A study on analysis of ship's navigation using OZT

Master's Thesis

A STUDY ON ANALYSIS OF SHIP'S NAVIGATION USING OZT

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CHAPTER I Introduction

With the development of AIS (Automatic Identification System), massive amounts of AIS data have been accumulated, which provides a promising approach to investigate and analyze ship's navigation behaviors. As Tokyo Bay is one of the most congested water areas in the world, it is crucial to analyze the AIS data in Tokyo Bay. The Obstacle Zone by Target (OZT) [5] is an evaluation method of collision risk. It can show the dangerous areas of other ships around the own ship, which means it can present the collision risk visually and concretely. This paper studies the navigation characteristics of the training ship Shioji Maru as well as the maritime traffic characteristics of the Tokyo Bay using OZT.

The traditional collision avoidance process is that the navigators use the Radar and APRA, though inter-ship communication to prevent collision between vessels. This collision avoidance process highly relies on navigators' experience and seamanship, which requires a long time accumulation. Many seafarers, especially new crew members only possess a vague perception of collision risk, they are unable to aware the different levels of risk let alone when to take avoidance actions and what kind of collision avoidance manipulation they need to take, which probably lead to collision accidents. As is known to all, ship technology is far behind the aviation, high-speed train and other modes of transport technology, and because the ship and the loading cargo itself are high valued property, once the ship collision accident happened, the economic loss is disastrous. Therefore, studying the dangerous areas and perceiving the existence of ship collision risk are of vital importance. The conventional DCPA (Distance of the Closest Point of Approach) and TCPA (Time to the Closest Point of Approach) which are used to check the risk of collision with the other ships are abstract and indistinct for navigators compared to the OZT theory. With the aid of the OZT technology, navigators can determine whether the existence of ship collision risk, how to take collision avoidance behaviors and what kind of actions should be taken.

Hayama Imazu [20] proposes an approach to improve the evaluation and expression of collision risk, and the expression of OZT will be easy to trace the origin target of OZT and to check the fault information transmitted by the target. He raises a computation of OZT by using collision course [5], and proposes the theory of Line of Predicted Collision (LOPC) and Obstacle Zone by Target (OZT) for evaluation of collision risk [17]. He believes that using those methods to evaluate collision risk with true motion has many advantages such as it is easier to find out a safety pass in congested water areas. Junji Fukuto [9] studies the algorithm for collision alarm using OZT and evaluates its reduction rate using recorded AIS traffic data. Jun Kayano [18] proposes and discusses collision avoidance support system which can warn the watch officer of the danger and starts planning collision evasion route with the collision avoidance algorithm when the ship faces the risk of collision. He also analyzes the data obtained by ship-handling simulation experiments using OZT algorithms for examining the differences of the characteristics of look-out methods between experienced navigators and inexperienced navigators [19]. Kei Kumagai [10] uses OZT to analyze the results of ship maneuvering simulation.

This paper attempts to apply the OZT theory in studying the navigation environment of the Tokyo Bay and ship navigator's handling behaviors. The author picks up several typical collision avoidance situations of the Shioji Maru and studies the collision avoidance actions of each ships in each situation using the OZT theory and the dynamic ship data from the AIS. Moreover, using the OZT theory, this paper studies the relative safety zones and dangerous areas in Tokyo Bay along the ship route of the Shioji Maru, the relative safety distance of the Shioji Maru, the normal distance between the Shioji Maru and the OZT areas and the ordinary heading when notable encounter situation appears.

According to the research, the navigator of the Shioji Maru is of good maneuvering and ship operation behaviors. The OZT theory is an effective way for ship collision avoidance and the OZT theory can improve the navigators' collision avoidance behaviors.

