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Analysis of adjustment of departure time for ferry collision avoidance based on OZT method

メタデータ	言語: eng
	出版者:
	公開日: 2021-11-30
	キーワード (Ja):
	キーワード (En):
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	所属:
URL	https://oacis.repo.nii.ac.jp/records/2264

Master’s Thesis

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Graduate School of Marine Science and Technology

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Content

1. Introduction

1.1. Background

Shipping is the main mode for world trade. It is estimated that around 90% of the 11 billion tons of goods handled globally in 2018 are transported by sea[1]. With the development of the economy, the demand for shipping is increasing year by year. In addition to the increase in quantity, ships are also developing towards high-speed and large-scale. This undoubtedly increases the potential safety hazards of ships. Especially in large ports, the consequences can be devastating in terms of human life as well as damage to the marine environment.

With the development of science and technology, ships are equipped with more advanced equipment, such as automatic radar plotting aid (ARPA), automatic identification system (AIS), electronic chart display and information system (ECDIS), et al. These devices can provide more information for ship's navigation. However, the improvement of information acquisition technology has not reduced the collision probability. According to the investigation of the nautical Institute, the main reason of collision is human errors[2]. The potential human factors are lack of experience, knowledge, and correct operation of the 1972 International Rules for Preventing Collisions at Sea (COLREGS) which intended to provide guidance to the crew responsible for managing the collision risk[3]. The collision risk will increase accordingly if these rules are not followed.

There are the large seaports having an annual traffic capacity of around 100 million tons of cargo and 4,500,000 twenty-foot equivalent units in Tokyo Bay[4]. Minimizing ship collisions is imperative. Although it is narrow, it is the busiest sea route in the world. According to statistical data, it is estimated that about 670 ships pass through Tokyo Bay every day. To reduce collisions, Japan was enacted the Maritime Safety Traffic Law based on GOLREGS and established the Uraga-Suido Traffic Route. But this cannot avoid the crossover encounter at the end of the traffic route. There is a high risk that ships passing through Uraga-Suido Traffic Route will collide with local ferries.

In this area with high traffic density, more factors should be considered. However, the law will be vague to follow in close-quarters situations due to the complex crossing scenarios. Generally, ships must be at right angles when crossing the traffic flow and must turn right when avoiding collisions. But it will lead to danger in some special cases. For example, both the front and the right sides of the ferry are potentially at risk of collision. That highly depending on the crew’s navigation skill and experience.

1.2 Related works on collision avoidance

In the 70s to 90s of the 20th centuries, the automatic collision avoidance of ships was still in the stage of theoretical research. In the 1980s, the expert system was first applied to solve the problem of ship automatic collision avoidance by Tokyo University of Mercantile Marine[5]. However, the disadvantage of the expert system proposed at that time was that it did not consider the requirements of international maritime regulations for collision avoidance. Later, FP Coenen from University of Liverpool, also launched a ship collision avoidance expert system[6]. This system uses knowledge bases from navigation experts and maritime professionals. However, the collision avoidance system cannot provide unique information in the complex multi-ship encounter situation.

In addition to the collision avoidance expert system, in order to meet the calculation speed and collision avoidance optimization purposes, mathematical algorithm models including artificial neural networks and evolutionary theory are also used in the calculation of collision avoidance decision-making. Tokyo University of Mercantile Marine proposed an artificial neural network collision avoidance model to improve the learning ability and real-time performance of collision avoidance algorithms[7]. Tsou et al. used genetic algorithms to find the optimal route by setting the three parameters of the most steering angle, heading recovery time and heading recovery angle[8]; Perera et al. chose fuzzy theory and constructed a decision-making system based on fuzzy logic and collision avoidance rules[9]; P.P. Tang aiming at telling the surface unmanned boat, he proposed a local obstacle avoidance method[10]; Taehwan Lee et al. analyzed the energy optimal path selection algorithm that integrates environmental impact and heading angle[11].

There are some studies aimed at avoiding collisions with ferries in narrow waters. M. Korçak proposed that the management of the passage schedule can be effective for a significant increase and decrease in the collision probability in Istanbul Strait[12]. However, the calculation of this study still lacks uncertainty. Luman Zhao proposed a COLREGS-compliant decision-making strategy that integrates the human expertise with the artificial intelligent method[13].

1.3 Research content of the subject

In this study, the hazards level for a possible collision accident between the ships were investigated in the Uraga-Suido Traffic Route. The ferries between Kanaya Port and Kurihama Port are set as own ships. Load the Tokyo Bay terrain data and AIS data of Tokyo Bay, draw the real maritime traffic situation by programming. Then, A non-holonomic model is used to predict the position of the ship. According to the analysis of relative position and speed between the own ship and the target ships. The risk detection system of ship collision is established by using the method of OZT (Obstacle Zone by target).

1.4. Outline

The structure of this article is addressed as follows.

The first chapter mainly introduces the significance of ship collision avoidance, the research status of the subject, the problems existing in the existing collision avoidance research, and the main work of this study. Followed by the overview of existing collision avoidance methods, the overview of AIS data and the advanced navigation system are presented in chapter 2. The collision detection methods of OZT, ship motion models, and AIS data visualization methods is introduced in chapter 3. In the 4 chapter, AIS data and OZT method are used to screen the data, which is convenient for the study of ferry navigation in the Uraga-Suido Traffic Route. In chapter 5, based on OZT data, the traffic situation at sea is analyzed. The method of delaying ship launching time to avoid collision is simulated.

2. AIS Overview

Due to the need of simulating the real maritime transportation situation, this research uses AIS data as the data source. So, this chapter will introduce the AIS (Automatic identification system).

2.1. AIS

The AIS system was first written into the International Convention for the Safety of Life at Sea (SOLAS) in 2002. It specified the minimum standards for ships of the Contracting States. Moreover, the convention covers a wide range of fields, from shipbuilding to radio communication. Maritime navigation safety is an important part, including the requirement of automatic identification system. The treaty clearly stated that the purpose of the AIS system is to provide ships with corresponding position information and ship-related movement information for ships to coordinate to avoid collision. Up to now, the application of AIS has been widely used, and much maritime-related research conducted based on it.

Following Chapter V of the 1974 Convention on the Safety of Life at Sea (SOLAS74), which came into effect on July 1, 2002, domestic law requires the following specific vessels to be equipped with AIS. (Rule 19).

(1) All vessels of 300 gross tonnage or more engaged in international voyages.

(2) All passenger ships engaged in international voyages.

(3) All vessels of 500 gross tonnage or more that are not engaged in international voyages[14].

Self-organizing time division multiple access (SOTDMA) technology is used for AIS to broadcast and receive information through VHF channels. The convention stipulates that the transmission power of the equipment is 12.5 W and 2 W, which are used for nearshore and ocean communication, respectively.

Its dedicated two VHF radio channels are used for AIS:

- Channel A 161.975 MHz (87B)
- Channel B 162.025 MHz (88B)

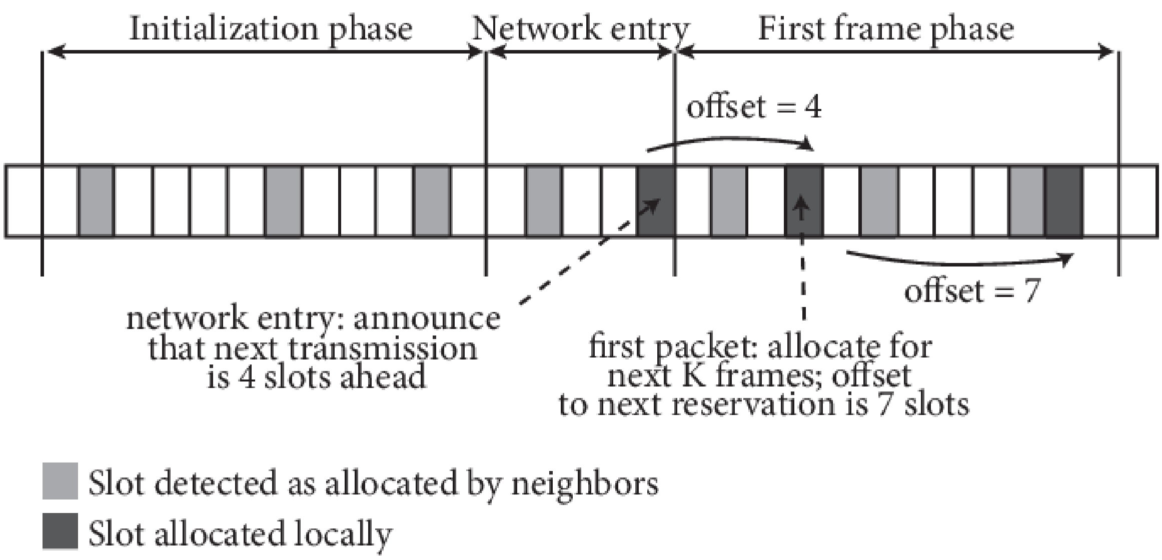
To better meet the needs of different types of AIS equipment, different types of AIS equipment are selected, and the specific AIS equipment categories are as follows:

Table 2-1 AIS data update frequency[15]

Transponder Type	**Vessel's Moving Status (Transponder ON)**	**AIS Transmission Rate**
Class A	Anchored / Moored	Every 3 Minutes
	Sailing 0-14 knots	Every 10 Seconds
	Sailing 14-23 knots	Every 6 Seconds
	Sailing 0-14 knots and changing course	Every 3.33 Seconds
	Sailing 14-23 knots and changing course	Every 2 Seconds
	Sailing faster than 23 knots	Every 2 Seconds
	Sailing faster than 23 knots and changing course	Every 2 Seconds
Class B	Stopped or sailing up to 2 knots	Every 3 Minutes
	Sailing faster than 2 knots	Every 30 Seconds

To satisfy that other ships can obtain the status information of the ship in time, the system uses a variable broadcast cycle to broadcast status information, that is, the broadcast of the ship's status information. The frequency will increase as the ship's speed and heading change. The self-organizing time division multiple access technology is shown in Fig. 2-1.

Fig. 2-1 The self-organizing time division multiple access technology[16]



2.2. Content of ais data

There are 27 different AIS message types containing different types of information. AIS broadcasts voyage related information (including ship position, speed, course, heading, rate of turn, destination, and estimated arrival time) as well as static information (including ship name, ship MMSI ID, message ID, ship type, ship size). Dynamic information such as the positional aspects (current latitude and longitude) is automatically transmitted, depending on the vessels' speed and course. While the vessel is on the move this information is transmitted every 2 to 10 seconds and while a vessel is anchored every 3 minutes.

AIS data comprised of the following three information categories: (Time does not exist in AIS frames. It is added by receivers[17].

1. Static data (information on ship characteristics)
2. Dynamic data (information on ship position and movements)
3. Voyage-related data (information on a current voyage).

Table 2-2 AIS data comprised of 3 information categories

Static	Information on ship characteristics	MMSI; IMO number, call sign; ship name; type; dimensions.
Dynamic	Information on ship movements	Ship's position (longitude, latitude). speed over ground (SOG). course over ground (COG). navigation status.
Voyage related	Information on current voyage	Destination; estimated time of arrival; draught

The terrestrial based AIS station or onboard transceiver could typically cover about 15-20 nautical miles (nm), depending on many factors such as transceiver type/location and weather conditions. In open seas, satellite-based receivers provide an efficient supplement while terrestrial stations are out of range[18].

In the following table, the typical AIS message types are presented.

Table 2-3 Typical AIS message types

Message ID	Name	Description
1	Position report	Scheduled position report; Class A shipborne mobile equipment
2	Position report	Assigned scheduled position report; Class A shipborne mobile equipment
3	Position report	Special position report, response to interrogation; Class A shipborne mobile equipment

4	Base station report	Position, UTC, date, and current slot number of base stations
5	Static and voyage related data	Scheduled static and voyage related vessel data report, Class A shipborne mobile equipment
6	Binary addressed message	Binary data for addressed communication
7	Binary acknowledgement	Acknowledgement of received addressed binary data
8	Binary broadcast message	Binary data for broadcast communication
9	Standard SAR aircraft position report	Position report for airborne stations involved in SAR operations only
10	UTC/date inquiry	Request UTC and date
11	UTC/date response	Current UTC and date if available
12	Addressed safety related message	Safety related data for addressed communication
13	Safety related acknowledgement	Acknowledgement of received addressed safety related message
14	Safety related broadcast message	Safety related data for broadcast communication
15	Interrogation	Request for a specific message type can result in multiple responses from one or several stations
16	Assignment mode command	Assignment of a specific report behavior by competent authority using a Base station
17	DGNSS broadcast binary message	DGNSS corrections provided by a base station
18	Standard Class B equipment position report	Standard position report for Class B shipborne mobile equipment to be used instead of Messages 1, 2, 3
19	Extended Class B equipment position report	No longer required. Extended position report for Class B shipborne mobile equipment; contains additional
		static information
20	Data link management message	Reserve slots for Base station(s)
21	Aids-to-navigation report	Position and status report for aids-to-navigation
22	Channel management	Management of channels and transceiver modes by a Base station
23	Group assignment command	Assignment of a specific report behavior by competent authority using a Base station to a specific group of mobiles
24	Static data report	Additional data assigned to an MMSI Part A: Name Part B: Static Data
25	Single slot binary message	Short unscheduled binary data transmission Broadcast or addressed

26	Multiple slot binary message with Communications State	Scheduled binary data transmission Broadcast or addressed
27	Position report for long range applications	Class A and Class B "SO" shipborne mobile equipment outside base station coverage

3. Obstacle zone by target

The OZT (Obstacle Zone by Target) method[19] is used to determine the degree of danger of the encounter state. OZT is a prediction area which indicate a risk of collision on the heading of the target ship. It is calculated from the ship's AIS data at the current time. As shown in Fig. 3-1, if the OZT of the target ship coincides with the route of this ship, there is the possibility of collision.

By voyages avoiding this restricted area, safe voyages are possible. And even if the behavior of other vessels changes, the location restricted by the behavior of each vessel can be determined immediately, and there is an advantage that it is easy to make an escape plan.

