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Analysis of ship domains in traffic separation schemes

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Abstract

The ship domain is a criterion of safety assessment in ship encounter situations. This criterion allows us to identify dangerous situations in open sea and restricted areas, the latter characterized by natural limitations such as the shore line, or artificial ones e.g., boundaries of Traffic Separation Schemes (TSSs). This article analyzes ship domains in TSSs. These schemes, being established in areas where vessel traffic is intensive, as a rule have virtual *traffic lanes* that indicate the direction of vessel traffic flow. The influence of the ship size and type on domain shape and size in a TSS has been examined. The domains have been defined on the basis of AIS data and statistical methods. The analyzed ship domains have been approximated by ellipses. The authors have determined intervals of changes in domain parameters.

Introduction

Heavy vessel traffic in frequented shipping routes and port approaches, increasingly larger ships, and higher shipping velocities create real threats to the safety of navigation. Traffic Separation Schemes (TSSs) are introduced in such areas to assure navigation safety and aim at proper management of traffic flows. The areas where a TSS is in operation are regarded as restricted areas. However, the constraining boundaries of these areas are virtual boundaries, as opposed to the physical boundaries of a shipping waterway (breadth, depth, navigational obstructions and dangers).

As the virtual restrictions of the area must be observed, and taking into account the volume of vessel traffic, it is often difficult or just impossible to use the situation assessment criteria commonly used in the high seas i.e. the closest point of approach (CPA) and the time to the closest point of approach. The Ship Domain, an alternative to CPA, is defined as the area around the ship which should be kept clear of other objects (Fuji & Tanaka, 1971; Zhao, Wu & Wang, 1993; Pietrzykowski, 2008). Unlike the CPA, using the Ship Domain, the navigator can change its shape and size. This criterion allows the navigator to identify dangerous situations in both open waters and restricted areas, where maneuvering is limited by natural and man-made restrictions. A number of factors, including the human element, make the formal description difficult and limit its applicability (Fuji & Tanaka, 1971; Zhao, Wu & Wang, 1993; Rutkowski, 1998; Śmierzchalski & Weintrit 1999; Zhu, Xu & Lin, 2001; Pietrzykowski, 2008; Pietrzykowski & Uriasz, 2009; Wang et al., 2009; Wielgosz & Pietrzykowski, 2012; Hansen et al., 2013; Wang, 2013; Marcjan & Gucma, 2014; Pietrzykowski & Magaj, 2016). The research in this field aims at developing methods for Ship Domain determination and verification, mainly in restricted areas, where the maneuvering areas are limited by the physical dimensions of the area. One may expect that the shapes and sizes of Ship Domains proceeding in a TSS may differ from corresponding domains in the above mentioned areas.

The use of identified domains of ships moving in a TSS will enable automatic identification of dangerous situations and provide for appropriate countermeasures such as anti-collision maneuvers.

The research area

TSS Bornholmsgat

TSS is a traffic management route system governed by IMO regulations. Specific traffic lanes are designated to point out the general direction of traffic flow within the scheme. The responsibility of the International Maritime Organization for ships' routing is formulated in the SOLAS Convention, Chapter V, Regulation 10, according to which the Organization is the only international body for establishing such systems (SOLAS, 1974). Ships' routing systems contribute to safety of life at sea, safety and efficiency of navigation, and/or protection of the marine environment. Rule 10 of the COLREGs (IMO, 1972) prescribes the conduct of vessels when navigating through traffic separation schemes adopted by the IMO. However, this in no way relieves ships from compliance with other COLREG rules. It should be noted that some TSSs exist that are not governed by the IMO.

The traffic lanes in these routing systems are marked by virtual boundaries, i.e. if a ship violates a lane boundary, it does not necessarily imply direct risk of grounding or collision with a land structure. In many cases the vessel intersects the TSS. In such situations, the ships shall cross on a heading orthogonal to the general direction of traffic flow.

Dense regions of vessel traffic, organized using separate lanes and virtual boundaries, allow us to expect that the safety criteria (safe distances to other objects) will be different from those determined in similar encounters in open waters or areas restricted, for example, by shore line.

Figure 1. TSS Bornholmsgat; six areas of traffic lanes (Pietrzykowski, Wołejsza & Magaj, 2015)

The Baltic Sea has a number of traffic separation schemes: TSS Adlergrund, TSS Bornholmsgat, TSS North of Rügen and TSS Słupska Bank (Pietrzykowski, Wołejsza & Magaj, 2015). Figure 1 presents the TSS Bornholmsgat with six traffic lanes.

