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Ship domains in Traffic Separation Schemes

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Abstract

Ship movement processes in selected Traffic Separations Schemes (TSS) of Southern Baltic Sea were analyzed. Ship domains in the analyzed water areas were calculated from Automatic Identification System (AIS) registered data. The purpose of investigation was identification of ship domain parameters taking into account different domain determination criteria. The results were compared and discussed. The conclusions were drawn.

Introduction

The increasing density of traffic with larger and faster ships poses a real threat to the safety of navigation. This particularly applies to waters with high traffic intensity: port approach areas and busy shipping lanes, where various maneuvering restrictions exist, associated with the ship, water area and other vessels or objects at sea. In such areas traffic separation schemes (TSS) are established to ensure the safety of navigation. TSSs are designed to organize the traffic by separating traffic streams moving in opposite directions.

Navigational equipment and systems are continuously developing for two primary reasons: to increase navigational safety and to improve the efficiency of transport. New systems increasingly support the decision-making processes using the prediction capabilities or statistical analysis. Increasing attention is being paid to navigational decision support which provides solutions to problematic situations involving ships. These solutions, presented to the navigator are particularly important in complex situations and difficult conditions which require critical decisions to be made. NAVDEC (Pietrzykowski, Borkowski & Wołejsza, 2012) is one example of a navigational decision support system installed on several sea-going vessels.

The use of decision support systems in areas where a TSS has been established requires the inclusion of regulations relating to TSSs as well as specific criteria for the analysis and assessment of navigational situations. Due to the nature of vessel traffic in the TSS and the resultant limited application of the Closest Point of Approach (CPA) as a safety criterion (passing distances less than CPA limit set by navigator), the alternative is to apply the criterion of ship's domain.

In Pietrzykowski, Wołejsza & Magaj (Pietrzykowski, Wołejsza & Magaj, 2015) the authors present the results of traffic processes research covering selected traffic separation schemes in the Baltic Sea. The objective of the study is to identify the behavior of navigators in terms of compliance with and interpretation of the rules, aimed at developing decision support algorithms for these areas. The criteria of analysis and assessment of a navigational situation are important elements of these algorithms.

As mentioned before, we have adopted ship's domain as the safety criterion. Further in this article we present the method of determining the domain and its modifications, taking into account the specificity of the TSS. Based on these methods, we have determined ship domains and discussed the results.

Traffic separation schemes

TSS is a traffic management route-system where International Maritime Organization (IMO) regulations apply. Designated traffic lanes indicate the general direction of traffic flow within the scheme. IMO's responsibility for ships' routing is enshrined in the Safety of Life at Sea (SOLAS) Convention, Chapter V, Regulation 10, which recognizes the Organization as the only international body for establishing such systems. 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 (Collision Regulations, 1972) prescribes the conduct of vessels when navigating through traffic separation schemes adopted by IMO. However, this in no way relieves them 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 a TSS are demarcated by virtual boundaries. This means that boundary violation does not imply direct risk of grounding or collision. In many cases vessels sail across a TSS. In such situations, ships are obliged to cross on a heading as near as practicable to right angles to the general direction of traffic flow.

The high density and ordered character of vessel traffic on the one hand, and virtual boundaries of traffic lines on the other, indicate that safety criteria - safe distances to other objects - will differ between open waters and waters where natural restrictions exist, such as the shoreline.

For this reason, we have analyzed vessel traffic in the TSS Bornholmsgate (Figure 1). The analyzed data recorded by the AIS covered four days in June 2011. Each traffic lane has been examined separately.

Figure 1. TSS Bornholmsgate; six areas of traffic lanes

Our purpose was to develop and test a ship domain determination methodology for TSS areas to be used in further research.

Domain determination

As it is difficult to apply the same safety assessment criteria in open seas and restricted waters, in reference to the latter a lot of attention is given to ship's domain criterion (Zhao, Wu & Wang, 1993; Pietrzykowski, 1998; 2008; Rutkowski, 1998; Śmierzchalski & Weintrit, 1998; Zhu, Xu & Lin, 2001; Pietrzykowski & Uriasz, 2009; Wang et al., 2009; Gucma & Marcjan, 2012; Wielgosz & Pietrzykowski, 2012; Hansen et al., 2013; Wang, 2013). One of the definitions of ship domain was formulated by Goodwin (Goodwin, 1975) in 1975 as "*the surrounding effective waters which the navigator of a ship wants to keep clear of other ships or fixed objects*".

