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SHIP DOMAIN IN VARIOUS VISIBILITY CONDITIONS IN RESTRICTED WATERS

ABSTRACT

Ship domain is one of navigational safety assessment criteria. Its shape and size depend on many factors, including visibility. This article examines the influence of visibility on the shape and dimensions of ship domain in restricted waters. The research was conducted using a simulator of the ECDIS system with the participation of experts' navigators. The domains of ships in good and restricted visibility have been compared.

Keywords:
navigational safety, restricted area, ship domain, visibility conditions.

1. INTRODUCTION

One of the basic tasks of navigation is to ensure ship's safety during its passage at sea. Navigational equipment and systems installed on board ships are important elements in sea navigator's decision making process. The use of latest information technologies enables the integration of information (e.g. integrated bridge) and significantly automated processing. This is particularly important in case of information referring to navigational safety, such as a radar, ARPA, ECDIS data, including the parameters known as the closest point of approach CPA and time to CPA (TCPA). The CPA as a safety criterion is commonly used in open sea navigation. Its use in restricted areas, such as narrow channels and fairways, in most cases is difficult to implement. The reason is that there is no free choice of the route. Therefore, a lot of attention is paid on developing methods and tools for the determination of area around the ship that should be clear of other vessels or objects – ship domain. This approach is justified by the fact that the concept of domain is intuitively accepted by humans and enables an analysis and assessment of the situation and working out decisions on manoeuvring in open and restricted areas [Pietrzykowski and Uriasz, 2009], [Wielgosz and Pietrzykowski, 2012], [Pietrzykowski et al., 2012]. The concept of domain is applicable on ships and in land-based vessel traffic centres.

The shape and size of ship domain depend on many factors, which makes it difficult to define it. Visibility conditions are identified as one of the most important factors. Authors' research concerning this issue is presented *inter alia* in [Wielgosz, 2015], [Siemianowicz, 2016].

2. METHODS OF SHIP DOMAINDETERMINATION BASED ON SIMULATION RESEARCH

There are two and three-dimensional domains proposed by various authors. The former describe an area around the ship. Typical shapes of two-dimensional domains include a circle, rectangle, ellipsis, polygon and more complex planar shapes. The determination of ship domain requires identification of its boundaries. There are different methods of ship domain determination, for instance statistical ones. These consist in recording trajectories of ships' movements to get data for identifying the area around the ship that navigators keep clear of other navigational objects [Coldwell, 1983], [Fuji, 1971].

Analytical methods are based on the analytical description of domain area. The domain boundaries in these methods may be defined on the basis of CPA and time to closest point of approach (TCPA), as well as formulas describing ship's manoeuvrability, hydrological and meteorological conditions and relationships applicable to ship in motion in a given area [Pietrzykowski, 2006a], [Pietrzykowski, 2006b], [Pietrzykowski, 2011].

The application of methods and tools of knowledge engineering, including artificial intelligence, enables acquiring, representing and using the procedural and declarative knowledge of expert navigators for the identification of ship domain. Examples are provided by artificial neural networks used for defining the level of navigational safety, the basis for outlining the ship domain [Pietrzykowski, 2004].

Chronologically, statistical methods were proposed first as methods to be used for ship domain determination [Goodwin, 1975]. The domain was determined by registering ship trails indicated by radar. In restricted areas the ship size has also to be taken into account. Using the equipment and systems currently fitted on board ships and in vessel traffic centres, capable of registering ship position with high accuracy, one can determine ship trails showing their dimensions and contours.

To determine the domain boundary these authors adopted the method proposed in [Pietrzykowski et al., 2012], based on the density analysis of ships' trails around the central ship. The ships' trails were assumed to be the points of water line of another ship at pre-set relative bearings, the nearest to the middle of the central ship.

2.1. Simulation research

A simulation research was conducted where it was possible to register vessel positions, aimed at determining the effective ship safety zones, i.e. ship domains. Positions (latitude and longitude) were registered with maximum available discretization – 1 s. Due to the large variety of domains found in the literature and different interpretations of domain boundaries, these authors decided to determine not one, but three effective domain boundaries: maximum, mean and minimum [Wielgosz and Pietrzykowski, 2012].

