A CONCEPT OF A SHIP DOMAIN FOR THE USE OF NAVIGATIONAL SAFETY ASSESSMENT

ANALIZA BEZPIECZEŃSTWA MORSKIEGO Z WYKORZYSTANIEM DOMENY WOKÓŁ STATKU

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Abstract: One of the most important concepts concerning the safety of navigation is the ship domain. The maritime domain is one of the oldest domains, which preceded the ones used in aviation, railway industry, chemical industry and medical. Through the concept of a ship domain is to be understood a certain area around the vessel, which the navigator wants to keep free of other fixed and moving objects. Navigational situation can be considered safe as long as no other ship neither any navigational obstacle would not exceed the area. In order to build and develop methods to assess the safety of the navigation, a ship probabilistic domains for three types of vessel encounter situations were determined based on the AIS traffic monitoring data. The aim of the paper is to present a method to identify navigational incidents on the basis of a probabilistic domain, which can be used to assess the safety of navigation and discovery places potentially dangerous for navigation in the selected areas of the Baltic Sea.

Keywords: safety of navigation, ships domain, navigational incident

Streszczenie: Jedną z ważniejszych koncepcji dotyczącej bezpieczeństwa nawigacji jest domena statku. Koncepcja morskiej domeny jest jedną z najstarszych domen, albowiem poprzedziła domeny stosowane w lotnictwie, branży kolejowej, przemyśle chemicznym oraz medycznym. Poprzez pojęcie domeny statku należy rozumieć pewien obszar wokół statku, który nawigator chciałby utrzymać wolnym od innych obiektów stałych i ruchomych. Sytuację nawigacyjną można uznać za bezpieczną tak długo, jak żaden inny statek lub przeszkoda nawigacyjna nie przekroczy tego obszaru. W celu budowy i rozwinięcia metody oceny bezpieczeństwa nawigacyjnego wyznaczono probabilistyczne domeny statku na podstawie danych z monitoringu AIS dla trzech typów sytuacji spotkaniowych między statkami. Celem pracy jest zaprezentowanie metody identyfikacji incydentów nawigacyjnych na podstawie domeny probabilistycznej, która może posłużyć do oceny bezpieczeństwa nawigacyjnego oraz odnajdywania miejsc potencjalnie niebezpiecznych na wybranych obszarach Morza Bałtyckiego.

Słowa kluczowe: bezpieczeństwo nawigacji, domena statku, incydent nawigacyjny

1. Introduction

Safety management systems based on risk assessment methods are the most advanced tools to improve the security and control the risk in various areas of human activity. The most widely used measure of safety of navigation is the ships accident rate. The statistical data relating to maritime traffic and ships accident rate can be used to monitor and to manage the safety of navigation. The study used the new opportunities presented by the introduction of automatic ship identification system AIS. It is a system that allows not only monitoring the vessel traffic, but also research on the basic processes regarding the ships movement in the selected area. The studies presented in this paper includes southwestern Baltic Sea, where there is a large movement of merchant vessels mainly from the Danish Straits towards the Eastern Baltic Sea and from the Kiel Canal across the TSS South of Gedser towards the TSS Bornholmsgat (in Fig. 1 both routes marked by red lines).

Fig. 1. Number of ships crossing AIS fixed lines in the southwestern Baltic Sea in 2012 according to the type of the vessel [6] with the main ships traffic lanes in the selected study area[8].

In the selected area passenger ships are moving mainly from the Port of Swinoujscie to the Port of Ystad and from Swedish Trelleborg to German port of Sassnitz (Fig. 1 marked with the orange line) crossing the main routes of merchant ships. Every year each of the three selected passages is used by more than 50 thousand vessels. Detailed information about the types of ships using the passage is presented in Table 1.

Table 1. Number of ships crossing AIS fixed lines of three main passages in the Baltic Sea in 2012 according to the type of the vessels [6].

Location	Type of ship					
	Passenger	Cargo	Tanker	Other	Unknown	Total
Drogden	6731	20784	4445	15094	7339	54393
Kadet Fairway	10514	29179	8697	7213	3541	59144
North of Bornholm	2028	32594	9840	4987	2039	51488

