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Publication date
2021

Document Version
Final published version

Published in
Proceedings of 'Siga2 Maritime and Ports, The Port and Maritime Sector: Key Developments and Challenges, 5-7 May 2021'

Citation (APA)
Altan, Y. C., & Meijers, M. (2021). Ship Domain Variations in the Strait of Istanbul. In *Proceedings of 'Siga2 Maritime and Ports, The Port and Maritime Sector: Key Developments and Challenges, 5-7 May 2021'* (pp. 14). http://www.gdmc.nl/publications/2021/Ship_Domain_Variations_Strait_of_Istanbul.pdf

Ship Domain Variations in the Strait of Istanbul

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Abstract

The aim of this study is to analyze and understand the clear distance of the ship encounters in the Strait of Istanbul. According to a GIS analysis, the site-specific ship domain is calculated. The maritime traffic is gathered from long-term AIS data. The Spatio-temporal analyzes are conducted with the aid of geographic database management software. The output of the analysis gives the distance between the ships during their encounters. Based on the clear distance, statistical analysis is conducted for creating the shape and size of the ship domain. Besides the clear distance, relative velocity, ship sizes are also recorded to find out the inside information for the ship domain.
The size and shape of the ship domain are found and the effect of parameters such as relative velocity and ship length on the ship domain is discussed. The parameters that are affecting the ship domain are discussed and inside information is given.
The ship domain variations are found out for the Strait of Istanbul. The relationship between the parameters and the ship domain can give inside information for congested waterways.

Keywords: ship domain, AIS, big data analysis, Strait of Istanbul, vessel movement analysis, massive movement data, restricted waterways

Introduction

Waterway transport constitutes 90% of the world trade, and cargo volumes represent a higher increase than the world economic growth rate (Kaluza et al., 2010). Also, the policy initiatives such as Green Deal encourage usage of waterway transportation in order to decrease the emission rates due to freight transport. As a result, the traffic load on waterways will increase and this increase will especially

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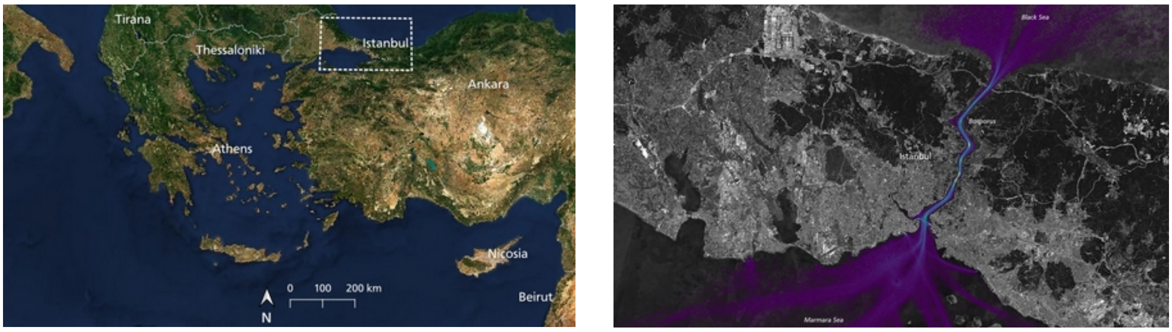
affect the narrow passages such as straits and inland waterways due to restricted navigational conditions.

In this study, the complex ship encounter mechanism is studied via long-term traffic data analysis. The end-product of this analysis will give us the general ship domain and the variations of ship domain according to parameter changes such as ship speed, length, relative velocity, day/night condition and ship type in the Strait of Istanbul (SoI), cf. Figure 1. During the analysis one month traffic data for August 2015 is used and the statistical calculation methodology of the ship domain is conducted with some certain improvements to reflect the real navigational conditions. One of most important ones is the usage of physical sizes of the ships to find out the clear area between the ships. It allows to understand the behavior of the captains during an encounter. Because, during the encounters captains make their assessments according to ship's physical sizes and clear distance between the ships perimeter rather than ship centers.

The remaining part of this paper is organized as follows. Section 2 gives related work. Section 3 explains the methodology, the source of data and tools used for processing the data. Section 4 presents results with associated discussion. Finally, Section 5 covers the conclusions of the study and describes future work.