The research was conducted on an Electronic Chart Display and Information System (ECDIS) simulator, depicting eight simulated independent ships. The simulator is able to register standard data transmitted by ships' Automatic Identification System (AIS). Installed at Maritime University of Szczecin, the simulator has sufficient functionalities to prepare and conduct practically any ship encounter scenario.

Ship models are able to manoeuvre by altering course and/or speed; it is possible to select area and hydro-meteorological conditions. Six typical encounter situations and medium size ships have been chosen for research purposes. Relevant scenarios were prepared and recorded, allowing later to repeat the initial situation with the possibility of individual manoeuvres by attending sea navigators. Each of the scenarios was repeated five times, resulting in 30 to 35 individual manoeuvring ships tracks in each scenario (depending on the number of scenario participants). The duration of one single scenario, depending on the situation and the type of vessel encounter situation was 10 to 20 minutes [Wielgosz, 2015a], [Wielgosz, 2015b]. The main purpose of that research was to determine influence of visibility conditions on the domain.

Some of the registered true and relative ships trajectories are shown in Figure 1. For further data processing, trajectories were recalculated into relative trajectories, separately for non-manoeuvring (Figure 1b) and manoeuvring ships. The data collected in the research were examined in two groups independently for the impact of visibility conditions on the effective domain.

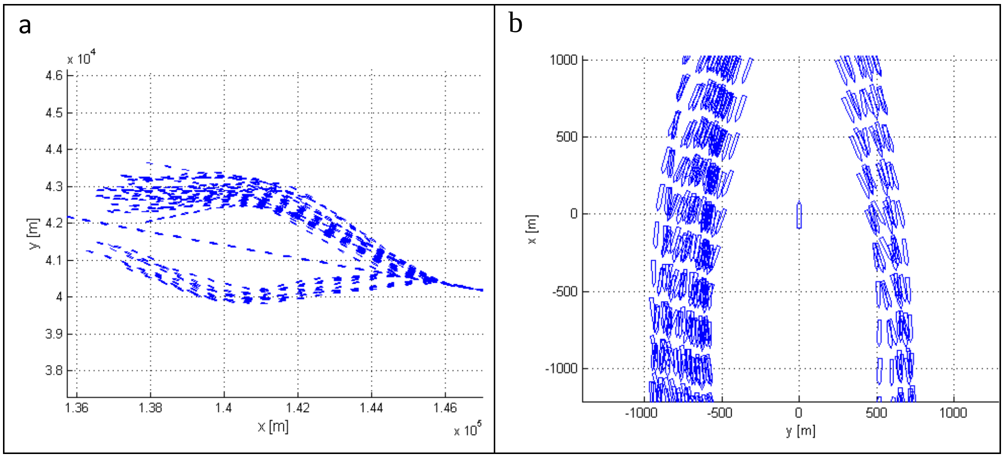

Figure 1. Example of recorded true and relative ship trajectories: a) true trajectories, b) relative trajectories. Source: Authors.

The effective domains were subjected to approximation. Because of elliptical character of effective domain data, we decided to approximate them to an ellipse [Wielgosz, 2015a]. In all cases three domains were approximated: maximum, mean and minimum (Figure 2).

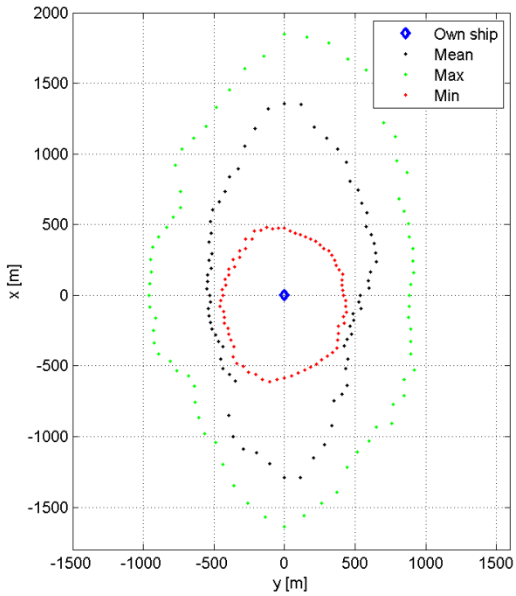

Fig. 2. Example of examined domains before approximation. Source: Authors.