Intensive traffic in that area includes vessels of various type and size, proceeding both to and from the Danish Straits and the Kiel Canal towards the Eastern Baltic Sea.

Vessel traffic

This analysis, based on vessel traffic data from the AIS over four days in June 2011, examines traffic in lanes No. 1 and 2 TSS Bornholmsgat and takes into account various ship types and sizes.

332 ships were recorded on the traffic lane 1 and 347 ships on the traffic lane 2. The prevailing types were bulk carriers, tankers and passenger ships (Tables 1 and 2). One can see similar numbers of

Table 1. Vessel traffic flows in analyzed TSS. Traffic lane No. 1

Ship type	Length [m]					Total
	<50	<100	<150	<200	≥200	
passenger	2	–	5	10	10	27
bulker	3	75	80	48	9	215
tanker	1	5	20	16	14	56
Total	6	80	105	74	33	298

Table 2. Vessel traffic flows in the analyzed TSS. Traffic lane No. 2

Ship type	Length [m]					Total
	<50	<100	<150	<200	≥200	
passenger	2	–	3	4	13	22
bulker	1	74	82	62	16	235
tanker	3	4	25	18	6	56
Total	6	78	110	84	35	313

Table 3. Vessel traffic flows in the analyzed TSS

Ship type	2011 – 4 days traffic lanes 1 and 2		Year 2011*	
	Number	%	Number	%
passenger	49	7	2 823	5
bulker	450	67	35 576	61
tanker	112	17	10 700	18
other**	64	9	9 577	16
Total	675	100	58 676	100

* source (HELCOM, 2011), ** without unidentified crafts.

ships within the examined traffic lanes for each corresponding ship type and size.

The comparison of these data to statistical data on vessel traffic in the examined area in the years 2006–2012, published in (HELCOM, 2011) shows a similar percentage share of each type of vessel.

The process of domain determination

The domain identification process is complex due to a large number of variable factors affecting domain shape and size. For example, these factors may include the type and parameters of the area, or whether or not a traffic separation scheme is present in the case under consideration. Various methods of domain determination using analytical techniques, statistical methods, or artificial intelligence may be found in the literature (Fuji & Tanaka, 1971; Rutkowski, 1998; Śmierzchalski & Weintrit 1999; Zhu, Xu & Lin, 2001; Pietrzykowski, 2008; Pietrzykowski & Uriasz, 2009; Wang et al., 2009; Hansen et al., 2013; Marcjan & Gucma, 2014; Pietrzykowski & Magaj, 2016). Approaches based on statistical methods or artificial intelligence make use of simulation studies based on operator controlled ship handling simulators and real data records on vessel movements, primarily AIS data.

In this study, ship domain determination in TSS areas makes use of ship tracks recorded in the AIS system. The distances between ships are analyzed. The procedure of ship domain determination consisted of the following steps (Pietrzykowski & Magaj, 2016):

1. Transformation of the data of ships moving within the TSS from real motion display to relative motion display, where the origin of the coordinate system is fixed to the AIS antenna position on the ship.
2. Determination of ship track density.
3. Selection of the domain determination method.
4. Ship domain determination – identification of domain parameters for the examined shipping areas, taking into consideration the types and dimensions of the recorded ships.

Figure 2 presents ship tracks recorded in the real motion display and, after transformation, relative motion display.

Densities of ship tracks were determined by dividing the area around the vessel into 37 m long squares (0.02 Nm) and counting the recorded tracks in each square. Then the track density values were standardized to the interval [0, 1] (Figure 3).

The ship domain was defined on the basis of ship track densities. To this end, the area around the ship was divided into 72 five-degree sectors. Each sector was assigned a point defining the ship domain boundary/limit. The following criteria were used in this step: cut-off mechanism (7.5%) and the first maximum (Figure 4).

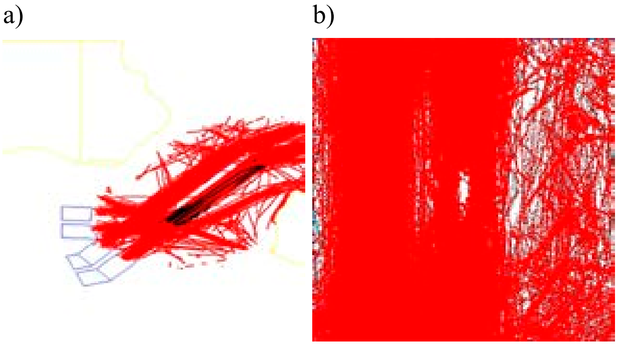

Figure 2. Tracks of ships in TSS Bornholmsgat, traffic lane 1: a) true motion, b) relative motion