The domain shape and size is affected by a large number and variety of factors which make the identification of the domain a complex issue. These factors include, but are not limited to, the type and parameters of water area, TSS in this case. In the literature on the subject, for example mentioned above, authors propose various methods of domain determination: analytical, statistical, artificial intelligence. Both statistical methods and artificial intelligence use the results of observation, mainly simulation studies using ship handling simulators (with operator) and observations of real traffic processes (Zhao, Wu & Wang, 1993; Pietrzykowski, 1998; 2008; Rutkowski, 1998; Śmierzchalski & Weintrit, 1998; Zhu, Xu & Lin, 2001; Pietrzykowski & Uriasz, 2009; Wang et al., 2009; Gucma & Marcjan, 2012; Wielgosz & Pietrzykowski, 2012; Hansen et al., 2013; Wang, 2013).

Information Technology (IT) and Information Communication Technology (ICT) developments enable researchers to register an increasing range of real vessel traffic processes, an opportunity created by AIS. As a basis for determining the domains of ships in TSS areas we have adopted ship tracks registered in the AIS. Based on AIS records the distances between ships are analyzed. To this end, the data of vessels operating in the area of TSS were transformed to relative motion display, with the center of the coordinate system fixed to the ship (AIS antenna position). Then the densities of vessel tracks were determined. This was done by dividing the area under examination into squares with a side length of 37 m (0.02 NM). The size of the unit area

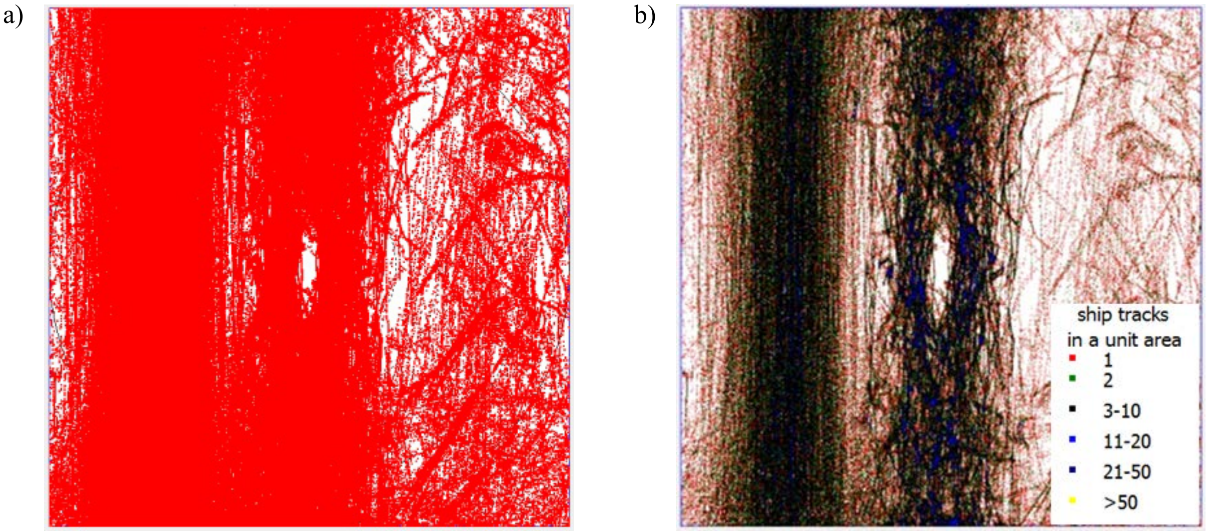

Figure 2. Tracks of ships in, traffic lane No. 1, TSS Bornholmsgate: a) ships tracks (2 091 230 tracks); b) the ship track density (part of the traffic lane)

was set arbitrary taking into account the analyzed water area and observed traffic intensity. Figure 2 illustrates ship tracks and their densities for the area 1 TSS Bornholmsgate (see Figure 2).

