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The Collision Risk Management Method for Ships Navigating on Coastal Waters Based on Ship Domain and Near-Miss Concept

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Abstract:

Purpose: *The purpose of the paper is to present an innovative method of identification of navigational near-misses on the basis of a probabilistic domain, which can be used to assess the safety of navigation and to discover places potentially dangerous for navigation.*
Design/Methodology/Approach: *Probabilistic domain construction based on a large amount of AIS data in a selected navigational area.*
Findings: *In order to build and develop methods to assess the safety of navigation, ship probabilistic domains for three types of vessel encounter situations have been determined based on the AIS traffic monitoring data. Domains have been constructed for vessels moving in open waters with high traffic density in the Southern Baltic Sea.*
Practical Implications: *One of the most important concepts concerning the safety of navigation at sea is the ship domain. The authors believe that data from vessel monitoring systems can be used to determine the limits of distances between passing vessels that are characteristic of specific water areas and fully take into account all factors influencing navigational decisions.*
Originality/Value: *The novelty presented in the article is the method of navigational near-misses identification based on the probabilistic ship domain, which is universal for all vessels in a selected area.*

Keywords: *Ship collision, navigational risk management, ship domain, AIS data analysis, near-miss of collision.*

JEL codes: *C55, R40.*

Paper Type: *Research Paper /Case Study.*

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1. Introduction

One of the most important concepts concerning the safety of navigation at sea is the ship domain. The authors believe that data from vessel monitoring systems can be used to determine the limits of distances between passing vessels that are characteristic of specific water areas and fully take into account all factors influencing navigational decisions. In order to build and develop methods to assess the safety of navigation, ship probabilistic domains for three types of vessel encounter situations have been determined based on the AIS traffic monitoring data. Domains have been constructed for vessels moving in open waters with high traffic density in the Southern Baltic Sea. The purpose of the paper is to present an innovative method of identification of navigational near-misses on the basis of a probabilistic domain, which can be used to assess the safety of navigation and to discover places potentially dangerous for navigation.

Despite large investments in technical equipment and the improvement of training of navigators, there is a lack of downward trend in navigation accidents in the Baltic Sea, which is a highly disturbing phenomenon. Ship collisions currently account for 10-20% of all marine accidents (EMSA, 2017) the percentage depending on the water area, the definition of collision between ships given in the source, and the effectiveness of minor incidents reporting. Their number is strictly correlated with the restrictions imposed due to the available manoeuvring area, traffic congestion in ship routes intersections and navigational conditions. The majority of accidents involving ships in the Baltic Sea occur in the Gulf of Finland, along the coasts of Sweden and Denmark, and in particular in the Danish Straits. Marine accidents can have catastrophic consequences, especially if passenger ships are involved.

Accidents at sea may also have a different impact on human life (Ceyhun, 2014). For decades, the European coast has suffered from the catastrophic effects of pollution caused by oil and petroleum spills from ships. Taking into account the characteristics of the Baltic Sea as a closed sea, with a long period of water exchange of up to 40 years (Osvath *et al.*, 2001), chemical spillage causes much more environmental harm than leakage of the same amount of substances in the open sea. The real and potential economic costs of marine accidents and minor scale incidents in the Baltic Sea waters are enormous.

Safety management systems based on risk assessment methods are the most advanced tools for improving and controlling safety in various areas of human activity. The most commonly used measure of the safety of navigation on a given water area is the ships accident rate. Statistics on ship traffic and navigation accidents can be used to monitor and manage safety (Kristiansen, 2013). In the paper, the AIS (Automatic Identification System) was used to assess safety by identifying dangerous situations between ships. The system allows not only monitoring of ship traffic, but also research on the basic processes governing the movement of vessels on a given water area.

Considering that despite high vessel traffic density, the number of accidents registered is too small in relation to the statistical assessment of navigational safety in the Baltic Sea, the article presents a method of navigational safety assessment based on navigational near-misses. Recently, many models have been developed working on AIS data, which, based on simple traffic density statistics and historical data on navigational incidents, determine the probability of an accident in the chosen area (OpenRisk, 2018). A near-miss is usually defined as an event or series of events that could potentially lead to an accident, but because of the preventive action the accident does not occur or its effects are negligible. The study assumes that by analysing data on vessels movement from the AIS, navigational near-misses can be determined and the relation between a near-miss and an accident can be identified.

2. Definition of Causes of Navigational Near-Misses

According to the analysis of the accident carried out by Baker C.C. (Kuan, 2004), about 50% of accidents are caused directly by human error, while about 30% is caused by human error in accident prevention. The causes of dangerous encounters between vessels can be divided in the same manner. Near-misses may be caused by an unintended navigational action; however, an intentional operation by a navigator who, due to manoeuvre limitations, approaches another vessel at a short distance, will also be classified as an incident. Such a situation may occur when more than one ship participates in the encounter, or when an action by the give-way vessel is restricted by available manoeuvring area.

A navigational near-miss shall be understood as an event at sea or in waters associated therewith, in which sea-going ships are engaged in navigation. The event is caused by or is related to such manoeuvres of the ship in which the vessel or a person aboard is exposed to danger or which can cause serious damage to the vessel's structure or harm the environment.