2. The definition of navigational incident for the purpose of the study

Despite of the high density of vessel traffic in the Baltic Sea the registered number of ships collisions is too small relative to the statistical evaluation of safety of navigation based only on those accidents (approx. 40 per year [6]). In the paper navigational incidents were used to built a navigation safety assessment model. The navigational incident is usually defined as an event or series of events that could potentially lead to an accident, but due to the preventive actions an accident does not occur or its effects are negligible. By analysing data on vessels positions from the AIS monitoring system navigational incidents can be identify and the relationship between the navigational accidents and incidents can be determined. Navigational incidents might be caused by the wider understood bad habits of ordinary practice of seaman, resulting in encountering at distances that other navigators would consider inadequate. This may be the result of misjudgment and thus inadequate prevention or lack of an action of a navigator. Such meetings occurs when the navigator assesses too late or incorrectly the situation in terms of risk of collision. Navigator after noticing the second ship is obliged to check whether there is a risk of collision with another ship, and if it exists, should immediately determine which vessel is directed to keep out of the way and possibly plan a give-way maneuver. This is done by performing radar plotting, or using an ARPA (Automatic Radar Plotting Aids) device. To properly plan a give-way maneuver with the second ship, the situation should be assessed in advance in order to have time to plan and execute the required action. Additionally, it should be taken into account the movement of other ships - e.g. through the use of Trial Maneuver functions in the ARPA device. Navigator using ARPA must be aware of the limits of the system, e.g. error in counting CPA (the Closest Point of Approach), which can reach 0.3 NM, and errors resulting from the destabilization of vectors of objects, which occurs both during own ship or other ship maneuver.

The navigational incident of ships, for the purposes of this paper was defined as an encounter between two ships (with taking or without taking anti-collision actions) passing each other at such a distance that most navigators, in a given situation, would consider dangerous.

3. Construction of the probabilistic domain around the vessel

One of the most important concepts relating to safety of navigation is the ship domain. The concept of maritime domain is one of the oldest domains that preceded the domain used in the aviation, rail industry, the chemical industry and medical [11]. Common to these domains is the importance of safety rules related to risk management in order to avoid unexpected events causing unnecessary losses [1]. By a ship domain, a certain area around a vessel which the navigator wants to keep free of other fixed or moving objects, shall be understood. Navigational situation can be considered safe as long as no other ship or navigational obstacle will exceed the area. The concept of a ship domain has been proposed for the first time by the Japanese authors [3]. Since then many concepts of domains have been arisen with different shapes, built on the basis of the characteristics of studied water areas. In [10] authors presented the domain of the ship as a figure in the shape of a hexagon. In [2] authors proposed to describe the dangerous area around the ship by a circle. The studies presented by [12], [9], are focused on assessing the risk of collision with the use of such mathematical tools as fuzzy logic and artificial neural networks to generate domain boundaries around the ship. An example of a domain that shape and size was determined based on statistical studies on vessels encounters was determined by [4].

Domain around the ship is an area that most navigators would leave free of any other ships or navigational obstacles. Part of the navigators intentionally or unintentionally exceeds the domain area allowing to encounter with another ship at distances shorter than the domain boundaries. In this paper any such encounter situation will be called a navigational incident. The following assumptions for the construction of the probabilistic domain were made:

- a) there is a maximum in the distribution of ships passing distances that can be considered as the distance limit, which the vast majority of navigators intends to be the shortest permissible distance for passing other vessels in a given encounter situation;
- b) delimitation of the limit distances in various sectors around the ship will allow the construction of a ship probabilistic domain;
- c) the ships passing distances depends on many factors, but most of them have been omitted, leaving only the type of ship, type of collision situation and the relative bearings. A navigator carrying out a collision-avoidance maneuvers, or not carrying them out because of the assumption that the distance is safe, behaves randomly.

The border of probabilistic domain is assessed by the distribution of vessels passing distances. It was assumed that the distribution of passing distances achieve a maximum around the point which is the distance over which most navigators will proceed clear of other vessels. To determine ships domain shape, area around the vessel has been divided into 8 sectors (every 45 degrees starting from 0 degrees) due to relative bearing at the approaching vessel (Fig.2). The International Regulations for Preventing Collisions at Sea (COLREGS) set out, among other things, the "rules of the road" or navigation rules to be followed by ships and other vessels at sea to prevent collisions between vessels. Section 2 of COLREGS refers to the conduct of vessels in sight of one another, rules of this section divide encounters between vessels and conduct in a given situation due to the relative bearing between vessels. The octagonal shape of the domain clearly describes the sectors around the ship which is important because of the section 2 of COLREGS. The bow sector is divided into right and left side, the same goes with the stern sector. Additionally, each side of the vessel is divided into sectors forward of the beam and abaft the beam which refers to the section 3 of COLREGS. The border of a probabilistic domain is assessed by the distribution of vessels passing distances. It was assumed that the distribution of passing distances achieve a maximum around the point which is the distance over which most navigators will proceed clear of other vessels. Creation 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.2).

Fig.2 Ship probabilistic domain boundaries based on the distributions of ships passing distances determined for each of the 8 sectors [5].

In Fig.3 an example of a ship probabilistic domain is presented. Domains boundaries are marked in red and the places where the distance of the closest approach occurred - blue. The center of the graph provides a reference point against which individual CPA has been calculated.

Fig. 3 An example of a ship probabilistic domain determined for the crossing encounters in the TSS South of Gedser [7].

