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Assessment Statistical Ship Collision Risk with Ship Encounter Data

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Abstract

Due to the high risk of personal injury and property damage, the safety of maritime transport is an important concern for everyone involved. Ship navigation officers usually look up a ship's collision profile for safety-at-sea information before entering an unknown coastal area. Near-ship collisions are very important when assessing the potential risk of shipping. This paper undertakes a ship encounter risk assessment, involving analyses of the trajectory data of merchant ships and then extracts ship encounter data, creates a probabilistic model to determine whether an encounter event is a near miss, and suggests risk indicators. The proposed method will be useful for navigators to plan safe passages.

Keywords: Ship Collision Risk, Near-miss, Maritime traffic information, Ship Encounter Data

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1. Introduction

The ship collision accident caused casualties, property losses and environmental damage. In order to reduce collision accidents in the water area, many regulations and guidelines have been implemented, such as navigation marks, route passages and land-based shipping services.

However, in coastal areas, it is difficult to install navigation equipment due to the distance from the coast and offshore infrastructure. In these areas, maritime safety information is currently obtained through other methods, such as publications or long-distance radio communications. Before entering an unknown coastal area, ship navigators need information such as ship crossing warnings, collision profiles and traffic conditions.

Obtain a summary of ship collision accidents, such as ship details, encounter location, human error related to collision risk judgment, equipment failure, etc. Some researchers used collision accident files to conduct statistical collision risk analysis to provide navigational safety information to navigators.

Although collision risk analysis has many advantages, the number of ship collision accidents is too small to use statistical methods. It also does not reflect the situation of the ship. In this paper, we focus on methods for assessing ship encounter risks for maritime stakeholders. A ship encounter is a situation where two ships are close to each other and there is a risk of collision. Using automatic identification system (AIS) ship trajectory data, ship encounter data can be calculated. These data have sufficient statistical power to overcome the problem of limited actual collision sample data.

In addition, the result of the ship's encounter can be classified as an attempted accident, including a collision accident or an attempted collision event. A ship collision hazard refers to a situation where the ship is close to collision, but there is no collision due to the actions or luck of the navigator.

In our previous research related to ship encounters, we proposed a method to analyze ship collision risk using ship collision risk cases(Kim et al, 2017). In order to develop the risk model, the ship encounters variables such as distance to the closest point (DCPA), time to the closest point (TCPA), collision avoidance variance (CAV), and risk results, which are used to train the logistic regression model. However, no evaluation method to support collision avoidance by ship navigators is considered.

In this paper, we propose a marine traffic data analysis method for assessing the risks encountered by ships in coastal areas. In order to calculate the risk of ship collision, a logistic regression model of ship collision risk is adopted. In order to assess and visualize ship encounter risks in grid cells, we proposed the concept of Ship Encounter Risk Index (SERI). Using the grid unit, the visualization of the ship's encounter risk map is introduced to effectively deliver it to the navigator.

The remainder of this paper is organized as follows. Section 2 introduces maritime traffic data and the proposed method of extracting ship encounter data. Section 3 describes the methods of ship encounter risk assessment, including visualization methods. In Section 4, the visualization results are displayed on the map of the target coastal area. Finally, the conclusion is given in Section 5.

2. Maritime Traffic Data

2.1. Ship Trajectory Data

In the sea area, the raw data used for maritime traffic analysis is collected by AIS equipment. All ships over 300 gross tonnage need to be equipped with ship identification equipment. This device automatically sends messages to other ships or shore base stations at intervals of 2-180 seconds.

At shore base stations such as Vessel Traffic Services (VTS) and port authorities, AIS equipment is used to monitor ship traffic and store maritime traffic data. Two types of information are stored-static and dynamic. Table 1 lists the ship trajectory information used to generate model variables (IMO 2002).

Table 1. Maritime traffic data lists.

Type of information	Information
AIS Static Information	· IMO and MMSI number · Call sign and name · Ship type · Length and beam · Location of GPS antenna
AIS Dynamic Information	· Ship's Position · Time · Course over ground · Speed over ground · Heading · Navigational status · Rate of turn

2.2. Ship Encounter Data

A ship encounter is a situation where two ships are close to each other and there is a risk of collision. This can lead to a close range situation, which may be almost missed or no missed.

It is associated with the collision predictors of DCPA, TCPA and CAV and the consequences of the attempted outcome. These data are derived from the overall ship trajectory data. The ship encounter data list is shown in Table 2.

Table 2. Ship encounter data lists.