(a) (b)

Figure 1: (a) Study area: Strait of Istanbul (Bosporus) (b) Vessel movement intensity in the Strait of Istanbul during August, 2015

Related work

The traffic density increase will have a direct effect on the number of encounters which can cause risky situations. The approaches to evaluate the encounter risk level of the waterway can be classified in two sub-groups. One of the sub-groups use the collision diameter to quantify the encounter of the ships (Altan and Otay, 2018; Christian and Kang, 2017; Kujala et al., 2009; Lušić and Čorić, 2015; Montewka et al., 2010; Pedersen, 1995; Silveira et al., 2013). The physical contact distance between the ships are calculated for the given approach geometry and with the aid of traffic data, the collision frequency of the waterway is calculated. The other group uses the risky encounter of the ships as near miss (Yoo, 2018; Zhang et al., 2016, 2015) and ship domain (Hansen et al., 2013; Hsu, 2014; Pietrzykowski and Uriasz, 2009; Szlapczynski et al., 2018; Szlapczynski and Szlapczynska, 2017; Wang et al., 2009; Wang and Chin, 2016).

The advantage of the collision diameter approach is its robust calculation methodology. It only depends on the geometric conditions of the two ships that are approaching each other (Altan, 2019). The disadvantage of the collision diameter is its under-estimation of the risky encounters in day-to-day navigation conditions. This lack is covered by the risky encounter approaches. However, application of risky encounter calculation methodologies is not straight forward. The calculation methodologies are changing according to certain parameters (such as traffic density, relative velocity, sizes of the ships, etc.) and have to be investigated according to site-specific navigational conditions.

When the risky encounter methodologies are tried to be applied to congested waterways the complications increase. In the case of the Strait of Istanbul (SoI), the local traffic creates nearly 75% of the total passages (Altan and Otay, 2017). Thus, they dominate the traffic density and their familiarity to the waterway affects the behaviour during an encounter. On the other hand, transit vessels have the right of way during an encounter. In addition to these facts, there is strong current variation along the SoI. This situation shows that it is not straightforward to calculate the risky encounters of the vessels in the SoI.

Considering the listed complications, this study focused on developing the basis for the risky encounter calculation methodology. As a first step the ship domain for the SoI is calculated based on statistical methods and long-term AIS data.

Methodology

We perform a statistical calculation of the ship domain. Using geographic information technology and AIS data, we present our methodology to calculate how the space around ships is used (or kept free) during their movements. The approach is similar to the known approach of Hörteborn et al., (2018), but differs in the sense that it takes into account the real size of the ships.

The Automatic Identification System (AIS) broadcasts navigation-related information over Very High Frequency (VHF) radio and can be received as National Marine Electronics Association (NMEA) sentences. When NMEA sentences are parsed, AIS messages related to navigation are obtained. The source of the navigation-related messages can be ship-based or shore-based and messages can be received by ships, coastal stations and satellites over AIS devices.

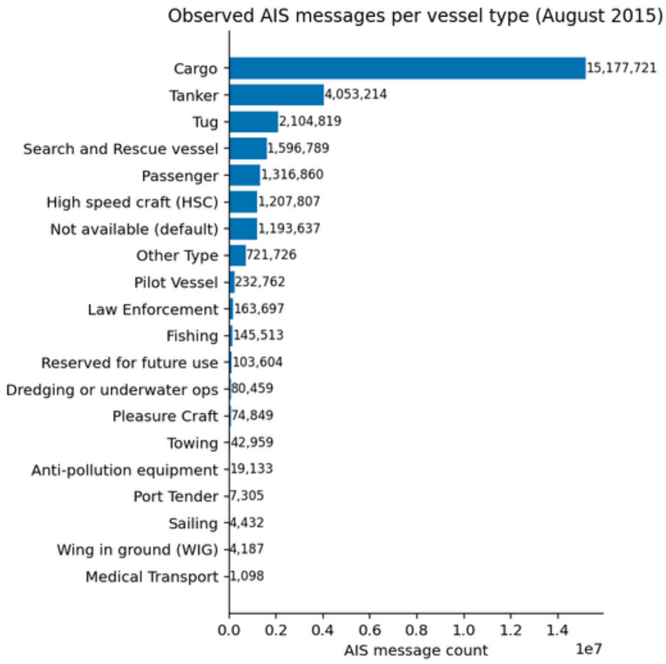


Figure 2: Number of AIS messages (position reports - message types 1, 2, 3) received in the study area during August, 2015, per ship type