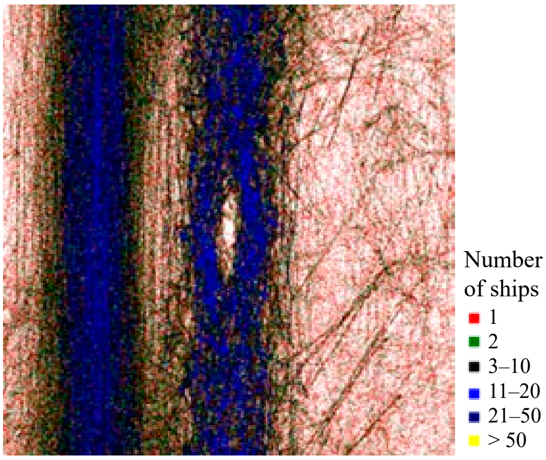

Figure 3. Ship track density in TSS Bornholmsgat, traffic lane 1 (Pietrzykowski & Magaj, 2016)

Due to irregularities of the shape, the determined domains were approximated to ellipses. The ellipses were described using the following parameters: x, y – shift of the ellipse center relative to the ship's antenna position, a, b – lengths of the ellipse minor and major semi-axes, α – angle of ellipse rotation (Figure 5).

The research

Domains of selected type ships

The presented method of domain determination was used to identify ship domains in the selected traffic lane 1 of the TSS Bornholmsgat. Table 4 shows the domain parameters for three types of ships: passenger, bulk carrier and tanker. TSS Bornholmsgat. The previously mentioned method of domain determination has been used.

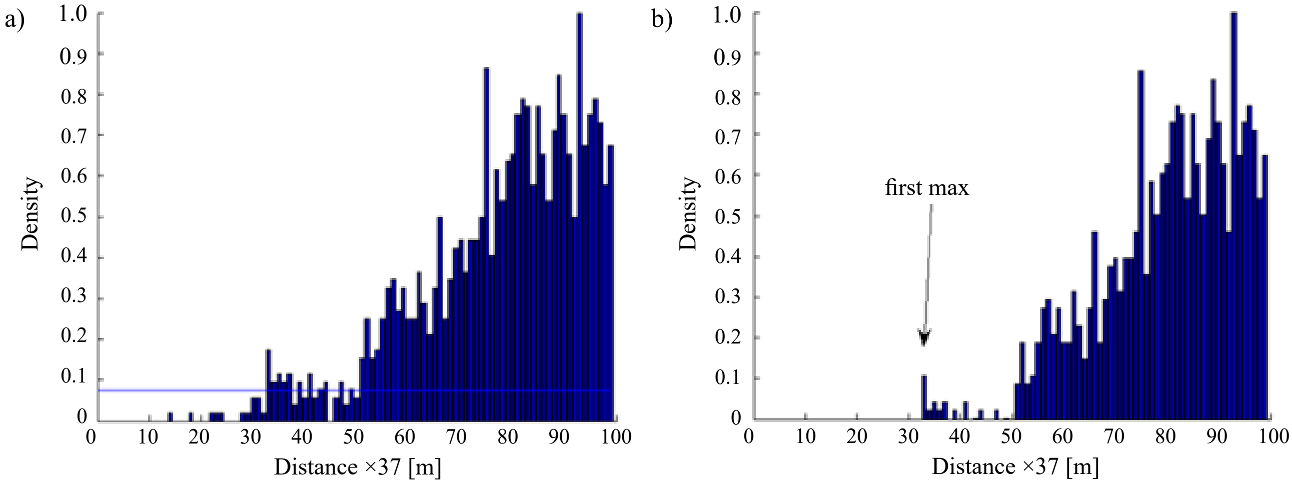

Figure 4. The method of determining the domain boundary for a selected sector 0–5°: a) cut-off mechanism; b) determination of the first maximum (Pietrzykowski & Magaj, 2016)

