

Ship Domain in Open Sea Areas and Restricted Waters: an Analysis of Influence of the Available Maneuvering Area

M. Wielgosz

Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: A ship domain is nowadays an important navigational safety assessment criterion. Its shape and size depend on many factors. The available manoeuvring area seems to be one of the most important of them. This article examines the influence of the available manoeuvring area on the shape and size of ship domain in the open sea and restricted waters. The research was conducted using a simulation method. Expert navigators participated in simulations using the ECDIS system. The domains of ship passages in open sea area and restricted area have been compared.

1 INTRODUCTION

Sea navigators of today face several important tasks in their work. One of the most important navigator's tasks is to ensure ship's safety during its passage at sea. There are several criteria currently used for ship safety assessment.

An intensifying debate has been held for the past five decades on the use of the ship domain for analysis and evaluation of the navigational situation (i.e. Fuji & Tanaka 1971, Coldwell 1975, Śmierchalski & Weintrit 1999, Pietrzykowski & Uriasz 2009, Wielgosz 2016).

The problem of ship domain determination is still up-to-date due to a large number of factors affecting its shape and size, so great that for practical reasons in the actual domain determination method some of these factors are taken into account. In many experts' opinion, the most important domain determinants include the size and speed of the vessel and the type of sea area – open or restricted.

The ship domain as a criterion for assessing the safety of navigation is of great importance for navigation in waters with high traffic intensity, where the vessel has limited available manoeuvring area due to physical and legal limitations and in open sea areas, with less traffic and a large available manoeuvring area.

The observed behaviour of marine navigators reveals large differences in distances kept to other vessels encountered and passed in either type of navigable area, which directly translate into differences in the size and shape of the domain.

In this paper the ship domains in open sea area and restricted area have been compared.

2 SIMULATION RESEARCH AND THE METHOD OF SHIP DOMAIN DETERMINATION

2.1 Simulation research

A simulation research was conducted in ECDIS (Electronic Chart Display and Information System) simulator lab. To analyze passing distances between ships kept by expert navigators, the data transmitted in the Automatic Identification System (AIS) were registered at one second discretization. Ships' positions (latitude and longitude), courses and speeds were used for further calculations. As there are many domain models found in the literature with differently interpreted domain boundaries, this author decided to determine three effective domain boundaries: minimum, mean and maximum. An example of the examined domains is presented in Figure 1 (Wielgosz & Pietrzykowski 2012).

The current stage of author's research on ship domain, herein concerning the open sea area, included the execution and analysis of 305 single ship encounter situations (scenarios were prepared in advance for three types of ships), performed by expert navigators in the ECDIS simulator.

Five relevant scenarios for each size of ship were prepared and recorded, thus allowing later to repeat the initial situation with the possibility of individual maneuvers by attending experts - sea navigators. A detailed description of the research and analysis method is described in author's earlier publications).

The main purpose of the conducted research was to determine the influence of the available maneuvering area conditions on the ship domain.

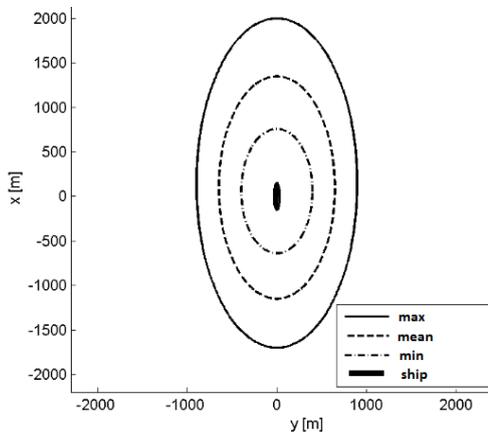


Figure 1. An example of the analyzed domains in a restricted area.

2.2 The ship domain in a restricted area

The problem and models of ship domain in the restricted area have been described in many publications lately (Hansen et al. 2013, Wielgosz & Pietrzykowski 2012, Wielgosz 2015). Most of the domains have an elliptical shape.