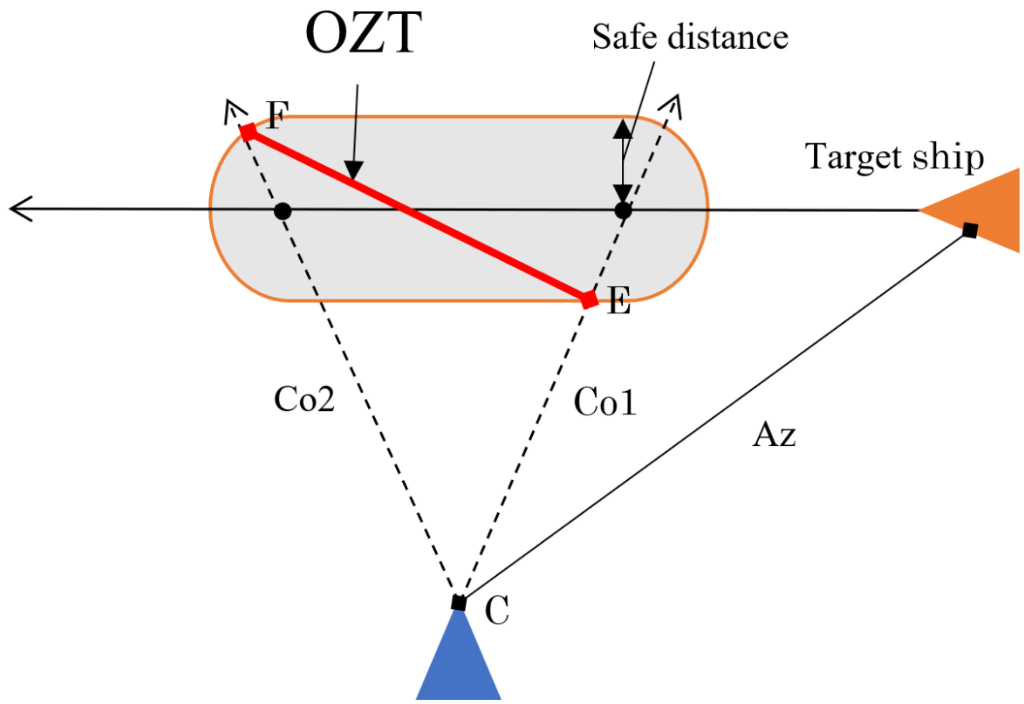


Fig. 3-1 OZT

3.1. The Mercator Projection

To facilitate the observation of the ship's movement in the program, this article uses the Mercator projection method to draw the map[20]. The projection method has the following characteristics:

(1) All longitude lines become parallel lines perpendicular to the equator and equally spaced; latitude lines become straight lines parallel to the equator and perpendicular to the longitude lines.

(2) The length of longitude 1'(1 equator mile) on the map is the same, but the length of latitude 1'(1 nautical mile) gradually increases with the increase of latitude, and the phenomenon of latitude

gradually increases.

(3) The rhumb line is a straight line on the figure.

(4) It has equiangular characteristics, and the azimuth angle of the object measured on the map is equal to the corresponding angle on the ground.

(5) The local scales of the latitude lines of the same latitude on the map are equal, and the local scales of different latitudes increase with the increase of latitude.

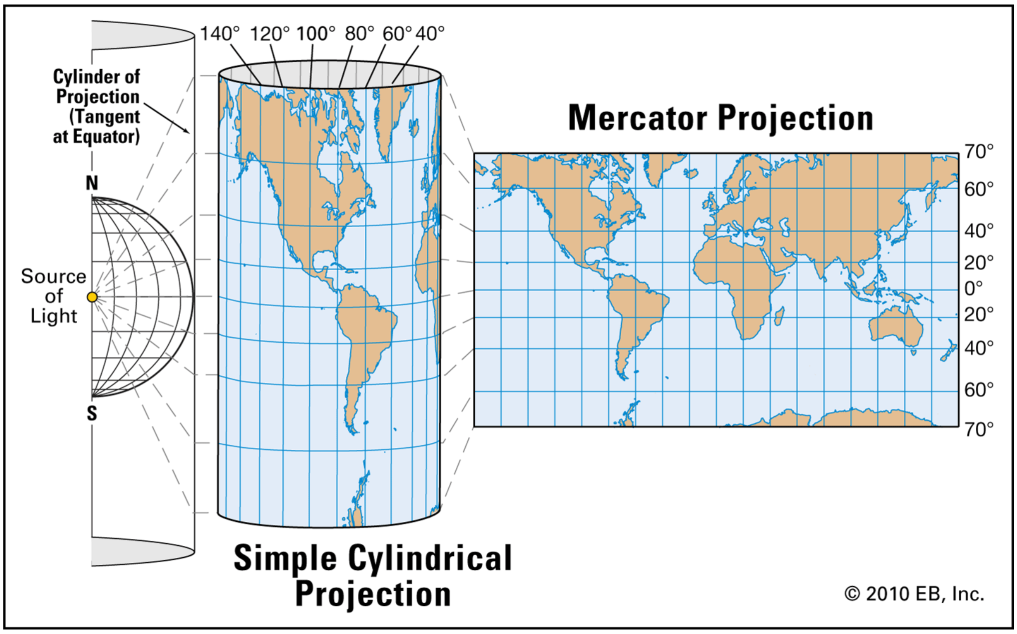


Fig. 3-2 Mercator projection[21]

With the isometric characteristics of the Mercator projection, the Mercator projection is often used for heading determination in a small area map. The AIS data used in this study is based on the geographic coordinate system, it is necessary to convert the coordinate system for calculating the OZT method.

Cylindrical projection with conformal conditions (angles at any point on the earth are correctly represented on the map).

$$\begin{cases} Rm = R(1-e^2)(1-e^2\sin^2 l)^{-\frac{3}{2}} \\ Rp = \mathrm{R}\cos\, l(1-e^2\sin^2 l)^{-\frac{1}{2}} \end{cases} \tag{1}$$

Course on Earth and course on nautical charts must be equal.

$$\tan(Co) = \frac{Rp(dL)}{Rm(dl)} = \frac{\mathrm{R}\cos l(R-e^2\sin^2 l)^{-\frac{1}{2}}dL}{R(1-e^2)(1-e^2\sin^2 l)^{-\frac{3}{2}}dl} = \frac{RdL}{dy} \tag{2}$$

Therefore

$$dy = \frac{R(1-e^2)}{\cos\ l(R-e^2\sin^2\ l)}dl \tag{3}$$

dy Length from the equator to latitude 1 on the nautical chart y

$$y = R\int_0^l \frac{R(1-e^2)}{\cos\ l(R-e^2\sin^2\ l)}dl \tag{4}$$

From the above formula, the basic conversion equation becomes:

$$\begin{cases} x = R(L-L_0) \\ y = R\ln\left[\tan\left(\frac{\pi}{4}+\frac{l}{2}\right)\left(\frac{1-\mathrm{esin}\,l}{1+\mathrm{esin}\,l}\right)^{\frac{e}{2}}\right] \end{cases} \tag{5}$$

The value measured by y with the arc length of 1 arcmin on the equator as the unit is called the gradual latitude Meridional Part (mp).

$$\begin{aligned} mp &= y/(\frac{R\pi}{180\cdot 60}) \\ &= (180\cdot\frac{60}{\pi})\{\ln[\tan(\frac{\pi}{4}+\frac{l}{2})] - \left(\frac{1-e\sin\ l}{1+e\sin\ l}\right)^{\frac{e}{2}}\} \end{aligned} \tag{6}$$

where:

Rm: Geographical latitude 1 meridian radius

Rp: Equal circle radius of distance at geographic latitude 1

e: Eccentricity of conformity ellipse

R: Equatorial radius

L: Longitude

l: Latitude

Calculation of longitude difference and course using gradual latitude. The scale factor is unity on the equator, as it must be since the cylinder is tangential to the ellipsoid at the equator. The ellipsoidal correction of the scale factor increases with latitude, but it is never greater than e^2, a correction of less than 1%. (The value of e^2 is about 0.006 for all reference ellipsoids.) This is much smaller than the scale inaccuracy, except very close to the equator. Only accurate Mercator projections of regions near the equator will necessitate the ellipsoidal corrections.

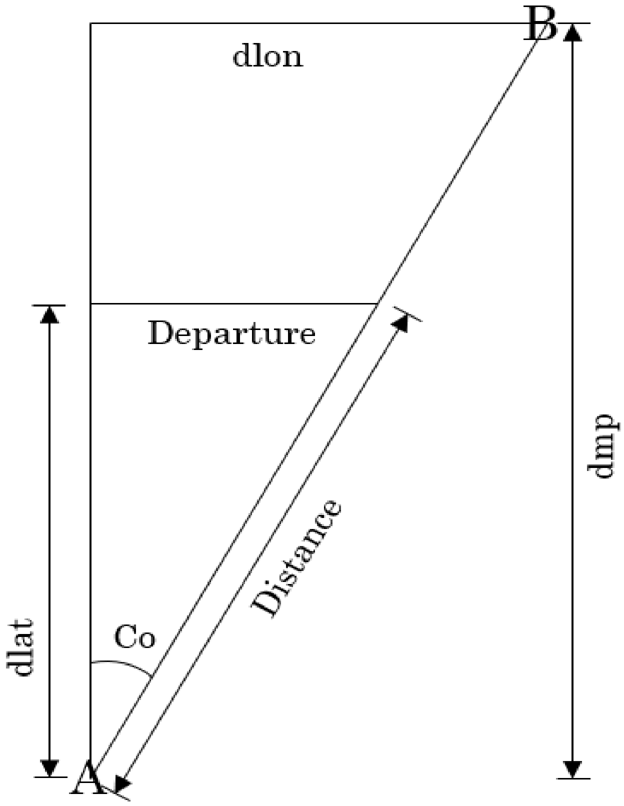


Fig. 3-3 Calculation of distance

Procedure to find the course and distance.

1. Calculate dlat, dmp and dlon. Lat_{target}

$$\mathrm{dmp} = \mathrm{mp}(l) - \mathrm{mp}(l_0) \tag{7}$$

$$\mathrm{dlon} = L - L_0 \tag{8}$$

$$dlat = l - l_0 \tag{9}$$

2. Calculate the course (Co) by using formula: Lat_{own}

$$\mathrm{Co} = \tan^{-1}\left(\frac{\mathrm{dlon}}{\mathrm{dmp}}\right) \tag{10}$$

Because of $-\frac{\pi}{2} < \tan^{-1}\frac{\mathrm{dlon}}{\mathrm{dmp}} < \frac{\pi}{2}$

If Lat_{own} <Lat_{target} and Lon_{own}<Lon_{target}: C_o

If Lat_{own} >Lat_{target} and Lon_{own}<Lon_{target}: $-C_o + \pi$

$$\text{If } Lat_{own} > Lat_{target} \text{ and } Lon_{own} > Lon_{target}\text{: } C_o + \pi$$

$$\text{If } Lat_{own} < Lat_{target} \text{ and } Lon_{own} > Lon_{target}\text{: } -C_o + 2\pi$$

3. Calculate the distance (D) by using formula:

$$\mathrm{D} = \frac{dlat}{\cos(\mathrm{Co})} \tag{11}$$

where:

dmp: Difference of meridional parts

dl: Difference of latitude

dL: Difference of longitude

D: Distance

3.2. Calculation of OZT

The AIS data of latitude, longitude, speed over ground (SOG), and course over ground (COG) were entered to calculate OZT. The distance and angle required for OZT calculation are calculated by the Mercator method (progressive projection).

The OZT calculation in this study uses visual basic. The first step is to use AIS data to provide the position, heading, and ground speed of the own ship and the target ship. The second step is to set the safe navigation distance (SD) of the closest distance to ensure that the ship will not collide with another ship. If the distance between the ship and another ship is less than SD, it can be judged as a collision risk. The third step is to perform calculations based on the data obtained in the first two parts. When predicting the relative movement of the two ships, the area where the closest encounter point is less than the SD is called the OZT.

3.2.1. Definition of safe distance

To obtain the OZT, several steps need to be taken. In the beginning, an expert parameter should be introduced in the calculation process: safety distance (SD). This parameter represents the minimum safe distance between own ship and target ship. At any time, TSs (Target ships) are banned to pass OS (own ship) within the range of minimum of SD .

Since the traffic in Tokyo Bay is very congested, a minimum safe distance 0.07NM[22] is introduced. The length of SD has usually defined the bigger value of 0.07NM or half the sum of the length of the own ship and target ship.

$$SD = \begin{cases} \frac{L_{\mathrm{own}} + L_{\mathrm{target}}}{2} & \mathrm{SD} > 0.07\mathrm{NM} \\ 0.07NM & \mathrm{SD} < 0.07\mathrm{NM} \end{cases} \tag{12}$$

Where L_{own} denotes the length of the own ship, L_{target} denotes the length of the target ship.

3.2.2. Calculation of OZT

The relative motion of the other ship with respect to the own ship was calculated as (6), (10), (11).

As shown in Fig. 3-4, draw a circle from own ship as the center and SD as the radius r. The line segment $\overline{OT}$ connects the center point of the own ship and the target ship, the length is D, and the included angle with the true north direction is $\angle Az$. Then draw two tangent lines passing through the center point of the target ship for the SD circle. The angle between the tangent and $\overline{OT}$ is $\angle\alpha$.

$$\alpha = \sin^{-1}\frac{\mathbf{r}}{d} \tag{12}$$

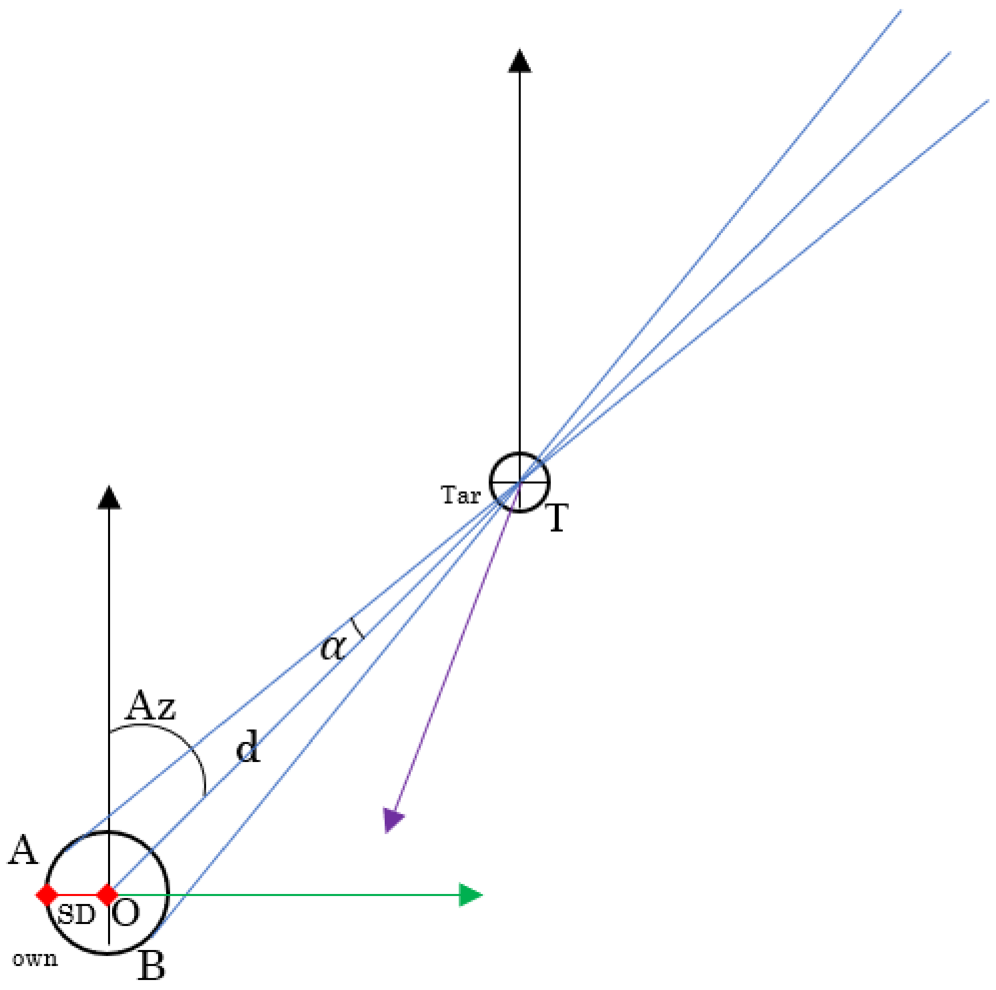


Fig. 3-4 Calculation process of OZT Part 1

As shown in Fig. 3-5, the starting point of the target ship motion vector $\overrightarrow{V_t}$ is the center of the circle, and the circle C is drawn with the speed vector $\overrightarrow{V_o}$ of the own ship as the radius. The intersection of the two tangent lines passing through the center of the target ship and the circle C is M, N.