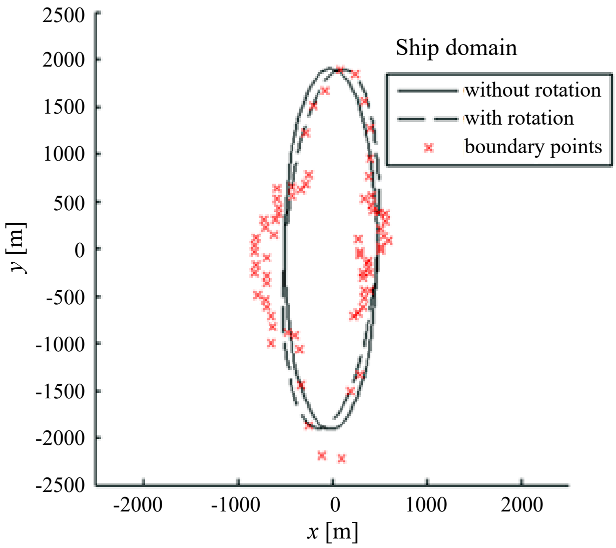

Figure 5. Ship domain boundary points and ship domains for the traffic lane No. 1 TSS Bornholmsgat (1) ellipse rotation angle *α* is not taken into account; (2) with ellipse rotation angle *α*

Table 4. Elliptical domain parameters of a ship for the traffic lane 1 TSS Bornholmsgat, without and with taking into account the ellipse rotation angle *α*; *a* – semi-major axis; *b* – semi-minor axis; *c* – shift of the ellipse center in *x*-direction; *d* – shift of the ellipse center in *y*-direction

Type	Parameter				
	α [deg]	*a* [m]	*b* [m]	*c* [m]	*d* [m]
passenger, bulker and tanker	0	503	2054	–10	–8
	5.1	499	1924	–9	–1
bulker	0	444	2128	–15	–6
	3.7	431	1962	–7	0
tanker	0	600	2356	–8	–6
	6.1	599	2123	–7	–3

Figure 6 depicts the determined ship domains.

Figure 7 presents values of the determined ellipse parameters for each ship group. Tankers, with average length of 161 m, were observed to have larger domains compared to other cargo vessels (average length 90 m), which may be explained by the differences in ship size and the number of ships sailing in the area.

Because the incoming and outgoing TSS traffic is disturbed, we performed more detailed research. To this end, the traffic at the 3 Nm sections where ships enter and leave the TSS was neglected, only the central section of the traffic lane 1 was analyzed. Tables 5 and 6 show the domain parameters with and without domain rotation.

Figure 8 presents the values of determined ellipse parameters for the selected cases. A slight increase of domain size was observed for the central section

Table 5. Domain parameters of a ship (ellipse) for selected sections of the traffic lane 1 TSS Bornholmsgat (without rotation); *a* – semi-major axis; *b* – semi-minor axis; *c* – shift of the ellipse center in *x*-direction; *d* – shift of the ellipse center in *y*-direction

Ships' type	Parameter				
	Traffic lane	*a* [m]	*b* [m]	*c* [m]	*d* [m]
passenger, bulker and tanker	whole	503	2054	–10	–8
	the central section	545	2165	–21	–8
bulker	whole	444	2128	–15	–7
	the central section	489	2188	–15	–10
tanker	whole	600	2356	–8	–6
	the central section	605	2356	–15	–7