Navigational incidents may be caused by broadly understood bad maritime practice resulting in wrong estimation of the CPA (the Closest Point of Approach), which the majority of navigators would consider insufficient. A wrong assessment of the situation may lead to taking inappropriate corrective action or failure to take any action. Such an encounter may occur when the navigator makes a late or incorrect assessment of the situation in terms of collision risk. As stated in Rule 7 of COLREGs – a vessel which identifies the presence of another vessel on the radar screen or by sight *"shall use all available means appropriate to the prevailing circumstances and conditions to determine if risk of collision exists*. Rule 16 states that "*Every vessel which is directed to keep out of the way of another vessel shall, so far as possible, take early and substantial action to keep well clear.*" Both the risk assessment and the planning of give-way are carried out by radar plotting or using the ARPA device. To properly plan the manoeuvre, the situation must be assessed well in advance, so that there is enough time to perform an appropriate manoeuvre.

In addition, the trajectories of all other vessels should be taken into account, e.g., by using the TRIAL manoeuvre function in the ARPA device. While performing the TRIAL simulation, the navigator should keep in mind the limitations of the available manoeuvring area. The user of the ARPA device must be aware of the system's limitations, such as the CPA error, which may be up to 0.3 NM, and errors resulting from the destabilization of object vectors, which occurs during both the manoeuvres of own ship and those of other ships.

The safety assessment presented in this paper is based on vessels' encounters considered by most navigators to be unsafe, without taking into account which vessel was obliged to take a give-way action. The subject of the work is not to check whether anti-collision action was taken or not. Due to the characteristics of some ships, such as tugs and pilot vessels, the distance of their encounters with other ships was not taken into consideration. A navigation near-miss for the use of the paper is defined as a situation in which two ships approach each other (whether taking an anti-collision action or not) at a distance that most navigators would find dangerous in a given situation. In order to determine the limit of this distance, the authors have constructed a probabilistic domain; every instance of crossing of the domain is considered a near-miss.

3. The Probabilistic Domain Construction

Domains around ships have been created since the early seventies of the 20th century to determine a certain area around the ship which the navigator would like to keep clear of other ships, obstacles or anything else which may be hazardous to navigation. At first, the shape of the domain was very simple, often represented by a circle in which the ship was located centrally. Later, domains of more complex shapes were built using the computational capabilities of computers, which made it possible to take into account an increasing number of factors affecting the shape of the domain.

With the introduction by the IMO of traffic monitoring systems, such as the AIS and LRIT (Long Range Identification and Tracking), both mandatory for vessels of 300 tonnes and bigger, and the VMS (Vessel Monitoring System) for fisheries control (Greidanus *et al.*, 2016), it has become possible to use real-time data from ship tracking systems. Until then, ship domains had been designated based on the navigators' knowledge from expert opinion surveys. Once the AIS was implemented, it became possible to take advantage of real situations that took place at sea. However, the use of the AIS to assess the distance of passing ships has some disadvantages. The vessel traffic monitoring system is not obligatory for small fishing boats or sailing yachts. If yachts do use the AIS, they use the B type, which sends information about vessels' movement at longer intervals. Therefore, system errors on sailing yachts are frequent (Miyake *et al.*, 2015). While engaged in fishing operations, fishing vessels often switch off the AIS device in order not to let other fishing ships identify their position.

Thus, the AIS system is an incomplete source of information on the distance of passing ships, which can be supplemented with data from the VMS on fishing vessels. The domain around the ship, as defined in, without limitation, (Hansen *et al.*, 2013; Pietrzykowski, 2008; Wang and Chin, 2016), is a certain area around the vessel which the navigator likes to keep clear of other fixed and movable objects. Referring to the above definition of the domain, similar solutions can be found in devices used daily on the navigation bridge. The navigator using the ARPA anti-collision system creates their own domain using functions such as:

a. the CPA (the Closest Point of Approach) limit and the TCPA (Time to the Closest Point of Approach) limit. Once the limits are set, a circular domain is created around the ship. Depending on the area of navigation, both values are adjusted to the prevailing conditions. The limits are determined so that the navigator is notified, by a sound alarm and visually on the radar screen by a triangular symbol on the object, when both the CPA and TCPA values for the object are lower than the established limits. An additional “Collision Warning” or “CPA/TCPA Warning” appears on the radar screen. The limit settings depend mainly on the navigational area where the ship is proceeding.
b. Trial Manoeuvre – it simulates the effect of own ship's manoeuvre on all tracked targets without interrupting the updating of target information. This function allows, among other things, to set the relative vectors of other vessels at a certain distance from the position of the ship. Effectiveness of the planned manoeuvre can be assessed, e.g., by checking the information about TRIAL CPA and TRIAL TCPA during the simulation.
c. Automatic Acquisition – the system is programmed to acquire targets which enter specified boundaries (Bole *et al.*, 2014). An Automatic Acquisition Area or Guard Zone, i.e., a precautionary area around the ship, is set at a distance which an object must cross to be located and acquired by the system.

