

A Decision Support Tool for VTS Centers to Detect Grounding Candidates

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ABSTRACT: AIS (Automatic Identification System) data analysis is used to define ship domain for grounding scenarios. The domain has been divided into two areas as inner and outer domains. Inner domain has clear border, which is based on ship dynamic characteristics. Violation of inner domain makes the grounding accident unavoidable. Outer domain area is defined with AIS data analyzing. Outer domain shows the situation of own ship in compare with other similar ships that previously were in the same situation. The domain can be used as a decision support tool in VTS (Vessel Traffic Service) centers to detect grounding candidate vessels. In the case study presented in this paper, one type of ship, which is tanker, in a waterway to Sköldvik in the Gulf of Finland is taken into account.

1 BACKGROUND INFORMATION

1.1 *Ship Grounding*

Ship grounding accounts for about one-third of commercial ship accidents all over the world [1,2], and has the second rank in frequency, after ship-ship collision, in global perspective [3]. The consequences of ship grounding could be devastating for both humans and the environment. In less grave accidents, ship grounding might result in only minor damages to the hull; however, in more serious accidents, it might lead to the total loss of the vessel, oil spills and human casualties, in which the compensation would be either highly costly or even impossible. Therefore it would be wise to think about tools that can prevent ships to be involved in such accidents.

1.2 *Ship Domain*

One of the methods that have never been tried for grounding candidate detection is using the ship domain. The concept of ship domain has been first in-

troduced by Fujii [4] in maritime transportation as an imaginary area around a ship, where the navigators try to keep it clear from other ships. Later on, Goodwin [5] redefined the concept as the effective area around a ship where navigators try to keep it clear from other ships and stationary objects. Since then, many other authors [6-16] have tried to define the size and shape of ship domain with different methods. However, the main common issue in between all introduced domains is that all are suitable for ship-ship collision accidents, as the used methods are ruled by the nature of this type of ship accident. This fact is also recently highlighted by Wang [15,16]. Although some authors have mentioned their domains are suitable for grounding scenarios as well [5,6,13,14], the affecting factors that they have used to define the size and shape of the domain and also the application of the domains are more useful for ship-ship encounter situations. This is the main courage for the present research in defining a ship domain proper for ship grounding scenarios, in order to be used as a decision support tool in VTS (Vessel

Traffic Service) centers to detect the ships that are grounding candidates.

2 SHIP DOMAIN FOR GROUNDING

Some factors that could affect the shape and size of a domain useful for grounding scenarios are ship main characteristics (length, breadth, draft, speed, and type), her maneuverability, navigator experience and his familiarity to the area, shape and depth of the waterway, engine and rudder characteristics, and weather condition; which some of them are not easy to consider and to model. In addition, the 3rd dimension (depth) is vital for defining the ship domain for grounding since the grounding is defined as the event that the bottom of a ship hits the seabed, in compare with stranding, which is defined as the event that a ship impacts the shore line and strands on shore [17]. Moreover, since normally ship has forward speed while goes aground, the domain for grounding could not be longitudinally symmetric. For the same reason lateral dimension of the domain should be always smaller than longitudinal dimension of the domain, when is defined for grounding and stranding cases.

One additional point about ship domain either for grounding or collision is that a domain should have two areas as they can be called inner and outer domains. *Inner domain* is the area, which is defined based on the dynamic of the ship. Because of the ship inertia, the ship's course cannot be altered in a moment. Inner domain defines the last/latest possible point/time that evading maneuver is possible for the ship by the most possible aggressive but safe maneuver, in order to avoid the accident. It means if the inner domain is violated by a shoal, even though the ship has not run aground yet, there is no way for her to survive an accident. *Outer domain*, on the other hand, can be defined as such that describes the area of different levels that mariners are advised to keep clear from any shoals or other stationary obstacles. Failing to do so, makes the vessel a grounding candidate with a certain degree. In contrary of the inner domain, the outer domain does not have clear border. Outer domain should be defined as such that if a ship does not do any evasive maneuver by certain time/distance, it is considered, by some degree, odd or unsafe for that particular ship with specific characteristics in specific situation and location.

It is worthwhile to mention, depends on the reason of the accident, ship grounding can be categorized into two major groups as powered and drift groundings. Nevertheless, drift grounding is a kind of accident that occurs as a consequence of an incident like engine or rudder failures, which makes the ship domain concept not applicable for this type of grounding.