Over 300 ships passing along each traffic lanes were registered. The mean ship length in the examined TSS was 126 meters. The mean time between subsequent recordings of ship tracks was about five seconds.

Based on the density of the traces of vessels, the ship's domain was determined for different parts of the TSS. To this end, the area around the vessel was divided into 72 five-degree sectors. For each sector a point defining ship's domain was determined.

The following criteria were applied:

1) cut-off level (7.5%):
   a) the first non-zero value;
   b) the first maximum (Figure 3).
2) cut-off level (7.5%) or occurrence of at least (Figure 4):
   a) 20 points in the sector;
   b) 60 points in the sector.

The cut-of level was set by analogy to the domain determination criterion in a restricted water area proposed in literature, for example in (Hansen et al., 2013). Criteria 2a and 2b may be applicable for a smaller number of registered ship tracks. This may concern areas of lower traffic intensity or shorter registration time.

The boundary points thus defined are the points of ship's domain boundary on headings 2.5°, 5°, 7.5°... 357.5° (Figure 5).

Due to irregular shapes of the domain and simplified calculations in the navigational decision support system (situation assessment, generation of solutions to a collision situation), the determined domains were

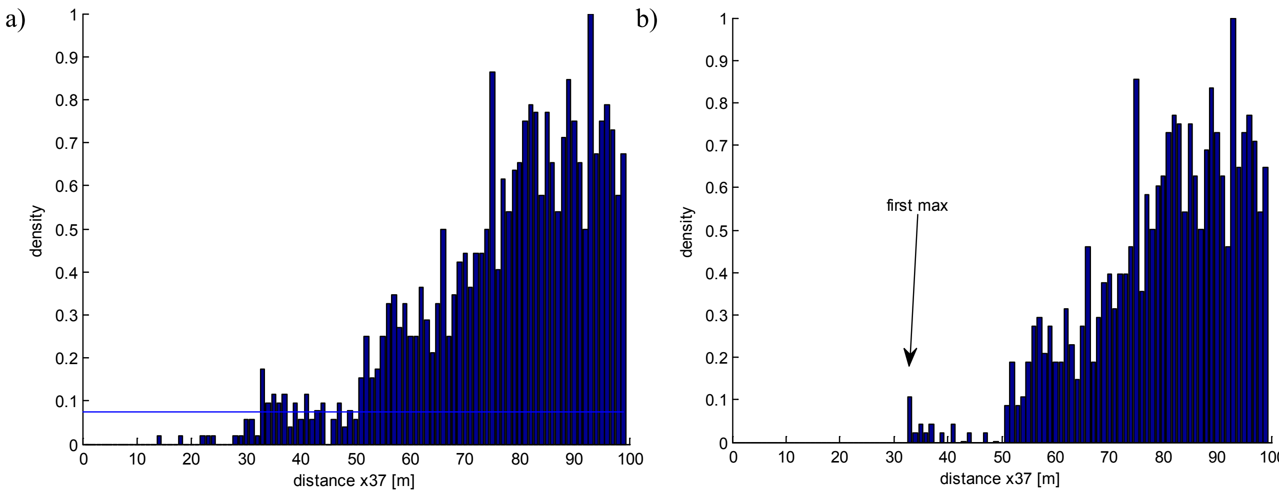

Figure 3. The method of determining the domain boundary for a selected sector 0 – 5 [°] as per criterion 1): a) cut-off mechanism; b) determination of the first maximum