CHAPTER II AIS

2.1 AIS Overview

The Automatic Identification System (AIS) is a maritime transponder/receiver system defined by the IMO (International Maritime Organization). The AIS operates in the VHF frequency band. It uses the Very High Frequency (VHF) radio broadcasting system to transfer data. AIS equipped vessels and shore-based stations can send and receive identification information that can be displayed on an electronic chart, computer display or compatible navigation radar. The main objectives of AIS are to improve navigation safety and to protect maritime environment by assisting in the effective navigation of ships. The information provided by AIS can help in situational awareness and provide a means to assist in collision avoidance. In addition, AIS can be used as an aid to navigation by providing location and additional information on buoys and lights.[11]

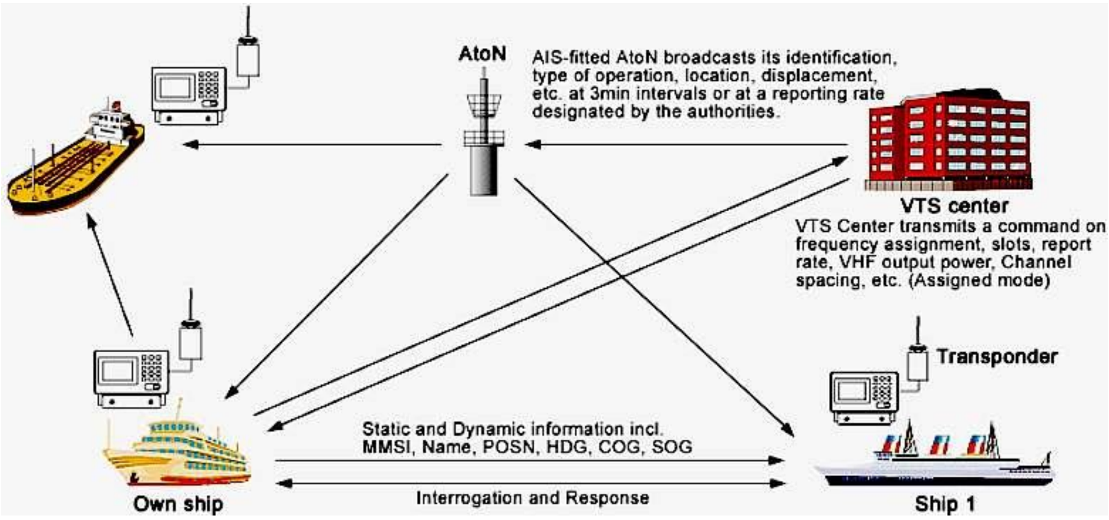

Figure 2.1 Automatic Identification System [2]

2.2 AIS Messages

The AIS has six different types: Class A, Class B, Search and Rescue Aircraft, AIS Aid to Navigation (ATON), AIS Search and Rescue Transmitter (SART) and AIS Base Station.[15]

Table 2.1 Six different AIS types [15]

Class A	Shipborne mobile equipment intended to meet the performance standards and carriage requirements adopted by IMO. Class A stations report their position (message 1/2/3) autonomously every 2-10 seconds dependent on the vessel's speed and/or course changes (every three minutes or less when at anchor or moored); and, the vessel's static and voyage related information (message 5) every 6 minutes. Class A stations are also capable of text messaging safety related information (message 6/8) and AIS Application Specific Messages (message 6, 8, 25, 26), such as meteorological and hydrological data, electronic Broadcast Notice to Mariners, and other marine safety information.
Class B	Shipborne mobile equipment which is interoperable with all other AIS stations, but, does not meet all the performance standards adopted by IMO. Similar to Class A stations, they report every three minutes or less when at anchor or moored, but, their position (message 6/8) is reported less often and at a lower power. Likewise, they report the vessel's static data (message 18/24) every 6 minutes, but, not any voyage related information. They can receive safety related text and application specific messages, but, cannot transmit them. There are two types of Class B AIS, those using carrier sense Time-Division Multiple Access (CS-TDMA) technology and those like the Class A using Self-Organizing Time-Division Multiple Access Technology (SO-TDMA). Class B/SO is generally more capable; Class B/CS is generally less expensive.
Search and Rescue Aircraft	Aircraft mobile equipment, normally reporting every ten seconds.
AIS Aid to Navigation (ATON)	Shore-based or mobile station providing location and status of an aid to navigation (ATON); which may also broadcast Application Specific Messages (message 6/8).
AIS Search and Rescue Transmitter (SART)	Mobile equipment to assist homing to itself (i.e. life boats, life raft). An AIS SART transmits a text broadcast (message 14) of either 'SART TEST' or 'ACTIVE SART'. When active the unit also transmits a position message (message 1 with a 'Navigation Status' = 14) in a burst of 8 messages once per minute.
AIS Base Station	Shore-based station providing identity, time synchronization, text messages, which can also act as an AIS ATON station or transmit Application Specific Messages (message 6/8) for meteorological or hydrological information, marine safety information, etc.