In this paper the author implements a model of anti-collision domain developed through his research (Wielgosz 2015). The adopted model is an ellipse with an offset centre, described by parametric equations (1

to 6), which takes into account the size and speed of the vessel.

$$x(t) = x_0 + a \cdot \cos(t) \quad (1)$$

$$y(t) = y_0 + b \cdot \sin(t) \quad (2)$$

$$a = (a_{1L} \cdot L^{b_{1L}} + c_{1L}) + a_{1v} (v^{b_{1v}} - 2^{b_{1v}}) \quad (3)$$

$$b = (a_{2L} \cdot L^{b_{2L}} + c_{2L}) + a_{2v} (v^{b_{2v}} - 2^{b_{2v}}) \quad (4)$$

$$x_0 = p_x \cdot L + q_x \cdot v + r_x \quad (5)$$

$$y_0 = p_y \cdot L + q_y \cdot v + r_y \quad (6)$$

where:

L – ship's length [m];

v – ship's speed;

$a_{1L}, b_{1L}, c_{1L}, a_{2L}, b_{2L}, c_{2L}$ – length influence coefficients;

$a_{1v}, b_{1v}, c_{1v}, a_{2v}, b_{2v}$ – speed influence coefficients;

t – relative bearing;

p_x, q_x, r_x – X-axis centre displacement coefficient;

p_y, q_y, r_y – Y-axis centre displacement coefficient.

2.3 The ship domain in an open sea area

Implementing the same method as for restricted areas (Wielgosz 2015), three types of domain were studied for the analyzed ships. In order to determine the shape and size of a domain in the open sea area, the author continued the research described above, using the same ship models of different size, considered to be representative for today's shipping.

Selected parameters of the ship models are presented in Table 1.

Table 1. Selected parameters of ship models

parameter	ship size		
	small	medium	large
type	Coaster	LO-RO	Tanker
length [m]	95.0	174.0	261.0
breadth [m]	13.0	23.0	48.0
displacement [T]	3 510.0	19 512.0	63 430.0
speed [knots]	11.1	16.3	16.3

The research was conducted only for 'full ahead' speed, typically developed when the ship proceeds in the open sea area.

Detailed results obtained in open sea area (after implementation of generic algorithms for approximation) are presented in Section 3 below.

3 COMPARISON OF THE RESULTS IN RESTRICTED AND OPEN SEA AREAS

The data published herein consist of previously presented data for the restricted area and the newly obtained results for the open sea area.

3.1 The domain shape

As expected, the domain shape in the open sea remains elliptical, as presented in Figures 2, 3 and 4.

These figures are drawn in the ship coordinate system, with the vertical X axis (X axis is commonly used in navigation as the longitudinal axis of symmetry) and the horizontal Y axis.

Approximated data for “small”, “medium” and “large” ship are visualised in Figures 2, 3 and 4, respectively.

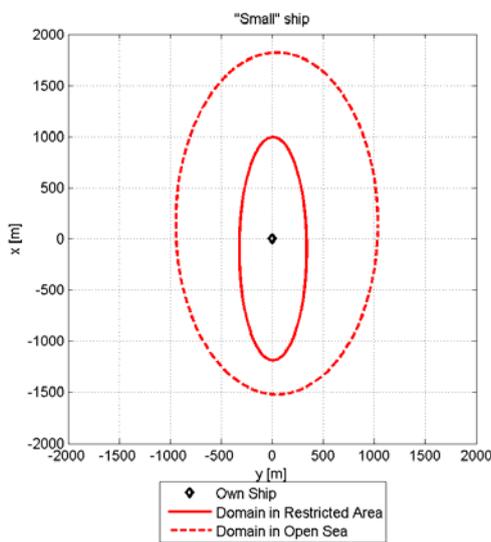


Figure 2. Comparison of the studied domains for a “small” ship.

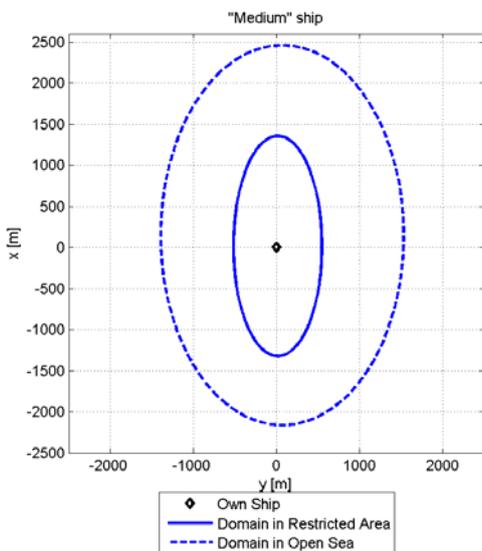


Figure 3. Comparison of the studied domains for a “medium” ship.