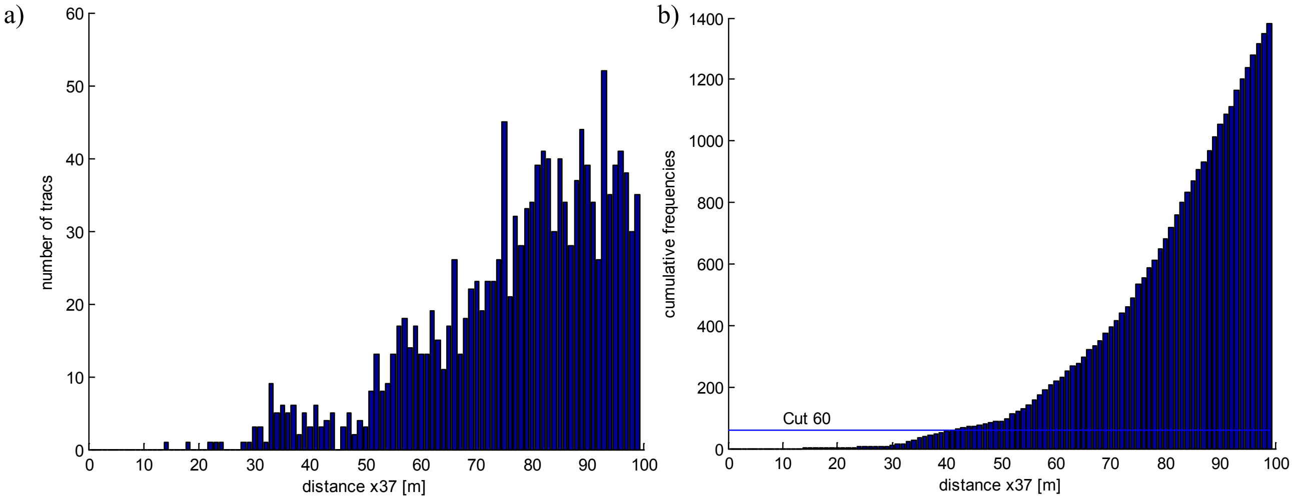

Figure 4. The method of determining the domain boundary for a selected sector as per criterion 2): a) numbers of points; b) cut-off by occurrence of at least 60 points in the sector

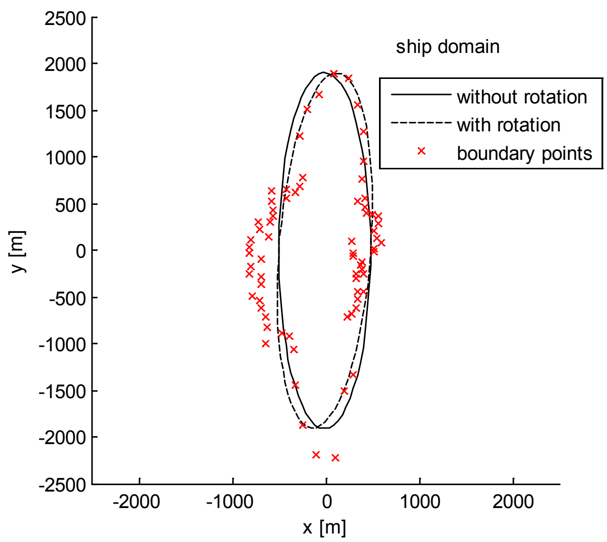

Figure 5. Ship domain boundary points and ship domains for the traffic lane No. 1 TSS Bornholmsgate (1) ellipse rotation angle *α* is not taken into account; (2) with ellipse rotation angle *α*

approximated to the shape of an ellipse. The ellipses were described by these parameters: *x*, *y* – displacements of the ellipse center relative to ship's antenna position, a, b – lengths of major and minor semi-axes, and *α* – angle of ellipse rotation (1), (Figure 5).

The results

We have used the presented method of domain determination to identify ship domains in selected traffic lanes of the TSS. Tables 1 and 2 show the domain parameters for traffic lanes Nos. 1 and 2 TSS Bornholmsgate. The mentioned criteria for domain determination have been used. Figure 6 depicts the determined ship domains.