The studies on building the ship domain based on the statistical analysis of ship passing distances were already made in the seventies of the 20th century. Considered the creators of this concept, (Fujii and Tanaka, 1971; Goodwin, 1975) demonstrated the possibility of limiting the area around the ship by safety sectors whose shape was determined by the passing distance of vessels, based on simulation and real radar measurements. (Fujii and Tanaka, 1971) presented the domain shape as an ellipse with the reference vessel in the centre. As described by Hsu (2014), the major axis of the first oval-shaped domain reflects a tolerated distance between the stand on vessel and the others, either ahead or abaft. While the minor axis would be described as the closest range between ships while travelling abeam. The ship's domain boundary was determined based on the first local maximum of the density function of probability of ships passing distances. In Goodwin (1975), and Goodwin *et al.* (1983), the area around the ship was divided into three sectors. The domain boundary is based on the intersection of distribution of distances of other ships form the reference vessel with a line defining the same distribution, assuming that the domain concept around the ship does not exist.

Continuing research on the statistical domain Davis *et al.* (1980), Caldwell (1983), and Calvert (1983), developed the concept of domain presented in the 1970s by the Japanese and the British scientists. Another way of determining the shape of the domain based on the distribution of distances between ships was presented by Hansen *et al.* (2013). In their work, a constant level of significance of 7.5% of the smallest distances between ships was adopted as a limit value. Thus, the authors assumed that regardless of the situation, 7.5% of navigators pass other vessels incorrectly.

In the article it was assumed that when constructing a probabilistic domain around the ship one should take into account both the COLREG rules and the principles of good seamanship, since the possible actions of both the give way vessel and in close quarter situation also the stand on vessel do depend mainly on the meeting situation between the ships. Thus, the passing distances and the actions taken by navigators depend directly on rules number 13 (Overtaking), 14 (Head-on) and 15 (Crossing). In this work, visibility is not taken into consideration, based on the simple premise that in restricted visibility, vessels pass each other at a larger distance. Thus, these situations do not affect the shape and size of the probabilistic domain boundaries. In addition, restricted visibility in the Baltic Sea occurs sporadically (BHMW, 2009).

The authors of this study assumed that by finding the estimated distance which constitutes the border between a near-miss and a safe passing, chosen by the majority of navigators, it is possible to build a probabilistic domain. In order to determine the shape of the domain, the area around the ship was divided into 8 sectors of 45° (Table 1) by the final value of the BCPA (Bearing to the Closest Point of Approach) from the reference vessel.

Table 1. *Sectors of the angular intervals around the ship.*

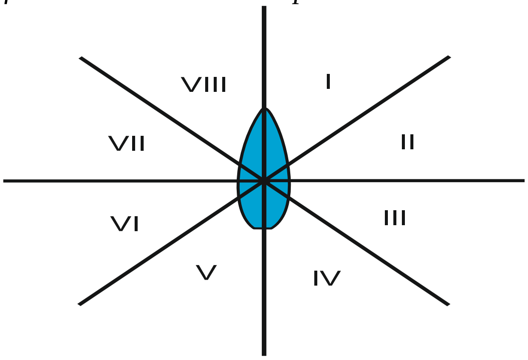
Sector	The angular interval relative to the bow - 000°
I	000° - 045°
II	045° - 090°
III	090° - 135°
IV	135° - 180°
V	180° - 225°
VI	225° - 270°
VII	270° - 315°
VIII	315° - 000°

Source: *Own study.*

The COLREGs determine the behaviour of the ship depending on the angle from which another ship approaches. The octagonal shape of the domain (Figure 1) clearly describes the sectors around the ship that are important in view of the required action of the ship to avoid a collision.

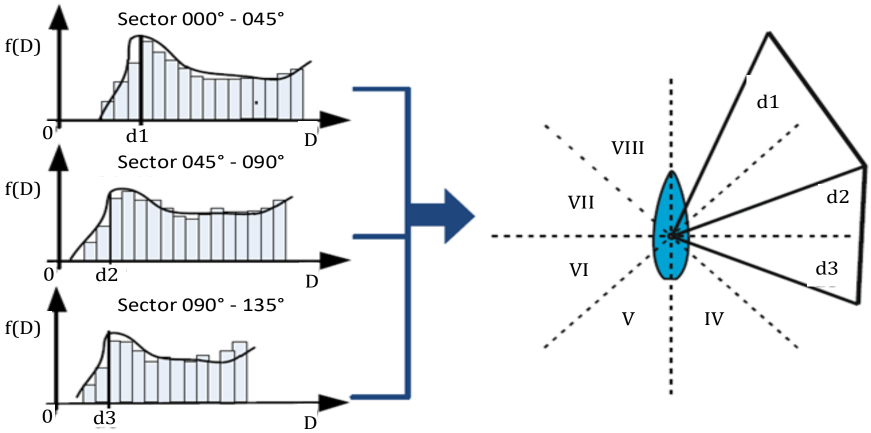
Determination of the domain was done by linking the distance (statistically defined domain boundary in a given sector) plotted in the middle of each sector (Figure 2).