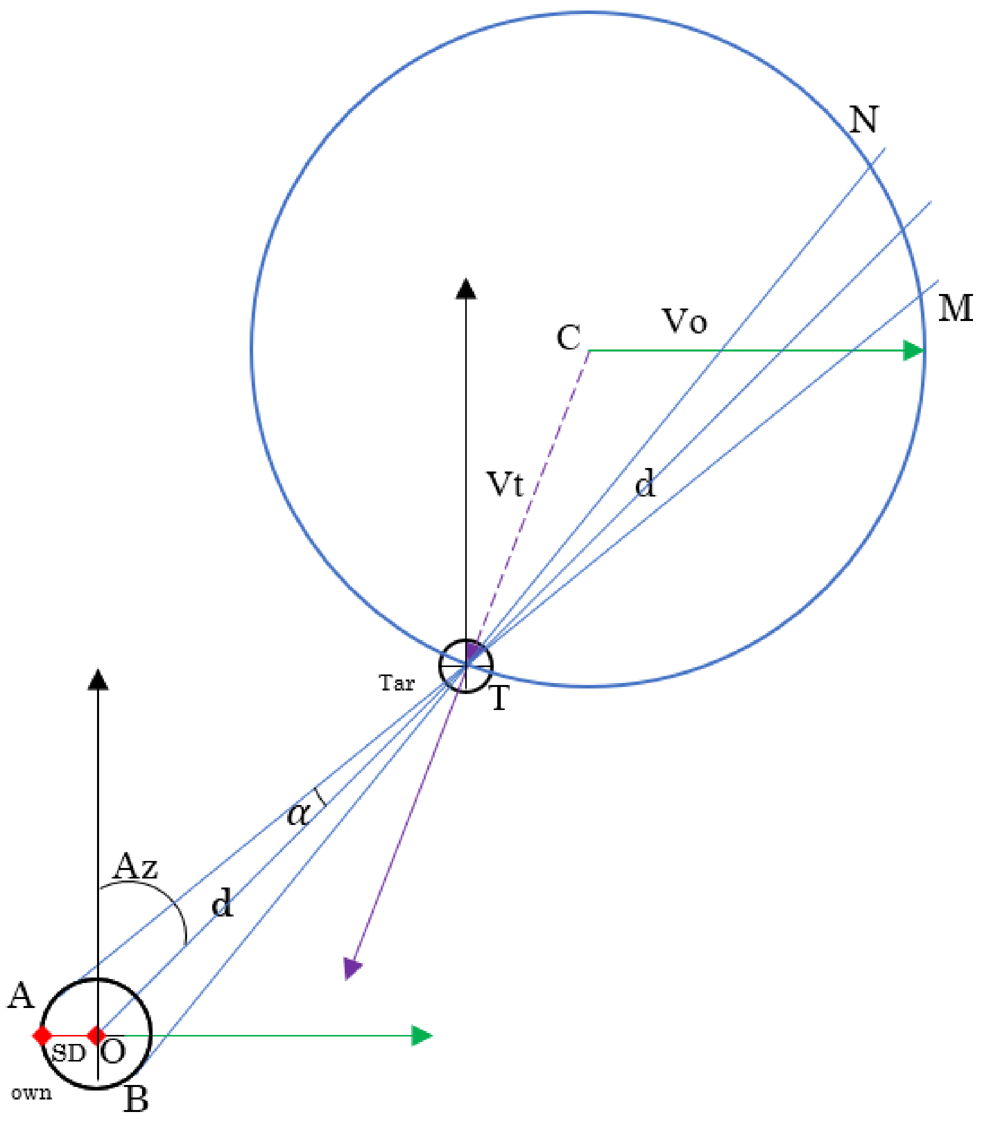


Fig. 3-5 Calculation process of OZT Part 2

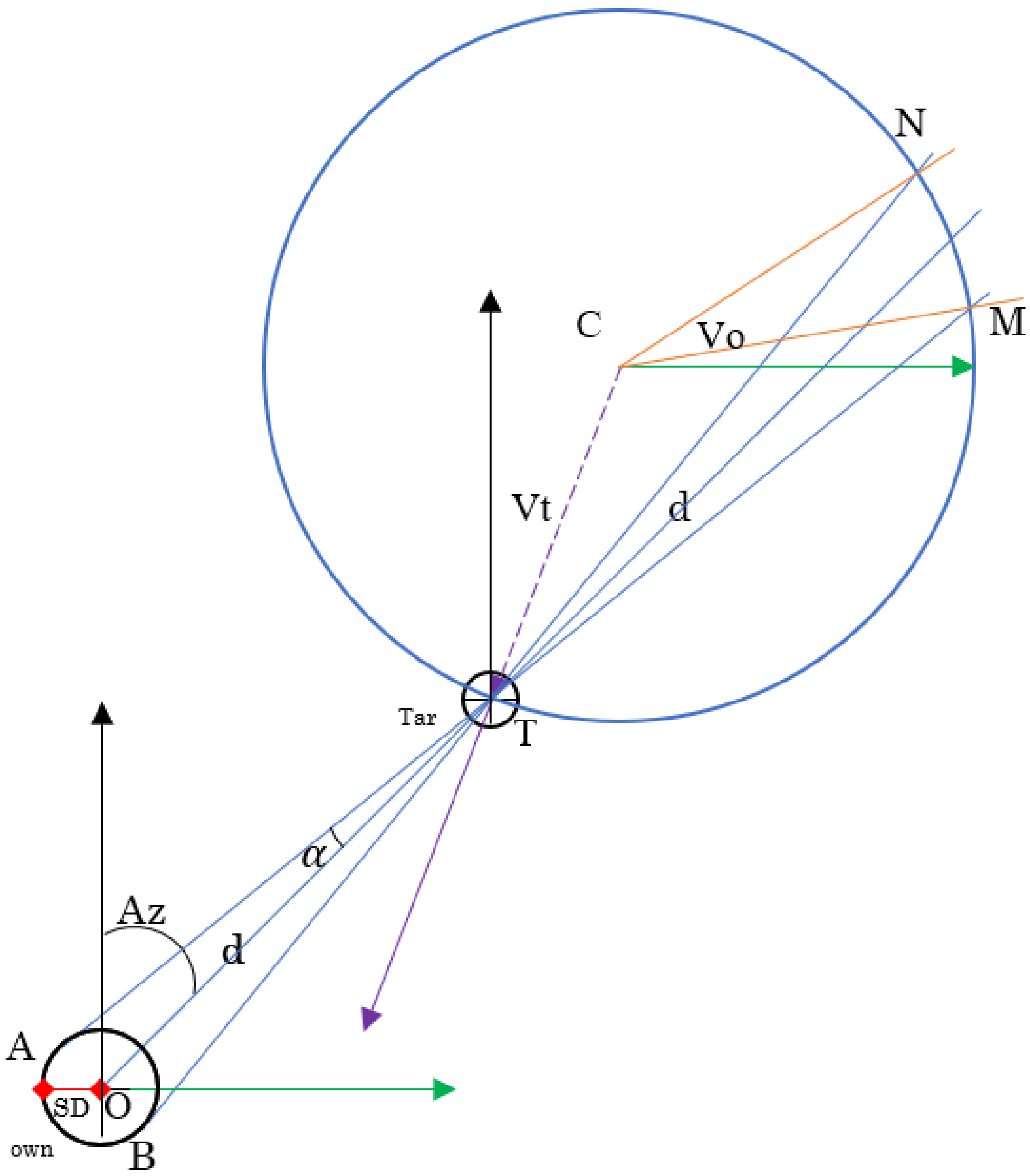


Fig. 3-6 Calculation process of OZT Part 3

Fig. 3-6 shows the course CM and CN for safely passing the nearest route. The angle calculation formula of CM, CN is as follows.

$$\frac{\sin(A_Z \pm \alpha - C_O)}{V_T} = \frac{\sin(C_T - (A_Z \pm \alpha) - \pi)}{V_O} \tag{13}$$

Therefore,

$$c_o = \begin{cases} Az \pm \alpha - \arcsin\left\{\frac{V_T}{V_O}\sin\left(Az \pm \alpha - C_T\right)\right\}(V_T \le V_o) \\ Az \pm \alpha - \pi + \arcsin\left\{\frac{V_T}{V_o}\sin\left(Az \pm \alpha - C_T\right)\right\}(V_T > V_o) \end{cases} \tag{14}$$

There will be up to four solutions for Co. And Co will exist only when the value in the following formula of this expression satisfies the following conditions.

$$\left(\left|\frac{V_T}{V_O}\sin\left(A_z \pm \alpha - C_T\right)\right| \leq 1 \text{ and } 0 \leq C_o \leq 2\pi\right) \tag{15}$$

In addition, even if the obtained Co is TCPA< 0, it will be removed from the solution. The TCPA is calculated by the following formula. First, the X-axis and Y-axis components ΔX and ΔY by each ship are obtained, and the relative motion is calculated from this.

$$\Delta X = V_T \sin\ C_T - V_O \sin\ C_O \tag{16}$$

$$\Delta Y = V_T \cos\ C_T - V_o \cos\ C_o \tag{17}$$

$$V_R = \sqrt{\Delta X^2 + \Delta Y^2} \tag{18}$$

$$C_R = \tan^{-1}\frac{\Delta X}{\Delta Y} \tag{19}$$

The calculation method of DCPA, TCPA is as follows:

$$\mathrm{DCPA} = \mathrm{d}\left|\sin\left(C_R - \mathrm{Az} + 180\right)\right| \tag{20}$$

$$\mathrm{TCPA} = \frac{\mathrm{d}\cos\left(C_R - \mathrm{Az} + 180\right)}{V_R} \tag{21}$$

When $\mathrm{N} = \frac{\mathrm{Vt}}{\mathrm{Vo}} < 1$, that is, the speed of the own ship is greater than the speed of the target ship, Co has two solutions, and when $\mathrm{N} = \frac{\mathrm{Vt}}{\mathrm{Vo}} > 1$, there are three solutions of 0, 2, and 4.

As shown in Fig. 3-7, translate the calculated $\overline{CN}$ and $\overline{CM}$ to the center point O of the own ship, and the intersection point with the target ship's velocity $\overrightarrow{V_t}$ is Q_1, Q_2. When the course of the ship is between $\overline{OQ_1}$ and $\overline{OQ_2}$, this is a dangerous behavior. Going through this range is a dangerous behavior because the closest approach distance will be less than or equal to the safe cruising distance. In other words, this area becomes an area blocked by another ship (0ZT).

1, When the ship is heading to each C_O, the TCPA of each Co is arranged in chronological order.

$$\mathrm{TCPA1} \leq \mathrm{TCPA2} < \mathrm{TCPA3} < \mathrm{TCPA4} \tag{23}$$

2, Then calculate the navigation distance in the corresponding direction according to each TCPA.

$$Q = Vt \times TCPA \tag{24}$$

$$Q1 \le Q2 < Q3 < Q4 \tag{25}$$

3, Finally, take SD as the radius, and draw a circle at the center of the calculated points Q1, Q2, Q3, and Q4, as shown in Fig. 3-7.

