Ship Domain as a Safety Criterion in a Precautionary Area of Traffic Separation Scheme

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ABSTRACT: The ship domain is one of the criteria for navigational safety assessment. It is particularly important in restricted areas with high intensity traffic, where the criteria of closest point of approach (CPA) and time to CPA are difficult to apply. This research continues to examine ship domains in Traffic Separation Schemes (TSS). We have analyzed precautionary areas established within TSSs in connection with changed arrangements of vessel traffic. Besides, we have defined ship domains in a precautionary area of a specific TSS, and compared them to domains of vessels proceeding along traffic lanes.

1 INTRODUCTION

The increasing traffic intensity along with vessel sizes and higher speeds continue to draw researchers interest and effort to the problems of marine shipping safety and effectiveness. This refers, in particular, to areas where vessel traffic is dense. One of the ways to reduce the number of accidents in these areas is the introduction of additional principles of traffic management. An example of these are traffic separation schemes (TSSs), regulating vessel traffic. TSSs are composed of traffic lanes, each indicating the directions of traffic flows within the TSS-covered area.

The increased, organized vessel traffic makes it difficult to apply the closest point of approach (CPA), one of the fundamental criteria of navigational safety. The ship's domain may be an alternative for the CPA criterion. The ship domain is defined as an area that the navigator should maintain free of other vessels (Fuji & Tanaka 1971). The most frequently reported domains are two-dimensional domains with defined shape and size. It is possible to include the third dimension - domain depth. Its introduction permits to take account of safe distances to underwater dangers. A number of factors affecting the size and shape of the domain causes difficulties in its determination. These factors comprise the type of area (open, restricted), types and sizes of vessels, hydro-meteorological conditions. The human factor should also be taken into account. The relevant research found in the literature deals with both restricted and open areas. TSSs are specific areas due to intensive vessel traffic. For this reason they are classified as restricted areas, even if they often lack physical boundaries of the manoeuvring area relating to depth, length or width. An analysis of the criteria for assessing navigational situations in these areas seems to be essential due to that specificity. For this reason TSSs may require criteria somewhat different from those used in both open and restricted areas where navigation is restricted by physically available manoeuvring area. This concerns traffic lanes as well as precautionary areas in TSS.

2 TRAFFIC SEPARATION SCHEMES

2.1 *TSS characteristics*

Traffic separation schemes are established to enhance the safety of navigation by introducing specific principles of vessel traffic organization in order to keep it under control. In accordance with the SOLAS Convention SOLAS (SOLAS 1974),, the IMO is the only international institution that issues guidelines and rules for TSS systems at the international level.

Principles for the establishment and organisation of TSS have been laid down in the IMO Resolution "General provisions on ships routing'(IMO 1985).. These systems, by separating the flows of vessel traffic, vitally increase the level of safety of life at sea, navigational safety and effectiveness, and environment protection. The designated traffic lanes encompass one-way vessel traffic within the scheme. TSS areas are governed by IMO regulations. Rule 10 of the International Regulations for Preventing Collisions at Sea (COLREGs 1972) defines the behavior of ships navigating in these systems. This, however, does not relieve ships from complying with the other rules of the Collision Regulations. An example of a traffic separation scheme is shown in Figure 1a. Traffic lanes are often defined by conventional boundaries. This means that a breach of the lane boundary does not lead to a direct risk of grounding or collision with a shore structure. In accordance with the definition, the traffic lane is 'an area within defined limits in which one-way traffic is established (IMO 1985).
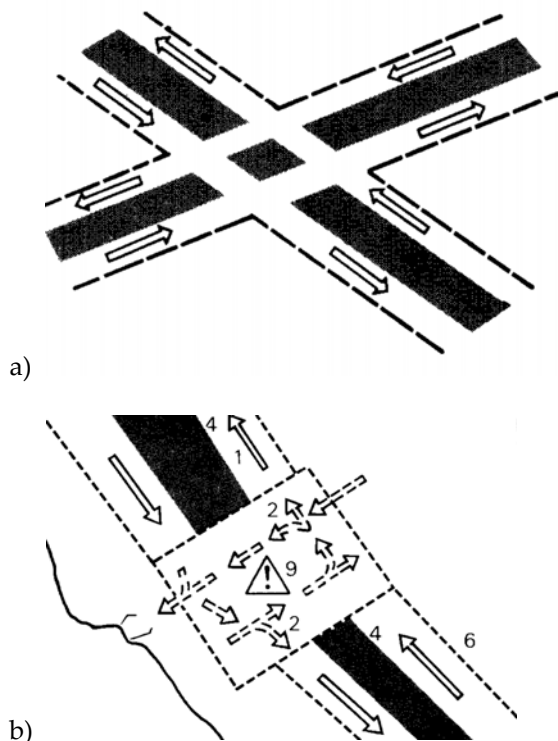

