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Collision Risk Assessment Techniques for INF Ship Using AIS Data

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Abstract

We propose techniques of arranging traffic information of a sea area using AIS data and then estimating conditional collision frequency for a ship passing the area. Then we perform a case study to show applicability to collision risk assessment. For two assumed routes of the most crowded coastal waters in Japan, route-C (close to the land) and route-F (far out at sea), we estimate collision frequencies against all ships, tankers and very large ships, and then discuss route selection in terms of INF ship collision risk. One of the findings is that average collision frequency for route-C, which is considered as a maximum measure of Japan coast, is at least a factor of 3 lower than the estimate of the SeaRAM study. The difference is caused by uncertain target population assumed in SeaRAM. This study proves that AIS data allows us to know accurate ship population and then estimate realistic collision frequency under a certain condition such as route, ship group to be collided, etc. This will open a new vista for a risk-based routing strategy of INF ship considering various relevant factors.

Introduction

Nuclear Fuel Transport Co., Ltd. (NFT) has safely conducted coastal shipping of spent nuclear fuels and nuclear wastes from NPP to reprocessing/disposal facilities in Japan. Exclusive INF ships operated by NFT have had a complete track record of safe operation so far without accident or malfunction.

For maritime transport of nuclear materials, one of the most concerning types of incidents is ship-to-ship collision. A collision event may cause damage of package due to mechanical or thermal load, and then the sinking of ship at worst. These can result in not only the radiological concerns but also strong negative reactions from society. So every effort has to be made to prevent ship collision even in terms of public acceptance and business continuity. This is also a lesson learned from the sinking case of the cargo ship Mont-Louis after collision with a large car ferry occurred in 1984.

An incidence of ship-collision generally depends on marine traffic environment on the ship route and the maneuvering technique of individual ships. Japan coast is known as one of the most crowded waters in the world. It suggests relatively higher risk to ship-collision, as shown in the marine transport risk study of the '90s, the SeaRAM project[1]. NFT is well aware of it and has taken precaution to ensure safety navigation. However, marine traffic environment surely changes compared with the '90s, for example, due to increased shipping between China and North America. Certain types of ships have also evolved to larger and faster such as a container ship. In addition, routing of INF ship will likely be changed as an interim storage facility for spent nuclear fuel begins to operate. It is necessary to examine an impact of these uncertain factors on safe navigation of INF ship.

We have studied the applicability of the Automatic Identification System (AIS)[2] data to collision-risk characterization and quantification for certain marine traffic environment. AIS is an automatic tracking system mounted on ships for identifying and locating self and nearby ships, and primarily used for collision avoidance in water transport. AIS data collected from both satellite and shore-based stations are globally aggregated. Data aggregated this way can also be viewed on Internet and used for another purpose. Since SOLAS74 was effectuated in 2002, AIS has been mounted as a duty for coastal ships of more than 300GT and ocean-going ships of more than 500GT. Thus, it becomes possible to see and analyze past traffic information of almost all the large ships on our concerned sea area.

In this paper, we propose techniques of arranging traffic information of a sea area using AIS data, and then estimating conditional collision frequency for a ship passing the area. Then we show results of a case study performed to examine applicability of our techniques to collision risk assessment. We also discuss issues of ship route selection becoming apparent by AIS data, such as possibility of salvage.

Methods

Preprocessing AIS data for arranging traffic information

At first, AIS raw data is preprocessed to prepare marine traffic information for our purpose, as shown in Fig.1. We display all of the ship tracks for one day to find major ship routes of a target sea area (e.g. Fig.2). Then we divide the area into route segments while considering shape of an area covering each route (e.g. Fig.3). Finally, we arrange the traffic information by items shown in Table1. Though ship type and GT are not available from AIS data, instead they can be searched by Internet[1].