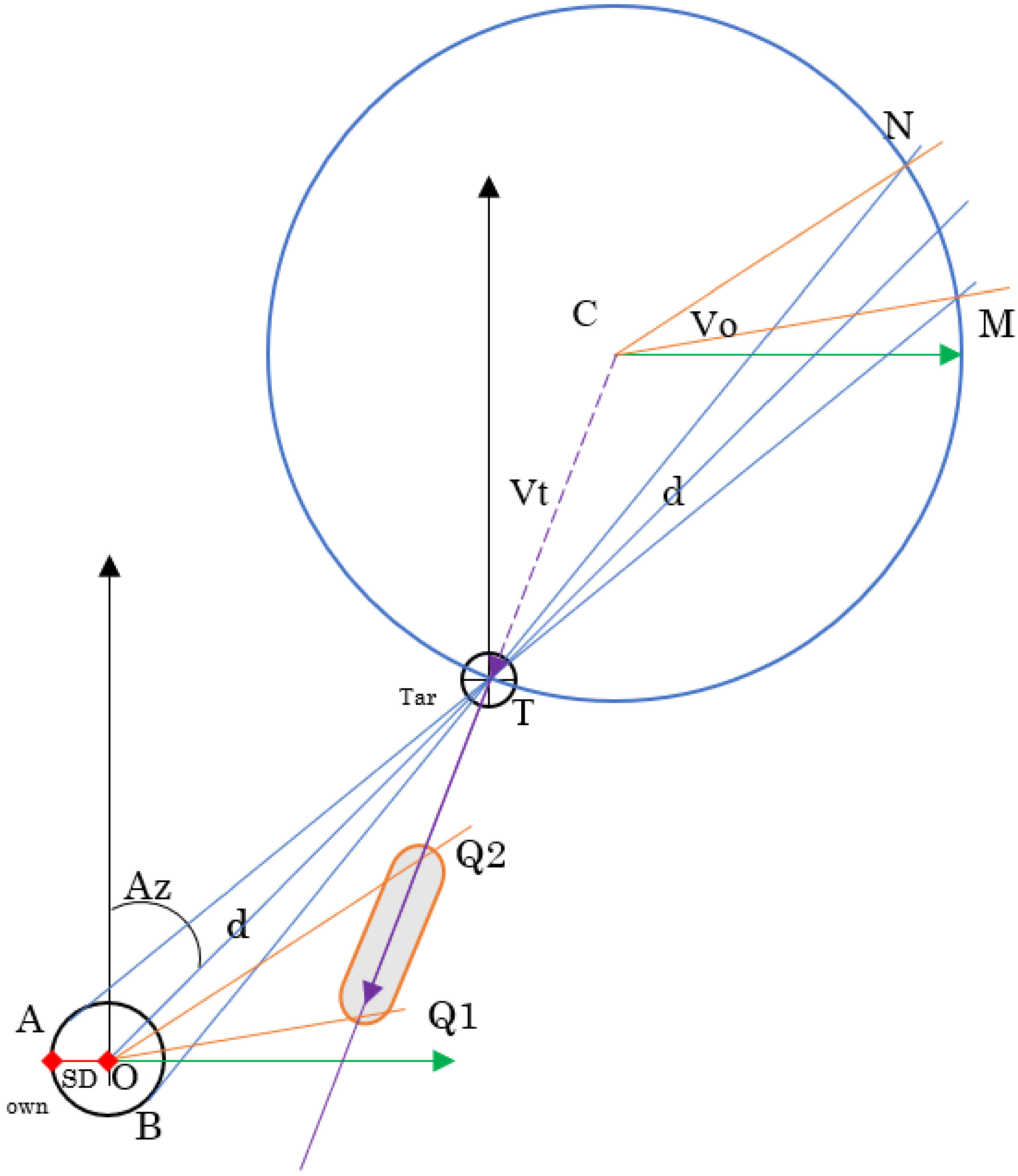


Fig. 3-7 Calculation process of OZT Part 4

4. Data screening and analysis

4.1. Information of Tokyo Bay ferry

The research objects in this study are the ferries going back and forth between Kurihama and Kanaya. Since this route is located on the south side of the Uraga-Suido Traffic Route is a congested area and the traffic situation is complicated. More research is needed to ensure safety. The static data of ferries needed for the calculation of OZT. Table 4-1 shows the ferries' information. The information in these two tables is used as the static information of the ship in the research.

Table 4-1 Tokyo Bay Ferry Information[23]

Name of ferry	Kanayamaru	Shirahamaru
Weight(ton)	3, 580	3, 351
Speed (knot /h)	13	13
Length(m)	79.0	79.1

Departure schedule is shown in the Table 4-2.

Table 4-2 Tokyo Bay Ferry departure schedule[24]

Timetable		
From Kurihama port	No.	From Kanaya port
6:20	1	6:20
7:20	2	7:15
8:20	3	8:15
9:25	4	9:20
10:20	5	10:25
12:10	6	12:00
13:50	7	13:40
15:25	8	15:20
16:20	9	16:30
17:25	10	17:20
18:15	11	18:25
19:15	12	19:30

The total length of the Tokyo Bay ferry route is about 6.2 nautical miles, and it takes about 30 minutes for one-way trip under normal sailing conditions. Fig. 4-1 is the interpretation of Tokyo Bay route, and Fig.4-2 is the picture of Kanayamaru.

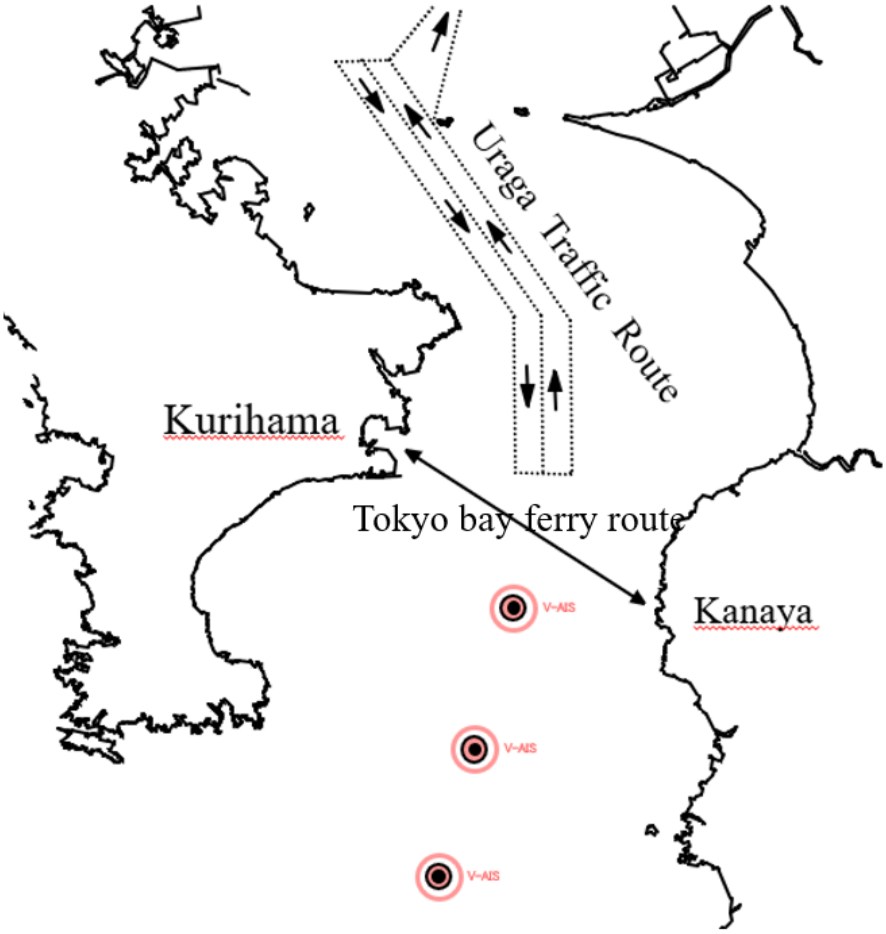


Fig. 4-1 Route of Tokyo Bay ferry

Fig. 4-2 Kanayamaru

4.2. Screening of OZT data

4.2.1. Definition of encounter based on OZT

The area with a radius of 6 nautical miles at 45 degrees to the left and right of the bow of the ferry is defined as the safety detection area. If the OZT of the target ship exists in the safety detection area, it indicates that the ship has collision risk. As shown in Fig. 4-3, target ships A and B will be considered dangerous, while target ships C will not.

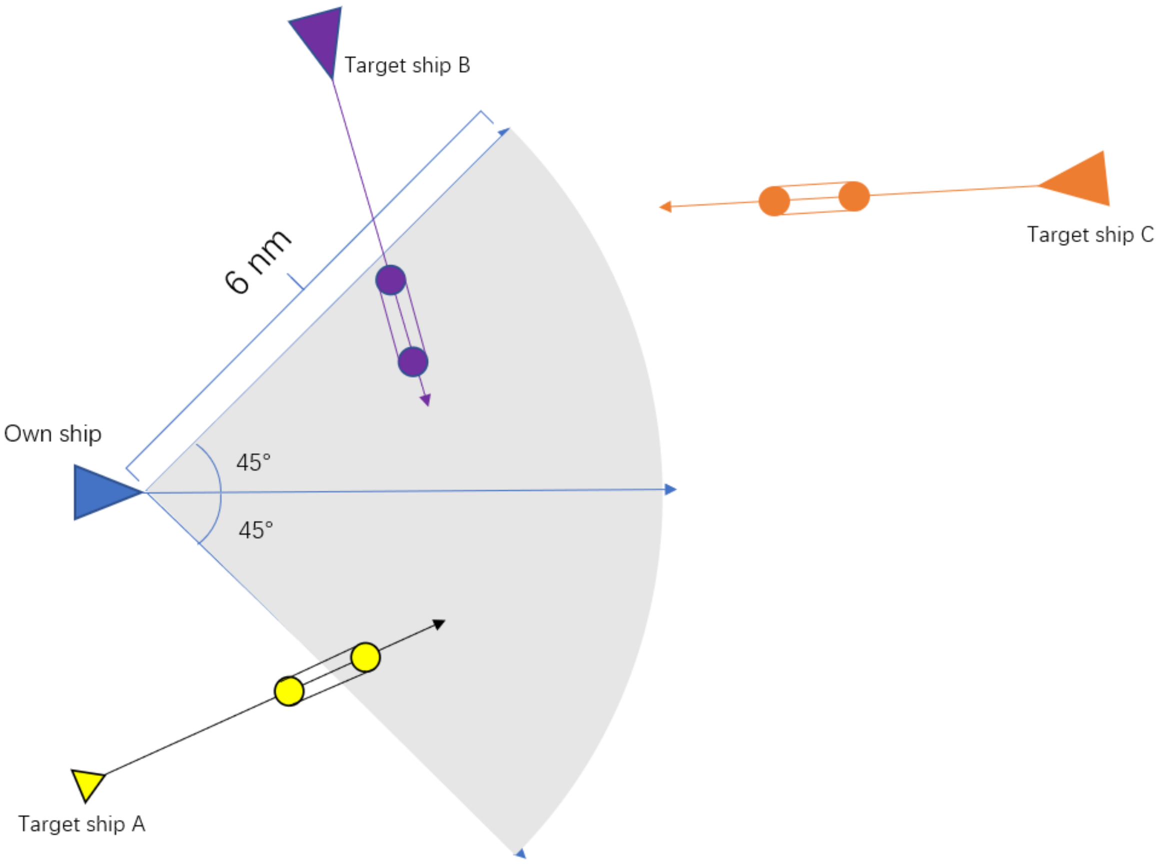


Fig. 4-3 Definition of encounter based on OZT

In order to investigate the actual encounter of the ferry at sea, OZT data of all vessels in Tokyo Bay from January 1,2014 to March 31,2014 were used. This data is based on the shipborne AIS data and obtained by the OZT calculation method in Chapter 3 above. The calculated OZT data will be saved according to the following structure:

Table 4-3 OZT data record structure

Index	Data
N	Information of $OS\ i$ (Including the number of target ships: m)
$N+1$	Information of $TS1$ for $OS\ i$
$N+2$	Information of $TS2$ for $OS\ i$
…	…
$N+m$	Information of TSm for $OS\ i$

Where:

OS represents own ship.

TS represents target ship.

M means: For $OS\ i$, there are m target ships.

The index N row records the data of own ship i. Then the OZT data of first target ship is recorded in row $N+1$, second target ship recorded in row $N+2$. Repeat until $N+m$, all the target ships for $OS\ i$ are recorded.

According to this rule, data can be grouped. Table 4-4 is an example of OZT data group. Column 3 represent the number of target ships. The target ships' data detail is ignored in this picture. Time stamps are not continuous, because of changes in maritime conditions, only data at dangerous times will be recorded.

Table 4-4 OZT data group

Time	mmsi	target	lat	lon	course	spd
2014/1/16 6:23:30	431000238	3	35.17153	139.81567333	310.6	7.6
2014/1/16 6:26:0	431000238	7	35.176115	139.8091	308.4	11.2
2014/1/16 6:27:0	431000238	7	35.17807667	139.80613167	308.1	11.2
2014/1/16 6:28:30	431000238	7	35.18104167	139.801665	308.7	11.3
2014/1/16 6:29:0	431000238	7	35.18202333	139.80019167	308.5	11.2
2014/1/16 6:29:30	431000238	6	35.183015	139.79867	307.2	11.3
2014/1/16 6:30:0	431000238	6	35.183985	139.79717667	309.9	11.2
2014/1/16 6:30:30	431000238	6	35.18503333	139.79576333	312.7	11.1
2014/1/16 6:31:0	431000238	6	35.18607833	139.79440667	311.9	11.2
2014/1/16 6:31:30	431000238	5	35.18709	139.79304833	312.9	11.1
2014/1/16 6:32:0	431000238	5	35.18814167	139.791685	313.3	11.1
2014/1/16 6:32:30	431000238	5	35.18925	139.790275	313.4	11.2
2014/1/16 6:33:0	431000238	3	35.19032167	139.78888667	312.7	11.2
2014/1/16 6:34:30	431000238	3	35.19359333	139.78478167	316.2	11.2
2014/1/16 6:35:0	431000238	2	35.194725	139.783475	316.2	11.2
2014/1/16 6:35:30	431000238	3	35.19586167	139.78218	317.3	11.2

4.2.2. OZT data detail interpretation

The previous section analyzes the data recording order, and then analyzes the details of the data. The recorded data detail of the own ship is different from that of the target ship, The data details are shown in table 4-5 and how the data is used to

Table 4-5 OZT data record structure

	Own ship data detail	**Target ship data detail**
1	Timestamp: time of data.	MMSI of target ship.
2	MMSI of own ship.	Position of target ship (distance, bearing based on OS).
3	Position (latitude, longitude): own ship's position	Course and speed of target ship.
4	Course of own ship	Length of target ship.
5	Speed of own ship	OZT1 position (distance, bearing based on OS)
6	Ship length	OZT2 position (distance, bearing based on OS)
7	Number of target ships.	OZT3 position (distance, bearing based on OS)
8	OZT occupancy angle.	OZT4 position (distance, bearing based on OS)

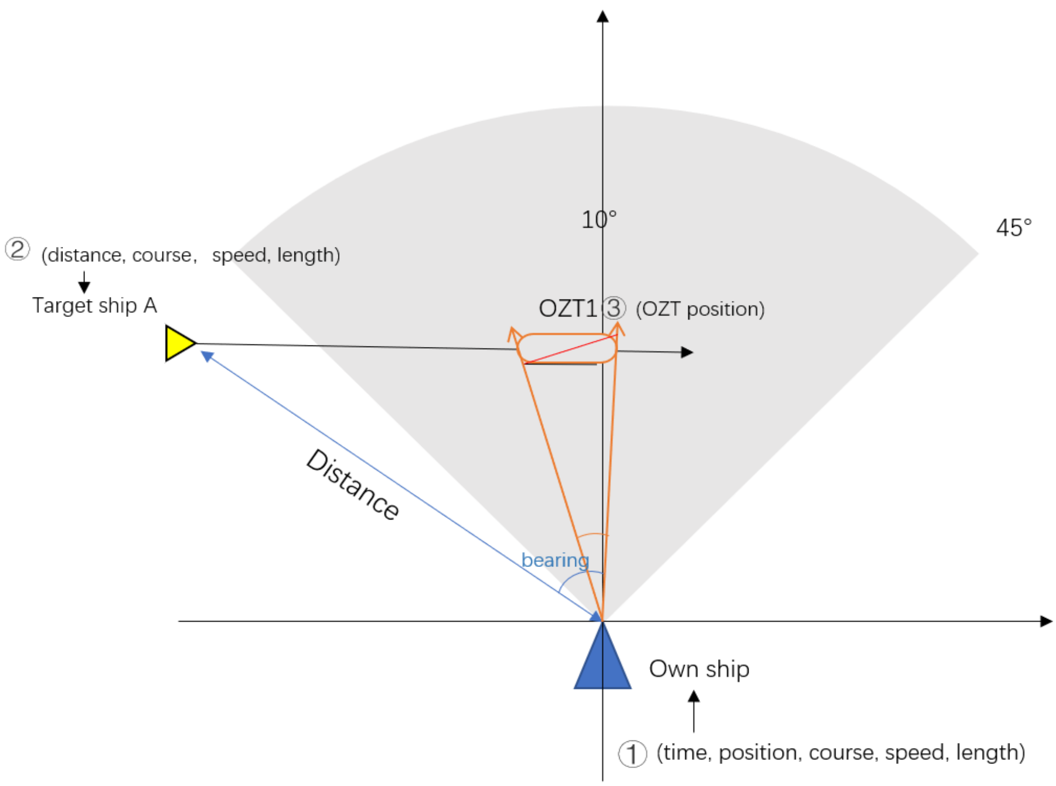


Fig. 4-4 OZT data interpretation

4.3. Analysis of ship encounter data

Due to changes in marine conditions, the number of encounters per day may fluctuate greatly. So, in order to reduce the deviation, three months of data from January 1, 2014, to March 31, 2014 has been used. And then filter out the ferry's information to obtain the following two figures. Fig. 4-5 shows the average encounter times of Kanayamaru from 1st to 31st of three months. The number of encounters per day of KANAYAMARU's is shown in Fig. 4-6. The data of each day is the average value of the same day in three months. Then the average encounters per day for KANAYAMARU and SHIRAHAMARU was 211 and 208, respectively.