Table 1. Domain parameters of a ship (ellipse) for the traffic lane No. 1 TSS Bornholmsgate, with and without 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

Method	Parameter				
	α	a [m]	b [m]	c [m]	d [m]
Cut-off level (7.5%) and the first non-zero value (1a)	0	505	1909	–8	4
	4.9	491	1918	–5	–3
Cut-off level (7.5%) and the first maximum (1b)	0	503	2054	–10	–8
	5.1	499	1924	–9	–1
Cut-off level (7.5%) or occurrence of at least 20 points in the sector (2a)	0	432	941	–9	6
	2.9	430	1000	–10	6
Cut-off level (7.5%) or occurrence of at least 60 points in the sector (2b)	0	619	1232	–8	6
	5.8	605	1270	–26	31

Table 2. Domain parameters of a ship (ellipse) for the traffic lane No. 2 TSS Bornholmsgate, with and without 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

Method	Parameter				
	α	a [m]	b [m]	c [m]	d [m]
Cut-off level (7.5%) and the first non-zero value (1a)	0	484	1462	–9	6
	2.7	485	1464	–8	–1
Cut-off level (7.5%) and the first maximum (1b)	0	501	1543	–9	–6
	1.6	490	1543	–11	–11
Cut-off level (7.5%) or occurrence of at least 20 points in the sector (2a)	0	438	1100	2	11
	0/01	441	1102	–1	91
Cut-off level (7.5%) or occurrence of at least 60 points in the sector (2b)	0	565	1290	4	8
	0.6	569	1254	7	78

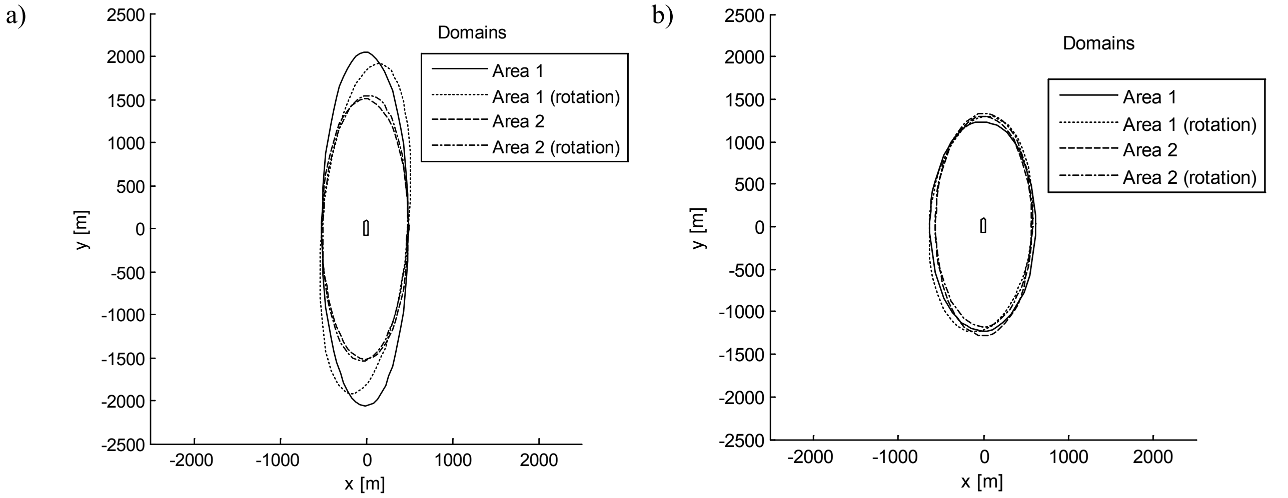

Figure 6. Ship domain for traffic lanes Nos. 1 and 2 TSS Bornholmsgate, with and without the ellipse rotation angle α: a) method 1b; b) method 2b

We have found that for methods 1a and 1b, essential differences appear in the domain size (semi-minor and semi-major axes). When methods 2a and 2b were used, the domain dimensions for the two traffic lanes were similar.

From the presented results we can ascertain that the domain rotation angle for both traffic lanes is slight (<6°) and it does not affect the domain size substantially. At the same time slight shifts of the center of the ellipse relative to the antenna position were found.

Because the vessel traffic at the entrance and exit of the TSS is disturbed, we conducted more detailed studies of the traffic lanes under consideration. For this purpose, the movement of vessels was examined in the central sections of entrance and exit, excluding the initial and final 1 Nm (1a), 2 Nm (1b), and 3 Nm (1c) stretches. Tables 3 and 4 show parameters of the domains. Figures 7 and 8 depict the determined ship domains.