Figure 1. *Division of the area around the ship into sectors.*



Source: *Own study.*

Figure 2. *Domain boundaries defined for given sectors around the ship d1, d2, d3 based on the probability density function of the passing distance between ships.*



Source: *Own study.*

The authors assumed that there is a peak in the frequency distribution of distances between passing vessels, which can be considered as the boundary, which the vast majority of navigators consider the smallest permissible distance of passing another ship in a given situation and at a given relative bearing on the other vessel. The algorithm searches a ship passing distances distribution in order to find a local maximum which can be considered characteristic for a given place and at the same time would be considered a borderline for a safe encounter (in view of real-time decisions made by navigators). Sometimes, when it is not possible to isolate the previous local maximum, the algorithm selects the global maximum of the distribution. The value limiting the algorithm is the value of 3% of meetings, so that a small number of encounters at the same small distances (early local maximum) does not constitute the result of the algorithm. Due to the assumption of this work to study only open sea water areas, the factors affecting the designated border distances are crossroads of routes, factors affecting sudden alterations in vessel course –

coastal movement of recreational and fishing vessels, etc. Verification of the hypothesis was carried out on the route between two Traffic Separation Schemes – the TSS Bornholmsgat and the TSS Sound South. In the southern and south-western Baltic Sea, ships move along designated routes between ports, between TSSs or along other types of restrictions that narrow down the routes taken by navigators.

Hence on each route, depending on the distance between the horizontal limits and on the traffic density, ships pass each other at different distances, and determine a certain maximum based on the typically chosen distance between vessels. Navigators establish CPAs in advance, considering various situations which may take place when following the designated route, such as head-on situations or overtaking (Burciu and Lizakowski, 2009). A random element is brought by ships joining the traffic on the designated route and vessels on intersecting routes, causing changes in the initially assumed passing distance of the ships.

Adverse weather conditions and restricted visibility also affect the decisions of navigators with increased distances to other ships. A navigator, when faced with the situation where the CPA to another vessel is lower than initially assumed, may take action to increase the distance or maintain it, if it is considered safe or if increasing the distance is impossible. Research on the variability of traffic flows caused by anti-collision manoeuvres is presented by Hasegawa *et al.* (2012) and Hasegawa and Yamazaki (2013). Those researchers have investigated the possibility of constructing a model that simulates anti-collision manoeuvres based on fuzzy logic. Crossing of the route by other vessels may cause traffic disruption on the route that often results in a reduction in the assumed passing distances of vessels:

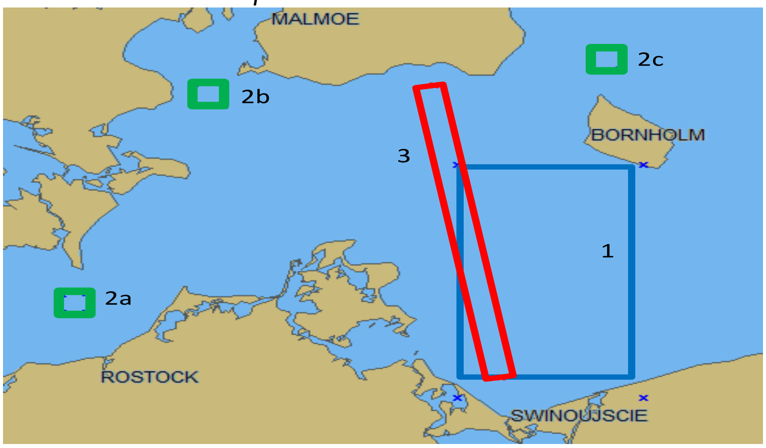
- ships for which the CPA is very small, within the limits of 0-3 cables, are forced to perform additional manoeuvres, the effectiveness of which will depend on the TCPA and the available manoeuvring area, often limited by other vessels coming up on parallel directions;
- vessels for which the CPA will reach 3-5 cables may manoeuvre, but they do not need to manoeuvre if they consider that the situation does not require it, or if they are unable to do so:
    - TCPA is very short,
    - they are the stand-on vessels,
    - their manoeuvre is restricted by other vessels;
- poor assessment of the situation could lead to a passing distance that other navigators would find unacceptable.

In order to confirm the thesis of various shapes and sizes of domains for each of the three meeting situations, a number of studies were carried out to determine domains for open sea waters with different characteristics of vessel traffic. Open waters means an area where the navigator is not restricted by the available depths or other navigational obstructions in taking any manoeuvre to avoid collision (Gucma, 2001). The method of identification of navigation near-misses described in the paper, based on data from the ship traffic monitoring system, was applied in the South Baltic area. The research was carried out in coastal areas, where ship traffic is very dense. The method of identification of near-misses was verified in various waters in terms of navigational characteristics, to corroborate the feasibility of its implementation. Reservoirs with the following characteristics were selected for the study:

- open coastal waters with no horizontal limitations, where vertical limitations associated with the available depths, if any, are sporadic and well known, so they do not affect the safety of navigation;
- water areas in the vicinity of vessel Traffic Separation Schemes, with a high density of vessel traffic, where vessels on routes initially leading along traffic lanes alter courses in different directions initiating encounters at short distances;
- ship's planned routes – in order to identify potentially dangerous places on the planned routes where the highest number of near-misses occur.

Surveys in the coastal area where there are no horizontal restrictions on ship traffic were carried out in the Pomeranian Bay and the south-western basin of Bornholm Island (from 54°05.0’N to 55°N latitude and from 14°E to 14°51.0’E longitude), marked with number 1 and a blue rectangle in Figure 3. The selected area does not feature any horizontal navigational limitations, such as vessel traffic separation schemes or port approaches, where vessel traffic is regulated. In area no. 1, ship traffic mainly takes place on the Świnoujście – Ystad route.