2.2. Ship domain in good visibility.

Examined domains in good visibility conditions (i.e. vessels visible according to the International Regulations for Preventing Collisions at Sea) are shown in Figure 3a as absolute domains. For relative domains it is necessary to convert units – rescale the graph using relative units (ship length - L) by dividing the distance by the length of the ship. Thus obtained relative domains are shown in Figure 3b. Both figures contain data before approximation (dotted lines) and after approximation (solid lines).

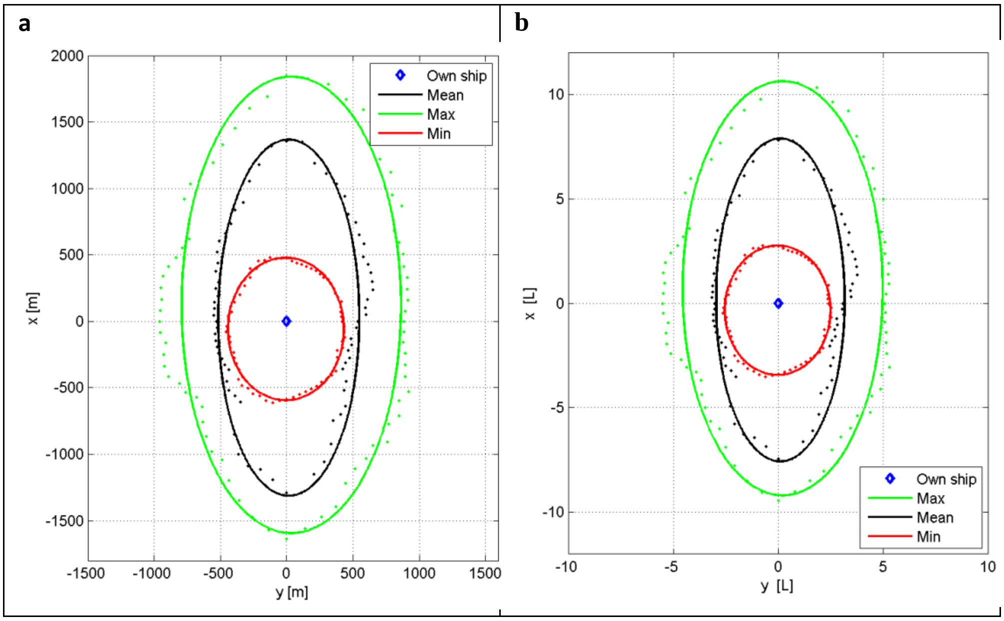

Figure 3. Absolute and relative domains in good visibility before and after approximation. Source: Authors.

2.3. Ship domain in restricted visibility

The domain in restricted visibility (visibility reduced to 1 cable) was obtained in the same way as the domain in good visibility. Figure 4 presents the absolute (a) and relative (b) domains after approximation.