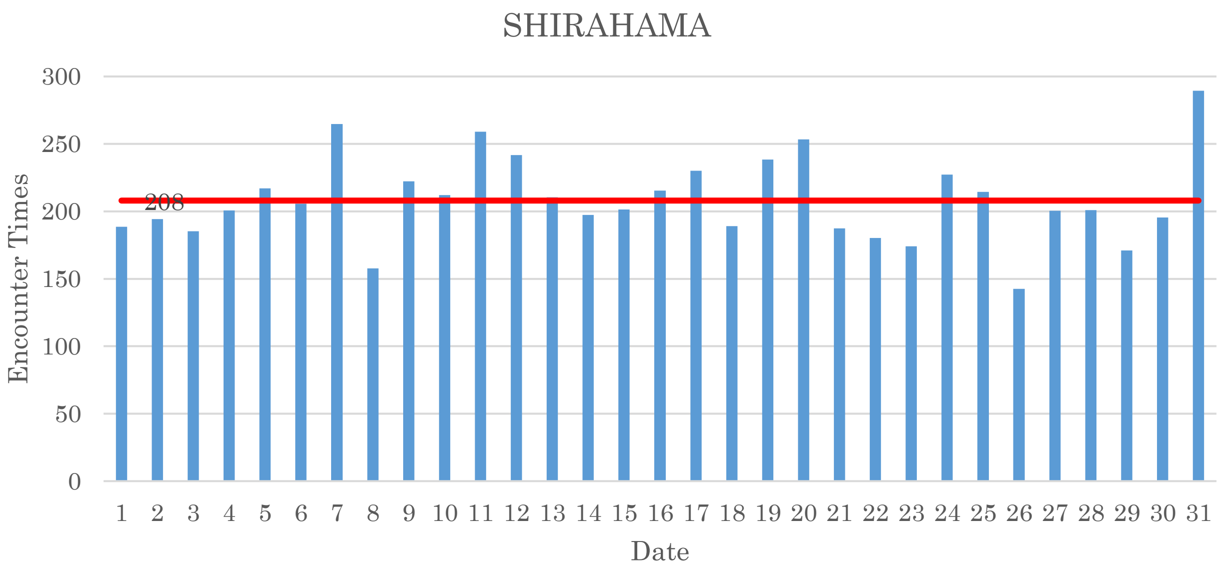


Fig. 4-5 SHIRAHAMARU's average encounters chart of three months

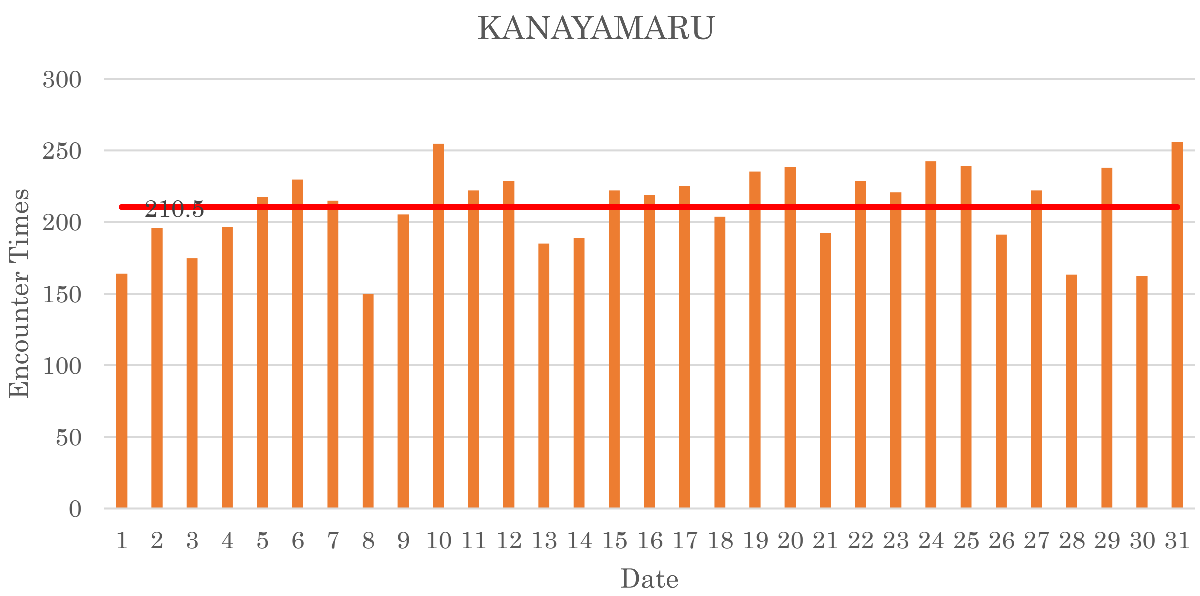


Fig. 4-6 KANAYAMARU's average encounters chart of three months

The following table 4-5 is a statistical table of KANAYAMARU encounters between January 16, 2014. The horizontal columns are timestamp, MMSI, target number, latitude, longitude, heading and speed. And the vertical arrangement is in the chronological order of the day The vertical arrangement is in the chronological order of the day. The total number of encounters on that day was 227.

Table 4-5 SHIRAHAMARU's Encounters chat

	Time	mmsi	target	lat	lon	course	spd
	2014/1/16 6:23:30	431000238	3	35.17153	139.81567333	310.6	7.6
	2014/1/16 6:26:0	431000238	7	35.176115	139.8091	308.4	11.2
	2014/1/16 6:27:0	431000238	7	35.17807667	139.80613167	308.1	11.2
	2014/1/16 6:28:30	431000238	7	35.18104167	139.801665	308.7	11.3
	2014/1/16 6:29:0	431000238	7	35.18202333	139.80019167	308.5	11.2
	2014/1/16 6:29:30	431000238	6	35.183015	139.79867	307.2	11.3
	2014/1/16 6:30:0	431000238	6	35.183985	139.79717667	309.9	11.2
	2014/1/16 6:30:30	431000238	6	35.18503333	139.79576333	312.7	11.1
	2014/1/16 6:31:0	431000238	6	35.18607833	139.79440667	311.9	11.2
	2014/1/16 6:31:30	431000238	5	35.18709	139.79304833	312.9	11.1
	2014/1/16 6:32:0	431000238	5	35.18814167	139.791685	313.3	11.1
	2014/1/16 6:32:30	431000238	5	35.18925	139.790275	313.4	11.2
	2014/1/16 6:33:0	431000238	3	35.19032167	139.78888667	312.7	11.2
	2014/1/16 6:34:30	431000238	3	35.19359333	139.78478167	316.2	11.2
	2014/1/16 6:35:0	431000238	2	35.194725	139.783475	316.2	11.2
	2014/1/16 6:35:30	431000238	3	35.19586167	139.78218	317.3	11.2

5. Collision avoidance algorithm and simulation

5.1. Collision avoidance algorithm

Based on the OZT data and maritime safety traffic law, a method to analysis OZT at the departure time to avoid collision is proposed and simulate in this study. The safety detection area is introduced in Chapter 4. In this chapter, the safety detection area of the ship is divided into 6 areas, namely I, II, III, IV, V and VI. The angular spacing of areas I, II, III, IV, V is 10 degrees. Starting from - 5 degrees directly ahead of the bow, 10 degrees is the interval for division. The divided image is shown in Fig. 5-1.

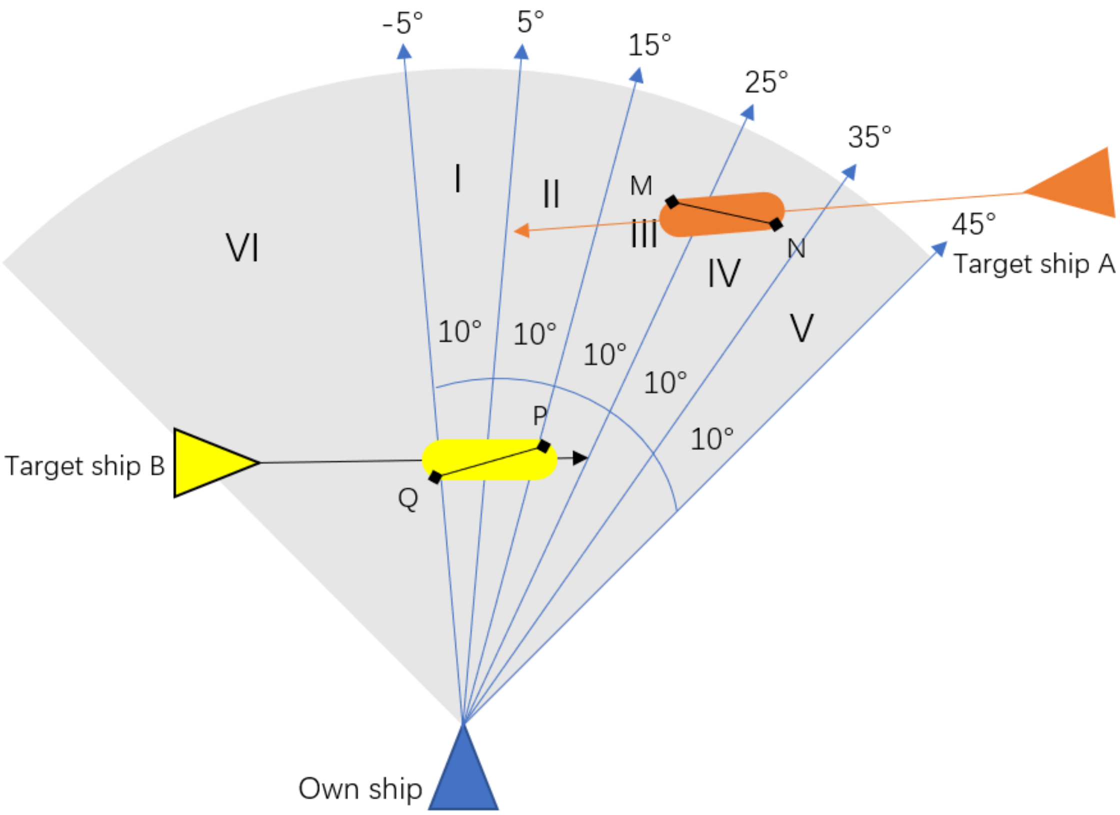


Fig. 5-1 Divided area of safety detection area

In the Fig. 5-1, there are two OZT exist in the safety detection area of the ship, belonging to target ship A and target ship B. The OZT of target ship A exists in III and IV, while the OZT of ship B exists in intervals I，II, III and VI. Each OZT is simplified to facilitate the program to identify the location of OZT. Then two feature points can be obtained for each OZT. Table 5-1 and Table 5-2 show the occupied angle of OZT of target ship A and OZT of target ship B.

For target ship A, point M exists in region III and point N exists in region IV. Therefore, the OZT of ship A occupies areas III and IV. Angle interval I is the closest route.

Table 5-1 OZT occupied area of target ship A

	I	II	III	IV	V	VI
Point M	0	0	1	0	0	0
Point N	0	0	0	1	0	0
OZT A	0	0	1	1	0	0

Point P and Q exist in area III and VI. OZT of target ship B occupied I，II，III and VI. The closest safe route is IV consequently.

Table 5-2 OZT occupied area of target ship B

	I	II	III	IV	V	VI
Point P	0	0	1	0	0	0
Point Q	0	0	0	0	0	1
OZT B	1	1	1	0	0	1

Next, a departure analysis algorithm based on the above division method is proposed. the departure collision avoidance algorithm is shown in Fig. 5-2. Six areas on the way are assigned different priorities based on marine traffic rule. The highest priority is area I, followed by area II. The higher the number, the lower the priority. Therefore, start from the area with the highest priority and detect whether OZT exists in the area in order. If it does not exist, the heading interval of the current area is the recommended heading interval. If OZT exists in the current interval, search the next area according to priority. Continue to repeat this step until V.