Figure 3. *Selected areas where studies were performed using the method of navigational near-misses identification*



Source: *Own study.*

Research on the possibility of constructing and using probabilistic domains in areas with high density of ship traffic was carried out in three areas located in the vicinity of vessel traffic separation schemes, marked in green in Figure 3 (2a, 2b, 2c). The research was undertaken to determine navigation safety on the basis of the identified near-misses and historical data on navigational accidents. Navigational safety analysis in an area close to a TSS will provide an opportunity to check how ships behave when leaving a system where their traffic is severely restricted and directed and then diverted in different directions. The characteristics of the three areas are similar in terms of the available manoeuvrability; therefore, the results obtained by using navigation incidents identification methods have been compared.

In order to verify the possibility of applying the described method of near-miss identification for the designated ship's route, the analysis of navigation safety in terms of the number and location of incidents on the route of passenger ferries between Świnoujście and Ystad, was carried out (marked in red and with number 3 in Figure 3). The method of identification of designated ship domain crossings in selected areas of the Southern Baltic Sea was verified by:

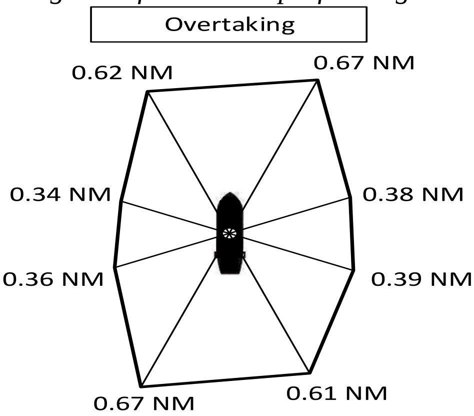
1. designation of probabilistic domains for different areas with similar navigational characteristics; monitoring the size and shape of each domain depending on the meeting situation and analysing the number of near-misses understood as each encounter where a domain is exceeded;
2. determination of the risk factor indicating the ratio of the number of contactless incidents (near-misses) per collision accident in a given water area. The risk factor was determined in order to monitor changes in ship traffic by analysing variations in the number of near-misses in a given area in consecutive time periods.

As a result of the analysis of the described method of navigational near-misses identification based on the constructed probabilistic domain, the procedure of navigational risk management in a given sea area has been proposed.

Big Data analyses, consisting in database searching and extraction and analysis of data, can be seen as an innovative IT solution which can improve the effectiveness of risk analysis of maritime safety systems. The topic of working with a large number of data is discussed in research in many different disciplines (Watson, 2014; Moffitt and Vasarhelyi, 2013). The presented domains were constructed based on an analysis of a large amount of data from the AIS traffic monitoring system. In order to build and verify domains in various areas of the Baltic Sea, an analysis of nearly 0.5 billion ship positions was performed.

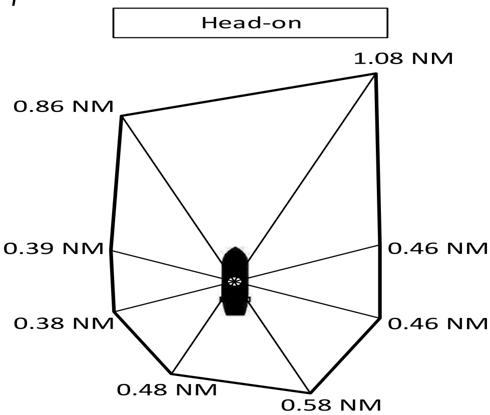
The method of navigational near-misses identification based on designated domains is still being developed, so that in the future it can be used as a real-time computing safety management system. Some fundamental technical issues of real-time computing were discussed by (Mazzarello and Ottaviani, 2007); (Buttazzo, 2011). In order to identify navigation near-misses, the domains developed for the selected areas of Baltic Sea were designated (Figures 4-6).

Figure 4. *The domain designated for a vessel performing the overtaking manoeuvre.*