A Class A AIS unit broadcasts the position report information every 2 to 10 seconds while underway, and every 3 minutes while at anchor at a power level of 12.5 watts. [16] In addition, the Class A AIS unit broadcasts the ship static and voyage related data information every 6 minutes. Should only be used by Class A shipborne and SAR aircraft AIS stations when reporting static or voyage related data.[1]

Table 2.2 Class A AIS position report [16]

Parameter	Bits	Description
Message ID	6	Identifier for this message 1, 2 or 3
Repeatindicator	2	Used by the repeater to indicate how many times a message has been repeated. See Section 4.6.1, Annex 2; 0-3; 0 = default; 3 = do not repeat any more
User ID	30	MMSI number
Navigational status	4	0 = under way using engine, 1 = at anchor, 2 = not under command, 3 = restricted maneuverability, 4 = constrained by her draught, 5 = moored, 6 = aground, 7 = engaged in fishing, 8 = under way sailing, 9 = reserved for future amendment of navigational status for ships carrying DG, HS, or MP, or IMO hazard or pollutant category C, high speed craft (HSC), 10 = reserved for future amendment of navigational status for ships carrying dangerous goods (DG), harmful substances (HS) or marine pollutants (MP), or IMO hazard or pollutant category A, wing in ground (WIG); 11 = power-driven vessel towing astern (regional use); 12 = power-driven vessel pushing ahead or towing alongside (regional use);13 = reserved for future use;14 = AIS-SART (active), MOB-AIS, EPIRB-AIS;15 = undefined = default (also used by AIS-SART, MOB-AIS and EPIRB-AIS under test)
Rate of turn	8	0 to +126 = turning right at up to 708 deg per min or higher; 0 to -126 = turning left at up to 708 deg per min or higher Values between 0 and 708 deg per min coded by ROTAIS = 4.733 SQRT(ROTsensor) degrees per min, where ROTsensor is the Rate of Turn as input by an external Rate of Turn Indicator (TI). ROTAIS is rounded to the nearest integer value.+127 = turning right at more than 5 deg per 30 s (No TI available);-127 = turning left at more than 5 deg per 30 s (No TI available); -128 (80 hex) indicates no turn information available (default).ROT data should not be derived from COG information.
SOG	10	Speed over ground in 1/10 knot steps (0-102.2 knots); 1 023 = not available, 1 022 = 102.2 knots or higher
Position accuracy	1	The position accuracy (PA) flag should be determined in accordance with the table below: 1 = high (<= 10 m); 0 = low (> 10 m); 0 = default
Longitude	28	Longitude in 1/10 000 min (+/-180 deg, East = positive (as per 2's complement), West = negative (as per 2's complement). 181= (6791AC0h) =not available = default)
Latitude	27	Latitude in 1/10 000 min (+/-90 deg, North = positive (as per 2's complement), South = negative (as per 2's complement). 91deg (3412140h) = not available = default)
COG	12	Course over ground in 1/10 = (0-3599). 3600 (E10h) = not available = default. 3 601-4 095 should not be used
True heading	9	Degrees (0-359) (511 indicates not available = default)
Time stamp	6	UTC second when the report was generated by the electronic position system (EPFS) (0-59, or 60 if time stamp is not available, which should also be the default value, or 61 if positioning system is in manual input mode, or 62 if electronic position fixing system operates in estimated (dead reckoning) mode, or 63 if the positioning system is inoperative)
Special maneuvre	2	0 = not available = default; 1 = not engaged in special maneuver; 2 = engaged in special maneuver; (i.e.: regional passing arrangement on Inland Waterway)
Spare	3	Not used. Should be set to zero. Reserved for future use.
RAIM-flag	1	Receiver autonomous integrity monitoring (RAIM) flag of electronic position fixing device; 0 = RAIM not in use = default; 1 = RAIM in use.
Communication state	19	-
Number of bits	168	-