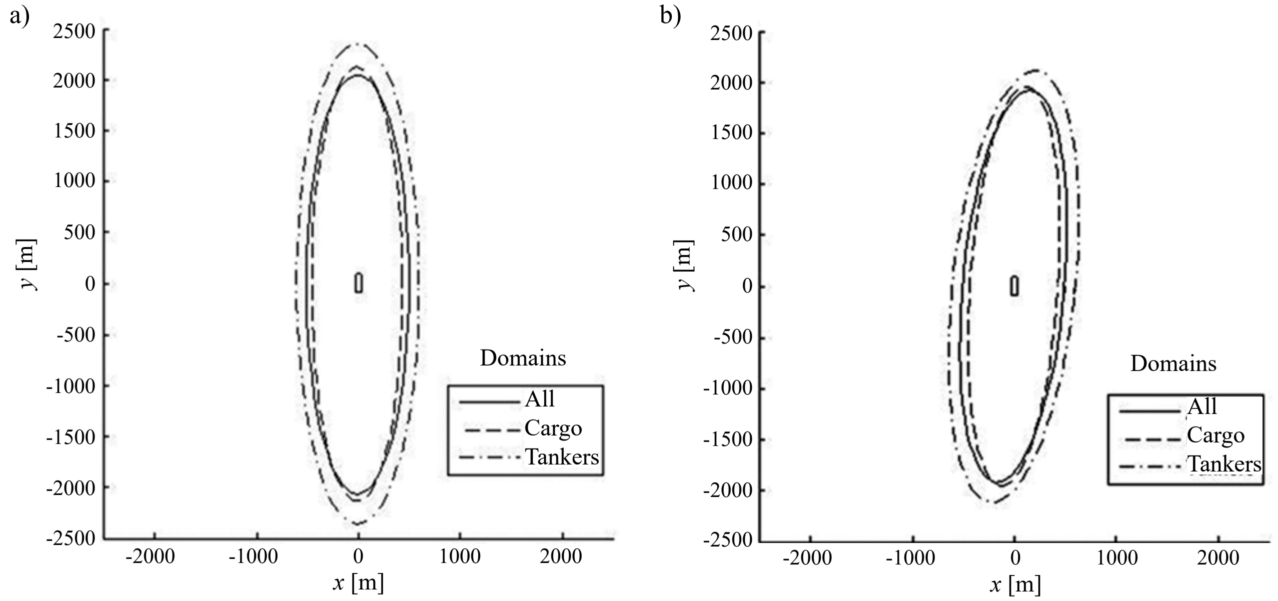

Figure 6. Ship domain for traffic lane 1 TSS Bornholmsgat: a) without the ellipse rotation angle *α*; b) with the ellipse rotation angle *α*

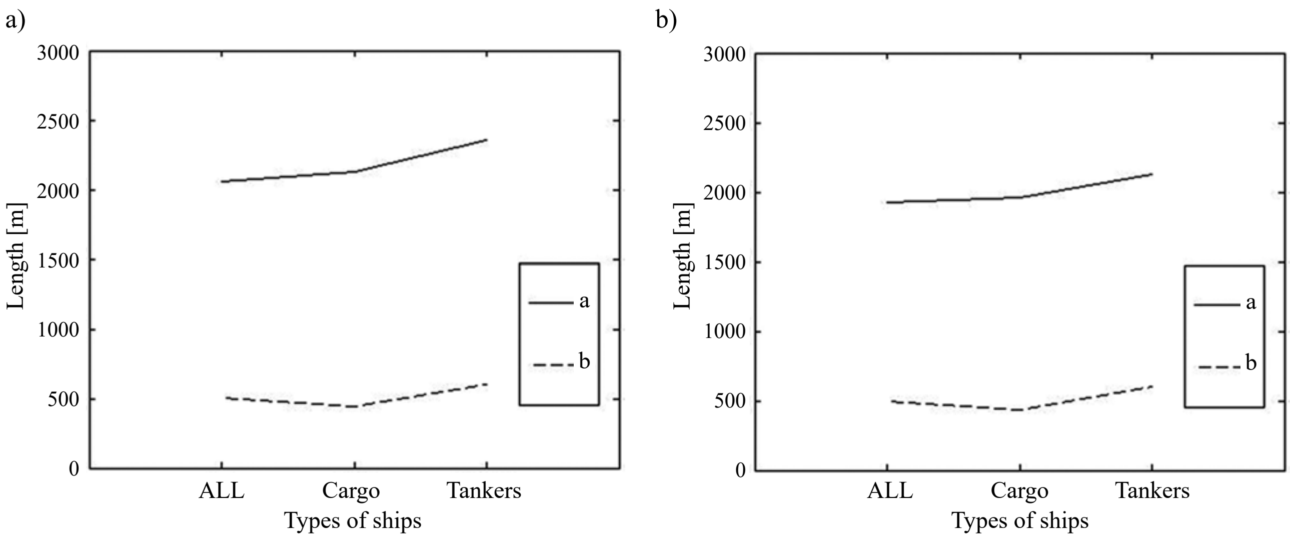

Figure 7. Ship domain parameters a and b for the traffic lane 1 TSS Bornholmsgat: a) without the ellipse rotation angle *α*; b) with the ellipse rotation angle *α*

Table 6. Domain parameters of a ship (ellipse) for selected sections of the traffic lane 1 TSS Bornholmsgat (with rotation); *a* – semi-major axis; *b* – semi-minor axis; *c* – shift of the ellipse center in *x*-direction; *d* – shift of the ellipse center in *y*-direction

Ships' type	Parameter					
	Traffic lane	*α* [deg]	*a* [m]	*b* [m]	*c* [m]	*d* [m]
passenger, bulker and tanker	whole	5.1	499	1924	–9	–1
	the central section	3.9	542	2237	–8	–1
bulker	whole	3.7	431	1962	–7	0
	the central section	3.3	495	2125	–4	–4
tanker	whole	6.1	599	2123	–7	–3
	the central section	4.6	599	2456	–4	–1

of the traffic lane 1. Besides, a significant increase of the major axis b was found in the rotated ellipse. Supposedly, this increase is an effect of less ordered traffic at both ends of the traffic lane.