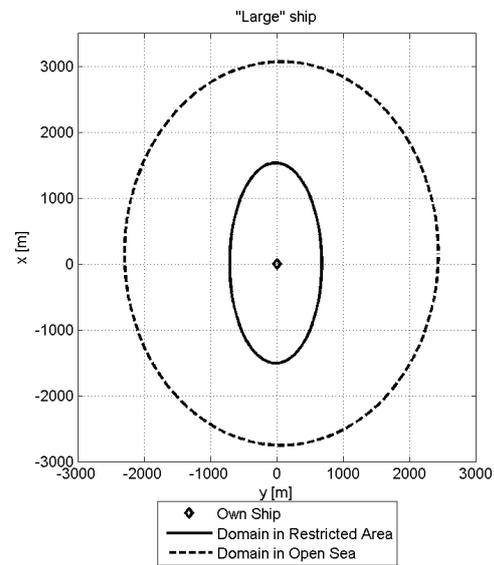


Figure 4. Comparison of the studied domains for a “large” ship.

3.2 Length of the semi-axes

3.2.1 Restricted area

Detailed data concerning the length of semi-major and semi-minor axis for 3 types of the examined domains in the restricted area are presented in Table 2.

Table 2. Semi-axis length in restricted area

semi-axis	domain type	ship size		
		small	medium	large
major	minimum	529	537	865
	mean	1093	1341	1524
	maximum	1730	1719	2667
minor	minimum	226	439	441
	mean	332	534	697
	maximum	477	829	1035

3.2.2 Open sea area

The lengths of elliptical domain semi-axes in the open seas are presented in Table 3.

Table 3. Semi-axis length in open sea area

semi-axis	domain type	ship size		
		small	medium	large
major	minimum	1058	1680	2044
	mean	1672	2312	2915
	maximum	2166	2470	3226
minor	minimum	602	992	1170
	mean	992	1464	1760
	maximum	1295	1826	2371

The research results are also presented in a graphical form in Figures 5 and 6 for semi-major and semi-minor axis, respectively.

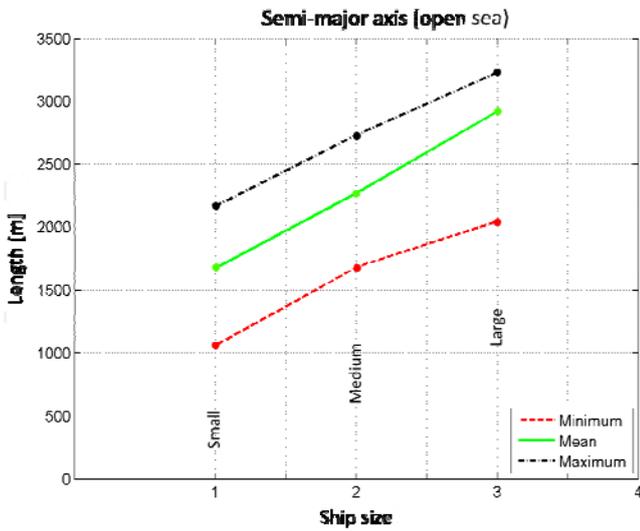


Figure 5. Length of the semi-major axes in an open sea area.

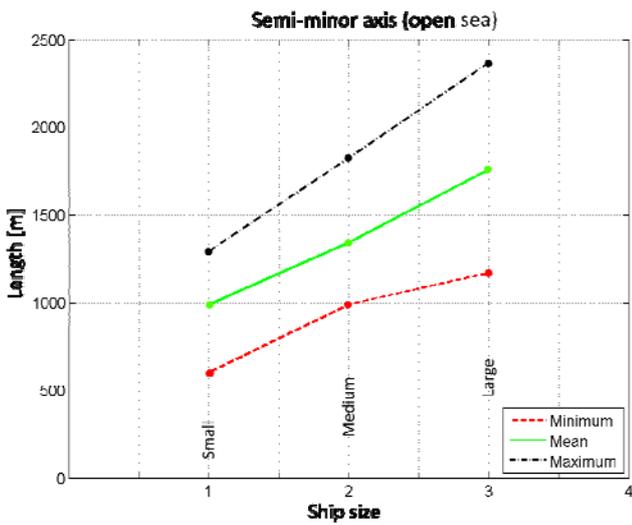


Figure 6. Length of the semi-minor axes in an open sea area.