In the case of methods 1a and 1b, the domain size is not much affected by the exclusion of the entrance and exit parts of traffic lane No. 1 an action taken to eliminate the impact of disturbances occurring mainly due to vessel traffic near TSS. The only effect is a slight increase of the major semi-axis length. The use of methods 2a and 2b results in a larger difference between lengths of both semi-axes.

In case of the traffic lane No. 2, methods 1a and 1b give a visible increase in the length of major semi-axis. The application of methods 2a and 2b results in difference in the length of minor semi-axis.

Table 3. Domain parameters of a ship (ellipse) for selected sections of the traffic lane No. 1 TSS Bornholmsgate (without rotation) with the use of two domain determination methods (1b and 2b); 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

Traffic line	Method	Parameter			
		a [m]	b [m]	c [m]	d [m]
Whole traffic line	1b	503	2054	–9	–8
	2b	619	1232	–8	–5
Traffic line excluding the initial and final 1 Nm (1a) stretches	1b	503	2181	–1	–1
	2b	662	1425	–11	–8
Traffic line excluding the initial and final 2 Nm (1b) stretches	1b	539	2165	–7	–5
	2b	693	1671	–10	–5
Traffic line excluding the initial and final 1 Nm (1c) stretches	1b	539	2165	–11	–7
	2b	717	1700	–7	–5

Table 4. Domain parameters of a ship (ellipse) for selected sections of the traffic lane No. 2 TSS Bornholmsgate (without rotation) in of traffic line with the use of two domain determination methods (1b and 2b); 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

Traffic line	Method	Parameter			
		a [m]	b [m]	c [m]	d [m]
Whole traffic line	1b	501	1510	–9	–6
	2b	565	1290	4	8
Traffic line excluding the initial and final 1 Nm (1a) stretches	1b	487	1712	–12	8
	2b	595	1310	7	10
Traffic line excluding the initial and final 2 Nm (1b) stretches	1b	467	1843	–9	–10
	2b	627	1333	6	10
Traffic line excluding the initial and final 1 Nm (1c) stretches	1b	454	1916	–8	–3
	2b	690	1336	8	12