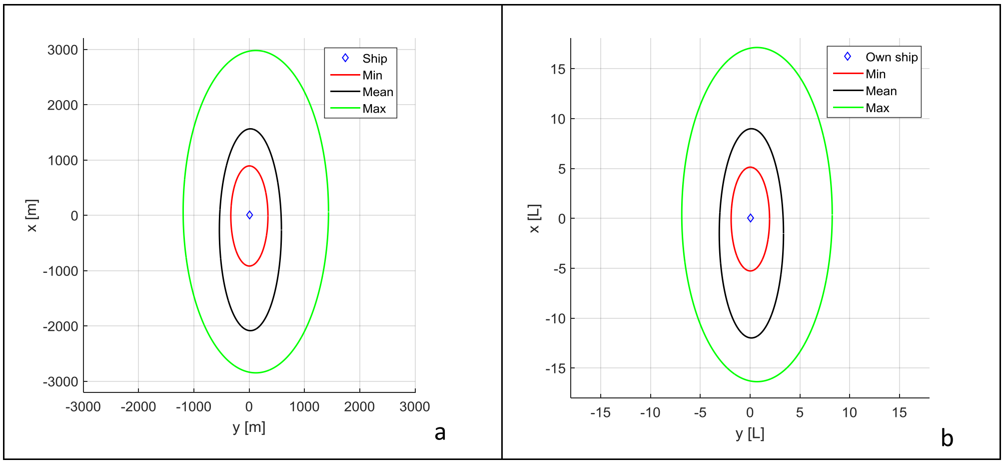

Figure 4. Ship domains in restricted visibility; a - absolute domains, b – relative domains. Source : Authors.

3. RESEARCH RESULTS

Using the collected data we determined ship domains in good and restricted visibility in restricted waters and analysed the three boundaries (minimum, mean and maximum) of domains. The parameters of the ellipses (ship domains) and their areas in good and restricted visibility condition are presented in Tables 1 and 2, respectively.

Table 1. Parameters of ship domains in good visibility

domain boundary	**x_0 [m]**	**y_0 [m]**	**a [m]**	**b [m]**	**area [m^2]**
minimum	-56.70	-6.60	537.26	438.55	$0.74 * 10^6$
mean	28.21	15.38	1341.17	534.01	$2.25 * 10^6$
maximum	124.82	34.23	1718.61	828.75	$4.47 * 10^6$

Source: Authors work.

Table 2. Parameters of ship domains in restricted visibility

Domain boundary	**x_0 [m]**	**y_0 [m]**	**a [m]**	**b [m]**	**area [m^2]**
minimum	2.77	-11.61	904.87	438.55	$0.95 * 10^6$
mean	21.11	-260.92	1824.38	534.01	$3.22 * 10^6$
maximum	119.20	66,12	2914.08	828.75	$12.04 * 10^6$

Source: Authors work.

3.1. Length of semi-axes (length and breadth)

Figures 5 and 6 graphically illustrate the lengths of semi-axis of domain boundaries.

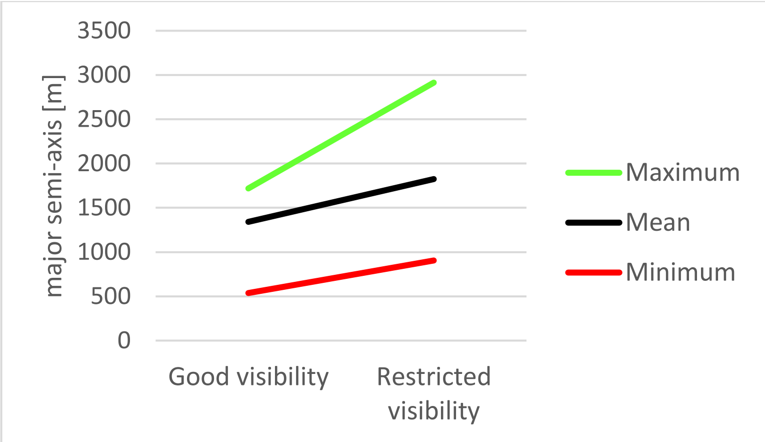

Figure 5. A comparison of semi-major axis lengths. Source: Authors.