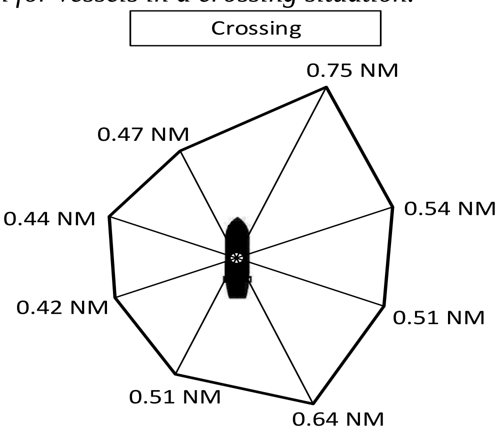
Source: *Own study.*

Figure 5. *The domain for vessels in a head-on situation.*



Source: *Own study.*

Figure 6. *The domain for vessels in a crossing situation.*

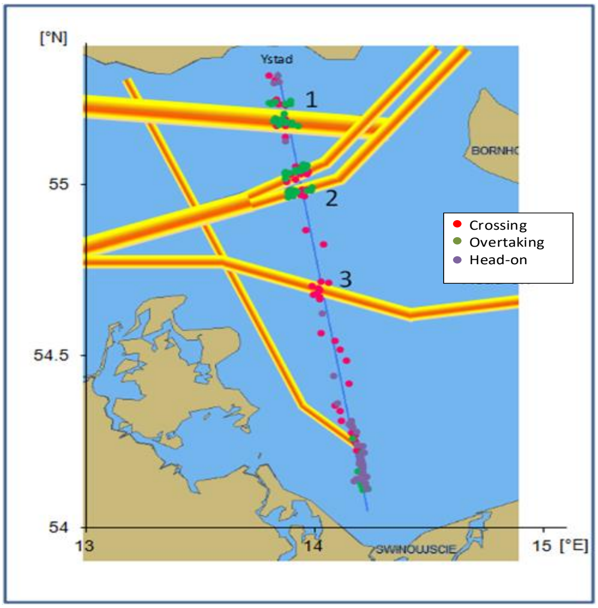


Source: *Own study.*

3. Identification of Ship Domain Crossings Involving Ferries on the Route between the Port of Świnoujście and the Port of Ystad Based on the AIS Data

The study included analyses of the passing distance of passenger ships with other vessels. They were carried out on the basis of a probabilistic domain. The domain designated on the selected route for all ships was compared with the domain designated for meetings of ships in which at least one passenger ship participated. An assumption was made that the concentration of vessel traffic at intersections of the main routes may reduce the distance at which ships pass each other. The main goal was to build a domain for the whole route followed by ferries, and to designate places of increased navigational risk. Areas with the highest number of navigational near-misses were defined as places of increased risk for navigation.

Figure 7. *The route between Port of Świnoujście and Port of Ystad, with the main shipping routes and places where navigation near-misses occurred marked*



Source: *Own study.*

The following geographical coordinates represent the locations where the highest number of ship domain crossings occurred:

- 55° 10.170’N - 55° 14.598’N and 13° 48.138’E - 13° 53.712’E (No. 1 in Figure7);
- 54° 57.732’N - 55° 03.306’N and 13° 52.926’E - 13° 58.086’E (No. 2 in Figure7);
- 54° 06.678’N - 54° 21.342’N and 14° 05.394’E - 14° 14.160’E (No. 3 in Figure 7).

These locations have been identified as areas of increased navigational risk. The length of the route between the Polish Port of Świnoujście and the Swedish Port of Ystad selected for the analysis is 84 NM. The survey shows that the Baltic Sea is an area with a high density of ship traffic, where the passing distances of ships are reduced not only in port approaches and in areas of limited manoeuvrability, but also at crossings of routes. Navigators approaching places of increased navigational risk should comply with the COLREG regulations, in particular Rule 5 on proper observation and regulation 8a and 8b on actions which should be taken to avoid collision.

Rule 8 a) *Any action to avoid collision shall, if circumstances of the case admit, be positive, made in ample time and with due regard to the observance of good seamanship*.
Rule 8 d) *Action taken to avoid collision with another vessel shall be such as to result in passing at a safe distance. The effectiveness of the action shall be carefully checked until the other vessel is finally passed and clear*.

4. Analysis of the Number of Navigational Near Misses in the Vicinity of Traffic Separation Schemes

Traffic Separation Schemes are established in areas with a high density of vessel traffic, often where a large number of navigational accidents and incidents occurs (Marcjan and Gucma, 2014a). Specific traffic lanes are designated to point out the direction of traffic flow within the scheme to improve the safety of navigation. Studies on the construction of a ship domain directly in the TSS was presented by (Pietrzykowski and Magaj, 2016). Difficulties of navigation in TSSs have been discussed by Szlapczynski (2013) and Squire (2003). This study focuses on areas near the terminations of TSSs, i.e., on places where the navigator is not restricted and can make any manoeuvre necessary to avoid collision.

Rule 10 f) "*A vessel navigating in areas near the terminations of traffic separation schemes shall do so with particular caution*".
Investigating the number of navigation near-misses at the exit of the traffic separation scheme will make it possible to use the navigational safety assessment method proposed in the paper, based on the probabilistic domain, as well as to draw conclusions concerning the passing distances between ships and navigation safety near the terminations of traffic separation schemes. An example analysis was carried out in the vicinity of high-density traffic separation schemes.

The main transit traffic flows in the Baltic Sea are arranged along the following routes:

- Great Belt – Bornholm Strait;
- Strait of Sound – Bornholm Strait;
- TSS South of Gedser – Bornholm Strait.

The number of navigational incidents was analysed at the western end of the TSS South of Gedser vessel traffic separation scheme, at the intersection of the traffic lanes of the TSS Off Falsterbo, and near the north-east end of the TSS Bornholmsgat (north of Bornholm Island). The selected areas were sites of at least one ship-to-ship collision over the last ten years (Figure 8). The purpose of the survey was to determine the ratio of the number of near-misses per accident in each area and to analyse the obtained results. On the basis of the constructed probabilistic domains around the ship, the number of near-misses in selected areas was calculated. The number of ship collisions was established using data provided by the marine accidents database HELCOM Baltic Sea data map service. In the last 10 years, in both areas in the vicinity of the TSS Bornhomsgat and the TSS South of Gedser, one ship-to-ship collision occurred directly in the study area, and one in the vicinity. In the area designed in the central intersection of the TSS Falstrbo, two collisions were found directly in the study area. The final objective of the incident investigation in the selected areas around traffic separation schemes was to determine the value of risk factor R_f as a ratio of the number of near-misses per accident (Marcjan et al., 2013):

$$R_f = n_I / n_A \tag{1}$$

where:
n_I- number of near-misses per 10000 ships passing,
n_A- number of collisions per 10000 ships passing.