3 METHODS TO DEFINE SHIP DOMAIN FOR GROUNDING

3.1 *Inner Domain*

The shape of the domain in this paper is taken as an imaginary half-elliptical prism. The ellipse is chosen to just explain the procedure of defining the size of the domain. To define a proper shape for the domain, in order to be rational for grounding accident analysis, more detailed data analysis and modeling are needed, which will be addressed in future studies.

The size of inner domain should be defined based on ship maneuverability, which is based on the dynamic of the ship. The length of the inner domain is defined to be equal to the summation of overall length of the ship (LOA), influence region of ship-shore interaction (bank effect), and stopping distance or the advance in turning circle maneuver, whichever is shorter. To define the length of the inner domain in this paper, it is assumed that length of the advance in turning circle is smaller than the stopping distance, which is a valid assumption for ships moving with speed more than 12 kn [18]. The advance in turning circle in this paper is estimated with a quasi-linear modular hydrodynamic model of the vessel in-plane motion. For detail explanation of the used hydrodynamic model, the readers are referred to [19].

The width of the inner domain is taken equal to twice of the width of the influence region of bank effect. The influence region of bank effect (y_{infls}) in this paper is estimated based on a formula suggested by [20]. It should be mentioned that for defining the width of the inner domain it is assumed the ship does not comply with the given commands if she enters the influence region of bank effect. Therefore, controlling the ship will not be possible with ordinary skills, which makes the ship eventually hitting a channel bank. Although this assumption is not far from reality, it should be considered that some expert mariners might still be able to control the ship in that condition and therefore be able to survive from an accident. However, to define the inner domain, rare situations are neglected and it has been tried to define it as such to be suitable for majority of the cases.

The depth of the inner domain is taken equal to the maximum squat plus the draft of the vessel. The maximum squat in this paper is estimated based on a formula suggested by [21]. The schematic figure of the defined inner domain is shown in Figure 1.

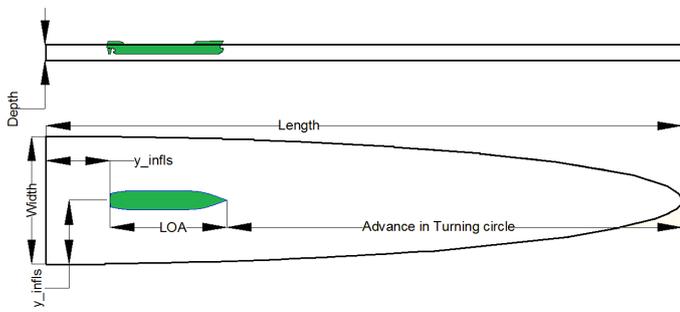


Figure 1: Three dimensions of the inner domain

3.2 Outer Domain

In this paper, outer domain is not defined by a unique imaginary shape; but as points in different waterway legs, in where the position and situation of the vessel is analyzed based on extensive AIS (Automatic Identification System) data analysis in respect to being a grounding candidate. The used algorithm is shown in Figure 2. The general idea is to choose a specific shoal/obstacle and analyze available AIS data transmitted by ships similar to the subject (own) ship, which have previously approached to the shoal, in order to find distribution for the longitudinal distance between ships and the shoal, in where ships start to turn to either evade the shoal or follow the fairway [Action Distance (AD), the point where it happens is named Action Point (AP)]. Thereafter, use the obtained probability density function (PDF) of AD to analyze the situation of subject ship in respect to the shoal, in regard to grounding accident. The PDF of action point will help the VTS operators to relate the present location of subject ship to the percentile of similar ships, which have chosen that specific location to start their maneuvers. In this regard, the appropriateness of the present location of the subject ship to start the turning maneuver can be judged by the safe maneuvers previously performed by ships similar to the subject ship. Similarity can be identified by indexes such as ship type, length, width, draught, speed, and even environmental conditions. The more indexes are defined, the more resembled cases can be retrieved and therefore the more reliable support for decision can be provided. However, more indexes need bigger and more complete databases to be used, in order to retrieve sufficient data for creating useful PDFs. Due to the scarce of data, the similarity in this paper is identified just by type and length of the ships.