There are 27 different types of AIS messages. Type 1, 2, 3 and 5 messages transmitting maritime traffic information are included in the analysis. The first three types are the dynamic messages carrying automatically updated position and motion information of a ship. Type 5 messages include static data describing the vessel type and its dimensions. For the SoI AIS messages are gathered by means of an VHF antenna and a receiver. Figure 2 shows the coverage of the AIS messages. The messages that are used in this study were collected during August 2015.

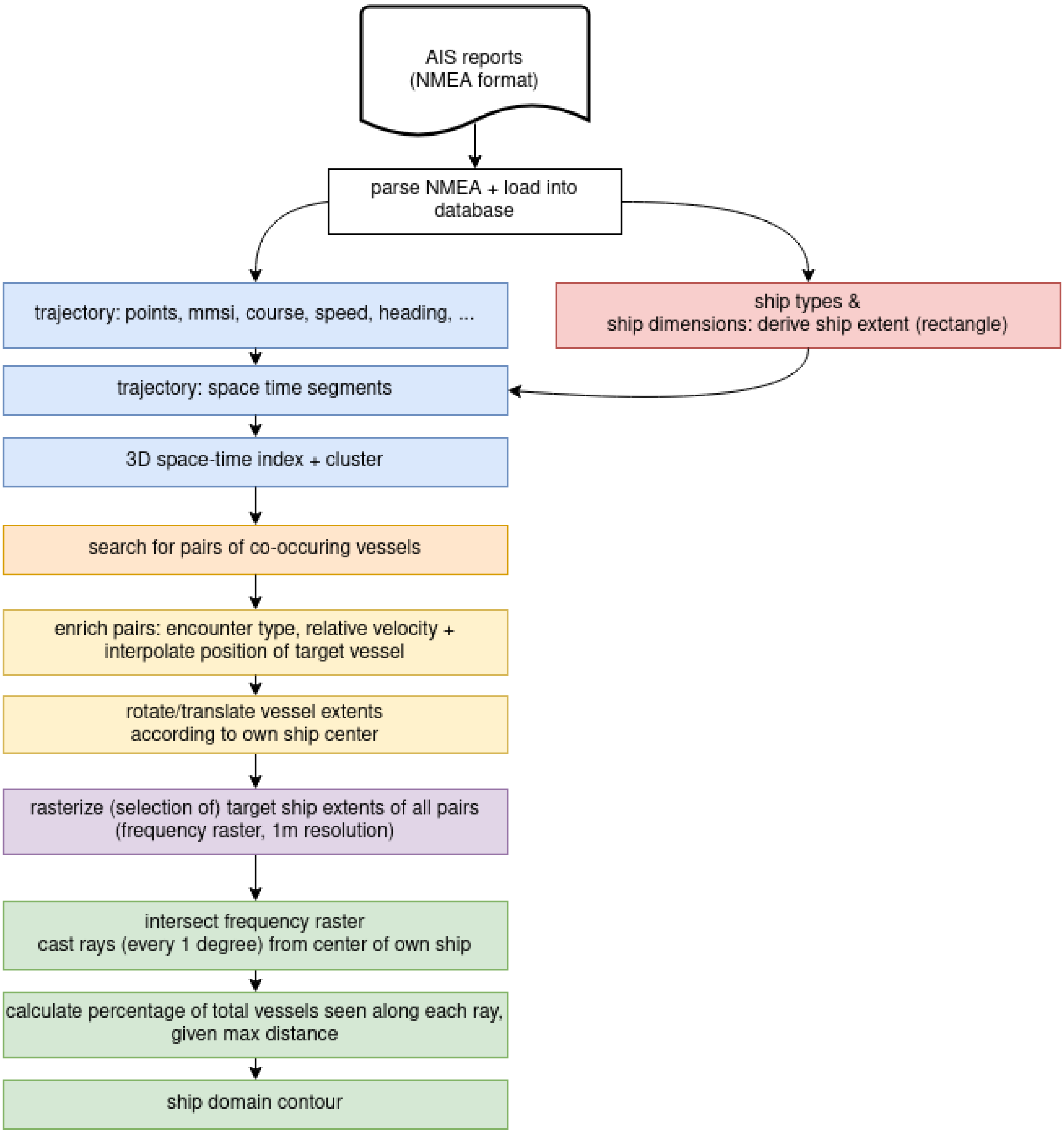


Figure 3: Analysis workflow overview

The received messages were stored in the standardized NMEA text format and are parsed (using Python) and loaded in a geographic database management system (PostgreSQL extended with PostGIS) for analysis (Figure 3, white boxes).

Using the position, the ship identifier (MMSI) and timestamp (which was added by the receiving station) obtained from the position reports (AIS type 1,2,3 messages), we construct a trajectory for each vessel and store this as 3D line segments, where two dimensions are used for the position (x, y) and the third dimension is the time in seconds since January 1970 (unix timestamp). A segment is only created if it looks reasonable (i.e. <44 sec time duration and <800m position difference between start and end point and occuring in the study area), this filters out incorrect or incomplete position messages. Per segment we also have access to the original movement attributes in the position report, like course over ground, speed and heading of the ship. The 3D segments are then indexed and physically clustered on disk using an R-tree, allowing to search efficiently for space-time segments that occur close in space and time (Figure 3, blue boxes; this step has been executed fully within the database using SQL).

While iterating over all starting points of all segments, a 3D square positioned with its center on the starting point of the segment is created, where the z-coordinate is set to the time of the space-time segment. We used a size of 5x5km for each search square. All segments intersecting this square for ships in the vicinity of the own ship are found. The ships in the vicinity that we find are what we call the ‘target ships’. This leads to a new database table with pairs of own and target ships that have been in each other’s vicinity (Figure 3, orange box, executed within the database, using SQL).

The table of co-occuring vessels forms the basis for the further analysis. Per found ship pair, we enrich the table with their relative velocity, the encouter type (head-on, overtaking, crossing) and we interpolate the position of the target ship and its GPS receiver to the time of the own ship.