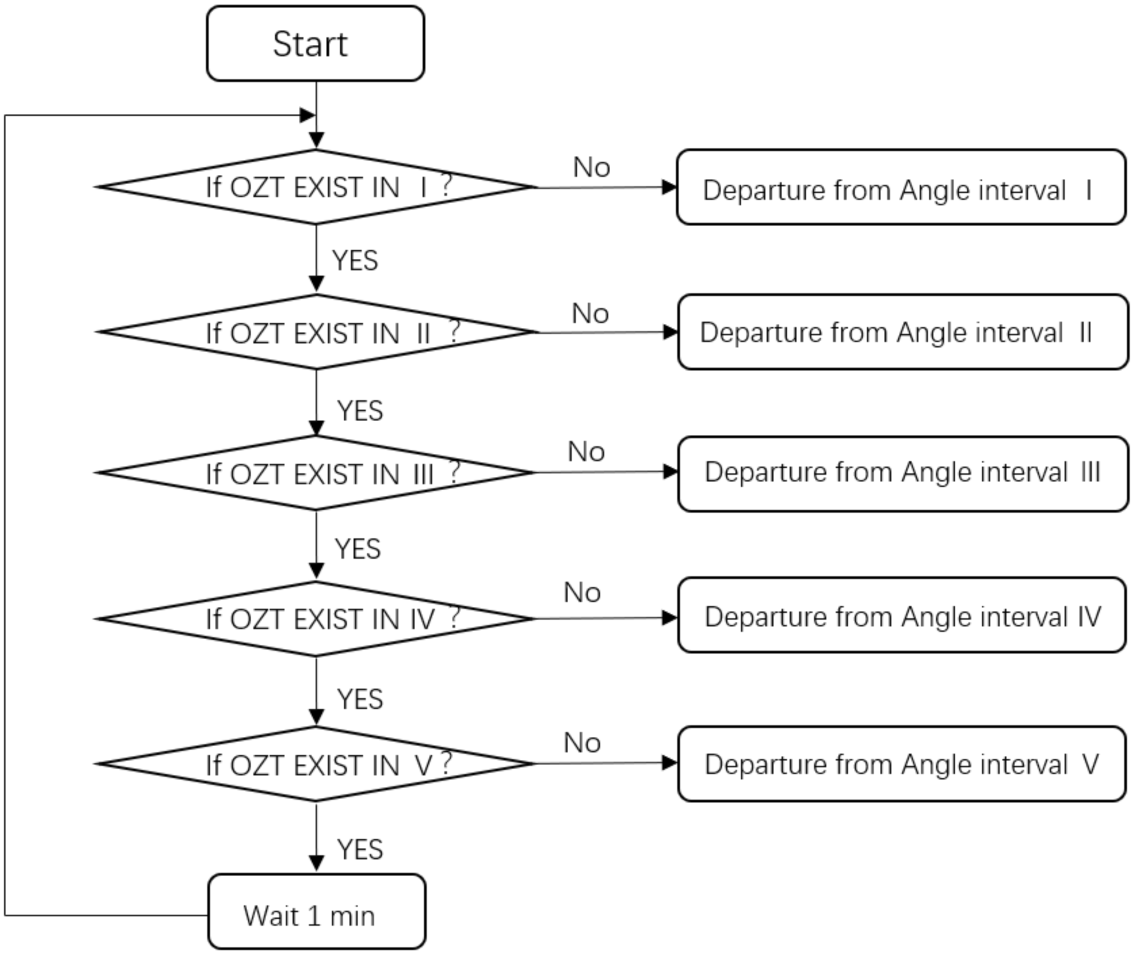


Fig. 5-2 Collision avoidance algorithm at departure

Under normal circumstances, it is not recommended for ships to turn left to avoid collisions. Therefore, area VI is omitted in the algorithm. When the OZT exists in all heading intervals of I, II, III, IV, and V, the ferry is recommended to be delayed departure by one minute to ensure the safety of the ship. This situation usually occurs in the case of traffic route congestion.

5.2. Simulation result

Based on the OZT data and algorithm, the programming simulation is carried out with VB. The position information of OZT is known as a parameter to calculate the azimuth with the ferry. When the azimuth angle is existing in the detection area of algorithm, the program will return safe route.

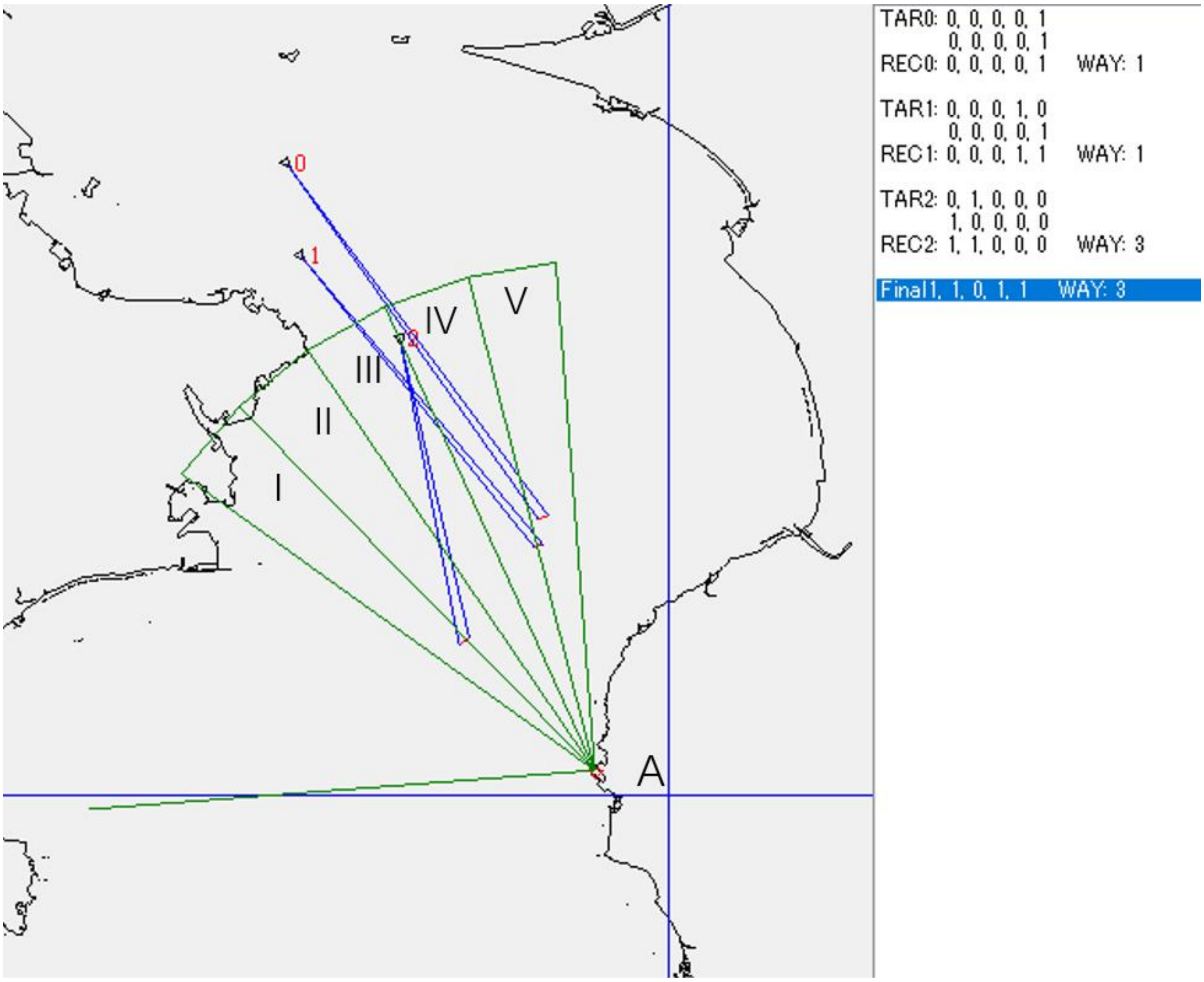


Fig. 5-3 Collision avoidance algorithm at departure

As shown in the Fig. 5-3, ship A is Kanayamaru which is departing from the Kanaya port. The area framed by the green line represents the safety detection area. Starting from the bow of the ferry - 5 degrees, an angle is divided every 10 degrees, with a total of 5 heading intervals. There are three target ships, and they are labeled as 0, 1 and 2 respectively. The OZT of ship 0 exists in area V. The OZT of ship 1 exists in areas IV and V. The OZT of ship 2 exists in areas I, and II. The upper right corner is the running answer of the program.

The following table 5-3 will give an example of the answer of the program: TAR0 means target ship 0 and it has two OZT points. REC0 means the answer of program for target 0. In the answer, the heading interval I is suggested. The last row of answer gives the final recommendation:

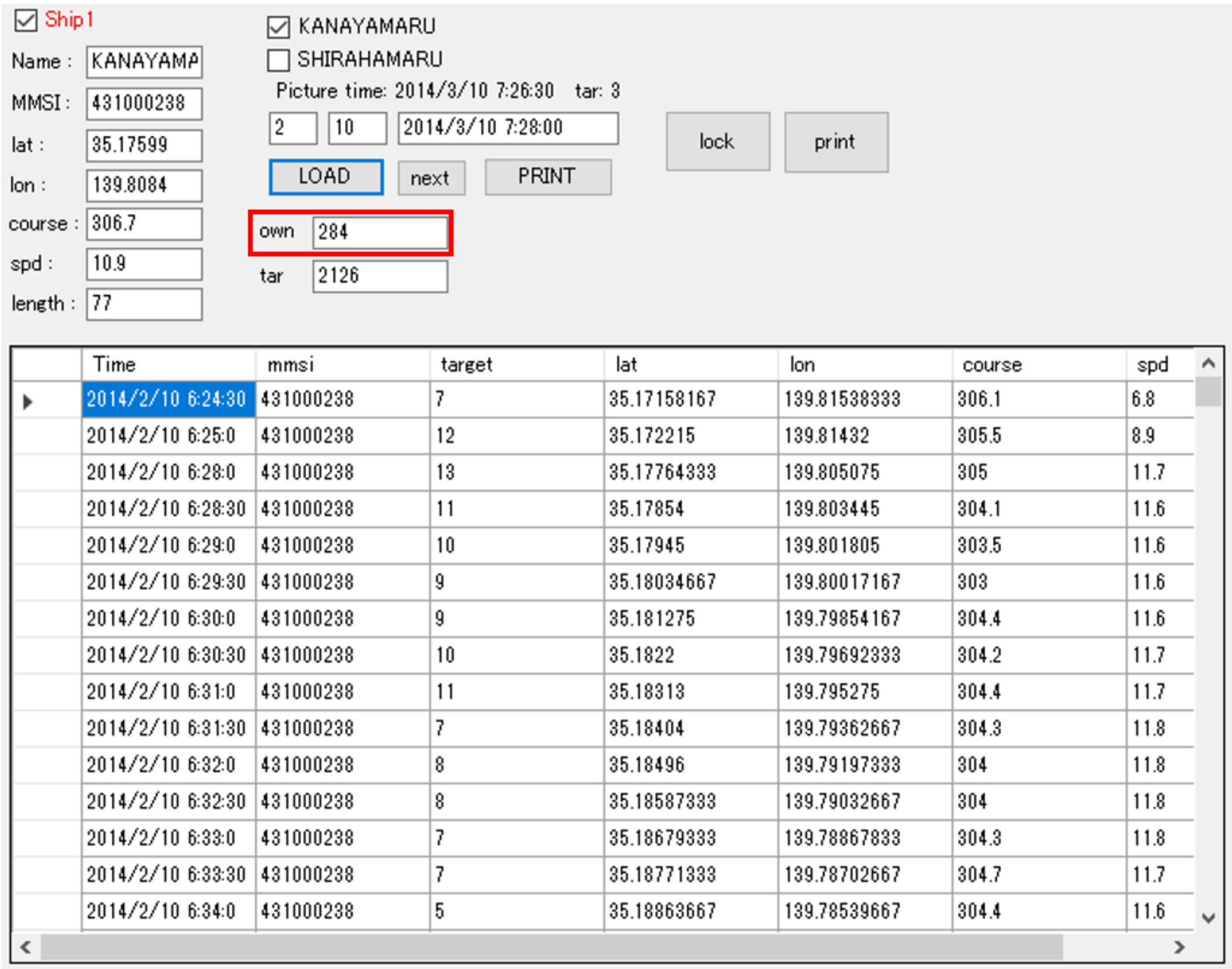
heading III.

Table 5-3 OZT occupied area by target 0

TAR0	I	II	III	IV	V
OZTpoint1	0	0	0	0	1
OZTpoint2	0	0	0	0	1
Ans	0	0	0	0	1

The number of encounters on February 10 was the most. Therefore, the day with the most encounters times will be selected as the verification data source in this study. From the table 5-4, textbox own means there are 284 encounters for Kanayamaru on February 10, 2014.

Table 5-4 2014/2/10 OZT data overview



	Time	mmsi	target	lat	lon	course	spd
▸	2014/2/10 6:24:30	431000238	7	35.17158167	139.81538333	306.1	6.8
	2014/2/10 6:25:0	431000238	12	35.172215	139.81432	305.5	8.9
	2014/2/10 6:28:0	431000238	13	35.17764333	139.805075	305	11.7
	2014/2/10 6:28:30	431000238	11	35.17854	139.803445	304.1	11.6
	2014/2/10 6:29:0	431000238	10	35.17945	139.801805	303.5	11.6
	2014/2/10 6:29:30	431000238	9	35.18034667	139.80017167	303	11.6
	2014/2/10 6:30:0	431000238	9	35.181275	139.79854167	304.4	11.6
	2014/2/10 6:30:30	431000238	10	35.1822	139.79692333	304.2	11.7
	2014/2/10 6:31:0	431000238	11	35.18313	139.795275	304.4	11.7
	2014/2/10 6:31:30	431000238	7	35.18404	139.79362667	304.3	11.8
	2014/2/10 6:32:0	431000238	8	35.18496	139.79197333	304	11.8
	2014/2/10 6:32:30	431000238	8	35.18587333	139.79032667	304	11.8
	2014/2/10 6:33:0	431000238	7	35.18679333	139.78867833	304.3	11.8
	2014/2/10 6:33:30	431000238	7	35.18771333	139.78702667	304.7	11.7
	2014/2/10 6:34:0	431000238	5	35.18863667	139.78539667	304.4	11.6

There were 14 round trips on March 10th. From Fig. 5-4 to Fig. 5-10 show the examples of encounter of kanayamaru at each departure on February 10, 2014.