a)

b)

Figure 1. Traffic separation Scheme: a) separation of traffic at a crossing; b) precautionary area at a junction, with recommended directions of traffic flow (IMO 1985)

Some TSS areas comprise precautionary areas (Figure 1b). Precautionary area is defined as 'a routing measure comprising an area within defined limits where ships must navigate with particular caution

and within which the direction of traffic flow may be recommended' (IMO 1985).

Precautionary areas may also be introduced for the termination of any single route.

Traffic separation schemes are established throughout the world. On the Baltic Sea these include TSS Adlergrund, TSS In Bornholmsgate, TSS North of Rügen, TSS Słupska Bank, TSS Gdansk Bay (Pietrzykowski et al. 2015).

2.2 *TSS Bornholmsgat*

TSS Bornholmsgat is one of the traffic separation schemes on the Baltic Sea (IMO 2005). Dense traffic of different vessel types and sizes is observed, moving from the Danish Straits and the Kiel Canal to the eastern Baltic Sea and in opposite directions (Figure 2a). Within that area there are six traffic lanes and one precautionary area.

The number of vessels that transited the area in 2011 was over 64000(HELCOM 2011). Figure 2b illustrates trails of vessels registered in the AIS system during four days of June 2011.
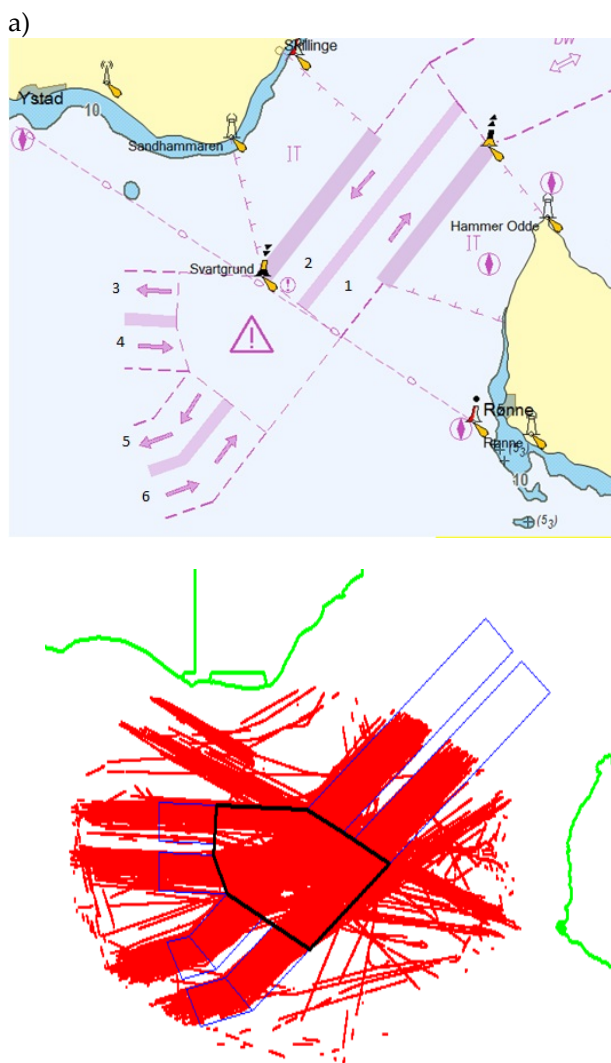
a)

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Figure 2. TSS Bornholmgate: a) traffic lanes and precautionary area; b) vessel tracks recorded in the AIS system within four days of June 2011

Table 1 lists the numbers of ships registered in the same period of four days in each traffic lane and the precautionary area.