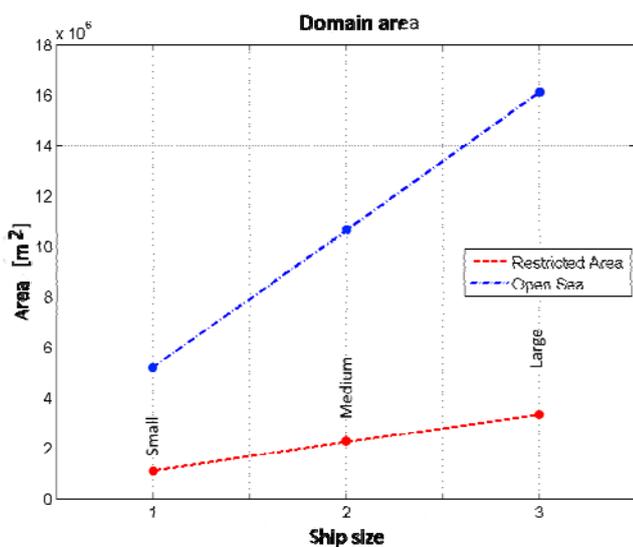


Figure 7. Domain area in a restricted and open sea area for selected ships

3.3 The domain area

The domain area can also be analysed as a criterion of navigational safety assessment, so the area of the domains (here counted as an area of an ellipse with known length of the semi-axes) was also analysed. The results are presented in Figure 7.

3.4 Comparison of the results for examined sea areas

The resulting length of semi-axes in both sea areas concerned are shown in Figures 8 and 9 for the major and minor ellipse semi-axes, respectively.

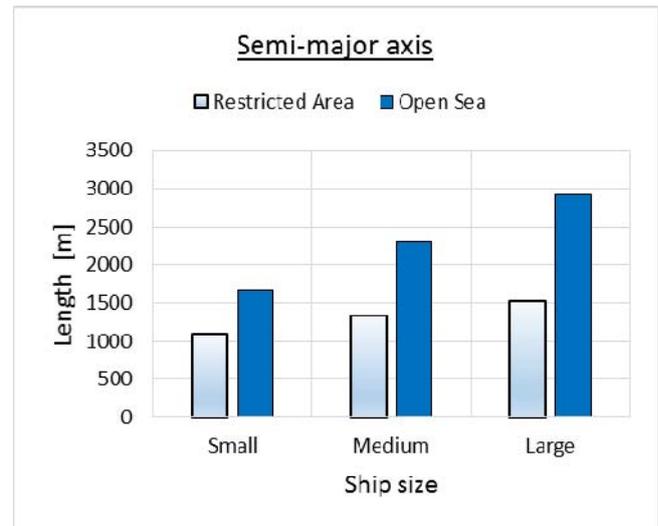


Figure 8. Length of the semi-major axis in restricted and open sea areas for selected ships

A comparison of the resulting domain areas is presented in Figure 7.



Figure 9. Length of semi-minor axis in restricted and open sea area for selected ships

Another approach to analyzing the obtained data is to calculate the coefficient of change (ratio) of the examined parameter values from the two sea areas - the relative magnitudes of two quantities.

The ratio of length to surface area of the analysed domain parameters in the waters under consideration is presented in Figure 10.

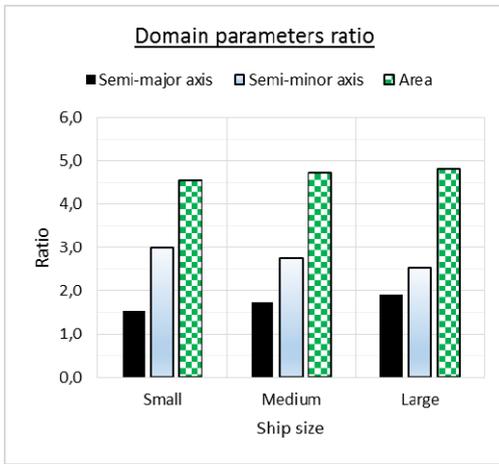


Figure 10. Ratio of length to area of the analysed domain parameters

As expected, all three analysed parameters show a significant increase in the open sea domain area in comparison with the restricted waters domain.