Domains of various size ships

Various size ships were analyzed, where ship length was the size criterion. All ships were divided into four size groups by length: 1) 50–100 m; 2) 100–150 m; 3) 150–200 m; 4) over 200 m. Like in the case of various ship types, we examined the traffic lane 1 TSS Bornholmsgat. Table 7 shows the domain parameters for the mentioned ships sizes. The same method of domain determination has been used.

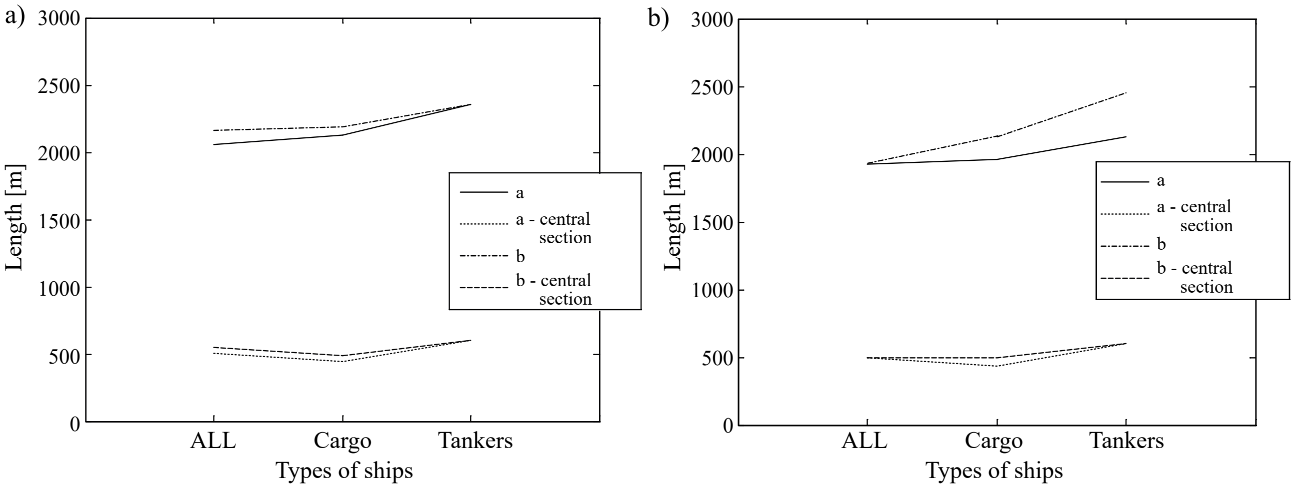

Figure 8. Ship domain parameters a and b for selected sections of the traffic lane 1 TSS Bornholmsgat: a) without the ellipse rotation angle *α*; b) with the ellipse rotation angle *α*

Table 7. Domain parameters of a ship (ellipse) for the traffic lane 1 TSS Bornholmsgat, without and with taking into account the ellipse rotation angle α; *a* – semi-major axis; *b* – semi-minor axis; *c* – shift of the ellipse center in *x*-direction; *d* – shift of the ellipse center in *y*-direction

Ship's length [m]	Parameter				
	α [deg]	*a* [m]	*b* [m]	*c* [m]	*d* [m]
50–100	0	390	2222	–20	–8
	3.6	401	2193	–8	1
100–150	0	437	2049	–18	–11
	1.6	430	2058	–6	–8
150–200	0	656	2448	–17	14
	0.7	648	2620	–5	3
> 200	0	529	2915	20	7
	1.6	526	2905	6	1

Figure 9 depicts the determined ship domains. The observed domain size increase was in line with ship length. No significant size difference was found between domains with or without rotation. A slight angle of rotation decreases with ship size, except for ships > 200 m, which may be due to a small size of the sample (The sample size of ships >200 m was half that for ships 150–200 m in length).

Figure 10 presents the values of determined ellipse parameters for the selected cases.

In this case, too, more detailed research was done due to less ordered traffic of vessels at the entrance and exit of the TSS lane. In this connection, the traffic at the 3 Nm sections where ships enter and leave the TSS lane was neglected, and only the central section of the traffic lane 1 was analyzed.