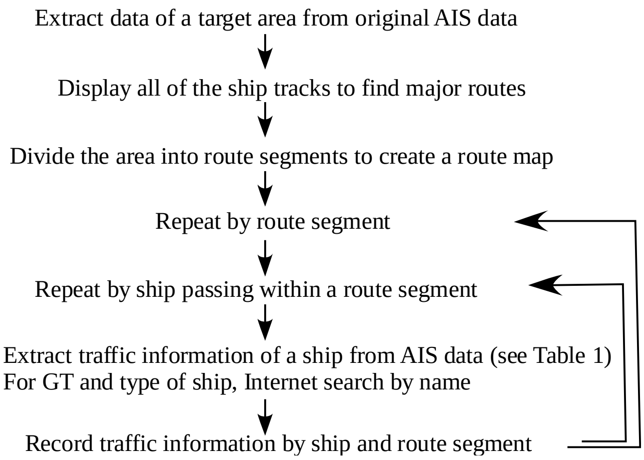


Figure 1 Preprocessing flow of AIS data

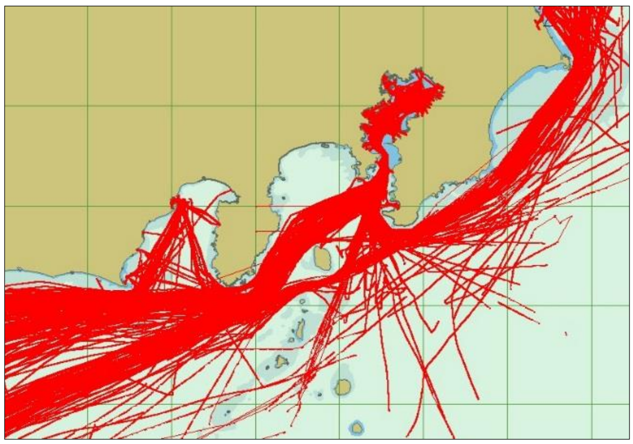


Figure 2 All ship tracks in a day

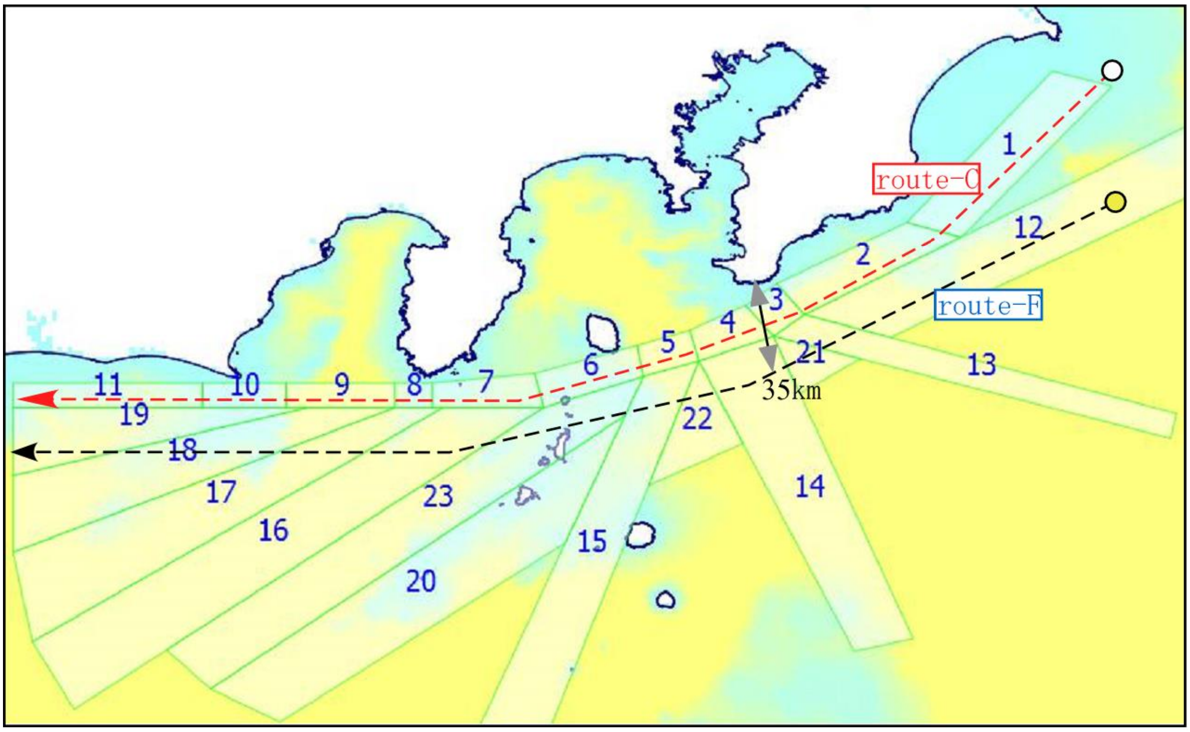


Figure 3 Route segments found in a target area

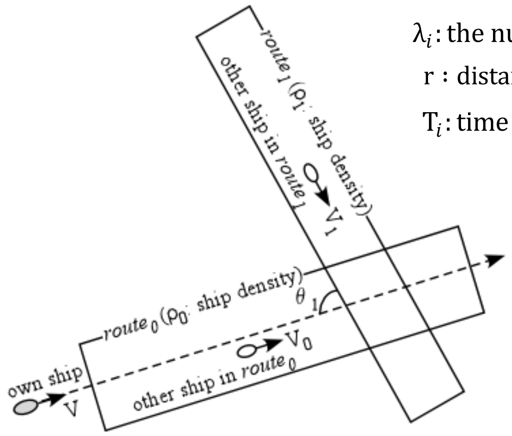
Table 1 Traffic information obtained by preprocessing AIS data

Ship particulars
Name
Type
Length
Width
Gross tonnage (GT)

Traffic data of a ship by route segment
Route segment within which a ship navigates
Representative time of passing within a route segment
Heading of ship within a route segment
Representative speed of ship in a route segment

Estimating collision frequency for a ship passing a target area

While an own-ship passes through a certain route segment, it is possible to roughly predict an incidence of encounter situation with other ships, which may result in potential collision. We refer this situation as 'collision-encounter'. We employ a navigation model proposed by Kaneko[3] for estimating the number of collision-encounter in general route segment, as shown in Fig.4. Model parameters can be obtained from the traffic information arranged above except one empirical parameter; the actual rate of collision per collision-encounter. Here we assume one collision per 20,000 encounters when the heading of own-ship is the same as that of other ship, and one per 10,000 when opposite. These are conservative figures often used before modern navigational equipment is introduced. For the other case of collision-encounter, the rate of collision is determined in proportion to the angle between own-ship and other ship.