A mathematical description (function) of increasing the length of ship domain semi-axes in transition from the restricted to open sea area has been developed. A curve fitting tool in the Matlab environment was used for approximation.

It follows from Figure 11 that the change of the analysed ratio is of linear character, which allows using a linear function (7) for approximation and mathematical description.

$$f(x) = m \cdot x + n \quad (7)$$

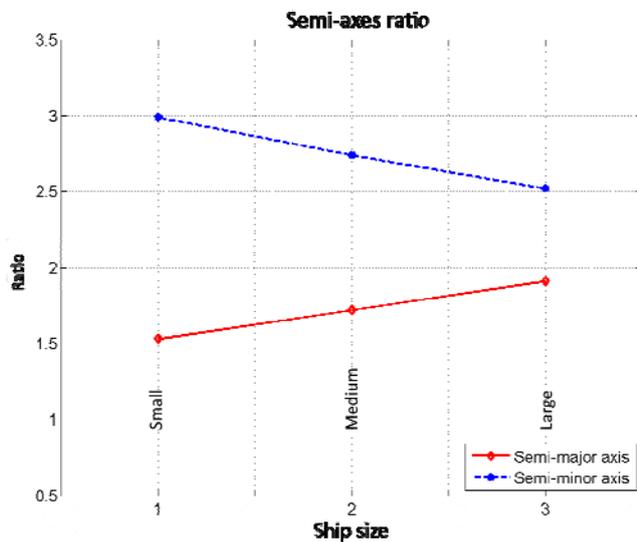


Figure 11. The length to area ratio of the analysed domain parameters.

Described by function (7), the change in the ellipse parameters while a ship transits from the restricted to the open sea area can be used to modify a domain model adopted for the restricted area (1, 2, 3, 4, 5, 6) for application in the open sea area.

3.4.1 The semi-major axis length increase

The result of ratio increase approximation referring to the semi-major axis is presented in Figure 12 and described by equation (8).

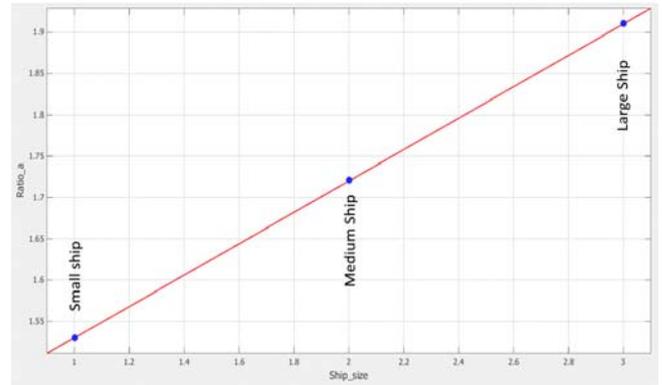


Figure 12. The ratio increase – the result of approximation for semi-major axis.

The linear model:

$$f_1(x) = m_1 \cdot x + n_1 \quad (8)$$

where:

x – ship size factor (to be calculated, see Table 4),

m_1, n_1 – function coefficients.

The coefficients (with 95% confidence bounds):

$$m_1 = 0.19 \quad (0.19, 0.19),$$

$$n_1 = 1.34 \quad (1.34, 1.34).$$

The goodness of fit:

- SSE: $2.958 \cdot 10^{-31}$

- R-square: 1

- adjusted R-square: 1

- RMSE: $5.439 \cdot 10^{-16}$

3.4.2 The semi-minor axis length increase

Figure 13 depicts the result of ratio decrease approximation concerning the semi-minor axis, described by equation (9).

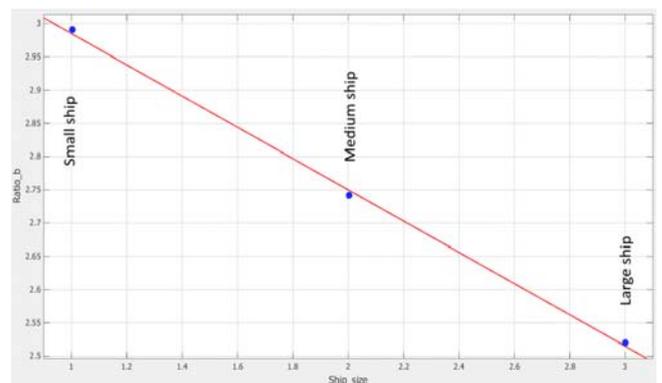


Figure 13. Ratio decrease – the result of approximation for the semi-minor axis.