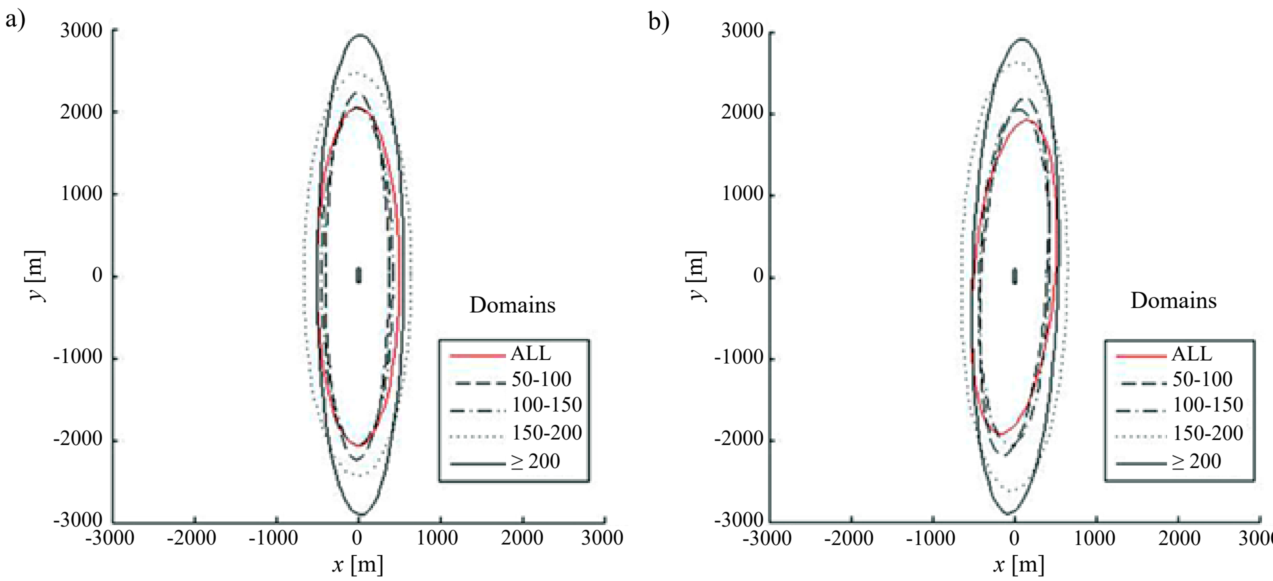

Figure 9. Ship domain for traffic lane 1 TSS Bornholmsgat: a) without the ellipse rotation angle *α*; b) with the ellipse rotation angle *α*

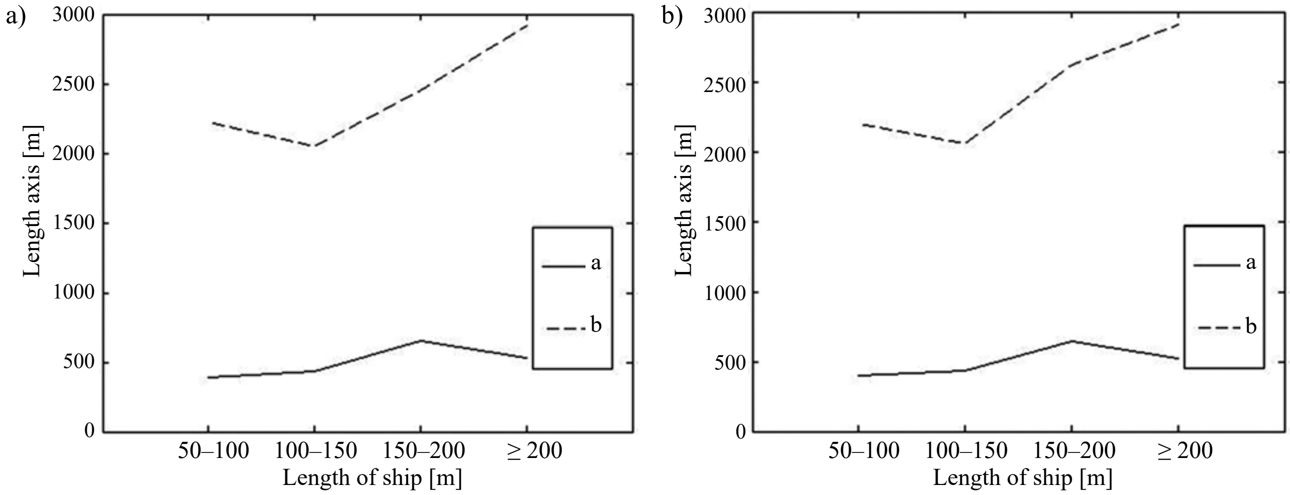

Figure 10. Ship domain parameters a and b for traffic lane 1 TSS Bornholmsgat: a) without the ellipse rotation angle *α*; b) with the ellipse rotation angle *α*

Table 8. Domain parameters of a ship (ellipse) for selected sections of the traffic lane 1 TSS Bornholmsgat (without rotation); *a* – semi-major axis; *b* – semi-minor axis; *c* – shift of the ellipse center in *x*-direction; *d* – shift of the ellipse center in *y*-direction