λ_i: the number of collision encounter between own and other ships in $route_i$

r : distance between own and other ship to identify collision encounter situation

T_i: time it takes for own ship to pass through $route_i$

$$\lambda = \lambda_0 + \lambda_1 \quad (1)$$

$$\lambda_0 = 2r\rho_0 V_0 T_0 \sqrt{1 + a_0^2 + 2a_0 \cos\pi} \quad (2)$$

$$\lambda_1 = 2r\rho_1 V_1 T_1 \sqrt{1 + a_1^2 + 2a_1 \cos\theta_1} \quad (3)$$

$$a_0 = \frac{V}{V_0}\ ,\ a_1 = \frac{V}{V_1}$$

Figure 4 Navigation model for estimating the number of collision-encounter situation

Case study of ship collision risk

In this case study, we target the coastal waters of the Kanto region along the Pacific Ocean, the most crowded sea area that INF ship is expected to pass. Real route of INF ship is confidential for security reasons, so we assume two different routes for comparison: one is ‘route-C’ close to land, another is ‘route-F’ far out at sea (see Fig.3). First we examine traffic features of those routes using AIS data of two days in each season (Mar., June, Sept. and Nov.), year of 2012. Then we estimate collision frequencies against three groups of other ships: all ships, very large ships more than 30,000GT and tankers, while INF ship navigates each route at normal speed. Tanker here carries chemicals, oil or gas. Special attention has been paid to very large ship and tanker in terms of collision impact, potential fire/explosion and sinking concerns.