2.3 The Advanced Navigation System [3]

The Advanced Navigation System was introduced by Tokyo University of Marine Science and Technology in March 2011. As shown in Figure 2.2 and Figure 2.3, this system creates databases of all types of information gathered as necessary from onshore radar stations, onshore AIS stations, ships and weather support sites, and displays this information on multiple monitors and computers. It is equipped with functionality that can show information on ships in Tokyo Bay, real-time display that aids in grasping ship movement conditions within the bay, and playback capability for redisplaying previous conditions. It is also used for instruction on confirming the wake of the training ship and observing changes in marine traffic flow. There are four main information can be obtained: Marine GIS, Tokyo Bay current condition, Weather and ocean condition information and Ship information.

1. Marine GIS

The system is equipped with marine GIS functionality, featuring superimposed displays of weather and ocean condition information with all types of gathered information. Combination (layer selection) of data types selected according to the research objective with multiple information samples is now easily performed, and visual recognition of analysis and testing results is available as well. Moreover, with the measurement tools that are a basic GIS feature, it is now possible to carry out measurements of route distance and area.

2. Tokyo Bay current condition

By displaying radar images from onshore radar stations and ship information from AIS receiving stations, it is possible to grasp the situation of ship movement in Tokyo Bay.

3. Weather and ocean condition information

Information on wave value predictions announced by the Meteorological Agency is displayed here, making it possible to estimate effects on ships.

4. Ship information

Ship information gathered through Tokyo University of Marine Science and Technology training ship's internal network is acquired via satellite connection, and ship handling conditions and mechanical operation conditions can be observed by displaying in real time. IP phone and videoconferencing communication equipment is available as well.

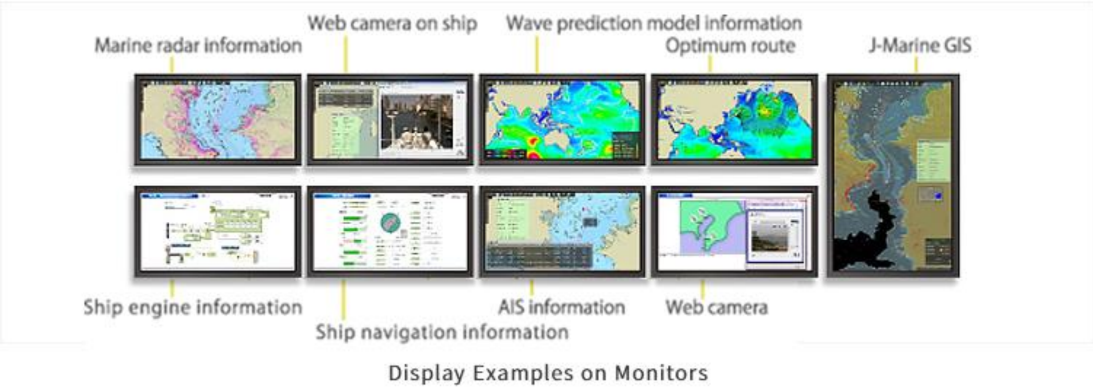

Figure 2.2 The Advanced Navigation System [3]

Figure 2.3 Configuration of Advanced Navigate System [4]

CHAPTER III Theory and Algorithm

3.1 The OZT Theory [5]

3.1.1 Definition of OZT

OZT is an abbreviation for "Obstacle Zone by Target". [5] It is a method of visually expressing areas that have a high possibility of colliding with obstacles such as other ships. As showed in Figure 3.1, Point A denotes the position of the own ship, while Point B denotes the position of the target ship. As ships are not dots but are with length and breadth, they should be considered of the safety passing distance (SD). The OZT areas can be obtained by the following steps:

1. First, draw a circle of radius SD centered on the own ship's position.

2. Draw tangent lines to this circle from the target ship's position, and set the intersection points with T1 and T2.

3. Draw the velocity vector of the target ship with the end of this vector is Point B, as indicate "OB" in the figure, and C_B denotes the course of the target ship.