Subsequently, we use the information from the AIS static reports (type 5 messages) to get a description of the rectangular geometry of the ship (as the GPS receiver giving the location of the vessel might be placed excentric on the ship). We orient (rotate) this rectangle using the course over ground value found in the position report of the target ship. We have ignored the pairs, for which no ship size information has been present.

Next, we translate and rotate the geometry of all target ships their oriented rectangles to a local coordinate system, where the center of the own ship is defining the new local origin and the course over ground of the own ship is set northwards, while preserving the relative position of the ship pair its geometries (Figure 3, yellow boxes; this step has been executed with SQL in the database).

Relevant oriented rectangles of the target ships (in the local coordinate system of the own ship, with the course over ground of the own ship set to north) are rasterized to a count raster having 1x1m cell resolution. Note that for this raster we can either use all ship pairs, or first make a subselection to analyse if there is an influence of this subset on the ship domain contours (see Results and discussion). From the center of the raster (which corresponds with the center of all own ships), we cast finite rays outwards, with an angular resolution of 1 degree, while setting a maximum distance on the ray (1km, 2.5km). We intersect every ray with the raster cells, obtaining a count and position for every intersection. Moreover, we record for every point to which ray the point belongs. This then allows us to compute a cumulative distribution of the counts along each ray, giving us a description of how space around the own ship is used along this ray. By thresholding the distribution along the ray (e.g. 10% and 25%) and connecting the locations found in a circular manner, we obtain the ship domain contour. Finally, we can visualize the obtained ship domain contours (Figure 3, green boxes; this step has been executed using GDAL for rasterization, the functionality “Profiles from Lines” provided by Saga GIS, a custom Python script to compute the cumulative distribution and contours and QGIS for visualizing the resulting information).

Results and discussion

By using the long-term AIS data analysis, the occupied area around the own ship with the usage frequency is determined. According to usage percentage along the constructed rays the ship domain is developed. The main outcome of the analysis shows a ship domain with an ellipsoid shape.