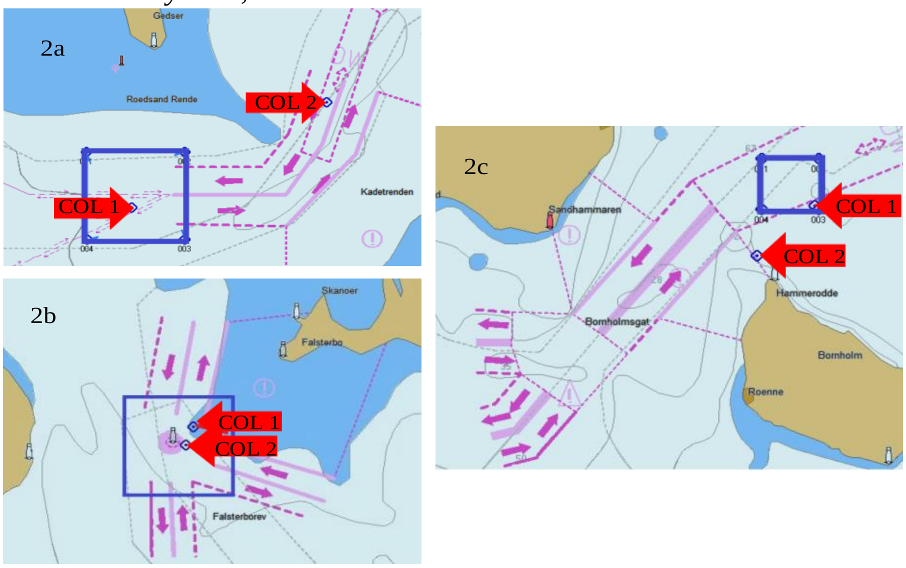
Table 2. *The risk factor for the studied areas (Marcjan and Gucma, 2014).*

Area	No. of collisions per 10,000 ships passing n_A	Type of encounter	No. of near-misses per 10,000 ships passing n_I	Risk factor R_f
TSS South of Gedser	0.024837	Head-on	26.2	1055
		Overtaking	26.5	1067
		Crossing	26.5	1067
TSS Falsterbo	0.037993	Head-on	21.3	561
		Overtaking	39.5	1040
		Crossing	23.9	629
TSS Bornholmsgat	0.032663	Head-on	3.1	95
		Overtaking	21.9	670
		Crossing	11.9	364

Source: *Own study.*

Table 2 shows the number of near-misses per accident for each of the three research areas in the vicinity of vessel traffic separation schemes. The coefficients were calculated depending on the meeting situation between vessels and on the basis of near-misses determined using a probabilistic domain. Due to the different traffic density in the water areas, in order to be able to compare the above mentioned areas with each other, it was decided that both the accident rate n_A as well as the near-misses rate n_i will be presented for 10000 crossings of ships on a given route. HELCOM historical data for a period of 10 years was used to get the number of maritime accidents on given routes, therefore the accident rate was defined as the number of accidents per 10 years. The accident which took place directly in a given area was counted as a full accident (1), but accidents which took place in the vicinity of the given reservoir were multiplied by appropriate weighting ϵ (0 , 1) depending on the distance to the selected area.

Figure 8. *Three areas selected in vicinity of the main TSS of Southern Baltic Sea – 2a TSS South of Gedser, 2b TSS Falsterbo, 2c TSS Bornholmsgat. Blue rectangle indicates the study area, red arrow shows the location where the collision occurred*



Source: *Own study.*

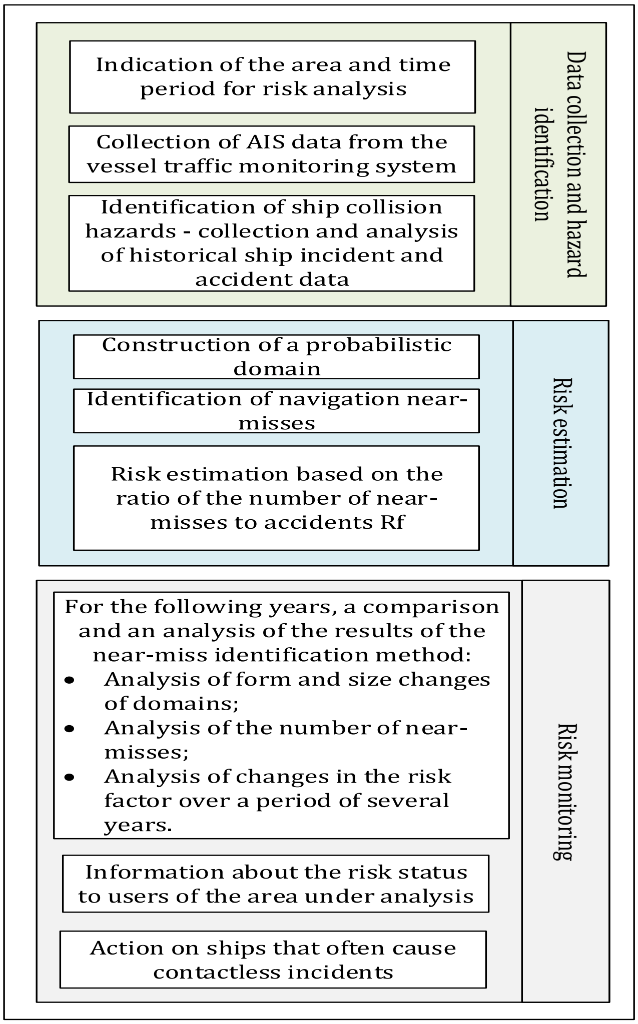
For an accident which took place in the South of Gedser TSS, northeast of the selected research area (Figure 8. 2a COL2), the weight was set at 0.5. For an accident southwest of the designated study area in the vicinity of TSS Bornholmsgat (Figure 8. 2c COL 2), a weight of 0.7 was established. Thereby, accidents from the last 10 years have been considered in the safety assessment in the studied areas, which occurred both in the designated areas and in their immediate vicinity.

