships passing distances distribution in the coastal waters in order to build a ship probabilistic domain

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Abstract
This paper presents a study of ships passing distances in coastal waters based on data from the AIS. Examinations are designed also to work towards the development of probabilistic domain that is an area in which the navigator is trying to keep free from other vessels. This article has been hypothesized for the distribution of ships passing distances from which you can build a probabilistic domain. The article summarizes the studies for three types of ships: tankers, passenger ships and cargo vessels and is comparing the shapes of domains for each of them in three situations: overtaking, crossing, vessels on the opposite courses. Studies were carried out in the Gulf of Pomerania.

Introduction

One of the major concepts concerning the safety of navigation is the domain of the ship. Through the concept of ship domain must be understood a certain area around the ship that the navigator would like to keep free of other fixed and movable objects. Navigational situation can be considered safe as long as any other vessel or navigational obstacle does not exceed this area. The article presents statistical analysis of the distance at which vessels are passing each other on the study area, based on data from the AIS (Universal Ship-borne Automatic Identification System). The shape of the vessels domain was dependent on the type of ship, type of the passing situation and distribution of the CPA (The Closest Point of Approach) distances.

The concept of the ship domain for the first time was proposed by Y. Fujii [1] in 1960. While studying the vessel traffic at the sea near Japan he designated the area around the ship, the elliptical shape, where other ships were not allowed to exceed not to cause a dangerous situation. This area Y. Fujii called the ship domain. Since then, a number of domains of different shapes were built on the basis of the characteristics surveyed water areas. R. Śmierzchalski introduced the domain of a ship as a figure in the shape of a hexagon (Fig. 1a). P. Davis proposed to describe the danger area around the vessel by a domain shape of circles figure 1b.

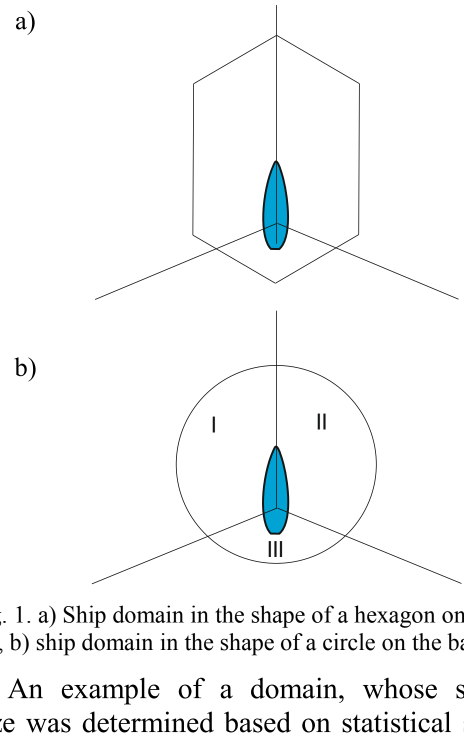

Fig. 1. a) Ship domain in the shape of a hexagon on the basis of [2], b) ship domain in the shape of a circle on the basis of [3]

An example of a domain, whose shape and size was determined based on statistical surveys is the domain determined by Elizabeth M. Goodwin (Fig. 2).

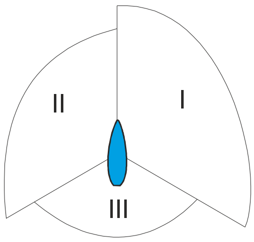

Fig. 2. Domain vessel divided into three sectors

On the basis of the COLREG *(Collision Regulations*) E.M. Goodwin setting a dangerous area around the ship has split it into three sectors:

Sector I (right sector) $0° \leq \theta \leq 112.5°$;
Sector II (left sector) $247.5° \leq \theta \leq 360°$;
Sector III (aft sector) $112.5° \leq \theta \leq 247.5°$.