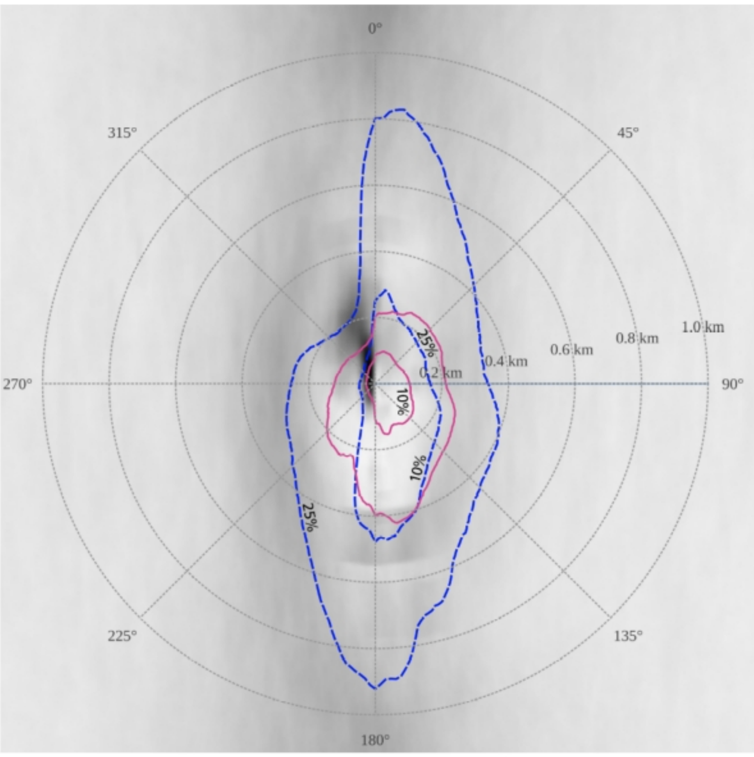


Figure 4: Influence of maximum search radius on the ship domain contours for 10% and 25% usage (maximum search radius for blue: 2.5km, red: 1.0km)

The search radius around the own ship determines the number of encounters. Two different search radii are used for the general ship domain analysis. Figure 4 shows the influence of choosing the parameter of the maximum search radius. Blue lines and red lines indicate the search radius for the target ships with a value of 2.5km and 1.0 km, respectively. As explained in the methodology section 10% and 25% usage along the rays are indicated in the figure. Shapes are similar for both 2.5km and 1.0

km search radius. The ships approaching from starboard side keep more distance when compared to ones that are approaching from port side which is in alignment with the Collision Regulations (COLREG).
Hörteborn et al., (2018) used 5% for the inner limit of the ship domain, since it represents 2σ in a normal distribution. When 5% usage is found for the SoI, the ship domain is a quite small polygon around the origin. There are two explanations for this outcome. One of them is the congestion level of the SoI. Due to congestion ships are passing closer to each other compared to open sea conditions. The second one is the usage of physical dimensions of the ships at the ship domain methodology. Since we use the physical sizes of the ships they occupy larger areas in the search radius. Also, the pair of own ship and target ship will appear more than once in the resulting raster for each pair when compared to representing each target ship with just one point. As a result 5% usage will be closer to the own ship. With these outcomes, the following results are found for 1.0km search radius and 10% and 25% usage areas.

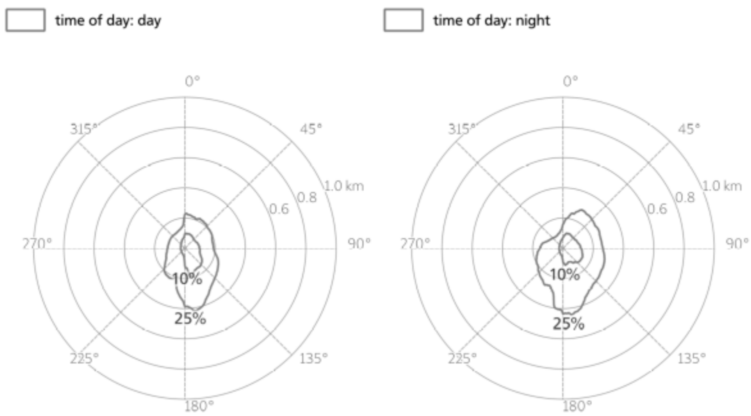


Figure 5: Day versus Night.