Data Characteristics	Information
Collision Predictor	· Distance to closest point of approach · Time to closest point of approach · Collision avoidance variable · Encounter type
Collision Consequence	· Near-miss / No Near-miss

In order to avoid ship collision, the ship usually calculates the DCPA and TCPA based on the vector between itself and the target ship to assess the risk of collision (Jeong et al 2012). Suppose the position coordinates of the own ship and the target ship are represented by (x_o, y_o) and (x_t, y_t) respectively, and the ship speed is v. θ represents the angle of intersection with the x-axis calculated from the heading of the ship. DCPA and TCPA can be derived using equations. (1) and (2).

$$\mathrm{TCPA} = \frac{-[\Delta y(v_t sin\theta_t - v_o sin\theta_o) + \Delta x(v_t cos\theta_t - v_o cos\theta_o)]}{(v_t sin\theta_t - v_o sin\theta_o)^2 - (v_t cos\theta_t - v_o cos\theta_o)^2} \quad (1)$$

$$\mathrm{DCPA} = \sqrt{\begin{matrix}[\Delta y + (v_t sin\theta_t - v_o sin\theta_o) \times TCPA]^2 + \\ [\Delta x + (v_t cos\theta_t - v_o cos\theta_o) \times TCPA]^2\end{matrix}} \quad (2)$$

The encounter variable CAV is a dichotomous variable that indicates whether the route variance is above or below the threshold. CAV(1) means less than the threshold, and CAV(2) means greater than the threshold.

According to the "Ship Collision Rules" (IMO 1972), ship encounters are categorized as head-on, cross, and overtake based on the difference between the heading bearing of own ship heading and target ship. The reference values for for head-on, cross, and overtake situations are $0° - 5°$, $5° - 112.5°$, and $112.5° - 180°$, respectively.

In order to distinguish between dangerous events and non-dangerous events, the elliptical ship safety zone is adopted as the risk standard. According to Fujii and Tanaka (1971) proposed the long semi-axis 8L and the short semi-axis 3.2L ship heading direction to rotate the ship domain.

The ellipse depends on the course and length of the ship (L_0). The slope of the ellipse is rotated to the angle of intersection with the x-axis (θ). Using the elliptic equation, equation (3) for discriminating near misses used. It discriminates whether the value on the left is less than 1 as a case of almost miss.

$$\frac{(\cos\theta \times (x_t - x_0) + \sin\theta \times (y_t - y_0))^2}{(4 \times L_0)^2} + \frac{(\sin\theta \times (x_t - x_0) - \cos\theta \times (y_t - y_0))^2}{(1.6 \times L_0)^2} \leq 1 \quad (3)$$

3. Experiments

3.1. Ship Collision Near-miss Model

In the statistical analysis based on collision accidents, there is a problem of limited sample data. Therefore, the ship encounter data needs to be considered. In the previous study, we adopted a ship collision risk probability model using logistic regression in the target area. The model can be used to estimate the probability of classifying the output result. The input arguments are

DCPAL, TCPA, CAV, and encounter type. Where DCPAL is obtained by dividing DCPA by the length of the ship.

The near-miss probability (NP) can be used as the probability value in the ship collision risk index. The classification according to the type of ship encounter is as follows:

$$NP^{headon} = \frac{e^{(3.7-2.01X_1-0.49X_2-1.14X_3)}}{1+e^{(3.7-2.01X_1-0.49X_2-1.14X_3)}} \quad (4)$$

$$NP^{cross} = \frac{e^{(2.13-1.41X_1-0.08X_2-1.06X_3)}}{1+e^{(2.13-1.41X_1-0.08X_2-1.06X_3)}} \quad (5)$$

$$NP^{overtake} = \frac{e^{(3.24-0.91X_1-0.26X_2-1.78X_3)}}{1+e^{(3.24-0.91X_1-0.26X_2-1.78X_3)}} \quad (6)$$

where $\boldsymbol{X_1}$: DCPAL, $\boldsymbol{X_2}$: TCPA, $\boldsymbol{X_3}$: $\text{CAV}(1) = 0,\ \text{CAV}(2) = 1$

3.2. Visualization to Grid Map

In order to effectively display ship encounter information to navigators, grid maps can be used to convey traffic characteristics by coloring cell risks. We proposed SERI, which considers the probability of an attempt in an encounter and the amount of traffic in a community.