4. Draw a circle of radius of the own ship's velocity centered on point O.

5. Suppose the TCPA1 and TCPA2 are obtained, with the time of TCPA1 and TCPA2, the target ship arrives at the point of M1 and M2 respectively. Draw two circles of radius SD centered on the point of M1 and M2. Then draw the parallel lines of BT1 and BT2 that are tangent to Circle M1 and Circle M2, with the most external tangency points of Q1 and Q2 separately. The direction of line connecting Point A and Point Q1 (CA1) and Point A and Point Q2 (CA2) become collision courses to be obtained.

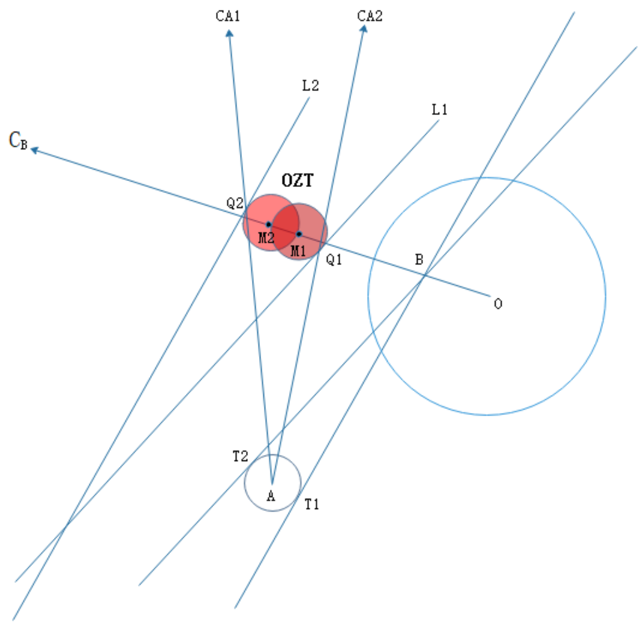

Figure 3.1 Definition of OZT

The course between CA1 and CA2 would be the situation that the DCPA is less than SD, so that this course is called collision courses. Since the own ship will collide with the target ship when passing through this zone, which means that the OZT areas are the collision places between the own ship and the target ship.

3.1.2 Calculation of OZT

In order to make the results of OZT meaningful, one basic requirement should be met-the Distance of Closest Point of Approach (DCPA) is equal or lesser than the radius SD (r).

$$DCPA \leqq r \tag{1}$$

From the relative research experience, the SD (r) is usually calculated by

$$r = \frac{L_{own} + L_{target}}{2} \tag{2}$$

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

The angle between tangent lines to the position of the own ship α , the distance between the own ship and the target ship d

$$\alpha = \sin^{-1} \frac{r}{d} \tag{3}$$

The bearing of the target ship A_Z, the course of the target ship C_T, the velocity of the target ship V_T, the collision courses C_O, the velocity of the own ship V_O meet the requirement of the following equation

$$\frac{\sin(A_Z \pm \alpha - C_O)}{V_T} = \frac{\sin(C_T - (A_Z \pm \alpha) - \pi)}{V_O} \tag{4}$$

Therefore,

$$C_O = A_Z \pm \alpha - \sin^{-1}\left(\frac{V_T}{V_O}\sin(A_Z \pm \alpha - C_T)\right) \tag{5}$$

$$\left(\left|\frac{V_T}{V_O}\sin(A_Z \pm \alpha - C_T)\right| \le 1 \text{ and } 0 \le C_O \le 2\pi\right)$$

In order to calculate the TCPA, relative motion equation is introduced here.