Traffic features of the target sea area

The total number of passing ships changes depending on the day within a factor of 2 yet there does not seem to be much change in route-segment distribution of ship type or gross tonnage (GT). Figure 5 shows traffic information of the one-day data (Mar. 7th) when the largest number of passing ships is observed. Route-C passes from segment#1 to #11 and the number of passing ships differs from 50 to 270 by segment. In particular, the number of ships in segment#1, #2, and #7 to #11 is large because they are on line to enter or leave Tokyo Bay. It is also observed that the rate of tanker is high and by contrast, the rate of very large ship is low. On the other hand, route-F passes from segment#12 to #23 and the number of passing ships is much less than that of route-C except segment#17 to #19. The rate of very large ship is high, almost more than half because a large ship is likely to navigate far-off route.

Estimation and comparison of collision frequency

As shown in Fig.6, cumulative collision frequency (CCF) against all ships is estimated to 1.0×10^{-4} while a ship navigates route-C for a distance of ~360km. This value is at least a factor of 5 larger than CCF of route-F under the same condition. In fact, it could reach a cautious level of collision risk (not sinking/leakage) assuming that a ship navigates ten times every year. CCF against tankers on route-C is lower than one-third of that against all ships but still indicates a non-negligible level. On the other hand, CCFs against tankers on route-F and very large ships on both routes are quite low.

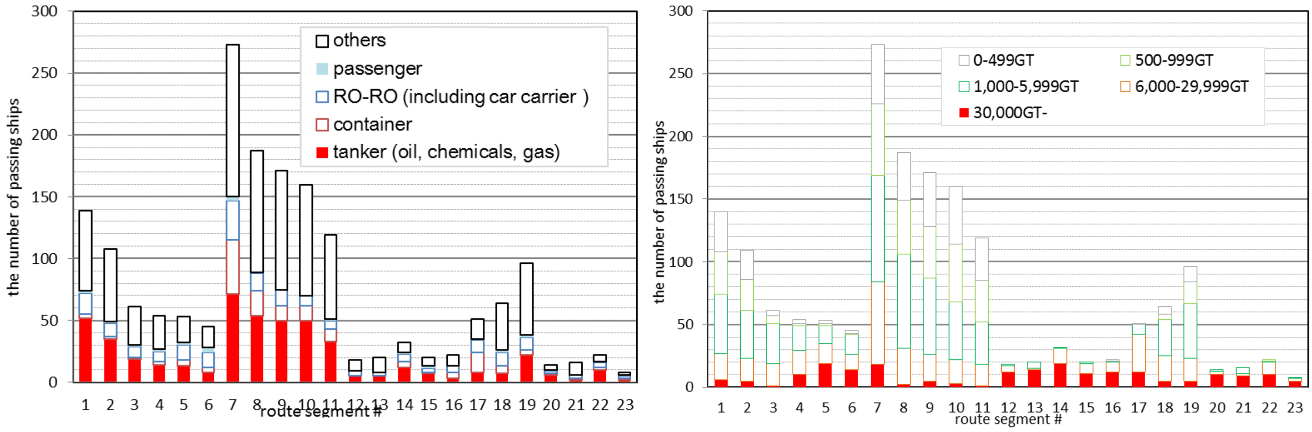


Figure 5 Marine traffic info of ship type(left) and GT group(right) by route segment

Table 2 lists average collision frequencies per nautical mile (ACFs) estimated in this study and the SeaRAM study for comparison. ACF against all ships on route-C is estimated to 5.45×10^{-7} and can be considered as a maximum measure all over the Japan coast. Nevertheless, our estimate is at least a factor of 3 lower than 1.9×10^{-6} of east coast of Japan provided in SeaRAM. The value of SeaRAM was obtained based on the number of accidents (1979-1993) and ship-years. The main reason for the difference is that a real target population, i.e. the number of passing ships and the distance of navigation, was uncertain. AIS data allows us to obtain accurate population data under a certain condition such as route, ship type to be collided and passing time, and then estimate more realistic collision frequency according to a change in traffic environment.