The water area is divided into several grid cells with an interval of cell_intv. Based on the location range (X, Y) of each cell, calculate the ship traffic density $Q_{(X,Y)}$ from the ship trajectory DB. Using $Q_{(X,Y)}$ and equations (4)-(6), SERI is defined as equation (7).

$$SERI_{(X,Y)} = Q^2_{(X,Y)} \sum_{i=1}^{n} NP^i_{(x,y)}\ ,where \quad (x \in X)\ \cap (y \in Y) \quad (7)$$

In Eq.(7), x and y denote CPA position coordinates between encountering ships, while X and Y denote x and y range of a grid cell, respectively in the target water area. $Q_{(X,Y)}$ is the ship traffic volume in the grid cell range (X, Y). Fig.1. is the data processing algorithm to calculate SERI.

In Eq. (7), x and y represent the coordinates of the CPA position between encountering ships. X and Y represent the x and y ranges of the grid cell in the target water area, respectively. $Q_{(X,Y)}$ is the volume of ship traffic in the grid cell range (X, Y).

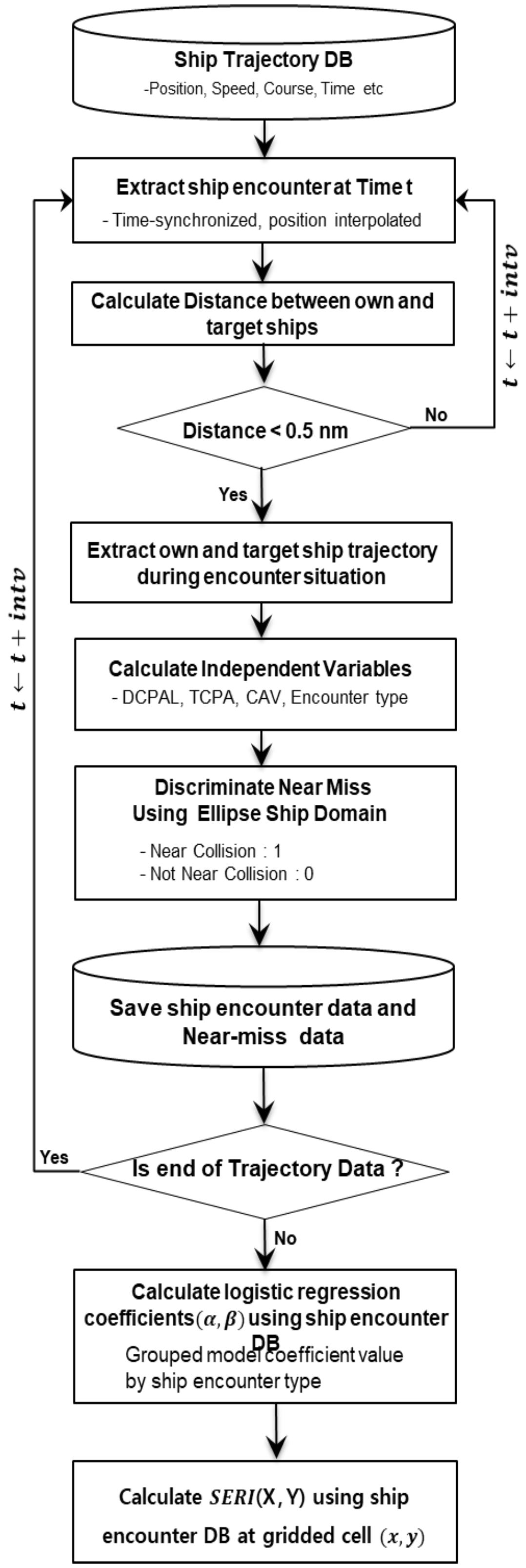

Figure 1: The data processing algorithm to calculate SERI.

4. Results

The proposed risk assessment method is applied to the coastal area of Busan Port located in southeastern Korea. For model application, four months of ship trajectory data were collected from AIS dynamic and static data. A grid cell length of 1,000 m is used in this method.

The results of 139 attempted events and 6,973 attempted events are stored in the ship encounter database, as shown in Table 3. Among all encounter types, the number of attempted cross encounters is the largest. In the case of overtaking, the marginal win rate is the highest (approximately 4.41%). Compared with the proportion of no near misses in the target area, the rate of near misses is very low (1.99%). Therefore, there is no need to consider near misses in the ship encounter risk assessment.

Table 3. The results of ship encounter database.

	Near-miss	No near-miss	Near-miss Ratio
Head-on	14	2,522	0.55 %
Cross	69	3,184	2.16 %
Overtake	56	1,267	4.41 %
Total	139	6,973	1.99 %

Using ship trajectory data, extract the traffic density $Q_{(X,Y)}$ of each grid unit as shown in Figure 2. The figure shows the grid distribution of ship traffic. The density of ship traffic along the trajectory of ships bound for Busan Port (ⓐ) and Busan New Port (ⓑ) is relatively high.