Domain boundary in a given sector was determined at the intersection of density graph and straightforward three-point moving average:

$$E(x) = \frac{1}{3}\left[Y(x-1) + Y(x) + Y(x+1)\right] \quad (1)$$

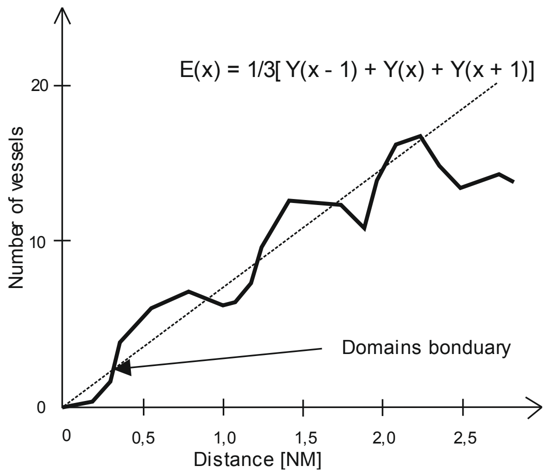

Fig. 3. The method for determining the domain boundary, own studies on the basis of [4]

Z. Pietrzykowski proposed designation of the shape of domains, based on expert studies with the use of artificial intelligence tools for the extraction and representation of navigators knowledge. The author introduced the concept of fuzzy ship domain

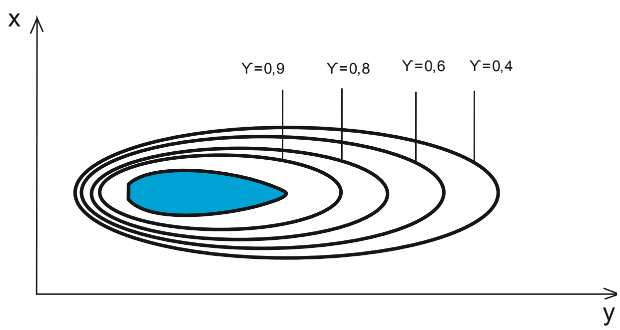

Fig. 4. Ship domain fuzzy, own work based on [5]

as an area around the ship that the navigator should maintain free from other units and objects, whose shape and size depend on the assumed level of navigational safety, understood as the degree of membership of a navigational situation for fuzzy set "dangerous navigation" [6]. Security level Υ is in the range from 0 to 1 (where 0 – is a very safe situation, 1 – is a very dangerous situation).

Description of the study area in the Baltic Sea

The study area includes the west-southern part of the Baltic Sea, extends from 54°N to 55°N latitude and 13°E to 14°E longitude. To eliminate the areas in which ships move in close to the tracks at fixed distances, i.e. narrow passages and approaches to ports, the study area have been cut out of places marked with red lines, shown in figure 5. The excised areas include Greifswalder Bodden Bay where ship traffic is narrowed because of the depth available, the next area is the approach to the port of Sassnitz.

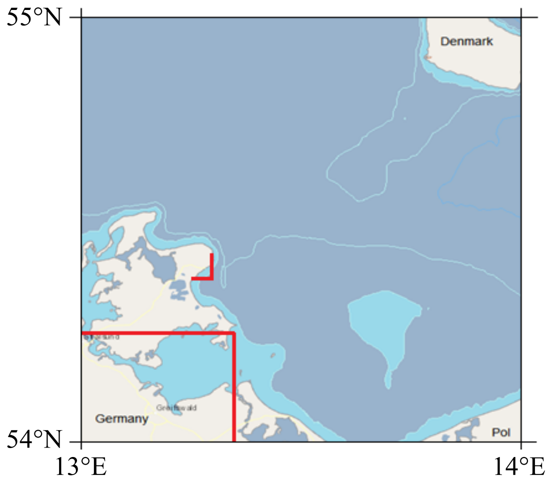

Fig. 5. The study area of the Pomeranian Bay

The method of research based on data from AIS

Universal Ship-borne Automatic Identification System is an automated tracking system used on ships and by VTS (*Vessel Traffic Services*) for identifying and locating vessels by electronically exchanging data with other nearby ships and VTS stations. AIS information supplements marine radar, which continues to be the primary method of collision avoidance at sea. Class A AIS unit sends information about the dynamic motion of the ship every 2 to 10 s while underway and every 3 minutes while at anchor. Dynamic data includes: MMSI number, navigation status, rate of turn, speed over ground, position accuracy, longitude, latitude, course over ground, true heading, time stamp. In addition, every 6 minutes Class A AIS unit sends static data which includes: MMSI number, IMO number, call sign, name, type of ship / cargo, dimensions of ship, type of position fixing device, vessel draught, destination, ETA at destination.

The surveys described in the article were made based on real data from the HELCOM (*Helsinki Commission*). Time between subsequent position of one vessel was about 4 minutes, for this reason to determine the exact CPA (*the Closest Point of Approach*) distance between two vessels, compaction algorithm was used. Statistical analysis included the period of one year 2008. Vessels are divided by type into:

a) passenger vessels;
b) tankers;
c) cargo vessels.