Ship's length [m]	Parameter				
	Traffic lane	*a* [m]	*b* [m]	*c* [m]	*d* [m]
50–100	whole	390	2222	–20	–8
	the central section	445	2329	–21	–21
100–150	whole	437	2049	–18	–11
	the central section	538	2002	–16	10
150–200	whole	656	2448	–17	14
	the central section	720	2307	–19	7
> 200	whole	529	2915	20	7
	the central section	585	3146	20	–6

Table 9. Domain parameters of a ship (ellipse) for selected sections of the traffic lane 1 TSS Bornholmsgat (with rotation); *a* – semi–major axis; *b* – semi–minor axis; *c* – shift of the ellipse center in *x*-direction; *d* – shift of the ellipse center in *y*-direction

Ship's length [m]	Parameter					
	Traffic lane	*α* [deg]	*a* [m]	*b* [m]	*c* [m]	*d* [m]
50–100	whole	3.6	401	2193	–8	1
	the central section	0.5	436	2499	–10	3
100–150	whole	1.6	430	2058	–6	–8
	the central section	3.9	522	2156	–4	2
150–200	whole	0.7	648	2620	–5	3
	the central section	0.1	704	2369	–5	7
> 200	whole	1.6	526	2905	6	1
	the central section	0.2	574	3144	8	0

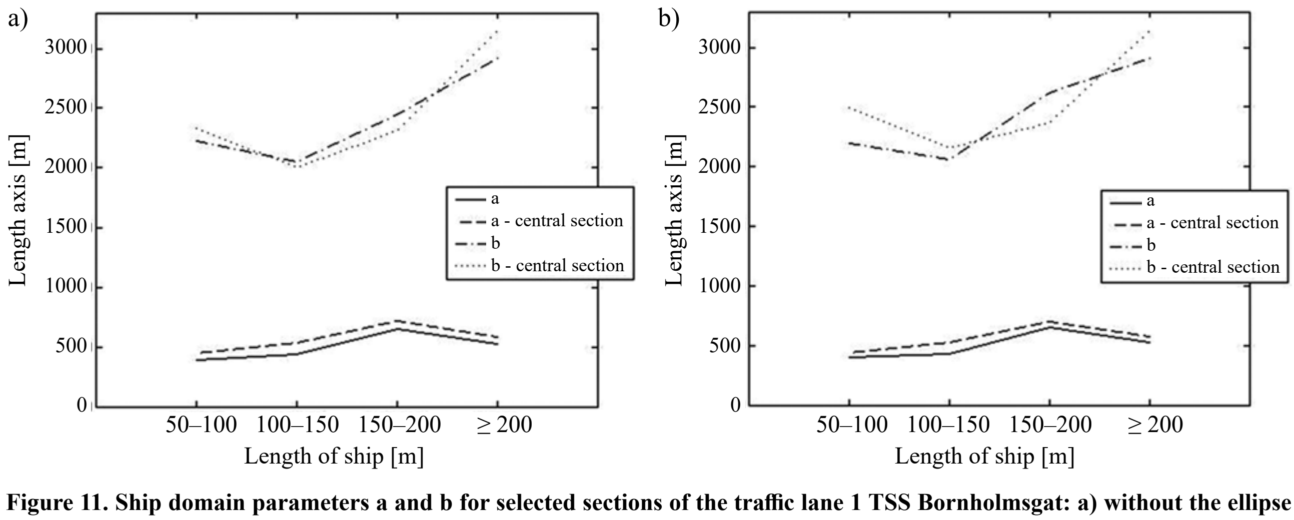

Figure 11. Ship domain parameters a and b for selected sections of the traffic lane 1 TSS Bornholmsgat: a) without the ellipse rotation angle *α*; b) with the ellipse rotation angle *α*

Tables 8 and 9 show domain parameters with and without domain rotation.

Figure 11 depicts values of the determined ellipse parameters for the selected cases. The domain length significantly increases (major axis b) as the ship length increases, while the domain breadth (minor axis a) changes slightly.

Conclusions

The authors have made a preliminary analysis of ship domains for various types and sizes of ships. The ship size visibly affects the ship domain, although its breadth grows slightly. Tankers were observed to have larger domains compared to bulk carriers. It should be noted, however, that the average length of tankers was greater than the average length of bulk carriers. Hence we may conclude that the ship type does not have much impact on ship domain size.

We plan to continue the research to cover the other traffic lanes in the TSS Bornholmsgat and other TSSs to verify the conclusions derived in this article.

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