5. The Proposed Navigational Risk Management Procedure Based on the Near-Misses Identification Method

The reason for the establishment of a navigational risk management procedure in the open waters of the Baltic Sea is the need to collect information on accidents and incidents in a given area by maintaining and updating an integrated database. The use of the R_f navigation risk factor proposed in the study for the purpose of assessing navigation safety in a given area is reasonable, provided that a long-term navigational accidents and near misses database is maintained for the purpose of:

- calculation of risk factors for subsequent years;
- analysis of changes in the values of the coefficients from which the risk factor is calculated and drawing conclusions concerning the causes of navigation accidents as well as the improvement or deterioration of navigational safety within the defined area of research.

Figure 9. *Navigational risk management procedure*



Source: *Own study.*

The procedure presented in Figure 9 consists of three stages:

1. Collection of data and hazard identification, where the area of analysis and the study period should be indicated. In order to be able to monitor changes occurring in a given area, the suggested period of research should be as long as possible and at least three years. It involves the collection of data from the AIS vessel traffic monitoring system for a defined period of time and collection of information on collision accidents occurring in a given area.
2. The risk estimation is performed by constructing a probabilistic domain, which is used to identify the number of navigation near-misses in a given area. The R_f risk factor is determined on the basis of the number of near-misses per collision accident.
3. Risk monitoring shall be carried out by combining the results of application of the method of identifying incidents over a defined investigation period. The size and shape of obtained probabilistic domains, as well as variations in the number of navigational near-misses per 10,000 passages and the changes in the risk factor over the following years, are analysed. The results of risk assessment can be shared with the users of the area, such as the VTS (Vessel Traffic Services) and – if recommended – with the navigators as well. At the same time, risk management authorities in a given area may also receive information about ships that frequently exceed a designated domain while passing other ships.

6. Conclusions

The paper presents the concept of a method for estimating navigation safety on the basis of an analysis of the number of navigation incidents based on data from the AIS vessel traffic monitoring system. The navigation near-miss identification method is based on a probabilistic domain around the vessel. Due to the different interpretations of encounter situations between ships presented in the COLREG 1972 and the different passing distances applied by navigators, three domains were assumed to be constructed:

- for crossing encounter;
- for head-on encounter;
- for overtaking vessels.

The proposed method of searching for navigational near-misses was applied in areas classified as open sea areas. The main objective of the study was to estimate navigational safety on the basis of the identified navigation near-misses and was achieved by applying the proposed method and analysing its results in the Baltic Sea. An important conclusion of the presented research is the fact that it is impossible to build a universal domain, which could be used in different areas. Analysing the results in terms of building a probabilistic domain, the following conclusions can be drawn:

1. The survey period has an impact on the size of the domain due to different vessel traffic density in the summer and winter months. The distances chosen by navigators to pass other vessels depend on both the available manoeuvring area and the number of nearby vessels which may represent a potential limitation on the manoeuvring rate.
2. The size of the domain is also affected by individual events, in which, e.g., the navigator who is to give way unknowingly (without making any manoeuvre) or having misinterpreted the situation, lets the distance to the passing vessel be reduced.

The Baltic Sea is a relatively small area with many intersections of ship's routes and vessel Traffic Separation Schemes which regulate ship traffic on one hand, and reduce the passing distance of ships on the other. The purpose of the study of near-misses in the selected open sea areas or areas in the vicinity of TSS is to determine the value of risk factors, defined as the ratio of the number of domain crossings per collision accident between ships. The risk factors are compared with one other and their interpretation is proposed for the navigational safety assessment. The near-miss identification method may be used for:

- research into causes of excessive close-ups of ships, through an analysis of the behaviour of navigators before and after the crossing of a designated vessel domain boundary,
- analyses of passing distance of vessels during proximity situations between two vessels and when more than two vessels participate in the encounter.

The article presents the need to create a method for identifying dangerous events between ships and proposes its exemplary use for construction a navigational risk management procedure to monitor the safety of navigation in the selected open sea area. Its major advantage is versatility - it can be applied in any location. The method takes into account directly or indirectly many factors characteristic for a given place, each time assigning individual safety factors for each area. The downside is the need to determine individual coefficients based on extensive databases (data for a minimum of 3 years from the vessel traffic monitoring system and historical data on marine accidents for a minimum of 10 years). The development of the method and the results of its implementation will be discussed in more detail in the subsequent works of the author.

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