The first parametric analysis is the day/night condition. In the analysis, day and night are chosen as 07h00-19h00, 19h00-07h00 next day, respectively. As can be seen in Figure 5, during day ships keep less distance than during the night. During the day time ship domain displays a more ellipsoid shape when compared to night time's circular shape. The result indicates that captains' clear distance changes according to visibility conditions. Also, we suspect that during the day time local ships are traveling more frequently and their familiarity to the waterway decreases the clear distance between the ships.

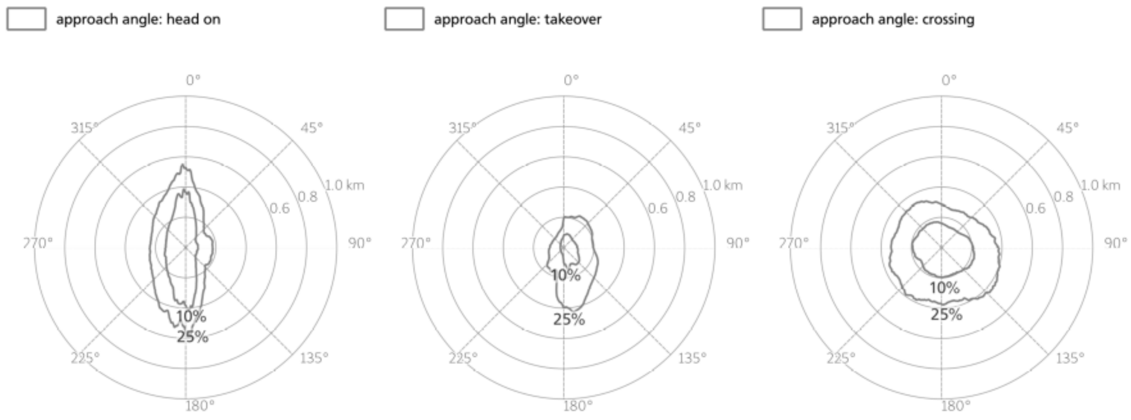


Figure 6: Approach angles: crossing, takeover, head-on (ΔCOG).

The third parametric analysis is conducted for the approach types according to Course Over Ground difference (ΔCOG) as listed below (in alignment with Chang, Hsiao and Wang, 2014):

- Head-on: 170° < ΔCOG < 190°;
- Overtaking: 0° < ΔCOG < 67.5° or 292.5° < ΔCOG < 360°;
- Crossing ΔCOG outside the range of the above cases.

Figure 6 shows that the encounter type changes the shape and size of the ship domain. Opposite from head-on encounter, takeover vessels move back to their original lane after takeover has finished. Crossing vessels show a circular pattern for the ship domain.

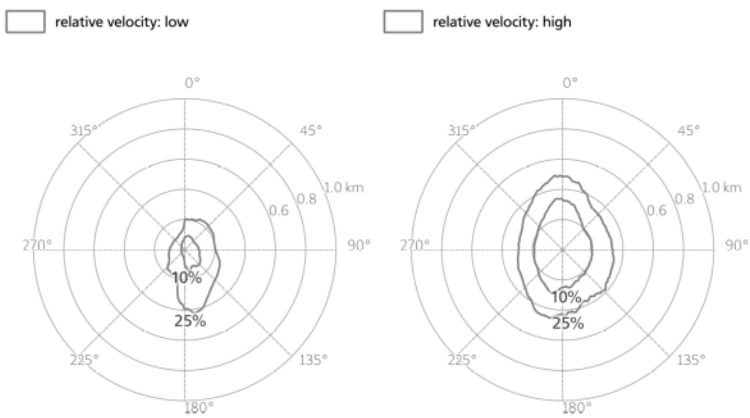


Figure 7: Relative velocities.