$$\Delta X = V_T \sin C_T - V_O \sin C_O \tag{6}$$

$$\Delta Y = V_T \cos C_T - V_O \cos C_O \tag{7}$$

$$V_R = \sqrt{\Delta X^2 + \Delta Y^2} \tag{8}$$

$$C_R = \tan^{-1}\frac{\Delta X}{\Delta Y} \tag{9}$$

(the relative velocity vector in the first quadrant, $C_R = C_R$

the relative velocity vector in the second quadrant, $C_R = C_R + \pi$

the relative velocity vector in the third quadrant, $C_R = C_R + \pi$

the relative velocity vector in the fourth quadrant, $C_R = C_R + 2\pi$)

$$DCPA = \mathrm{d} * \left|\sin(C_R - A_Z + \pi)\right| \tag{10}$$

$$TCPA = \frac{\mathrm{d} * \cos(C_R - A_Z + \pi)}{V_R} \tag{11}$$

Based on the four C_O, C_{O1}, C_{O2}, C_{O3}, C_{O4}, four TCPA, $TCPA_1$, $TCPA_2$, $TCPA_3$, $TCPA_4$ could be determined, so four OZT circles could be obtained.

3.2 Ship Movement Parameters

Suppose the own ship position (x_o , y_o), the own ship velocity V_o , the own ship heading H_o . The target ship position (x_t , y_t), the target ship velocity V_t , the target ship heading H_t .

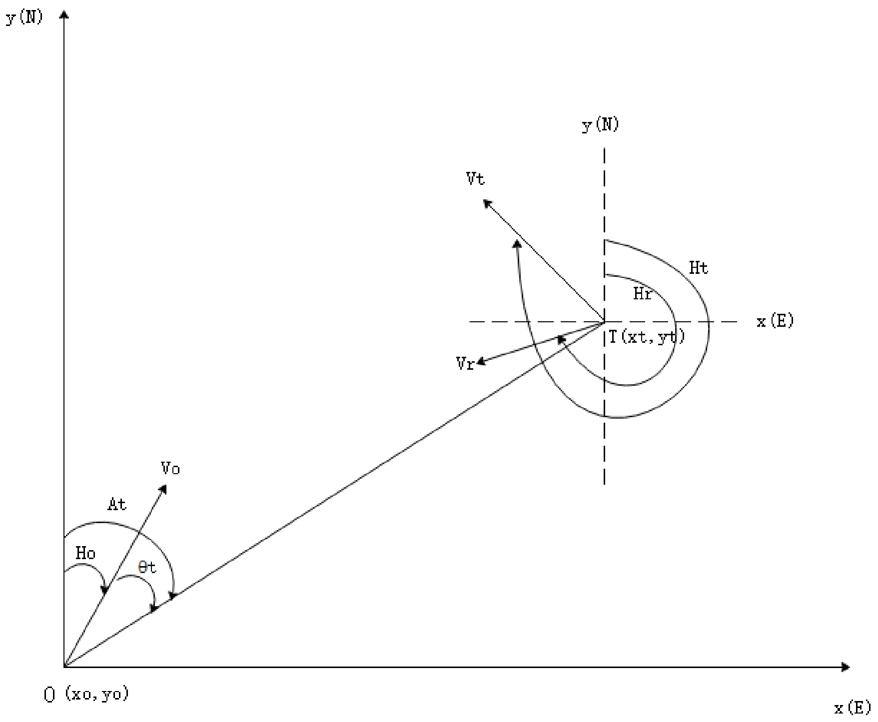

Figure 3.2 Ship movement parameters

The x component and y component along the x axe and y axe of the own ship velocity

$$V_{xo} = V_o \bullet \sin H_o$$

$$V_{yo} = V_o \bullet \cos H_o$$

The x component and y component along the x axe and y axe of the target ship velocity

$$V_{xt} = V_t \bullet \sin H_t$$

$$V_{yt} = V_t \bullet \cos H_t$$

The x component and y component along the x axe and y axe of the ship relative velocity

