# Identification of Near-Miss Situations Between Ships Using AIS Data Analysis and Risk Indicators

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This paper describes a model to estimate the frequency of near collision situations between ships, which can be an indication of collision risk. The proposed model uses several risk indicators to identify near-miss situations, such as Automatic Identification System (AIS) data, ship domain, speed, rate of turn, ship type and more. The model utilizes a ship domain approach to find potential near collision situations. If a ship domain was violated and a last-moment evasive manoeuvre was performed, the situation is identified as a near-collision (identified by an abnormal ship rate-of-turn (ROT)). With the new model a case-study is performed at an area in Vestfjorden in North-Norway for a three-year period. The case-study detected 476 ship domain violations and 46 near collision. All detected near-collisions were graphically plotted and examined; from the 47 detected situations, 19 were positively identified as near-collisions. The conclusion is that the current state of the model, with the uncertainties in both dataset and model, should be considered as a risk indicator that can be used to identify areas of interest for further risk assessment, and has a potential to become a solid risk assessment tool with further development.

*Keywords*: AIS, collision, near-miss, ship domain, risk model, accident, navigation.

## 1. Introduction

The amount of international shipped cargo grows steadily, and seas are exploited for seabed mining and energy production more than ever. As a result, there is an increase in traffic density and decrease in free navigational space, potentially causing a higher incidence of close encounters that may lead to ship collisions. There are several methods to evaluate the risk of a collision such as accident statistics analysis, causation-probability models, computer simulation, or utilising experts' knowledge. An alternative approach is to use the knowledge of near collisions reports to understand the circumstances which might have led to a dangerous situation. Nevertheless, the amount of near-miss collision reports is very limited primarily due to the unwillingness of ship crews and operators to report near-miss accidents. Therefore, several studies, such as by Goerlandt et al. [2012], Zhang et al. [2015] van Westrenen and Ellerbroek [2017], proposed to detect near-collision situations from historical Automatic Identification System (AIS) data. The AIS was introduced as an aid tool for the safety of navigation for navigators in 2002, and through its short history it has found an application also in maritime accident investigations, and traffic monitoring and analysing. Ships equipped with the AIS transmit their navigational information such as The AIS provides frequently updated relevant navigational information such as a geographical position, course-over-ground, rate-of-turn, heading, ship speed, or dimensions. These AIS messages are transmitted in ship-to-ship or ship-to-station communication that allows stations to store all messages for later use. The common ground of the models to detect near-collisions is a ship safety domain. The ship domain is defined as an area that a navigator wants to keep free of other vessels and objects, and any violation of this area can be understood as a threat to navigation. Above the ship domain violation, this method uses an idea introduced by Mestl et al. [2016] that a critical manoeuvre may indicate the danger of collision. An abnormal high ship rate-of-turn identifies this critical manoeuvre. A theoretical assumption of this study is that a near-miss is related to actual risk of

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accident, i.e. that vessels that more often are involved in near-collisions are at higher risk of an actual collision. Further studies should seek to empirically test this notion.

The present study is part of an ongoing development project concerning the development of AIS-based indicators in the maritime industry. An indicator can be defined as a measurable variable that is assumed to correlate or relate to a phenomena or factor (Øien, 2001). AIS-data represents an interesting input into indicators of maritime risk.

## 2. Methodology

The AIS provides all relevant navigational information that allows identifying a near-collision situation. A near-collision is detected when the following conditions are met:

- The ship domain of a vessel equipped with the AIS is violated by another one with the AIS.
- One of the vessels performed a last moment evasive manoeuvre. This manoeuvre is accompanied by abnormal ship rate-of-turn (ROT).

The first condition ensures that the examined situation was a close-encounter and potentially dangerous situation. The following condition identifies that a navigator reacted abnormally and performed an unusual manoeuvre to avoid the danger of collision. Based on collision reports in the period from 2010 to 2019 accessible at the Nautical Institute (Nautical Institute [2019]), 78% of all collision were preceded by a last-moment evasive manoeuvre (rudder hard over). An example near-collision progress is depicted in Fig. 1.