Table 1. Numbers of ships in the examined TSS Bornholmsgat areas.

Area	Ships	
	All	bulk carrier
traffic lane 1	298	215
traffic lane 2	313	235
traffic lane 3	107	84
traffic lane 4	124	89
traffic lane 5	213	145
traffic lane 6	175	124
precautionary area	618	443

Additionally, the most numerous group of bulk carriers was considered. The main flows of vessel traffic were observed along traffic lane 2 – traffic lane 4 traffic lane 3 – 1.

3 THE RESEARCH

3.1 Method of ship domain determination

There are a number of methods for domain determination (Fuji & Tanaka 1971, Zhao et al. 1993, Rutkowski 1998, Smierzchalski & Weintrit 1999, Zhu et al. 2001, Pietrzykowski 2008, Pietrzykowski & Uriasz 2009, Wang et al. 2009, Wielgosz & Pietrzykowski 2012, Hansen et al. 2013, Wang 2013). These are mainly analytical, statistical and artificial intelligence methods. By statistical and artificial intelligence methods, the ship domain is determined on the basis of ship trails obtained from simulations performed on navigational simulators, or real data studies, in which ships' positions in the examined area are recorded. Currently such data are acquired from the AIS. The method used for ship domain determination in this study includes the following stages (Pietrzykowski & Magaj 2016a, b):
1. Acquisition of data on ship positions in the analyzed area (AIS)
2. Transformation of ship positions from true motion to relative motion display, with the coordinate system centre associated with the ship's AIS antenna position.
3. Determination of vessel tracks density.
4. Determination of the ship domain boundary for ship's sectors (in this study 72 sectors are defined).
5. Approximation of the domain boundary to a geometric form (2D domain).
6. Stages 3, 4 and 5 are depicted in Figure 3.

This method has been used for the ship domain determination in the precautionary area of TSS Bornholmsgat.