Other types of vessels such as pilot vessels, fishing vessels etc. were not analyzed because of the nature of their work, which enabled them close encounters with other units. Units of length greater than 60 meters with speed of at least 2 knots were chosen for examination to eliminate ships standing in the drift or at anchor. Close encounters between vessels have been divided due to the angular difference in the courses of both ships (ΔCOG):

- Crossing courses ΔCOG ϵ (170°, 190°);
- Overtaking ΔCOG < 67.5° υ ΔCOG > 292.5°;
- Opposite courses (ΔCOG > 67.4° ∩ ΔCOG < 170.1°) υ (ΔCOG > 189.9° ∩ ΔCOG < 292.6°).

Only those situations were analyzed where two ships at a distance of less than 2.5 nautical mile were passing each other.

The research

The study adopted the following hypothesis: Probabilistic domain can be built based on data from the distribution of the passing ships CPA. Close encounter distance depends on many factors, most of them have been omitted leaving only the type of vessel, type of collision situations and relative bearing to the ship which is passing. Navigator performing anti-collision manoeuvres or not performing any manoeuvres because of the assumption that the distance is safe behaves randomly, but also the conditions of navigation and manoeuvring characteristics and other factors influence the situation in navigation and because of that passing distances are random. Figure 1 shows the distributions in the form of histograms of ships encounters in 4 different directions. Combining distance values at a given level of probability (95%, 50%) areas in which the navigator avoids other vessels at a given level of probability can be identified.

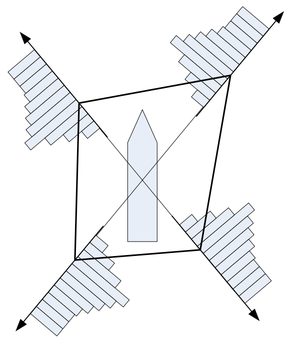

Fig. 6. Distributions of ships encounters distance in 4 directions

The paper also assumes a hypothesis about the distribution of vessels passing distance (Fig. 7). It was assumed that the distribution of passing distances *D* will have a maximum around the point *Dm* that is the distance over which most navigators will proceed clear of other vessels. Using this distribution and estimated distance *D*max it is possible to build a probabilistic domain. Using the assumed probability of exceeding a given distance, based on the identified distribution, the domain can be built on the assumed level of significance.

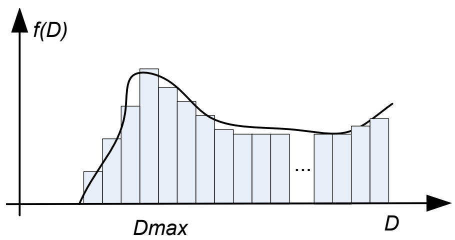

Fig. 7. Hypothetical distribution of vessels passing distances

At the given confidence level α in given relative bearing the domain can be calculated as:

$$1-\alpha = \int_{D\,\mathrm{min}}^{D_\alpha} f(D)\,\mathrm{d}D \qquad (2)$$

It is proposed that the first maximum of the function of distance can be regarded as the most common distance of passing vessels and the domain can be built as *D*max = max(*f*(*D*)), where *D* is the smallest distance of all local maxima.

Results

Close encounters between tankers and other vessels

At first, the results of designated hazardous areas for tankers are presented. There was a total number of 9555 tanker encounters with other vessels in the studied area. These encounters were divided into three situations: ships on crossing courses, overtaking, ships on opposite courses. To determine the domain shape, area around the vessel has been divided into 8 sectors (every 45°) due to relative bearing at CPA (Fig. 8).

I sector: 000° – 045°
II sector: 045° – 090°
III sector: 090° – 135°
IV sector: 135° – 180°
V sector: 180° – 225°
VI sector: 225° – 270°
VII sector: 270° – 315°
VIII sector: 315° – 000°

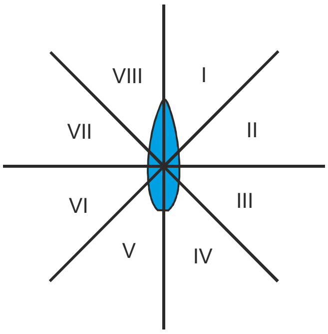

Fig. 8. Domains division by sector

Construction of domain shape was held together by linking distances (determined statistically domain boundary in a particular sector) plotted in the middle of each sector.