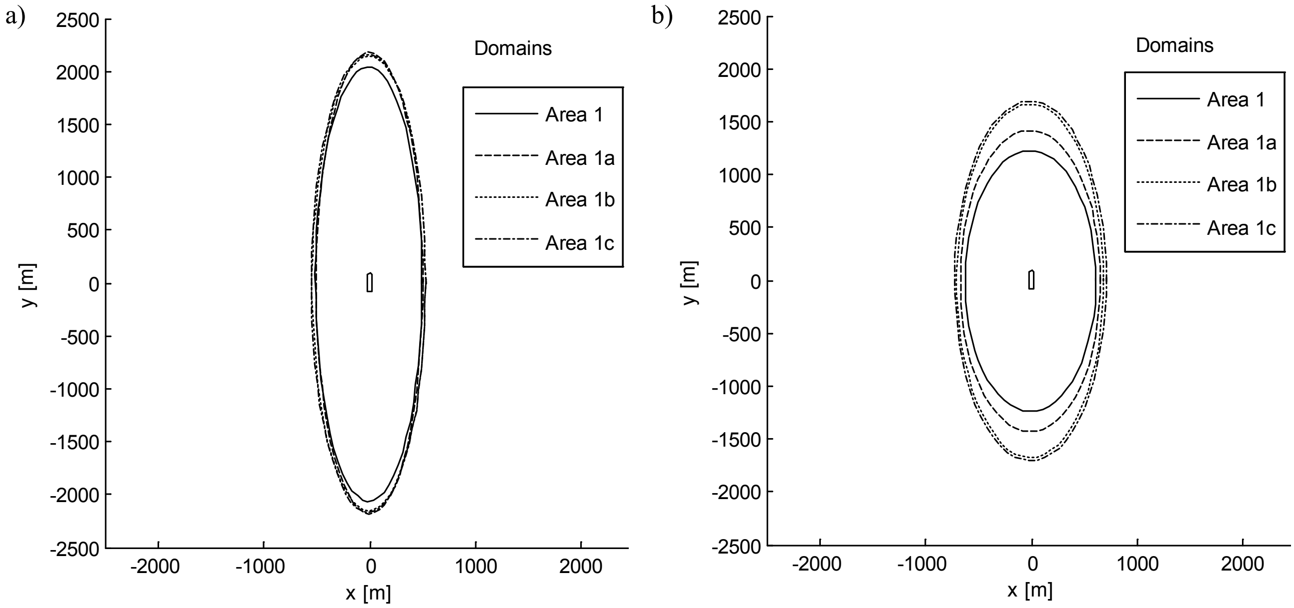

Figure 7. Ship domain for selected sections of the traffic lane No. 1 TSS Bornholmsgate: a) domain determination method 1b; b) domain determination method 2b

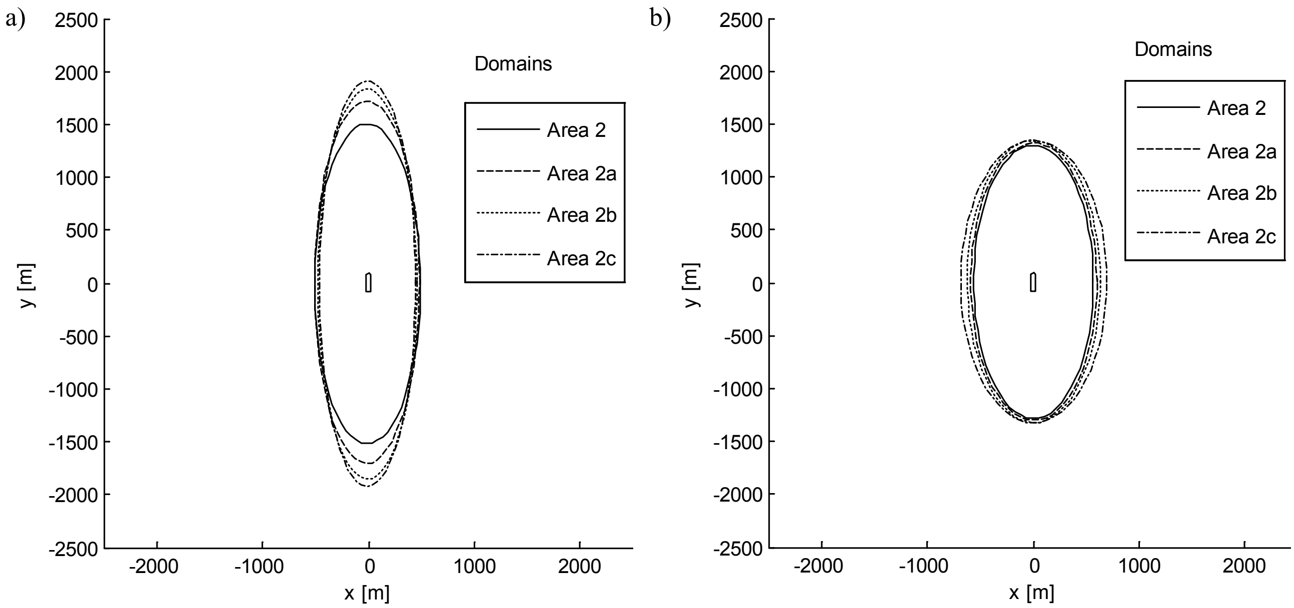

Figure 8. Ship domain for selected sections of the traffic lane No. 2 TSS Bornholmsgate: a) domain determination method 1b; b) domain determination method 2b

Conclusions

The authors have performed preliminary research on ship domains in Traffic Separation Schemes. The research was aimed at the development of methodology for the identification of ship domains in TSS in real conditions. This will allow the use of ship domains as a safety criterion in decision support systems in areas where TSSs are established.

The AIS data of the chosen traffic lanes in TSS Bornholmsgate have been analyzed. Different criteria for ship domain determination have been examined.