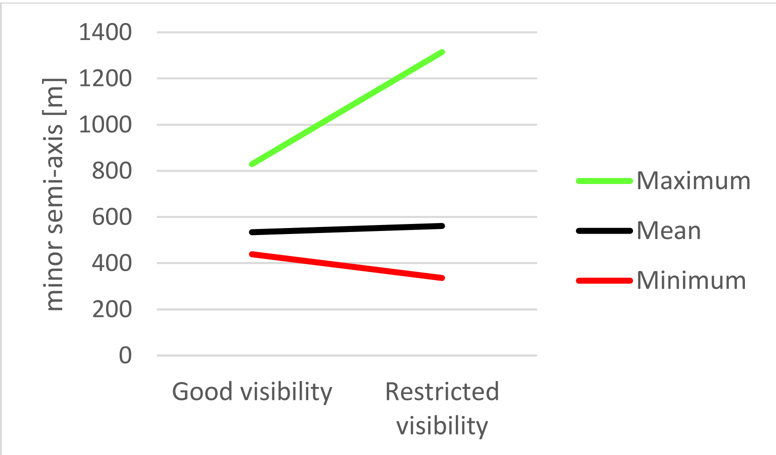

Figure 6. A comparison of semi-minor axis lengths. Source: Authors.

As it was expected, the lengths of semi-major axis for all three domain boundaries are increased for restricted visibility. The same was observed for semi-minor axis for maximum boundary. The lengths of other semi-minor axes differ from expected ones, especially for the minimum boundary.

3.2. Area of domains

Domain area can also be considered as a factor for safety assessment, so the areas of the domains were also analysed (Figure 7).

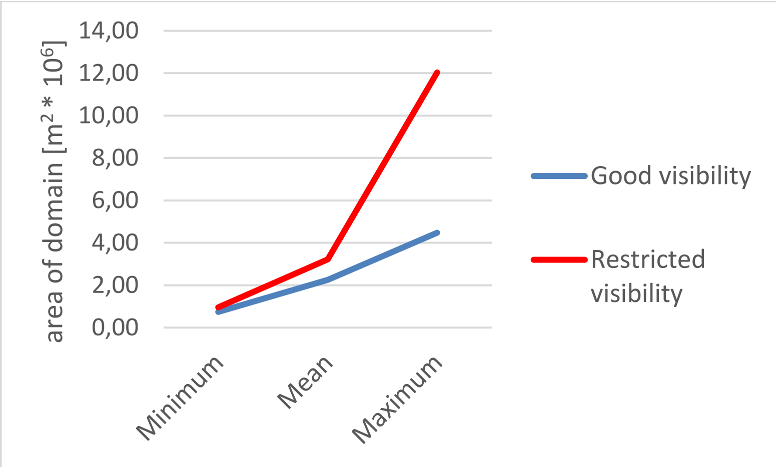

Figure 7. A comparison of ship domains areas. Source: Authors.

As it was expected, distinct differences between areas of domains were observed in areas of domains depending on visibility conditions. Navigators steering in restricted visibility tended to maintain larger domains comparing to good visibility. Next step of the analysis was the calculation of the ratio of domain parameters in restricted visibility in comparison to good visibility (Table 3).

Table 3. Comparison of domain parameters in restricted and good visibility (ratio).

domain boundary	**a**	**b**	**area**
minimum	1.68	0.77	1.29
mean	1.36	1.05	1.43
maximum	1.70	1.59	2.69

Source: Authors.

The values of semi-major axis are within acceptable limits. The same applies to semi-minor axis for maximum boundary of ship domain. The values of semi-minor axis for other boundaries (minimum and maximum) are too small. The ratio of areas for minimum and mean boundaries are within acceptable limits, but the value of 2.69 for maximum domains are considered too high.

CONCLUSIONS

It has been observed that domain size changes distinctly depending on visibility conditions. The simulation shows that navigators manoeuvring in restricted visibility tend to keep larger domain (especially in forward and aft sectors) comparing to good visibility. Another observation is that semi-minor axis for the minimum and mean boundaries in restricted visibility is much smaller than expected. On the other hand, the proportions of maximum domains are much higher than anticipated. Is seems purposeful to carry out additional survey to verify the obtained results. In addition, it seems meaningful to extend research to include other areas of restricted waters to get a better insight into the influence of visibility conditions on domain size.

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STRESZCZENIE

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