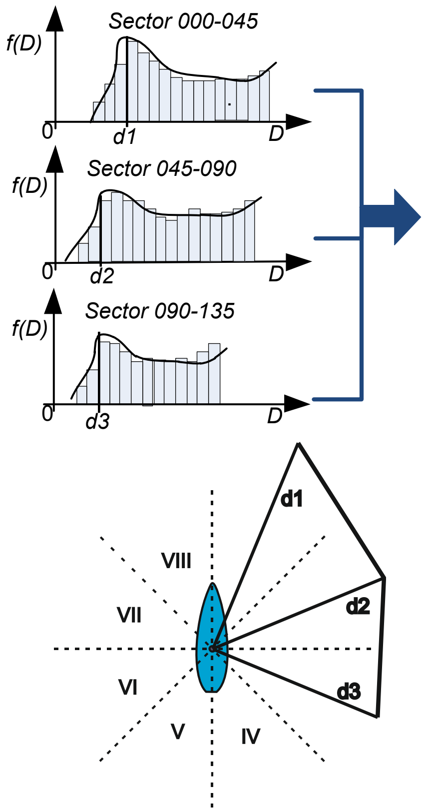

Fig. 9. Construction of a domain based on distance distribution in each sector

Tankers – situation on crossing courses

In year 2008 there were 2964 encounters found in the study area of ships on crossing courses, involving tankers, where passing distances were less than 2.5 mile. Figure 10 shows an example of the distribution of distances at which the tankers were passing other vessels at relative bearing between 000 – 045°. The domain boundary was designated at a value of 0.81 NM.

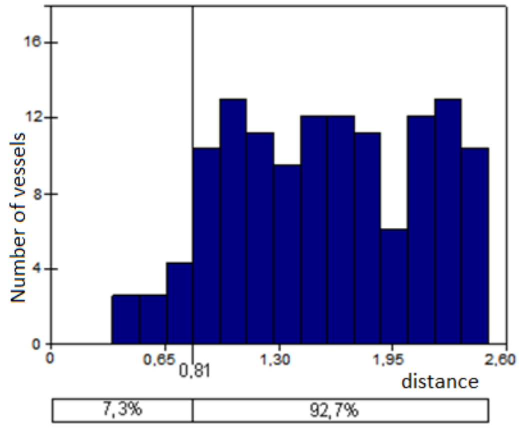

Fig. 10. Example of distribution of vessel passing – crossing situation, determination of domain boundary

Figure 11 shows the shape of the domain calculated for tankers in crossing situation with other vessels. The figure describes the boundary distance of each sector of the domain, and the likelihood of passing at a smaller distance than the distance of the border.

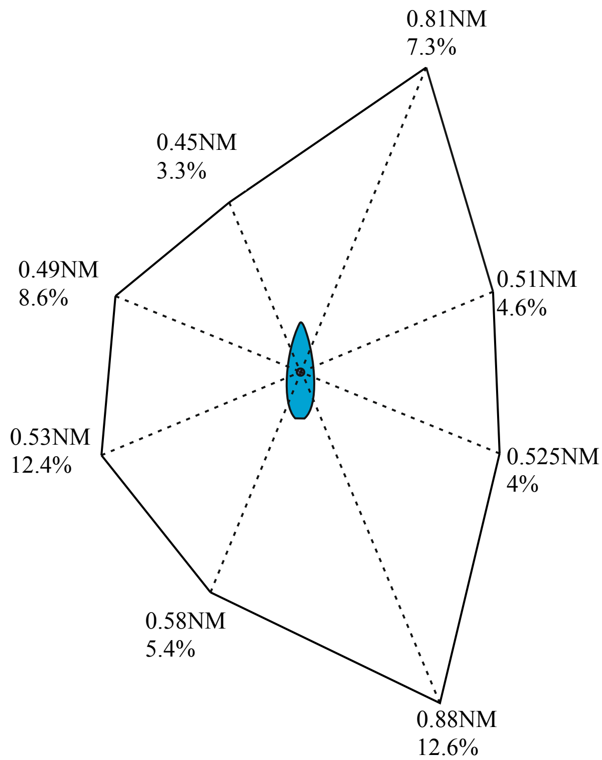

Fig. 11. Domain shape on the basis of distributions of distances (tankers with other vessels), crossing situation

Tankers – overtaking

In 2008 in the study area there were 2896 overtaking situations involving tankers, in which the encounter distance was less than 2.5 miles. Figure 12 shows the shape of the domain, its boundary limits, and the probability of vessel passing at a smaller distance.