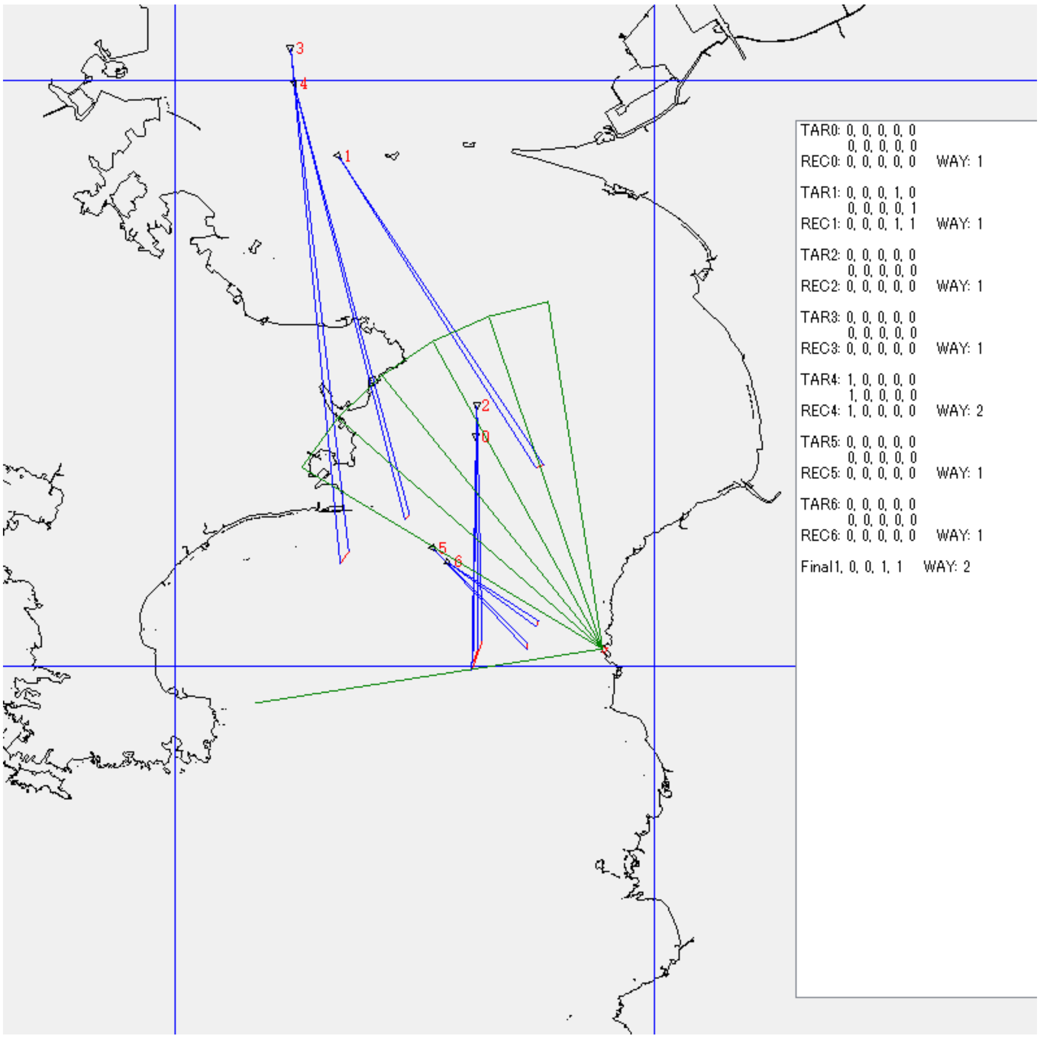


Fig. 5-4 2014/2/10 6:24:30 Kanayamaru's first departure

There are 7 target ships in Fig. 5-4, and the final answer is 1, 0, 0, 1, 1. According to the algorithm, heading II is the best departure course.

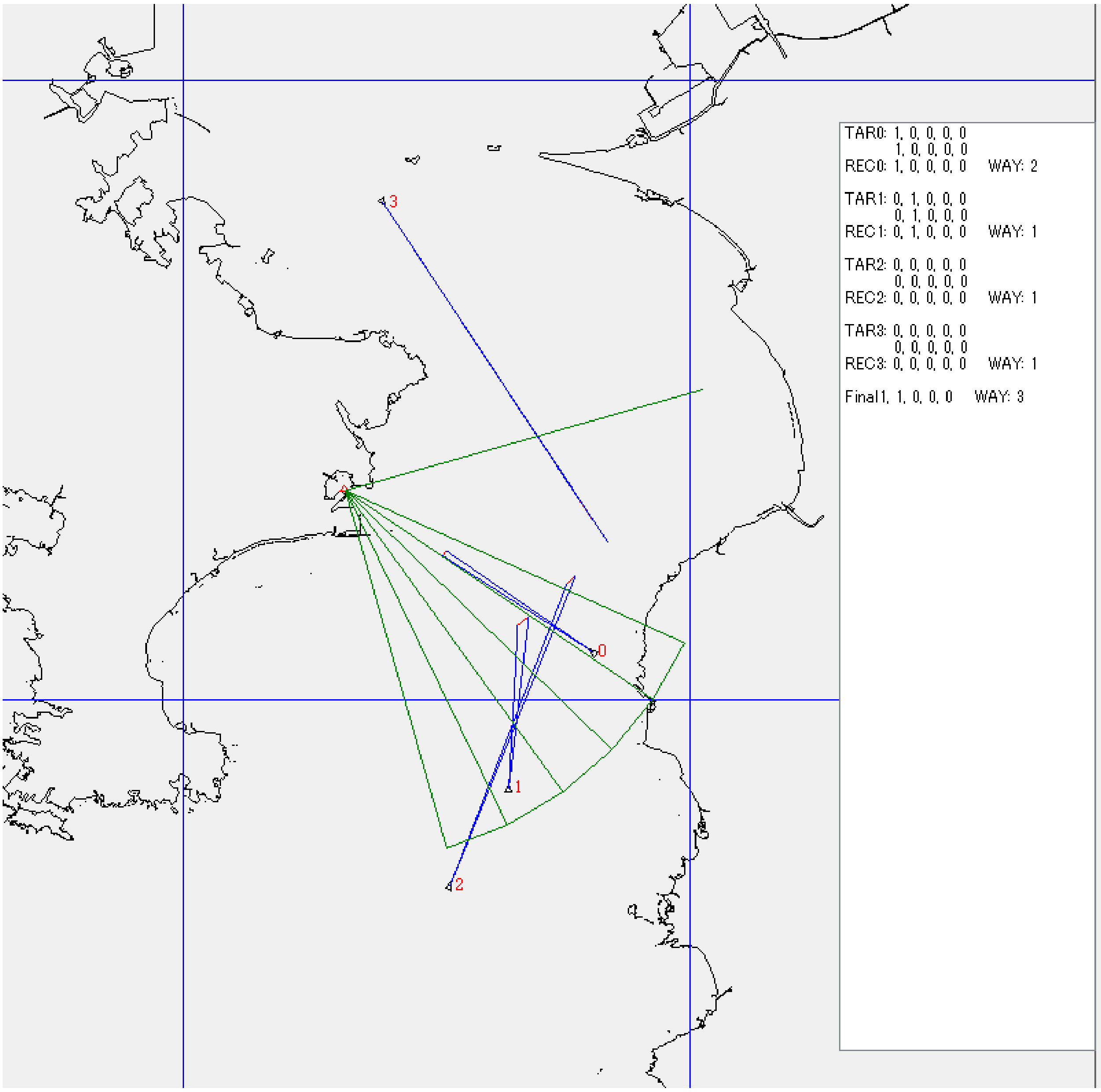


Fig. 5-5 2014/2/10 7:28:30 Kanayamaru's second departure

There are 4 target ships in Fig. 5-5, and the final answer is 1, 1, 0, 0, 0. According to the algorithm, heading III is the best departure course.

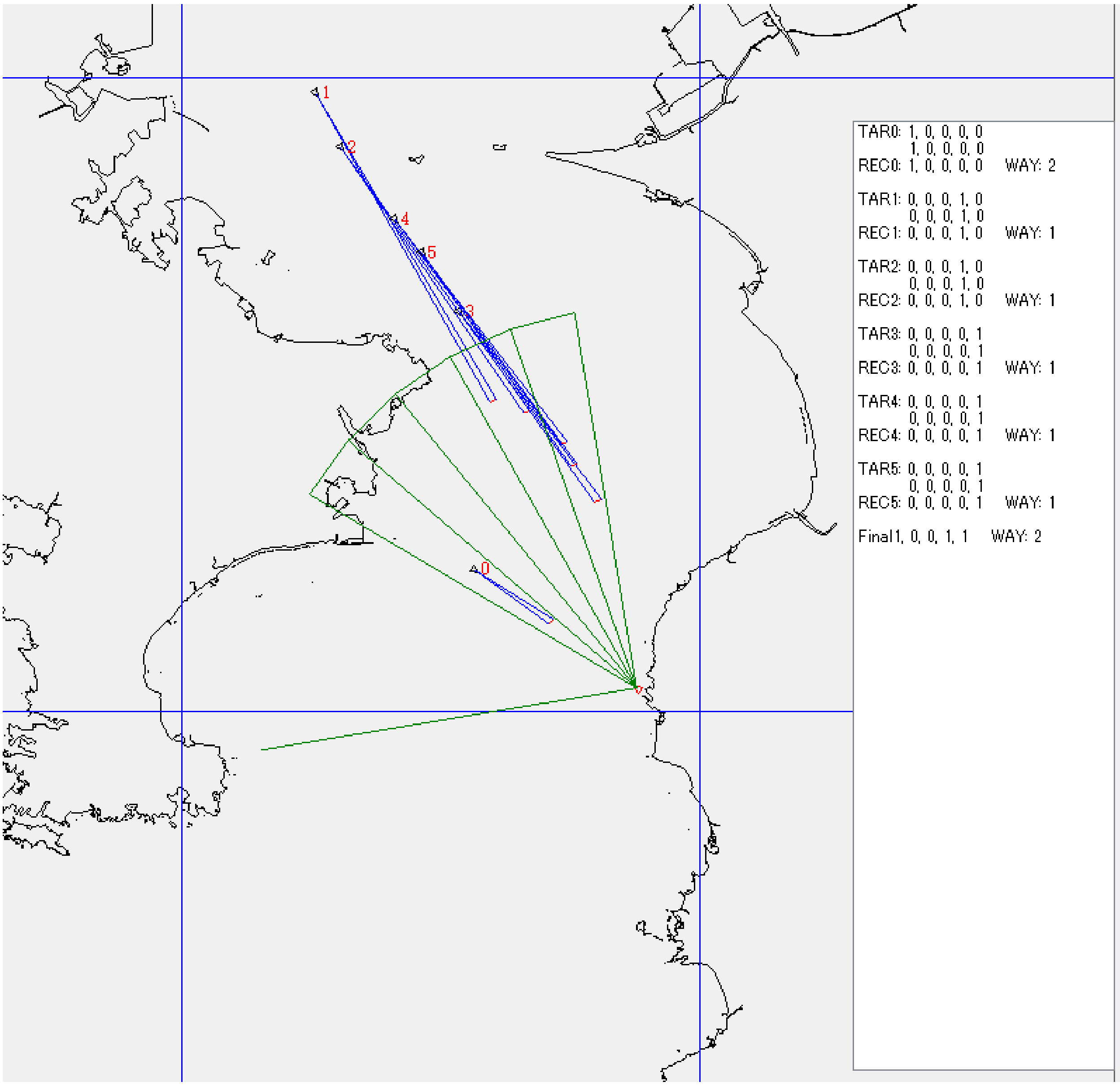


Fig. 5-6 2014/2/10 8:27:00 Kanayamaru's third departure

There are 6 target ships in Fig. 5-6, and the final answer is 1, 0, 0, 1, 1. According to the algorithm, heading II is the best departure course.

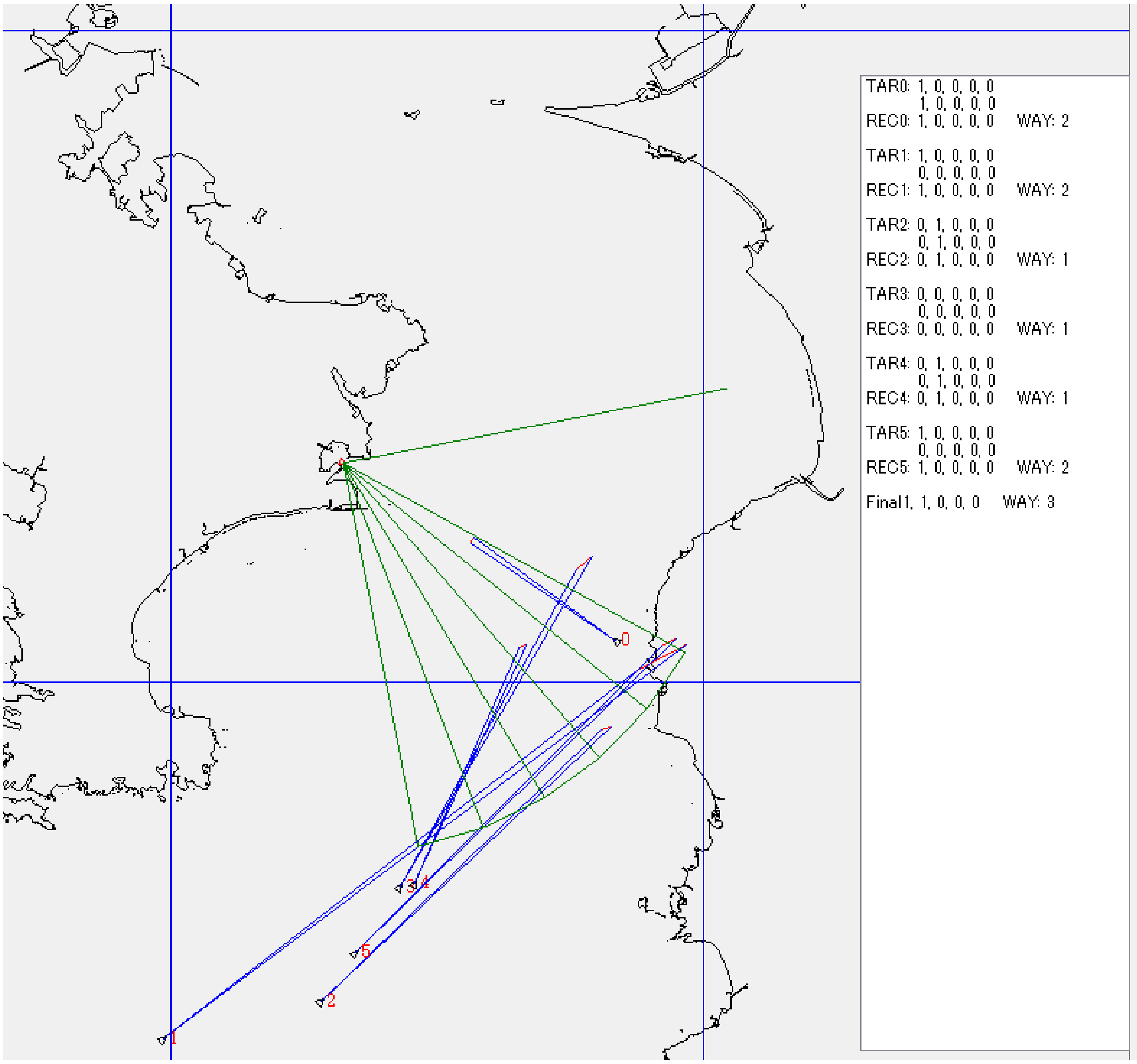


Fig. 5-7 2014/2/10 9:27:00 Kanayamaru's fourth departure

There are 6 target ships in Fig. 5-7, and the final answer is 1, 1, 0, 0, 0. According to the algorithm, heading III is the best departure course.