The vessels are approaching to each other according to their relative velocities. Therefore, it is expected that the relative velocity changes the risk perception during the navigation. In this analysis two different relative classes are used as low relative velocity: <= 14.4 knots and high relative velocity > 14.4 knots, with relative velocity defined as in Equation 1, (Silveira et al., 2014).

$$\sqrt{{v_{own}}^2 + {v_{target}}^2 - 2 \cdot v_{own} \cdot v_{target} \cdot \cos(cog_{own} - cog_{target})} \quad (1)$$

As Figure 7 clearly shows vessels with high relative velocity keep more distance, than vessels with low relative velocity.

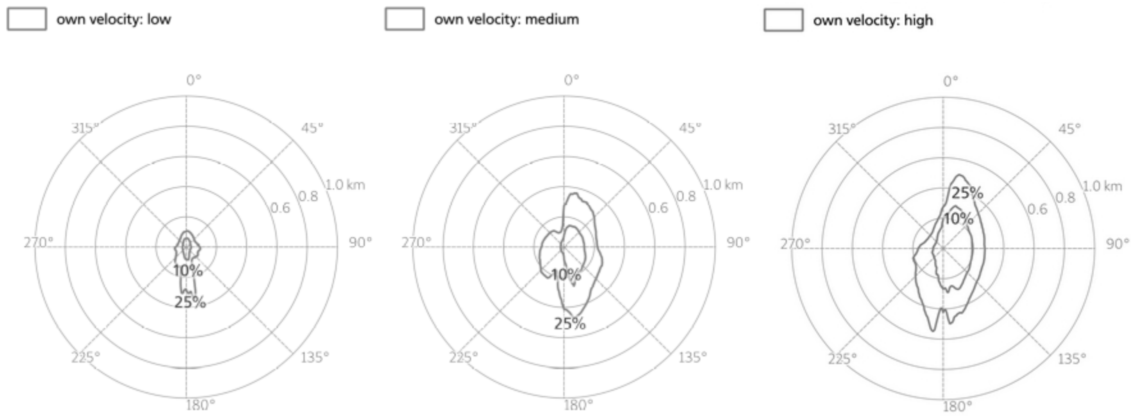


Figure 8: Own velocities

Similar to relative velocity, own ship's velocity affects the risk perception. To analyze the own ship velocity effect, three different groups are created as given:

- low: speed < 5.6 knots;
- medium: 5.6 knots <= speed < 10.2knots;
- high: speed >= 10.2 knots.

Figure 8 shows that as the own ship speed increases not only the size of the ship domain increases but also the pattern of the domain changes. This change can especially be observed as an increase of the ship domain at the bow part clearance area.

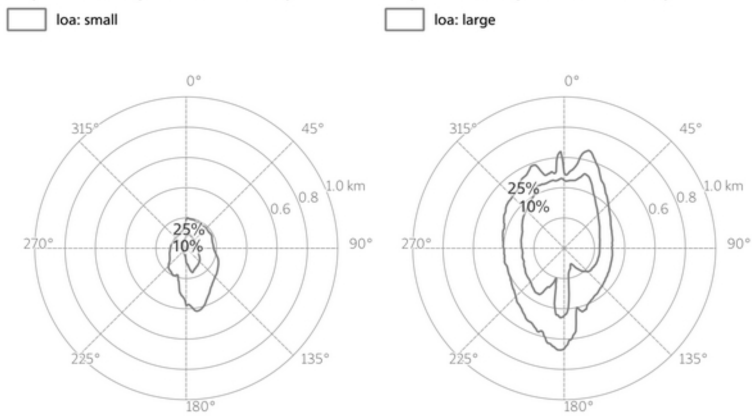


Figure 9: Length Over-All (LOA)

The effect of the ship size on ship domain is analyzed based on the Length Overall (LOA) of the vessels. Therefore two groups with small LOA <= 157m and large LOA > 157m are defined. As given in Figure 9, the LOA of the own ship affects the size and shape of the ship domain. For large LOA, at 10% usage area there are two notches at the stern side of the own ship. The main reason is the ships passing from the stern part of the ships keep away from the large ship's wake zone. Also, the ship domain for large LOA, represents a more clear area in the bow part of the own ship. It shows that ships do not prefer to pass from the bow side of the ship when the own ship's LOA is large.