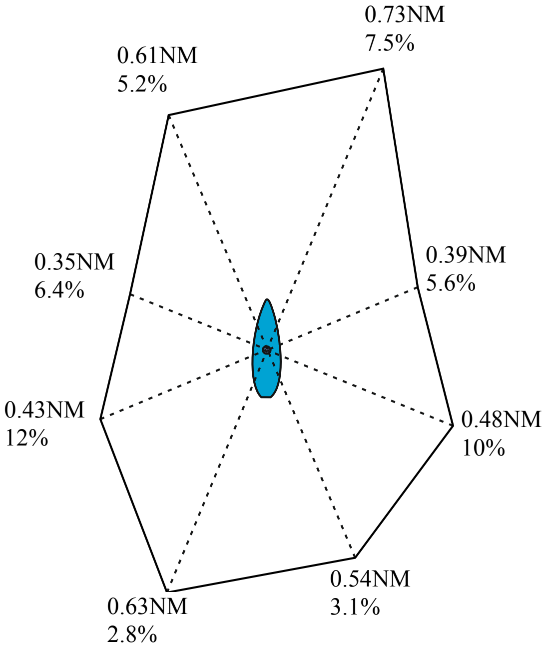

Fig. 12. Domain shape on the basis of distributions of distances (tankers with other ships) – overtaking

Tankers – head on situation

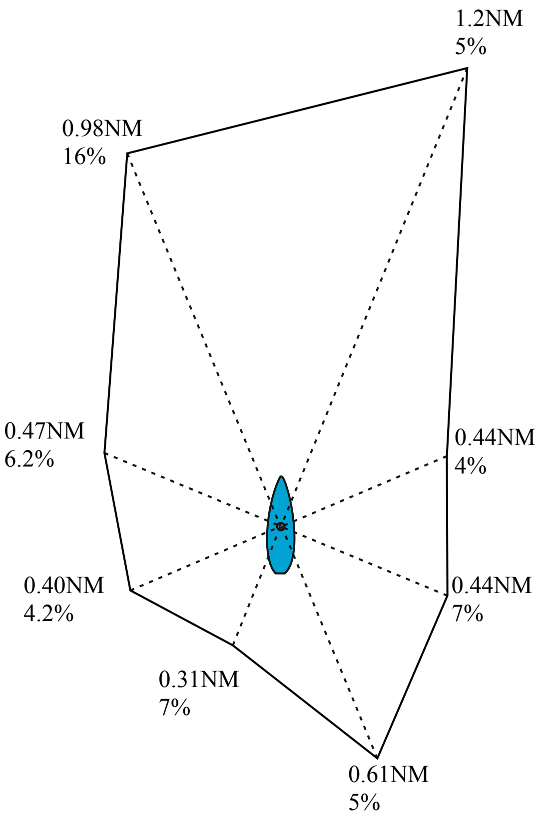

Fig. 13. Domain shape on the basis of distributions of distances (tankers with other ships) – head on situation

In 2008 in the study area there were 2896 head on situations involving tankers, in which the encounter distance was less than 2.5 miles. Figure 13 shows the shape of the domain, its boundary limits, and the probability of vessel passing at a smaller distance.

Close encounters between passenger vessels and other vessels

For passenger vessels moving in the study area 12,122 cases were found in which they were passing other vessels on a distance of less than 2.5 mile in year 2008.

Passenger ships – situation on crossing courses

In 2008 in the study area 6008 cases of vessels crossing courses situations, in which passenger ships were passing at a distance of less than 2.5 miles by the other ships. Figure 14 shows the shape of the domain statistically calculated based on the passing distance distribution.

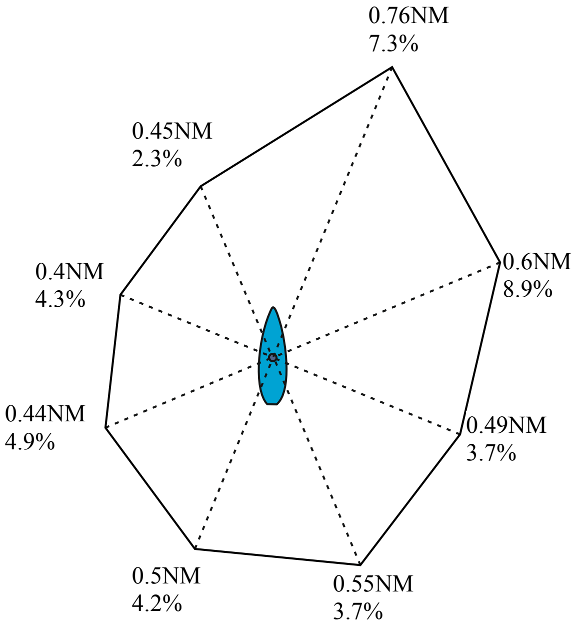

Fig. 14. Domain shape on the basis of distributions of distances (passenger vessels with other ships) – crossing situation