3.2 The ship domain in the precautionary area

The determination of ship domains in the precautionary area TSS Bornholmsgate was based on AIS data recorded within four days (cf. Table 1). All vessels that were found within the analyzed area and period were included. Bulk carriers, the most numerous ship group, were considered separately. The domains were determined by the method described in section 3.1, approximating them to ellipses with semi-axes A and B (minor and major, respectively). Thus, domain length and width were, respectively, 2A and 2B (Fig. 4).
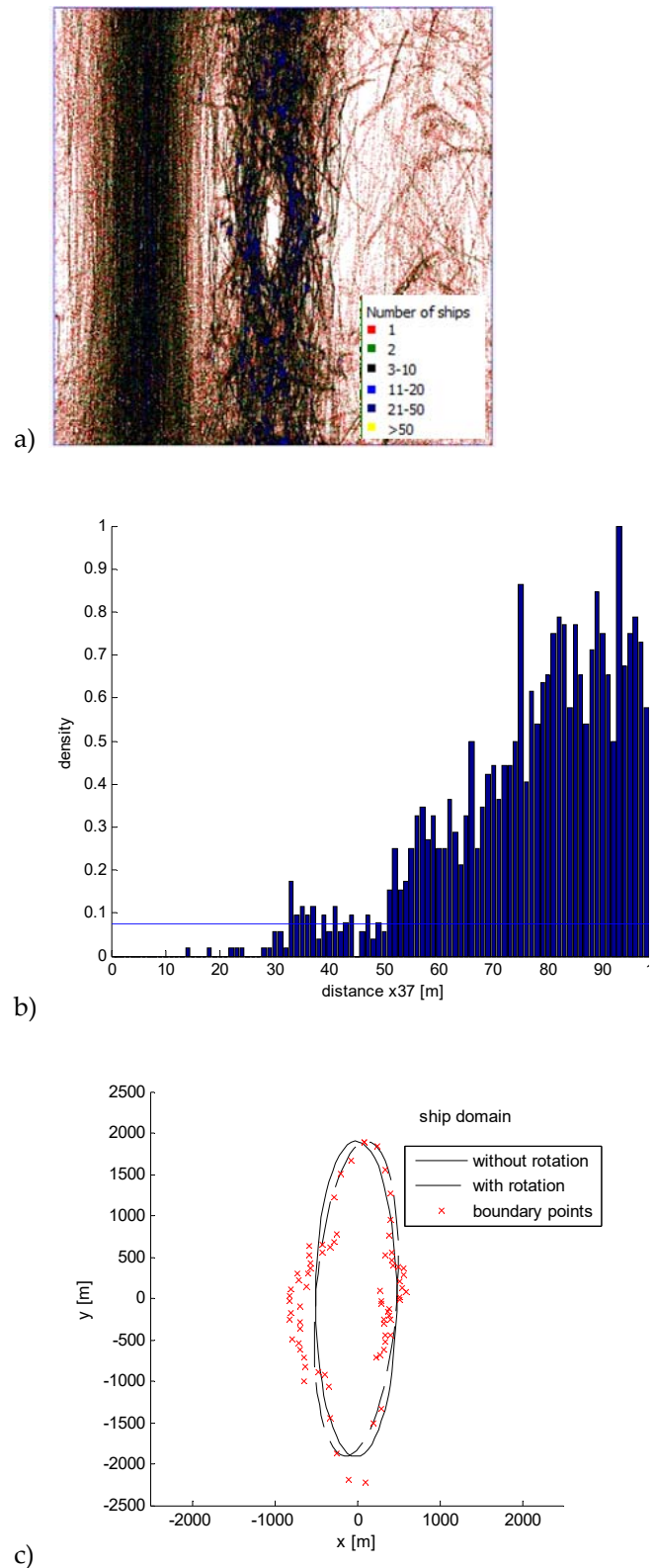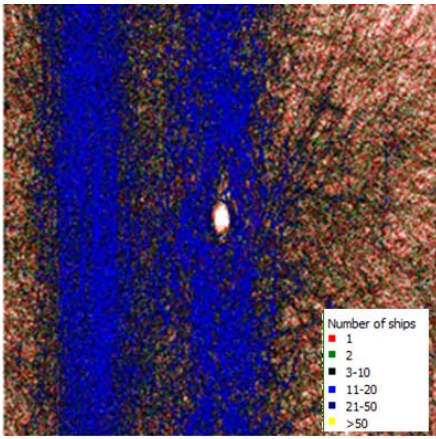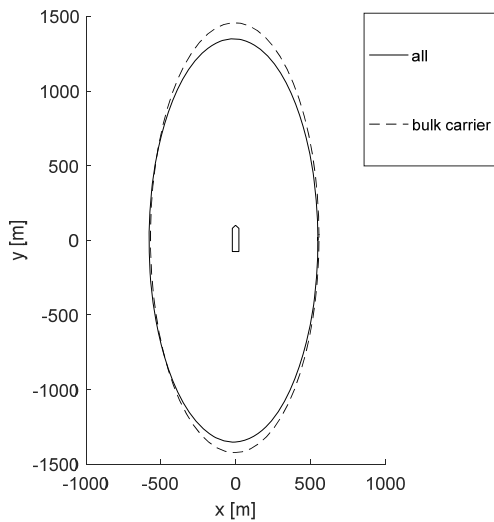
a)

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c)

Figure 3. The method for ship domain determination based on ship tracks: a) method of first maximum for the domain boundary determination for a given sector; (c) approximation of domain boundary (ellipse) (Pietrzykowski & Magaj 2016a,b).

a)

b)

Figure 4. The ship domain in the precautionary area: a) ship track density (all ships), b) ship domains (all vessels, bulk carriers)

The domain parameters are given in Table 2. Relative dimensions of the domains refer to mean ship lengths, 136 m and 127 m for all ships and bulk carriers, respectively.