The linear model:

$$f_2(x) = m_2 \cdot x + n_2 \quad (9)$$

where:

x – ship size factor (to be calculated, see Table 4),

m_2, n_2 – function coefficients.

The coefficients (with 95% confidence bounds):

$$m_2 = -0.235 \quad (-0.345, -0.125),$$

$$n_2 = 3.22 \quad (2.982, 3.458).$$

The goodness of fit:

- SSE: 0.00015
- R-square: 0.9986
- adjusted R-square: 0.9973
- RMSE: 0.01225.

Table 4. Ship size factor “ x ” for equation (8) and (9).

	ship size				
	very small	small	medium	large	very large
length [m]	60,0	95.0	173.5	261.3	294.0
factor (x)	0.5	1	2	3	3.5

The values for “very small” and “very large” ship are suggested only - for extrapolation - and to be verified in the future research, as preliminary research has been conducted only for such size of ships. Intermediate values from 1 to 3 are to be interpolated for a specific ship length.

In conclusion, the length of elliptical domain semi-axes in the open sea area can be presented as (10, 11):

$$a_0 = f_1(x) \cdot a \quad (10)$$

$$b_0 = f_2(x) \cdot b \quad (10)$$

where:

a_0 – length of semi-major axis of elliptic domain in open sea area,

a - length of semi-major axis of elliptic domain in restricted area, as described in equation (3),

b_0 – length of semi-minor axis of elliptic domain in open sea area ,

b - length of semi-minor axis of elliptic domain in restricted area, as described in equation (4),

$f_1(x), f_2(x)$ - function value described above.

These are alternative forms of the above equations:

$$a_0 = (0.19 \cdot x + 0.34) \cdot a \quad (12)$$

$$b_0 = (-0.235 \cdot x + 3.22) \cdot b \quad (13)$$

4 CONCLUSIONS

It has been observed that, generally, the domain size changes distinctly depending on available maneuverable area dimensions. The simulation research proves that navigators maneuvering in open sea areas tend to keep a larger domain comparing to restricted area.

In particular, the following changes have been observed for navigation in the open sea:

- 1 increase in length of semi-major axis;
- 2 increase in length of semi-minor axis;
- 3 increase in the size of the domain area;
- 4 changed displacement of ellipse centre (x_0, y_0) is proportional to length increase of the relevant semi-axis.

Another important observation is that the proportions of domain axes changes - domains in the open sea are relatively wider and more oval than those relatively slim in restricted areas.

Regularity is observed in the increase of semi-axis length in relation to ship size. It is possible to describe it by equations (10 and 11 or 12 and 13).

It seems purposeful to verify the results with real data from AIS based research as proposed by Hansen et al. (2013) for a restricted area.

This research outcome has been achieved under the research project No 1/S/ITM/2016 financed from a subsidy of the Ministry of Science and Higher Education for statutory activities.

REFERENCES

- Fuji, Y. & Tanaka, K. 1971. Traffic capacity. *Journal of Navigation*, no. 24. Cambridge
- Goodwin, E. M. 1975. A statistical study of ship domain. *Journal of Navigation*, no.28. Cambridge
- Hansen, M. & Jensen, T. & Lehn-Schiøler, T. & Melchild, K. & Rasmussen, F. & Ennemark, F. (2013) Empirical Ship Domain Based on AIS Data. *Journal of Navigation*, no 66. Cambridge.
- Pietrzykowski Z. & Uriasz, J. 2009. The ship domain – a criterion of navigational safety assessment in an open sea area, *Journal of Navigation*, no. 62. Cambridge.
- Śmierczalski, R. & Weintrit A. 1999. Domeny obiektów nawigacyjnych jako pomoc w planowaniu trajektorii statku w sytuacji kolizyjnej na morzu (in Polish). *Proceedings of III Navigational Symposium*, Gdynia
- Wielgosz, M. 2015. Ship domain in navigational safety assessment. Unpublished PhD Thesis (in Polish). *Maritime University of Szczecin*.
- Wielgosz, M. 2016. The ship safety zones in vessel traffic monitoring and management systems. *Scientific Journals, Maritime University of Szczecin, No.48(120)/2016: 153-158*.
- 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, no. 30(102)/2012* .