Passenger vessels – overtaking

In 2008 in the study area there were 3244 overtaking situations involving passenger vessels, in which the encounter distance was less than 2.5 miles. Figure 15 shows the shape of the domain, its boundary limits, and the probability of vessel passing at a smaller distance.

Passenger vessels – head on situation

In 2008 in the study area there were 2870 head on situations involving passenger vessels, in which the encounter distance was less than 2.5 miles.

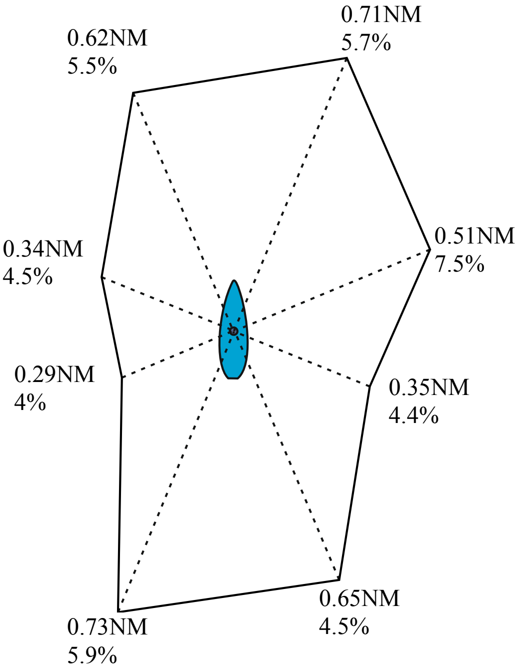

Fig. 15. Domain shape on the basis of distributions of distances (passenger vessels with other ships) – overtaking

Figure 16 shows the shape of the domain, its boundary limits, and the probability of vessel passing at a smaller distance.

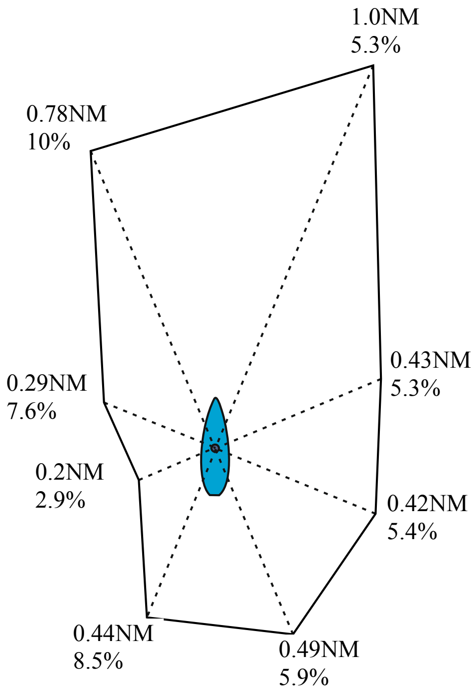

Fig. 16. Domain shape based on distributions of distances (passenger vessels with other ships) – head on situation

Close encounters between cargo vessels and other vessels

For cargo vessels moving in the study area 33,002 cases were found in which they were passing other vessels on a distance of less than 2.5 mile in year 2008.

Cargo vessels – situation on crossing courses

In 2008 in the study area 11,493 cases of vessels crossing courses situations, in which cargo ships were passing at a distance of less than 2.5 miles by the other ships. Figure 17 shows the shape of the domain statistically calculated based on the passing distance distribution.