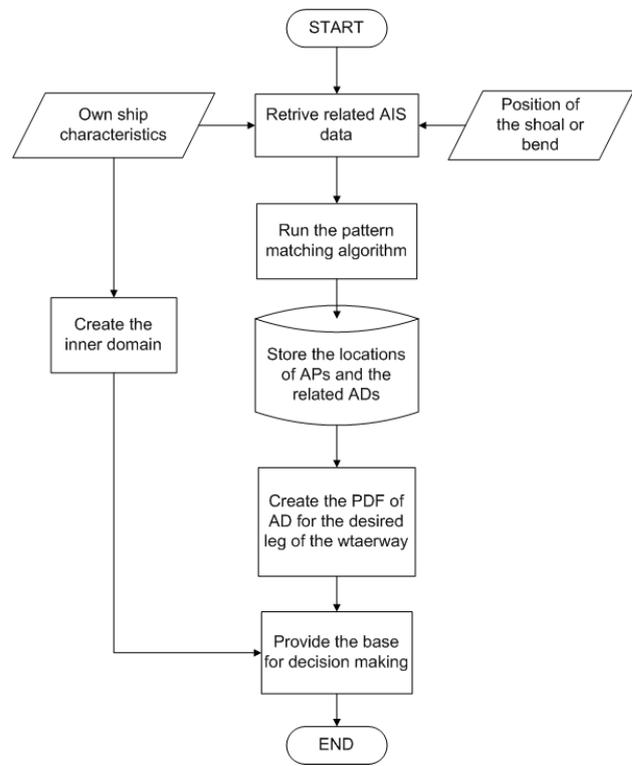


Figure 2: Algorithm to define outer domain

It should be borne in mind that because of the ship inertia, the ship's course cannot be altered in a moment; therefore it takes time between when the command is given to the controlling devices till when the command is started to be obeyed by the vessel, in where is defined to be Action Point. Nonetheless, this difference is neglected in this paper.

The action point detection process is based on a pattern matching algorithm shown in Figure 3. The pattern matching is based on course-over-ground (COG) of ships. The idea is to visualize COG of the ship in her path and then use the algorithm to detect the performed maneuvers based on the visualized COG. Here, visualizing means making the sequence of COGs smooth in order to not have any disruption in between. To explain visualizing and the algorithm, part of waypoints in a trajectory of a tanker in route from Sweden to Sköldvik in the Gulf of Finland (GOF) for year 2007 is shown in Figure 4-Left as an example. The history of COG of the shown trajectory of the tanker is shown in Figure 4-Right.