Criteria 1a, 1b, 2a and 2b may be applied to cases with a large number of registered ship tracks, wherein the number of occurrence of at least tracks (points) in the sector for methods 2a and 2b should be made dependent on the number of registered ship tracks.

Criteria 2a and 2b may be used for a smaller number of registered ship tracks. This may concern areas of lower traffic intensity or shorter registration time.

When methods 1a and 1b are used, essential differences occur in the domain size, while for methods 2a and 2b the domain dimensions for the two traffic lanes are similar.

From the presented results we can state that the domain rotation angle is slight for both traffic lanes (<6°) and it does not significantly affect the domain size.

The exclusion of the entrance and exit parts of the traffic lanes Nos. 1 and 2 in order to eliminate the effect of disturbances, resulting mainly from vessel traffic near the TSS, has led to an increase of the domain size, different for each traffic lane.

We intend to use the presented methodology to examine the other traffic lanes within TSS Bornholmsgate, then other TSSs situated within the Baltic Sea.

References

1. Goodwin, E.M. (1975) A statistical study of ship domains. *Journal of Navigation* 28. pp. 328–344.
2. Gucma, L. & Marcjan, K. (2012) Examination of ships passing distances distribution in the coastal waters in order to build a ship probabilistic domain. *Scientific Journals Maritime University of Szczecin* 32 (104) z. 2. pp. 34–40.
3. Hansen, M., Jensen, T., Lehn-Schiøler, T., Melchild, K., Rassmussen, F. & Ennemark, F. (2013) Empirical ship domain based on AIS data. *Journal of Navigation* 66. pp. 931–940.
4. Pietrzykowski, Z. & Uriasz, J. (2009) The ship domain – a criterion of navigational safety assessment in an open sea area. *Journal of Navigation* 62 (1). pp. 93–108.
5. Pietrzykowski, Z. (1998) Ship fuzzy domain in navigational safety assessment in restricted area. *3rd Navigational Symposium*, Gdynia, I, pp. 253–264 (in Polish).
6. Pietrzykowski, Z. (2008) Ship's fuzzy domain – a criterion of navigational safety in Narrow Fairways, *Journal of Navigation* 61 (3). pp. 499–514.
7. Pietrzykowski, Z., Borkowski, P. & Wołejsza, P. (2012) Marine integrated navigational decision support system. Telematics in the transport environment. *12th International Conference on Transport Systems Telematics. TST 2012.* Katowice-Ustroń, Poland, October 10–13, 2012. Selected papers, J. Mikulski (Ed.). CCIS 329, Berlin Heidelberg: Springer-Verlag. pp. 284–292.
8. Pietrzykowski, Z., Wołejsza, P. & Magaj, J. (2015) Navigators' Behavior in Traffic Separation Schemes. *Journal on Marine Navigation and Safety of Sea Transportation* (*TRANSNAV*) 9 (1). pp. 123–128.
9. Rutkowski, G. (1998) Ship domain – navigational safety in areas difficult to navigate. *Scientific Works of Navigation Faculty* 6. Gdynia: Gdynia Maritime University (in Polish).
10. Śmierzchalski, R. & Weintrit, A. (1998) Domains of navigational objects as an aid to route planning in collision situation at sea. *3rd Navigational Symposium*, Gdynia, I, pp. 265–279 (in Polish).
11. Wang, N. (2013) A novel analytical framework for dynamic quaternion ship domains. *Journal of Navigation* 66 (2). pp. 265–281.
12. Wang, N., Meng, X., Xu, Q. & Wang, Z. (2009) A unified analytical framework for ship domains. *Journal of Navigation* 62 (4). pp. 643–665.
13. Wielgosz, M. & Pietrzykowski, Z. (2012) Ship domain in the restricted area – analysis of the influence of ship speed on the shape and size of the domain. *Scientific Journals Maritime University of Szczecin* 30 (102). pp. 138–142.
14. Zhao, J., Wu, Z. & Wang, F. (1993) Comments of ship domains. *Journal of Navigation* 46 (3). pp. 422–437.
15. Zhu, X., Xu, H. & Lin, J. (2001) Domain and its model based on neural networks. *Journal of Navigation* 54. pp. 97–103.