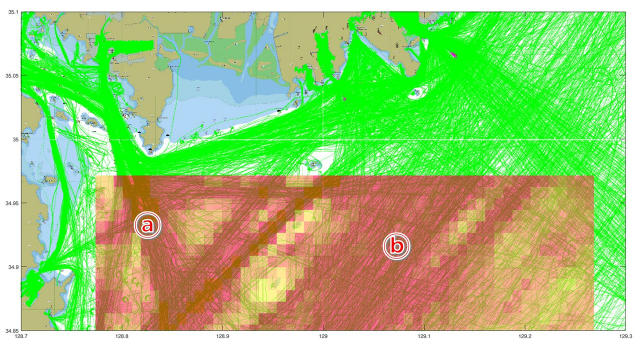

Figure 2: The ship traffic volume density plot in grid map.

From the ship encounter database, the near-miss probability (NP) values categorized by ship encounter type are obtained using Eqs.(4)-(6). Using NP and Q, the SERI distribution of the target coastal waters is obtained. Figure 3-5 show the distribution of SERI in a head-on, cross, and overtake situation, respectively.

The ship encounter risk distributions of Figure 2. did not match the ship trajectory pattern of Figure 3-5. Based on the analysis results of the experiment, navigators can be cautioned about the crossing situations with other ships. In the area ⓐ in Figure 5, the ship traffic gathered in the port fairway and crossed the east and west bound traffic. On the other hand, in area ⓑ, there is a wide navigable space. Furthermore, the encounter risk is relatively low as compared to the ship traffic density.

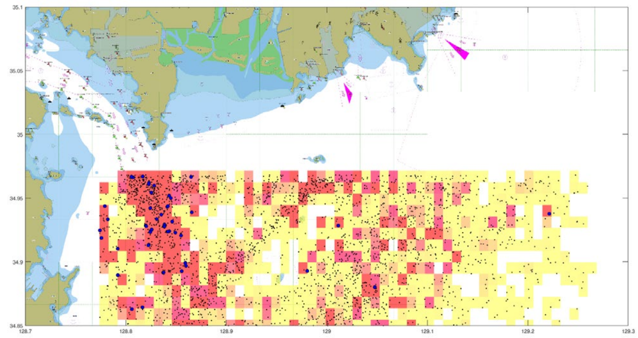

Figure 3: The distribution of SERI in head-on situation

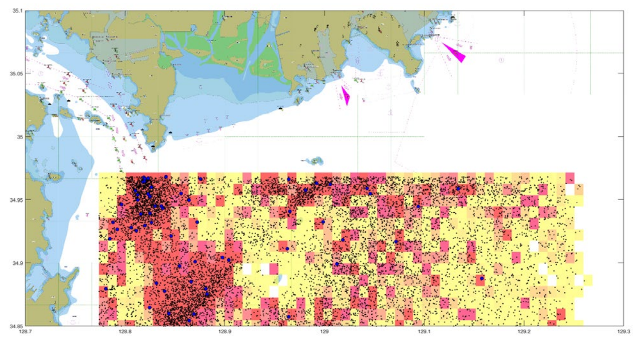

Figure 4: The distribution of SERI in cross situation

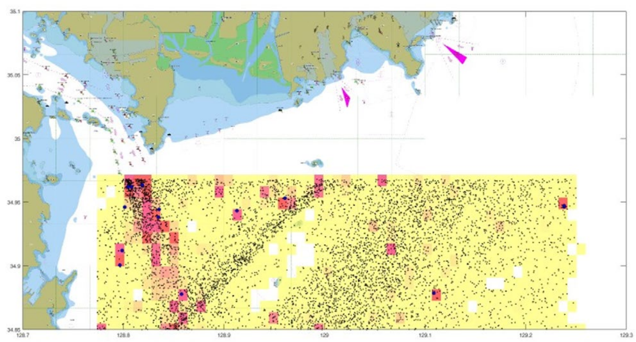

Figure 5: The distribution of SERI in overtake situation

5. Conclusions

In this paper, we discussed a method for assessing the risks of ship encounters for maritime stakeholders. In order to obtain ship encounter data, the proposed data processing algorithm is used to analyze ship trajectory data. As a result of the analysis, we obtained a sample of 7,112 ship encounter cases for use in the probabilistic and sinister risk assessment model.

In order to visualize the risk of ship collision intuitively, we propose an indicator called SERI and its data processing algorithm to evaluate the risk of ship collision in the water area map grid unit. The index not only considers the probability of attempted encounters, but also considers the volume of ship traffic. The results of the risk assessment for ships will provide maritime safety information for navigators, ship traffic operators and port authorities.

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