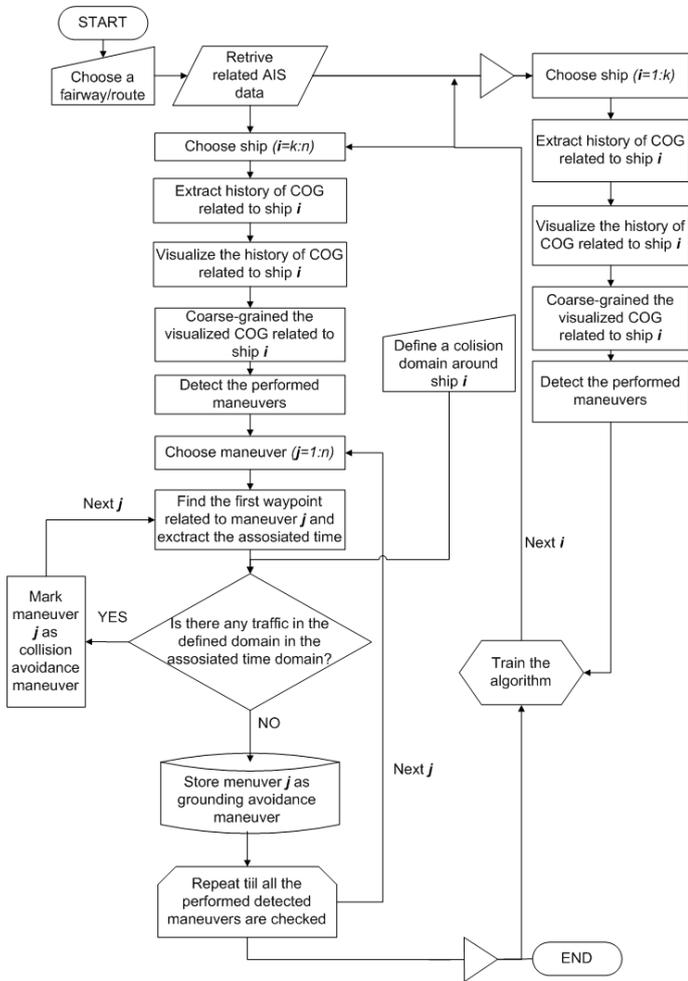


Figure 3: Pattern matching algorithm

The normal method being used for recording COG is to mark the heading to the North as 0° , to the East as 90° , to the South as 180° , and to the West as 270° (turning clockwise). As a result, COG can never get negative values; and if, for instance, the ship is turning clockwise and COG value passes 359.99° , the COG will be registered again as 0° . Therefore, if the graph of the history of COG be drawn, there might be some jumps in the graph (Fig. 4). To remove the disruptions and making the sequence of COGs smooth (visualizing), the COGs are transferred to another discipline that is shown in Figure 5. In the new discipline COG can get negative values as well as values more than 360° . The history of COG after visualizing is shown in Figure 4, which shows the jumps are disappeared. The visualized COGs of ships navigating in a fairway are somehow unique for the fairway, and can act as fingerprint of the fairway, which the pattern matching algorithm can recognize. By knowing the position of turns/shoals in a fairway and having the visualized COGs of the ships navigating in the same fairway, the evasive maneuvers that have been done to follow the turn/avoid the shoal can be identified. The starting point of the associated maneuver is stored as AP and the shortest distance between AP and the shoal is reported as AD. It should be added that for de-

creasing the margin of error for pattern matching, the visualized COGs are coarse-grained in order to remove the small changes in COG, which are normally appears due to course adjustment. Moreover, to minimize the possibility of choosing a collision avoidance maneuver, the presence of ship traffic in instance time domain in an area around the vessel, which is defined by the domain proposed by [15] for collision scenarios, is also investigated and taken into account.

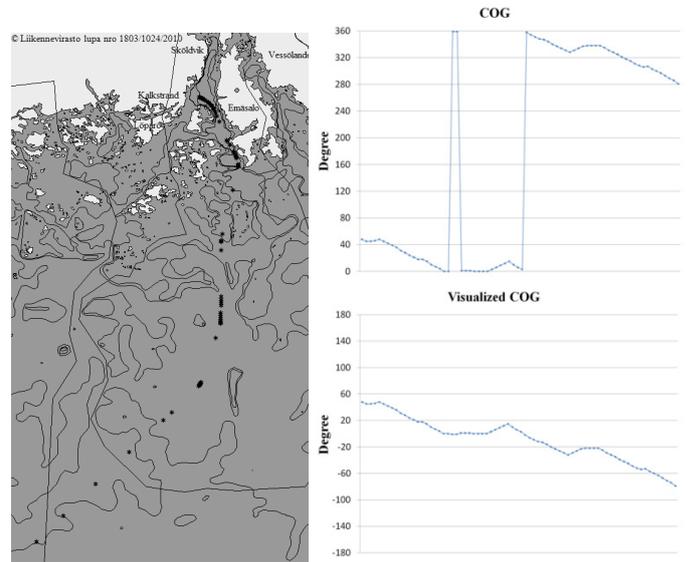


Figure 4: Left: Part of a trajectory of a tanker in route from Sweden to Sköldvik in GOF for year 2007, Right: COG and visualized COG of the trajectory of the tanker

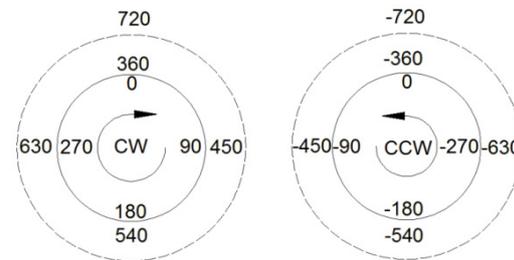


Figure 5: Discipline used for visualizing the history of COG

4 CASE STUDY AND RESULTS

The analyzed AIS data in this paper is for the year 2007 of ship traffic in the Gulf of Finland, which was gathered by the Finnish Transport Agency. The Gulf of Finland is used for the study due to availability of data, and also because of the importance of grounding accident in the area. The studied area is a waterway in GOF with approximate length of 40 km, in where the ships have to navigate in between shoals in order to reach to Sköldvik. The waterway is located in a rectangle which end points of one of its hypotenuses have positions of 60.0° N 025.4° E, and 60.4° N, 025.7° E in WGS-84 reference system (Fig. 6-Left). The majority of the traffic in this area belongs to tanker traffic. Therefore, the other types

of ships are eliminated from the analyzed data due to data scarce. In total 850 tankers navigated in that area in 2007 with the shortest length of 75 m and the longest length of 265 m. The AIS data analysis is done with Mathwork's MATLAB. Thus, for the sake of coding, the shoals in the area are defined as polygons. In total, five shoals in the area are defined and taken into account for data analysis. The shoals and vertices of the polygons are shown in Figure 6-Right.