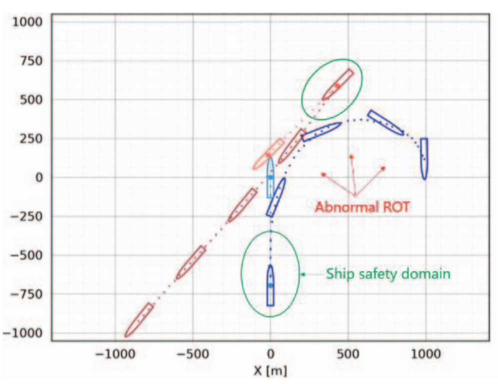


Fig. 1 An example of a near collision situation, the ship domain is violated, and abnormal ROT is detected

### *2.1. Ship domain*

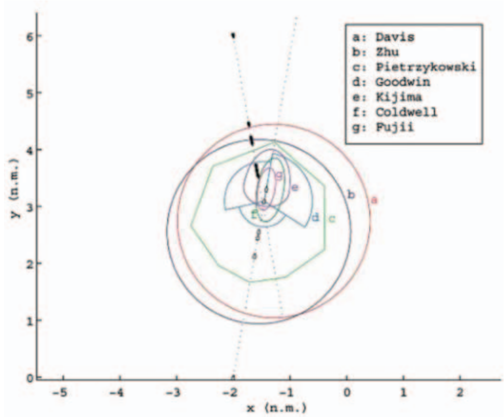


Fig. 2 Comparison between different ship domains

Ship domain has, since it was introduced in the 70s, been used in risk analysis and proposed as a tool for navigators to evaluate various risks. Several definitions for ship domains have been proposed, but a definition that has been used in several studies by Goodwin [1975] is: "A ship domain may be thought of as the sea around his ship which the navigator would like to keep free, with respect to other ships and fixed objects" (Goodwin, 1975). In his study Pietrzykowski [2008] claims that the ship domain shape and size is determined by the officer on watch who considers several factors such as the ship's speed and length, sea area, traffic density, etc. This means the domain boundary varies depending on the current navigational situation (Pietrzykowski, 2008). Several ship domains have been discussed and proposed over the last 50 years. Fig. 2 shows a comparison done by Wang [2009] of some of the different domains proposed from different studies for the same vessel (Wang et al., 2009). Fig. 2 shows that there is quite a large difference in size and shape of different ship domains.

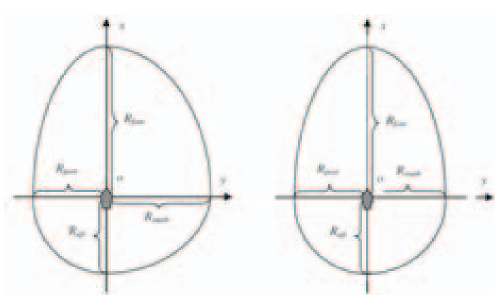

Fig. 3 Original (left) and modified quaternion ship domain

With such a broad range of defined ship safety domains varying in dimensions, shapes and purposes, a modified quaternion ship domain developed by Wang [2010] was chosen, as it fits the model's requirements the best. These domain dimensions are dynamic with respect to the ship length and speed, i.e. it increases its dimension with increasing length and speed. The original quaternion ship domain, the left side of Fig. 3, empathizes the right (starboard) side because it takes into account navigator behaviour in respect to the COLREG rules #15 and #19 (give way to a vessel coming of your starboard). The modified version used for the method, the right side of Fig. 3, excludes the impact of these rules because it is assumed that a last moment was performed which implies that COLREGs rules were not followed properly by navigators.

### *2.2. Abnormal rate-of-turn*

To decide what value of a rate-of-turn (ROT) is already an abnormal ROT for a specific ship, a method determining a ROT threshold was developed. The ROT threshold is based on the ship length and speed, and it combines two formulas. The first, Equation 1 Arimura et al. [1994], approximates a ship's tactical diameter (TD) according to the ship's length and speed. TD is a measure of the extent of turn a vessel could have in the moment when its heading is changed by 180 degrees after the ship performed a hard-to-port/starboard manoeuvre.

$$TD\ [m] = 10^{0.5441 \times \log(Speed) - 0.0795} \times Length \quad (1)$$

The second, Equation 2 Đurdevic [2013], determines a ship ROT needed to sail smoothly through a turn with the known radius and ship speed.

$$ROT\ [deg/min] = \frac{57.3}{60} \times \frac{Speed\ [knots]}{Turn\ Radius\ [nm]} \quad (2)$$

This method is primarily handful and accurate for conventional middle size vessels sailing with speed around 10-15 knots. All extremes, both in a ship length or speed, will eventually lead to inaccuracy of the ROT threshold estimation. Several example estimations of the ROT threshold for various ship lengths and speeds are listed in Table 1.

Table 1. ROT threshold examples

| Ship Length (m) | Speed (knots) | TD (m) | ROT (deg/min) |
|---|---|---|---|
| 100 | 8 | 258 | 110 |
| 100 | 12 | 322 | 132 |
| 100 | 16 | 376 | 150 |
| 200 | 8 | 516 | 55 |
| 200 | 12 | 644 | 66 |
| 200 | 16 | 753 | 75 |
| 300 | 8 | 774 | 37 |
| 300 | 12 | 966 | 44 |
| 300 | 16 | 1129 | 50 |

## 3. Case study

The proposed method was applied at Vestfjorden in Norway on three years of AIS data from 2013 to 2015. Vestfjord is high-density traffic area with a variety of shipping, such as fishing, cargo, and ferry vessels. This coastal area is also prone to collisions; seven collisions had happened there since 2002 when the IMO introduced the AIS. The following section describes the case study procedure.