A method of navigational incidents identification was developed on the basis of probabilistic domain around the ship. Identification of navigational incidents in a selected area consists of constructing a probabilistic domain based on the ships passing distances in the area and afterwards finding the encounters where the constructed domain had been exceeded. Each encounter in which domain boundaries had been exceeded was identified as the incident of navigation. Due to the different interpretation of the situations between vessels depending on the relative bearings between vessels presented in the International Regulations for Preventing Collisions at Sea and also because navigators are passing each other at different distances in a given situation, construction of three domains for each encounter situation in examined area was assumed:

- Overtaking (Rule 13 of COLREGS);
- Head-on situation (Rule 14 of COLREGS);
- Crossing situation (Rule 15 of COLREGS).

4. Uses of navigational incidents identification method based on ship probabilistic domain for navigational safety assessment

One of the ways to use the presented method for assessing the safety of navigation is to compare the domains obtained for the water area for different types of ships. The study allows to specify the tendency of navigators to decrease or to increase the passing distance to other vessels depending on own ship characteristics and the type of transported cargo. An analysis of ships passing distances was conducted in the coastal area of southern Baltic Sea. The aim of the study was to compare domains and check whether the vessel type has an impact on the domain size in a given encounter situation. Ships were divided according to type on tankers, cargo vessels and passenger vessels and for each of them a separate probabilistic domain was constructed. An example of three domains for each encounter situation determined for passenger vessels is shown in Fig. 4.

Fig. 4. Passenger vessels probabilistic domains constructed for three encounter situations[5]

The biggest domains were constructed for tankers for all three encounter situations. Domains determined for tankers were an average of 10% bigger than the domains constructed for passenger vessels and nearly 15% bigger than the domains constructed for cargo ships. When analyzing particular situations:

- the ship domain for head-on situations that was determined for tankers was about 15% larger than the ones constructed both for passenger and for cargo vessels;
- for crossing encounters the domain constructed for tankers is about 12% larger than for passenger vessels and almost 18% larger than for cargo vessels;

- for overtaking situations domains constructed both for tankers and passenger vessels are about the same size and the domain constructed for cargo vessels is about 9% smaller than the others.

The domains shapes for a chosen encounter situation are similar to each other regardless of the type of vessels.

Next research included waters with high density ships traffic in the southern waters of the Baltic Sea. Western end of vessel traffic separation scheme South of Gedser has been analyzed. Another area was chosen set at the intersection of traffic lanes of TSS Off Falsterbo (southern part of the Sound). The last area was designated near the north-eastern end of the TSS Bornholmsgat (north of Bornholm island). The study areas were selected in those places where in the past ten years one or more collisions between vessels had been observed. The aim of the study was to identify the value of a risk factors being the ratio of the number of incidents per accidents which occurred in a given unit of time in a chosen area. The risk factors were compared and their interpretation due to assessing the safety of navigation was proposed. The highest values of the risk factors were determined for overtaking situations where theoretically navigators feel safest, although the maneuver last the longest. In addition, there are dangerous interactions between the hulls of ships. The lowest values of risk factor were calculated for head-on situations. It is the most dangerous situation due to the high speed of approach between the two ships, which gives little time to take appropriate action to avoid a collision. It should be noted that at the entrance of the first area (TSS South of Gedser) the value of the risk factor for head-on encounters was by far the highest [7]. The most orderly movement of vessels takes place at the northern entrance of the TSS Bornholmsgat, where ships follow along deepwater route so that the number of incidents crossing encounters and for head-on encounters is the lowest. This has a direct impact on low value of risk factor in this area.

5. Conclusions

A number of ships probabilistic domains were determined in different areas of the southwestern Baltic, based on the assumption that there is a maximum in the distribution of ships passing distances that can be considered as the distance limit, which the vast majority of navigators intends to be the shortest permissible distance for passing other vessels in a given encounter situation. An analysis of the position of the assumed maximum was performed based on ships probabilistic domains determined for a total of over 54 thousand encounter and identified more than 3,000 incidents. In 95% of the cases the maximum was located in the range from 3% to 11% of all encounters. By comparing the shapes of determined probabilistic domains it has been proved as an appropriate to construct three domains -

separately for each encounter situation described in COLREGS because all these domains, regardless of the analyzed area, had different shapes and different sizes. The biggest domains were obtained for head-on situations, the smallest for overtaking vessels. Important conclusion of this study is that you can not build a universal ship domain, which could be used on different areas. It is because a large impact on the domains size and its shape have horizontal restrictions, traffic density, the number and places of intersections with other vessels routes. The Baltic Sea is a small body of water considering its high density of vessel traffic, where there are numerous intersection of shipping routes and traffic separation schemes, which on the one hand order and direct ship movement, on the other hand, have the effect of reducing the distance of vessels encounters.

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