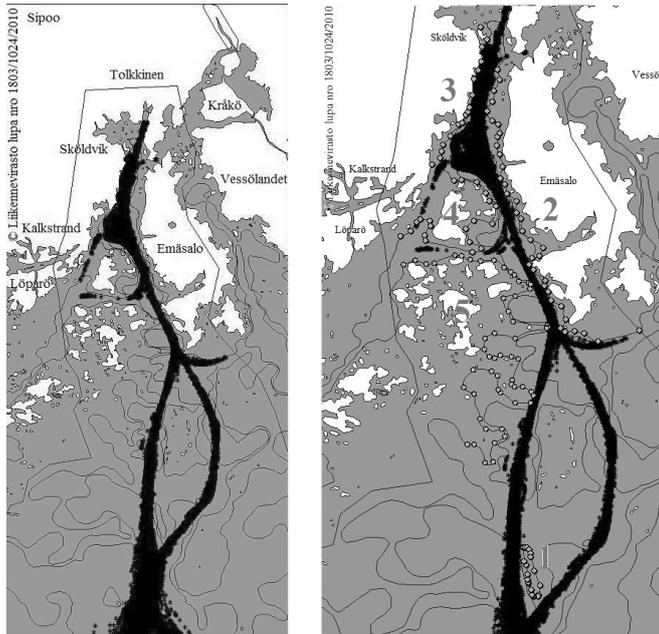


Figure 6: Left: The waterway to Sköldvik in the Gulf of Finland with the traffic in 2007- Right: The same waterway with the analyzed shoals as polygons. The vertices of the polygon shoals are shown in dots.

To define the domain in order to be used for VTS operators, PDF of AD for the ships in each leg of a waterway should be extracted. Based on the extracted distributions, inner domain, and speed of the vessel, the VTS operator can have a good analysis of the present position of the vessel. By way of illustration, it is assumed that the subject ship is a most common tanker for this harbor, with the dimensions of $L=145$ m, $B=17$ m, $T=10$ m navigating in the studied waterway with speed of 15 kn. Using ship type and ship length as indexes, the related PDF for AD can be extracted from the database. The PDFs for shoals 1 and 2 are shown in Figure 7 as examples. With the help of the extracted PDFs, the percentile of the similar ships that have started to turn by specific point in the same leg of the waterway can be estimated. In addition, the defined inner domain gives the remained time to go aground on approaching shoals. The inner domain for the studied tanker is estimated based on the advance of turning circle in maximum rudder angle, which is assumed to be 35° . Example of analysis of nine positions of

the chosen tanker in the studied area (Fig. 8) is shown in Table 1 as a way of illustration.

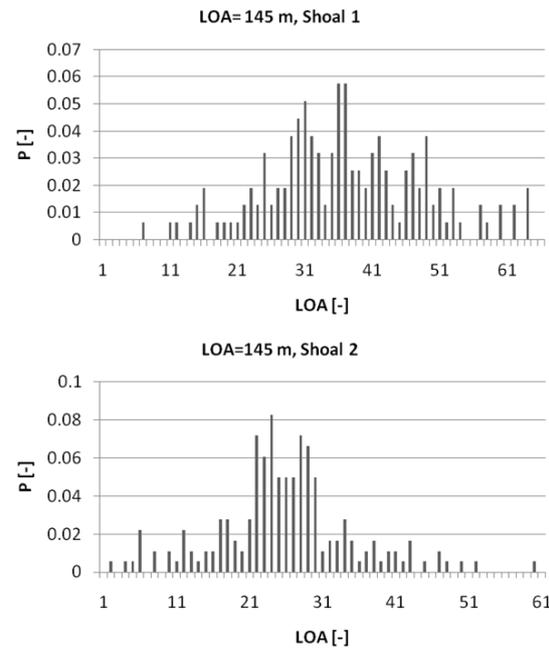


Figure 7: PDF of Action Distances for tankers with LOA of 145 m approaching shoals 1 and 2