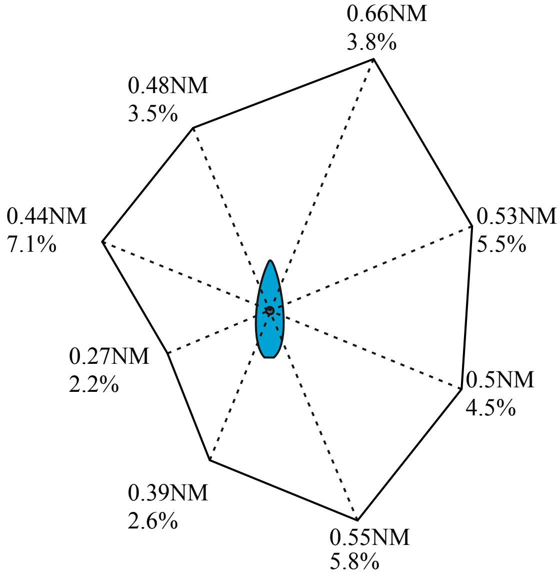

Fig. 17. Domain shape on the basis of distributions of distances (cargo vessels with other ships) – crossing situation

Cargo vessels – overtaking

In 2008 in the study area there were 12,177 overtaking situations involving cargo vessels, in which the encounter distance was less than 2.5 miles. Figure 18 shows the shape of the domain, its boundary limits, and the probability of vessel passing at a smaller distance.

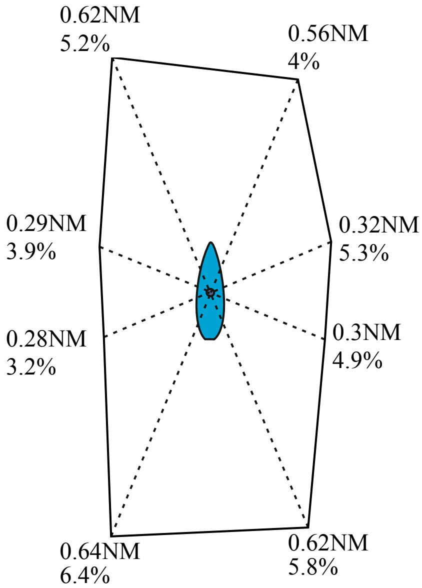

Fig. 18. Domain shape on the basis of distributions of distances (cargo vessels with other ships) – overtaking

Cargo vessels – head on situations

In 2008 in the study area there were 9392 head on situations involving cargo vessels, in which the encounter distance was less than 2.5 miles. Figure 19 shows the shape of the domain, its boundary limits, and the probability of vessel passing at a smaller distance.

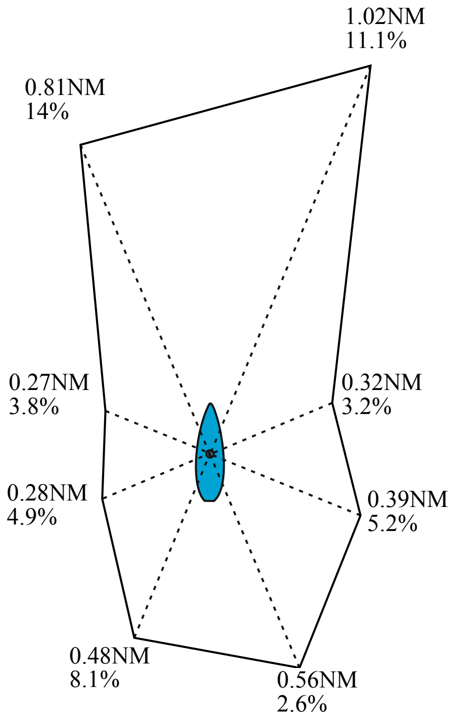

Fig. 19. Domain shape based on distributions of distances (cargo vessels with other ships) – head on situations

Conclusions

The article presents the concept of constructing a probabilistic ship domain based on the minimum distance at which vessels are passing each other in the study area. The assumption about the occurrence of a maximum on the distribution of ships minimum passing distance which can be considered as a boundary of ship probabilistic domain has been proven on the basis of large sample of vessels positions (1,491,678) engaged in navigation in the Gulf of Pomerania.

Based on the results, it can be concluded that the shapes of a domain for each situation do not change depending on the type of a vessel. Minor differences occur in the domain boundary distances. The smallest are for cargo ships, which include a large number of small units such as general cargo ships. Greater distances of domain boundaries were determined for tankers carrying hazardous materials, which are usually larger and faster vessels than cargo ships.

Ship domains shape will tell us what is the real distance of collision incident on a given relative bearing and this will allow us to improve our collision incidents models.

Further research should be conducted towards the construction of domains for different sizes of ships and their dependence on the conditions of navigation.

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