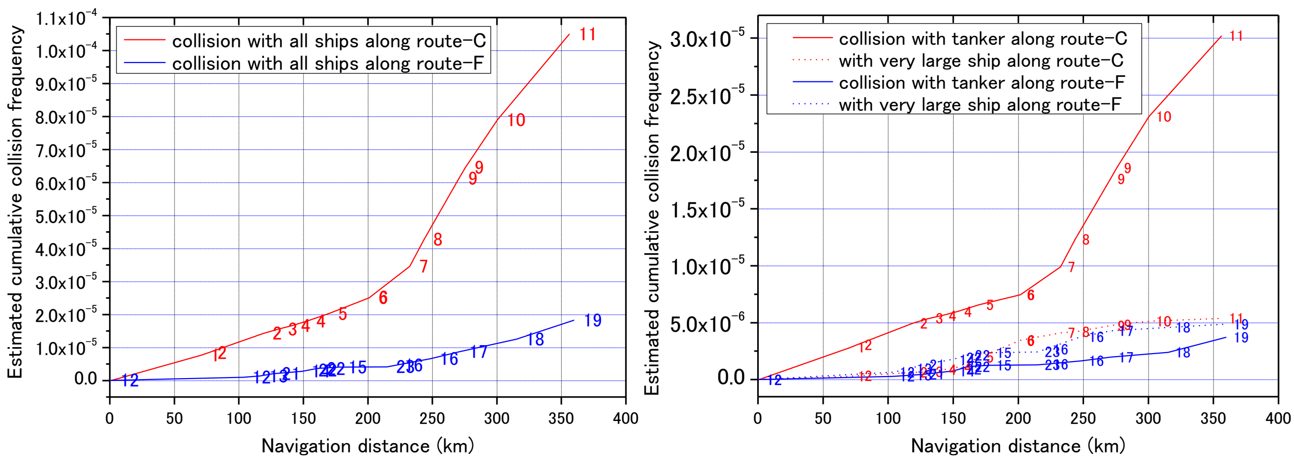


Figure 6 Estimated cumulative collision frequencies with all ships(left), with ship groups of concern(right). [the figure in the graph indicates route-segment#]

Table 2 Estimated average collision frequencies in the target sea area

Other ship group to be collided	Navigation route (~ 360km)	Average collision frequency (/nmi)	
		This AIS study	**SeaRAM study**
All ships	Route-C	5.45×10^{-7}	1.9×10^{-6} (East coast of Japan)
	Route-F	9.44×10^{-8}	
Tankers (oil, gas, chemicals)	Route-C	1.57×10^{-7}	—
	Route-F	1.92×10^{-8}	—
Very large ships (> 30,000GT)	Route-C	2.81×10^{-8}	—
	Route-F	2.51×10^{-8}	—

Findings from the viewpoint of route selection

Marine route selection should be comprehensively determined based on the estimated collision frequency, fire/collision-resistance of ship, feasibility of salvage after sinking, etc. For example, although it is hard to imagine sinking for INF ship, feasibility of salvage roughly depends on the water depth on site. Here we refer to the sea area over 1,000m depth shown by yellow in Fig.3 as a cautious area. If we simply compare routes in terms of ACF against all ships, route-F is more preferable than route-C. However, on the possibility of salvage, route-F seems not so good as route-C because the ratio of a cautious area covered by route-F is more. As far as ACF against very large ship is concerned, route-C is nearly the same as route-F and in particular the number of very large ships in route-segment#8 to #11 is much less than far segments#16 and #17. Thus it cannot be said that route-F is always better when various risk factors are considered. Routing strategy depends on which factors are considered relatively important – including economical factor such as fuel consumption or transport time. Future prospects include making a risk-based model of ship routing by listing and weighting such relevant factors.

Conclusions

We propose techniques of arranging traffic information of a sea area using AIS data and then estimating conditional collision frequency for a ship passing the area. We perform a case study for two assumed routes, route-C (close to the land) and route-F (far out at sea), in the coastal waters of the Kanto region along the Pacific Ocean. CCF against all ships on route-C reaches a cautious level while a ship navigates for a distance of ~360km. ACF on route-C can be considered as a maximum measure all over the Japan coast and nevertheless, our estimated value is at least a factor of 3 lower than the estimate of the SeaRAM study. The difference is caused by uncertain target population assumed in the SeaRAM. This study proves that AIS data allows us to know accurate ship population and then estimate realistic collision frequency under a certain traffic condition. This will open a new vista for a risk-based routing strategy of INF ship considering various relevant factors.

Acknowledgments

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