### *3.1. Processing AIS data*

While processing the AIS data, 13.3% of AIS messages had to be filtered out because they were damaged or incomplete. The rest 86.6% was suitable for the method; however, these messages may still contain errors caused by human inputs or technical malfunctions.

### *3.2. Ship domain violation detection*

The AIS messages provide ship dimensions, heading, speed, geographical location; this information allows us to develop a ship safety domain and check whether this area was violated by another vessel equipped with the AIS. Total of 572 ship domain violations was detected in the period from 2013-2015 as depicted in Figure 3. The spatial distribution of the ship domain violations identifies locations where ships met in close distances, i.e. where potentially dangerous situations for collisions happen.

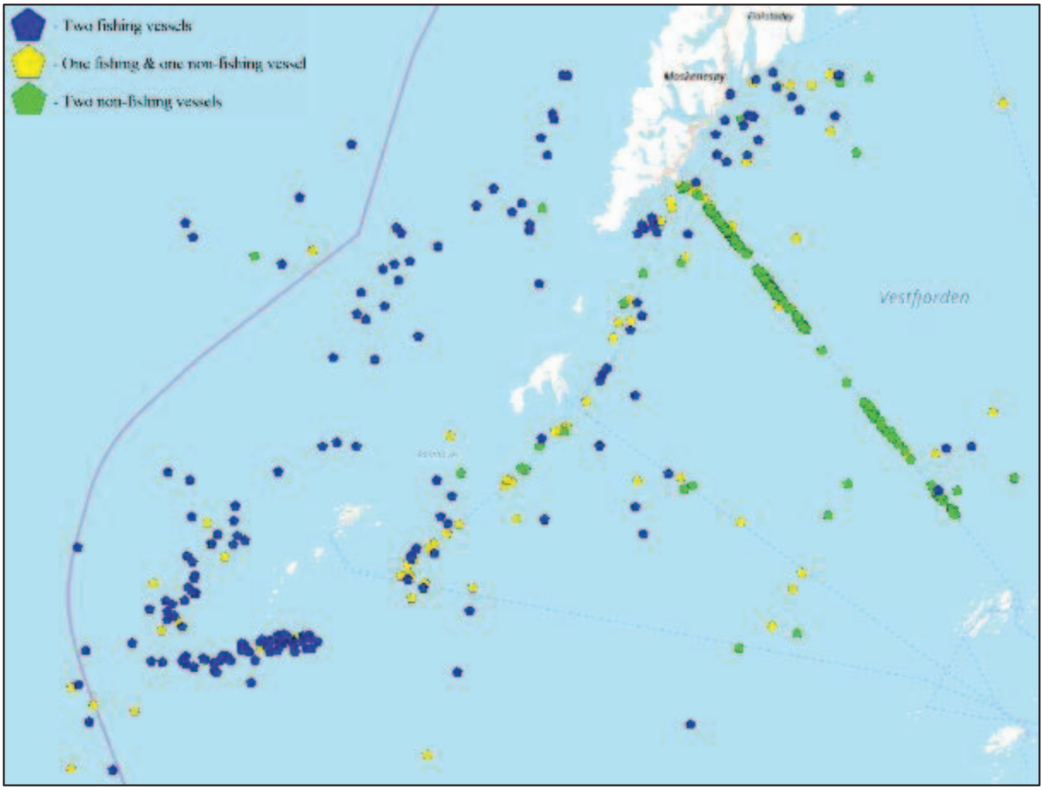


Fig. 4 All 572 detected ship safety domain violations

### *3.3. Near collision detection and visual inspection*

After the ship domain violations were detected, the ships involved in these situations were checked for the ROT threshold and thus was decided whether the situation contained a last-moment manoeuvre and was a near-collision. The method detected 46 near collisions, all these situations were plotted and manually/visually inspected by an experienced navigator. An example of a plot is depicted in Fig. 5, then all false detections were filtered out.