Table 2. Parameters of ship domain in the precautionary area of TSS Bornholmsgat.

| Parameter	Ships	
	All	bulk carrier
Length (2B) [m]	2702	2880
Breadth(2A) [m]	1130	1136
Length (2B) [L]*	19.8	22.6
Breadth(2A) [L]*	8.2	8.9

* relative length/breadth in ships length L.

The results show a visible change in the length to breadth ratio: increased length, reduced breadth. At the same time, compared to test results for domains of vessels in areas restricted physically by the available manoeuvring area (Hansen et al. 2013), the determined lengths and breadths of domains are larger. The ratios of lengths to breadths are also different. In one case, the ratio approximately equals 2, in the other (precautionary area) it is 2.4 to 2.5.

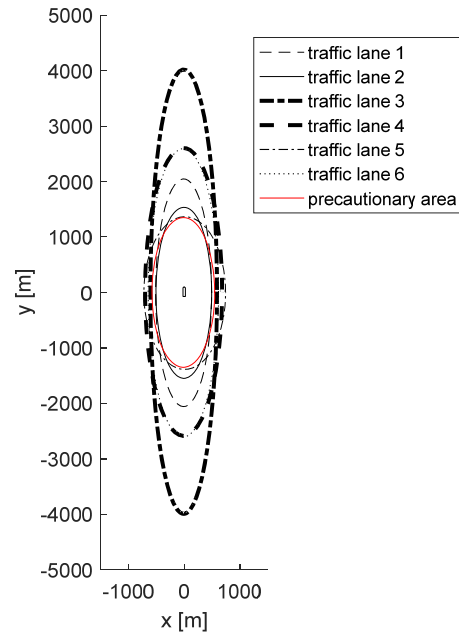Further, we compared the sizes of domains in the precautionary area to those in the adjacent traffic lanes.

4 COMPARATIVE ANALYSIS OF DOMAINS IN TSS

4.1 *Domains on the traffic lanes and in the precautionary area (PA)*

Ship domains on all traffic lanes were determined, then compared to the domains in the precautionary area. The results are shown in Figure 5.
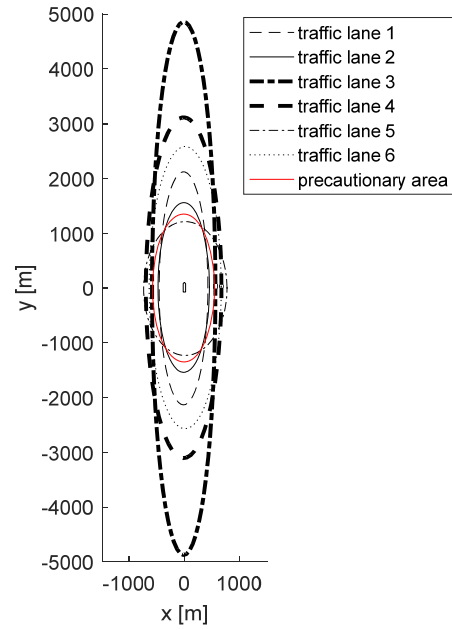
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Figure 5. Ship domains in the distinct TSS Bornholmsgat areas: a) all vessels); b) bulk carriers

A large diversity of domain lengths can be seen, while the breadths are comparable. Similar domain breadths can be explained by equal widths of all traffic lanes (2.7 Nm). Supposedly, a similar domain breadth in the precautionary area stems from the fact

that for the traffic lanes going in and out of the PA the domain breadths are also similar.

The smallest values of domain lengths were found in the PA and traffic lanes 1, 2 and 5. These waters were transited by the largest number of vessels (cf. Table 1). Traffic lanes 2 and 5 are part of the shipping route from the Eastern Baltic towards the Danish Straits and the Kiel canal.

In this connection the ship domains for traffic in both directions were determined and compared.