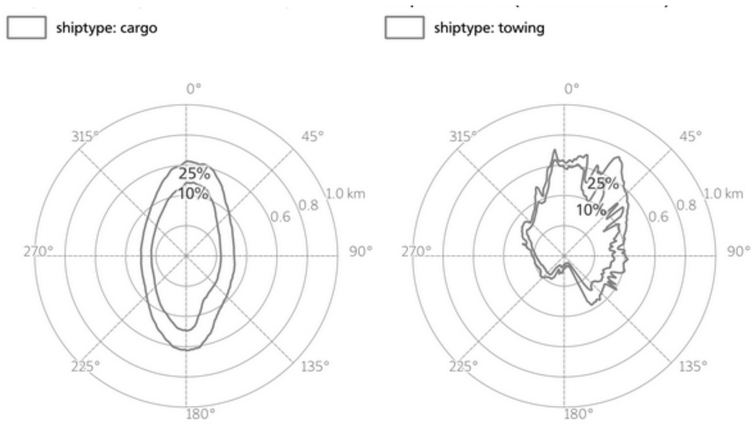


Figure 10: Vessel Type: Cargo versus Towing

As the last parametric analysis is conducted for the ship type as cargo and tug boats (Figure 10). The ship types are determined according to shiptype information from static AIS messages. The shiptype with 31 and 32 is taken as towing and between 70 and 79 is taken as cargo. Ship domain is found as a nearly perfect ellipsoid shape for cargo, with minor and major axis length for 10% and 25% of 400m by 1,000m and 600m by 1,200m respectively. Towing vessels show big differences according to their position with respect to the target ship. When towing vessels are at the front of the target ship they keep close to target ships but when they are the stern part they keep away from the target ship. Also, 10% and 25% showing close lines which indicates they are showing similar behavior during their encounters.

Conclusions

We have given a ship domain definition by analysing large volume of AIS data for different parameters (day/night condition, approach angle, relative velocity, own velocity, LOA and ship type). An important contribution is that in the analysis we consider the space the vessels occupy on the water way by taking into account their physical size. The outcome of the encounter analysis shows that the ship domain shape and size changes according to navigational conditions during the encounter.

The comparison between day and night shows that visibility has a limited, but noticable effect on the ship domain. The approach angle of the vessel pairs has an influence on the size and shape of the ship domain. The domain follows an ellipsoid shape for head-on and takeover encounters, while a circular pattern is observed for crossing encounters. According to parametric analysis, the risk perception is changing with the speed of the ships. One of the analyzed parameters is the own ship speed, the other one is the relative velocity of the ships. The analysis shows that ship domain is sensitive to these parameters.

Unlike the earlier result of Hörteborn, et al., (2018), we found that LOA is affecting the ship domain in terms of size and shape. Target ships keep more distance to ships with larger LOA. Also, navigational patterns are different when compared with small LOA ships. One more important effect on the ship domain in terms of size and shape is observed at the ship type. The ship domain around the cargo ships is ellipsoid however, for the tug boats it is a complex shape.

Although not looked at in detail in this study, the maximum radius to search for close vessels has an effect on the final ship domain its size (the larger the radius, the larger the size of the found ship domains). The visual comparison that we carried out of 2.5km and 1.0 km search radius, did not show that the shapes of the ship domains differ enormously. However, a more in-depth analysis should be carried out what is the effect of the search radius parameter in connection to the geography of the study area (is it different for a different location, what is the correct search radius).

To understand the ship domain and parametric effect further analysis can be conducted with combined parameters (e.g. analyse the combination of large LOA combined with approach angle, in comparison with small LOA plus approach angle). The result of the analysis will help to understand the parameter clusters that affect the ship domain. With the usage of these clusters a further analysis can be conducted for the risk level of the encounters.

In addition to combined parameter analysis, using the ship domain risky encounters can be quantified and we can find the hotspot locations on the water way via AIS data. The data model of ship pairs we have used also keeps for every pair of ships the original location on the water way. Those pairs for which the target ship occurs inside the ship domain contour give the locations for further investigation. Last but not least, the methodology can be applied to other waterways to make comparative analysis.

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