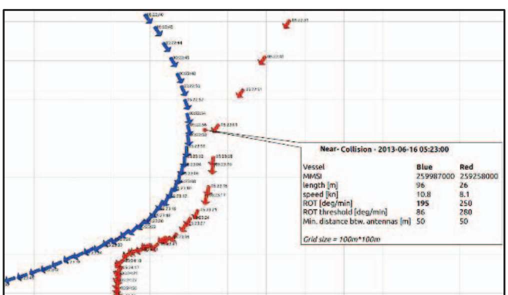


Fig. 5 Detected near collision

From the total of 46 detected potential near-collisions, 19 situations were positively confirmed as actual/real near collisions. These are depicted in Fig. 7 and from the spatial distribution, we may assume that the highest chance for a collision is located in the south-west area. More than half of detected near-collisions are located there, and this distribution fits very well the locations of historical collisions that happened in Vesfjorden since 2002 (symbolized by black wrecks). Another positive aspect is that the method managed to detect the only collision that happened in the examined period from 2013 to 2015.

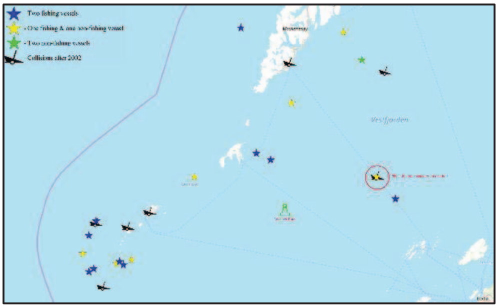


Fig. 6 All 19 correctly detected near collisions

Having the amounts of ship domain violations, near-collisions and collisions for a specific area, the accident triangle can be built to understand the relation between potentially dangerous situations, dangerous situations and accidents.

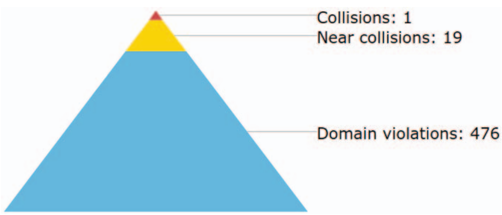


Fig. 7 A collision triangle

### *3.4. Sea and weather influence*

The case study is located in the northern part of Norway, where harsh weather and heavy seas can be expected. Therefore, the influence of heavy seas on the probability that a near-collision occurs was examined. A developed method based on ship dimensions and an actual significant wave height decided whether the sea state is high enough to affect the ship navigation. The results showed there is no correlation between heavy seas and chance that a ship domain violation occurs, i.e. that ship domains violations happen in bad weather with the same probability as in good weather. On the other side, there was a twice higher chance that a near-collision happens in heavy seas. This may be caused by the fact that it is more challenging to master the ship navigation and navigators' situational awareness drops in heavy seas.

## 4. Discussion

There are several advantages to this method compared to the earlier near-miss detection method. Firstly, the method is based on a simple mechanism (ship domain violation + abnormal ROT), and it is easy to tune the method for various purposes. Secondly, this method may be applied to various waters such coastal, enclosed or inland waters. Thirdly, the method can cover large areas with reasonable computational power. The case study was computed on a personal laptop, and a year of AIS data was processed in approximately 72 hours which is still a reasonable duration while speaking about an area of 13, 000 km$^2$.

### *4.1. Limitations*

On the other side, the method possesses limitations that are difficult to remove or limit. Firstly, not every near-collision is preceded by a last-moment manoeuvre. According to research for this paper, in about 78% of collisions, a last-moment manoeuvre was performed. Secondly, not every abnormal manoeuvre indicates a dangerous situation. Thirdly, even after a visual inspection of the near-collision situation, it was difficult to decide whether the situation was truly dangerous and close to collision, e.g. we do not know what happened on the bridges of ships, navigators might have agreed by VHF on such abnormal manoeuvre. And lastly, although the AIS data provides all navigational information needed, AIS messages also possess a considerable error-rate.

### *4.2. Applicability*

Having a database of near collisions provides us valuable insight into the dangers in navigation. A high concentration of near collisions may indicate collision-risky areas which should be assessed by further risk assessment. Understanding the circumstances of near collisions may improve the knowledge about why and how collisions happen. The effect on the safety of navigation after a waterway design was changed may be evaluated by applying the method on the waterway before and after the change. When aggregating across time, vessel types and/or geographic area, and complemented by relevant exposure data (e.g. nautical miles) number of near-misses might be used as leading indicators of collision risk. And finally, if a reliable ratio of between near-collision and collision is possible to develop, we may quantify the risk of collision based on the amount of near collision even for areas where a collision never happened.

## 5. Conclusion

Our goal with this research project was to further develop a near-miss detection model using ship domains and AIS data, with the use of a case study in Vestfjorden in Norway. To conclude, the current state of the model, with the uncertainties in both dataset and model, could be considered as a risk indicator that can be used to identify areas of interest for further risk assessment, and has a potential to become a solid risk assessment tool with further development.

## 6. Recommendations for further work

An important step further is to validate revisions of the model for larger areas, e.g. the whole coastline of Norway, and to correlate the data and findings with relevant parameters to investigate the convergent validity of the model, for example number of reported collisions.

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