4.2 *Ship domains for selected traffic flows*

We analyzed vessel traffic flows from the Eastern Baltic towards the Danish Straits and the Kiel canal and in the opposite direction. To this end the domains were determined for vessels passing the route running through traffic lane 2, PA and traffic lane 5 (stream 1) and, separately, traffic lane 6, PA and traffic lane 1 (stream 2). The defined ship domains are shown in Figure 6. For comparison, domains for each area are additionally marked.

There is a clear difference of domain lengths for both streams. The domain length for stream 1 is approximately about half shorter than for stream 2. This may be caused be the vessel traffic flow from the Oresund towards the Eastern Baltic (traffic lane 4 - PA - traffic lane 1) intersecting the analysed stream 1.

5   CONCLUSIONS

This article presents the results of research into ship domains in the precautionary area of TSS Bornholmsgat. Domains of two groups of ships were taken into consideration. The domains had similar lengths and breadths. The results show a clear change in the domain length to breadth ratio for both open areas and areas restricted by the available manoeuvring area.

The determined domains were then compared to the domains defined for all traffic lanes of the analyzed TSS. The domain breadths were found to be similar, while domain lengths differed considerably. The smallest differences concerned those traffic lanes with the largest number of vessels recorded.

The authors also examined ship domains for identified vessel traffic streams. Large differences in domain sizes were observed. It was pointed out that one of the reasons may be the interaction of two traffic flows.

The determined domain data can be used for analysis and assessment of a navigational situation by vessel traffic services.

It seems purposeful from the perspective of ship control to define a single domain, e.g. for a particular type of ship in a specific traffic flow. Further studies are planned in this field, also for other traffic separation schemes
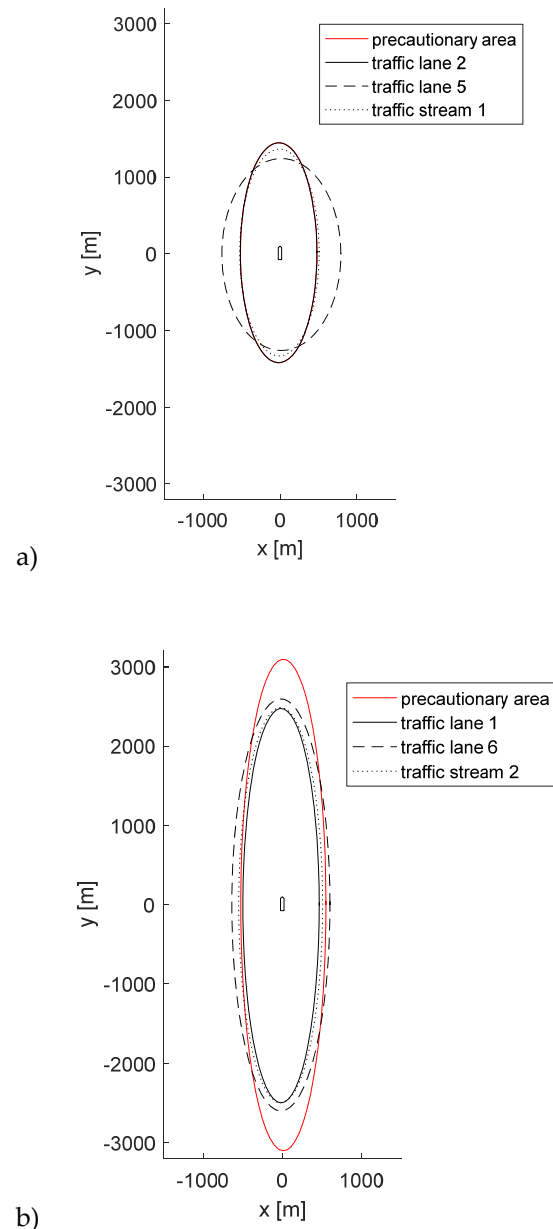

a)

b)

Figure 6. Ship domains for selected traffic flows in the TSS Bornholmsgat: a) stream 1 (all vessels); b) stream 2 (all ships)

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