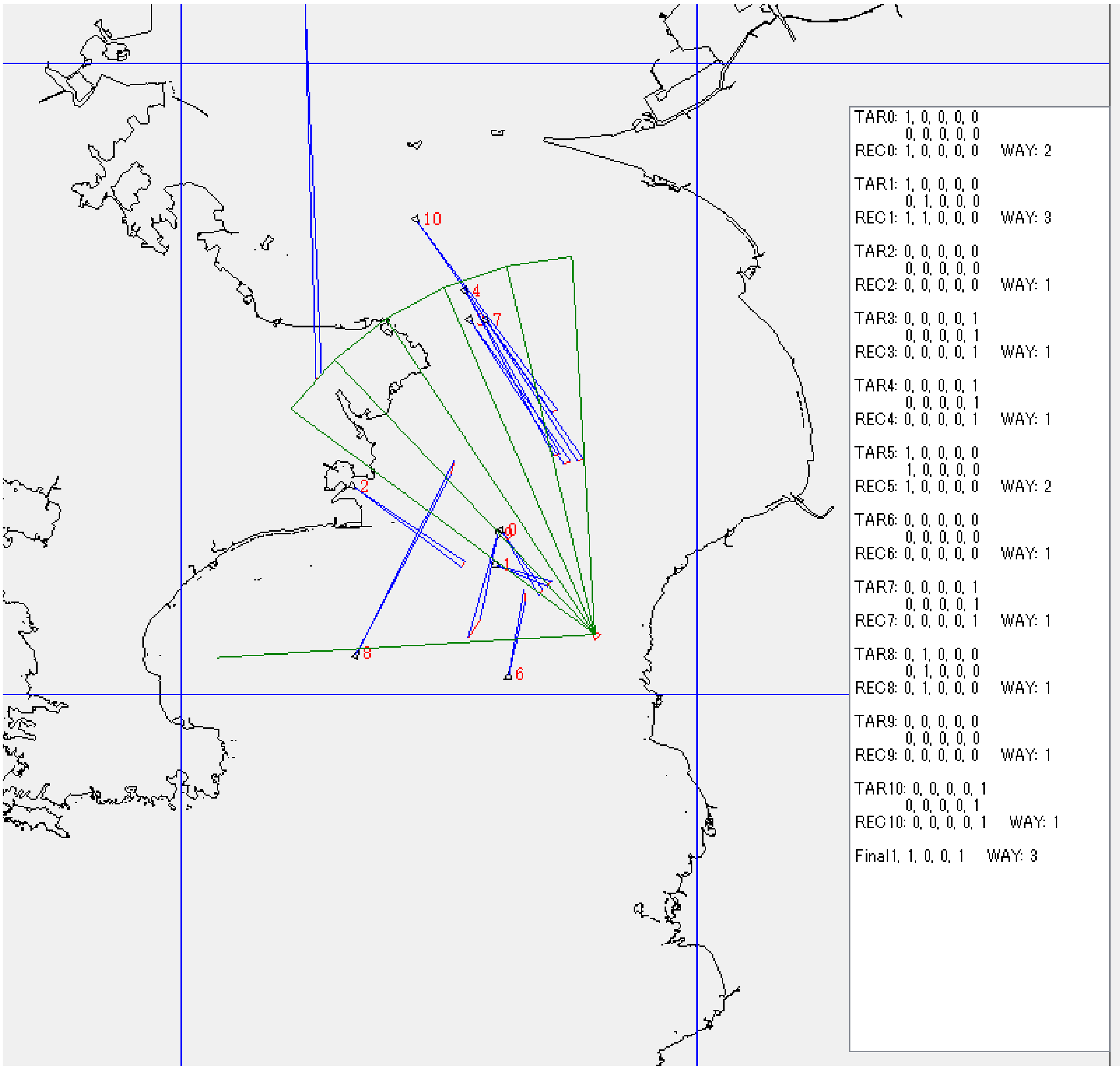


Fig. 5-8 2014/2/10 10:28:30 Kanayamaru's fifth departure

There are 11 target ships in Fig. 5-8, and the final answer is 1, 1, 0, 0, 1. According to the algorithm, heading III is the best departure course.

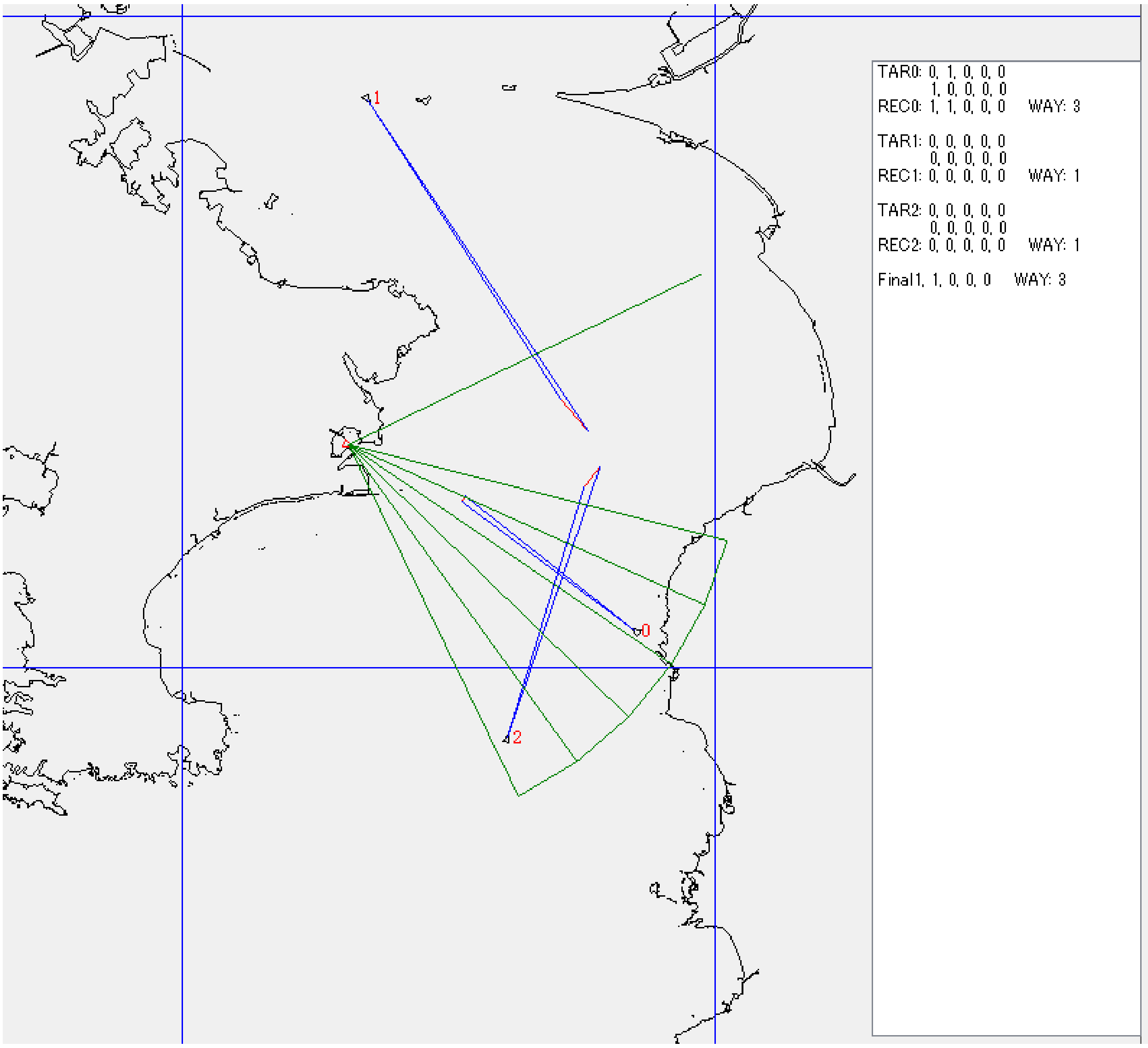


Fig. 5-9 2014/2/10 11:27:30 Kanayamaru's 6th departure

There are 3 target ships in Fig. 5-9, and the final answer is 1, 1, 0, 0, 0. According to the algorithm, heading III is the best departure course.

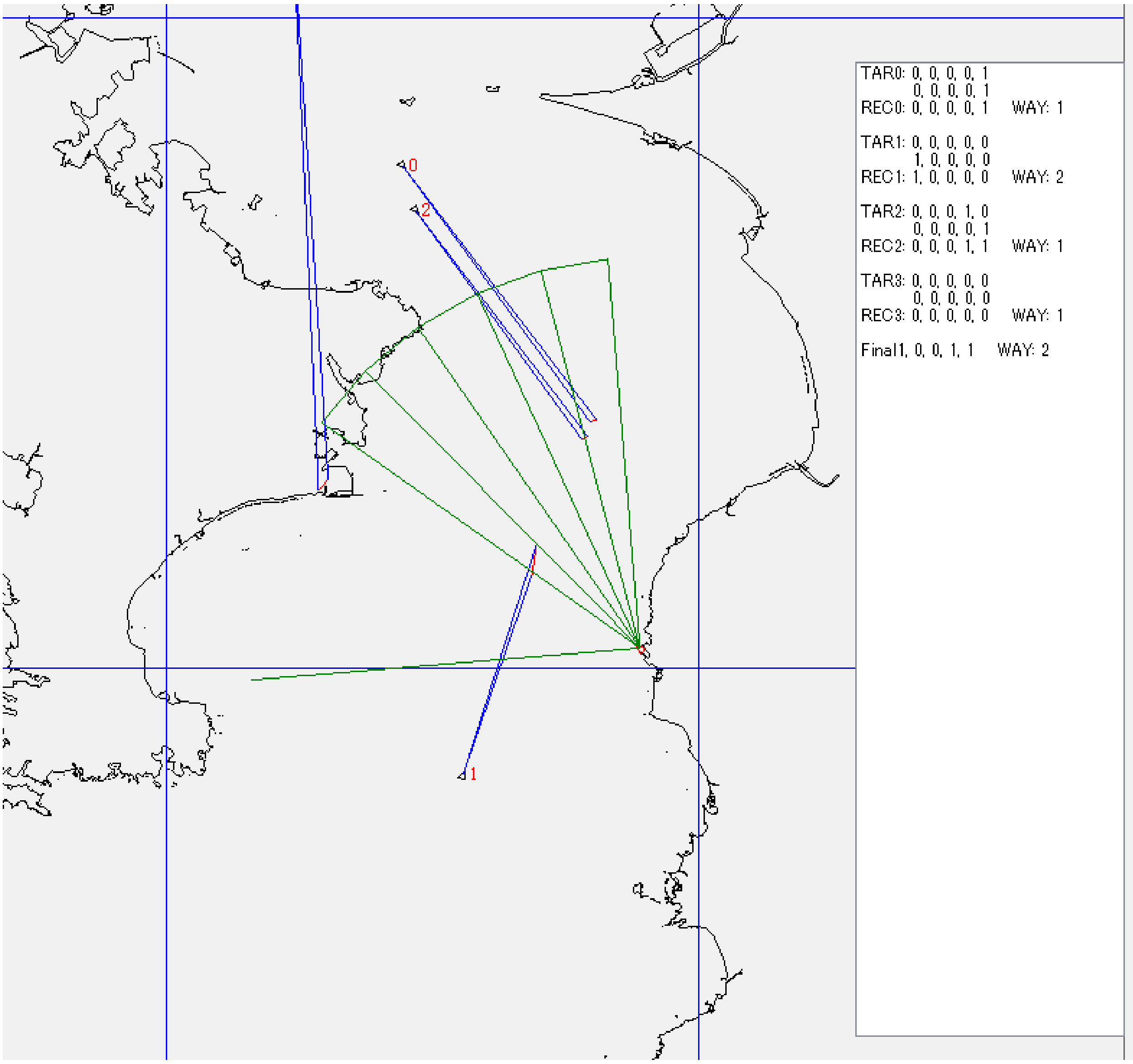


Fig. 5-10 2014/2/10 12:24:30 Kanayamaru's 7th departure

There are 4 target ships in Fig. 5-10, and the final answer is 1, 0, 0, 1, 1. According to the algorithm, heading II is the best departure course.

6. Summary

6.1. Conclusion

The traffic in Tokyo Bay is very complex, especially near Uraga-Suido Traffic Route. Due to the crossing of ferries, the traffic near the route is particularly heavy. The purpose of this study is ferry collision avoidance analysis on departure in this sea area.

In the research of this study, the content of ship AIS data and the characteristics of data transmission are summarized. In order to further study the content of the subject, the Mercator projection method is used to visualize the data through programming, so as to directly see the ship navigation in the Tokyo Bay.

In order to realize ship collision detection, OZT method is used. OZT method is a method that can calculate potentially hazardous areas.

Next, based on the OZT method, the ships within 45 degrees and 6 nautical miles on the left and right of the bow are defined as the safety detection area. The OZT data of all ships in the Tokyo Bay from January 1, 2014 to March 31, 2014 were screened to obtain the OZT encounter data of ferries in the target sea area.

Finally, under the premise of traffic regulations of maritime safety traffic law, the safety detection area is further divided. A collision avoidance algorithm is proposed in this study. Based on the OZT data of the ferry, the simulation and analysis are carried out. Through the algorithm, the recommended departure angle and the scheme of delaying departure are obtained.

The main academic contribution of this study is proposing a collision avoidance algorithm based on OZT method. With this algorithm, safe departure course and delay for collision avoidance advise can be obtain.

6.2. Prospect

At present, this study realizes the scheme of providing departure angle and whether to delay departure, which is used to realize the collision avoidance function of ferry. However, the method proposed in this study still has shortcomings.

The collision avoidance departure angle provided in this study can be further subdivided. To obtain a more accurate departure angle, so as to optimize the route of the ferry.

Due to the lack of the target ship's OZT trajectory prediction, the optimal departure time cannot be predicted. To accomplish this, the OZT trajectory in the next few minutes needs to be predicted through the AIS data of the current time. It is recommended for the future researchers to focus on the ship motion predict to obtain concise proposal for departure route and delay time.

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Acknowledgement

Two years of study time passed. I want to express my sincere thanks to my supervisor Professor Hitoi Tamaru for the support of my study and life. With his patient guidance, enthusiastic encouragement, I gradually adapted to life in Japan. He taught me about the knowledge of nautical navigation and collision methods of OZT. Deepened my understanding of ship collision avoidance and realized the purpose of studying in Japan. In addition, he provides me all kinds of data needed during the research period, makes me complete my research successfully.