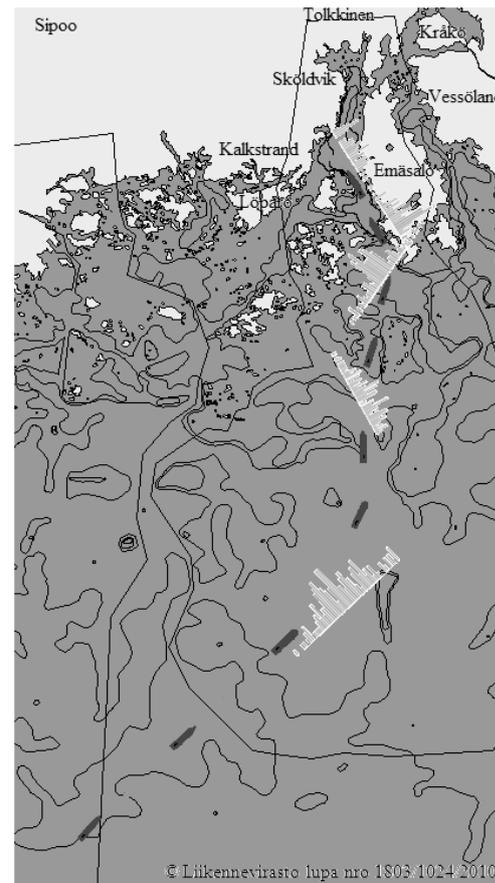


Figure 8: The subject ship ($L=145$ m, $B=17$ m, $V=15$ kn) in a way to Sköldvik shown with her inner domain. The dark areas are the inner domains. The tanker is seen as a small black dot in this scale

It can be seen in Table 1, wherever the outer domain shows that the majority of the similar ships,

previously navigated in the same waterway leg, had started their turning maneuver in that specific position to either evade the shoal or follow the waterway, the inner domain shows less available time for maneuvering in order to avoid grounding. Information as such will help the VTS operators to detect those ships that their remaining chance to survive from a grounding accident are getting less and less, with the aim of marking them as the ship that her actions should be monitored more closely. Later on, the VTS operator may decide to contact the ship to find if the officer on watch is aware of the situation. In this way, the VTS operators are capable of being more proactive.

5 DISCUSSION AND CONCLUSION

A new approach to define ship domain for grounding scenarios based on AIS data analyzing and ship maneuverability is presented in this paper. The introduced domain is suggested to be used as decision supports tool in VTS centers. It is shown the introduced domain is capable of providing useful information, like remaining time to point of no-return and going aground, based on the vessel maneuverability. In addition, the proposed method is able to provide the ground for judging the safeness/oddness of the performing maneuvers. Since the method uses previously performed maneuvers to analyze the current maneuvering action, it can be argued the method is providing expert opinions as a support for decision making process.

The turning circle and stopping distance are used in the definition process of the inner domain for grounding in this paper. Since those concepts are unique for every single vessel in unique conditions, this method neutralizes the effects of type and number of controlling devices in hand. Nonetheless, it makes hard to estimate the area of inner domain precisely, as the available hydrodynamic models for predicting the ship motion are not completely flawless. However, the quasi-linear modular hydrodynamic model used in this paper can predict the turn-

ing circle of vessels precisely enough for the scope of this paper [19]. In addition, using turning circle to define inner domain area limits the usability of the suggested domain to when all reserved maneuverability of the ship is available, which means when the vessel is moving straight. The maneuvering task is somehow different while the ship is in turning process, as she does not have all the reserved maneuverability in hand. Due to this fact, grounding ship domain in complex turns might be different than what has been introduced in this paper.

The analyzed AIS data used for defining outer domain in this paper are indexed based on ship type, ship length and the location. This has been done due to the scarce of the data. By increasing the size of the used database and also using data about weather and sea conditions, the indexes can be expanded to other characteristics of the vessel and also to environmental conditions, in order to provide more reliable supports for decision making process. Moreover, the analyzed data are limited to year 2007. Analyzing more data from other years will help the used algorithm to be more precise in providing the grounds for decision making. In addition, the algorithm can be made smarter if a learning loop be added, in order to teach the algorithm by new performing maneuvers.

The introduced domain is proposed as a decision support tools for VTS centers. Nevertheless, it is possible that the introduced domain be used as a decision support tools onboard the vessels, in order to provide expert opinions for officer on watch to perform maneuvers.

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Table 1: Situation analysis of the subject tanker in nine positions shown in Figure 8

Position	COG [deg]	Percentile of similar ships that have started to turn	Time to breach inner domain, maintaining COG and speed [min]	Time to ground on the approaching shoal, maintaining COG and speed [min]
1	48	0%	54	56
2	45	0%	36	38
3	48	5%	15	17
4	18	38%	10	12
5	0	6%	15	18
6	12	4%	15	17
7	15	83%	6	8
8	331	75%	7	9
9	338	83%	6	8

* Position numbering is started from left-down corner of the Figure 8. The first position in left-down corner is position 1, next position is 2 and so on.

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