$$V_{xr} = V_{xt} - V_{xo}$$

$$V_{yr} = V_{yt} - V_{yo}$$

The ship relative velocity magnitude

$$V_r = \sqrt{V_{xr}{}^2 + V_{yr}{}^2}$$

The heading of the ship relative velocity

$$H_r = \arctan\frac{V_{xr}}{V_{yr}} + H_a$$

$$H_a = \begin{cases} 0^\circ, V_{xr} \geq 0, V_{yr} \geq 0 \\ 180^\circ, V_{xr} < 0, V_{yr} < 0 \\ 180^\circ, V_{xr} \geq 0, V_{yr} < 0 \\ 360^\circ, V_{xr} < 0, V_{yr} \geq 0 \end{cases}$$

The true bearing of the target ship relative to the own ship

$$A_t = \arctan\frac{x_t - x_{\text{o}}}{y_t - y_{\text{o}}} + H_b$$

$$H_b = \begin{cases} 0^\circ, x_t - x_{\text{o}} \geq 0, y_t - y_{\text{o}} \geq 0 \\ 180^\circ, x_t - x_{\text{o}} < 0, y_t - y_{\text{o}} < 0 \\ 180^\circ, x_t - x_{\text{o}} \geq 0, y_t - y_{\text{o}} < 0 \\ 360^\circ, x_t - x_{\text{o}} < 0, y_t - y_{\text{o}} \geq 0 \end{cases}$$

The true bearing of the own ship relative to the target ship

$$A_o = \arctan\frac{x_{\text{o}} - x_t}{y_{\text{o}} - y_t} + H_c$$

$$H_c = \begin{cases} 0^\circ, x_{\text{o}} - x_t \geq 0, y_{\text{o}} - y_t \geq 0 \\ 180^\circ, x_{\text{o}} - x_t < 0, y_{\text{o}} - y_t < 0 \\ 180^\circ, x_{\text{o}} - x_t \geq 0, y_{\text{o}} - y_t < 0 \\ 360^\circ, x_{\text{o}} - x_t < 0, y_{\text{o}} - y_t \geq 0 \end{cases}$$

The relative bearing of the target ship

$$\theta_t = A_t - H_{\text{o}} \pm 360^\circ$$

The relative bearing of the own ship from the target ship [7]

$$\theta_o = A_o - H_t \pm 360^\circ$$

The relative heading angle

$$H_{\_R} = H_t - H_{\text{o}} - 180^\circ$$

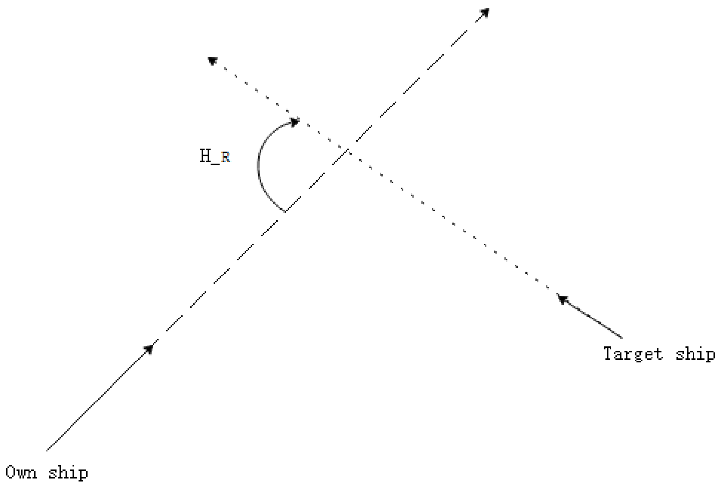

Figure 3.3 The relative heading angle

3.3 The Mercator Projection

The Mercator projection is a cylindrical map projection. It became the standard map projection for nautical purposes because of its ability to represent lines of constant course, known as rhumb lines or loxodromes, as straight segments that conserve the angles with the meridians. The linear scale is equal in all directions around any point, thus preserving the angles and the shapes of small objects (which makes the projection conformal).[6]

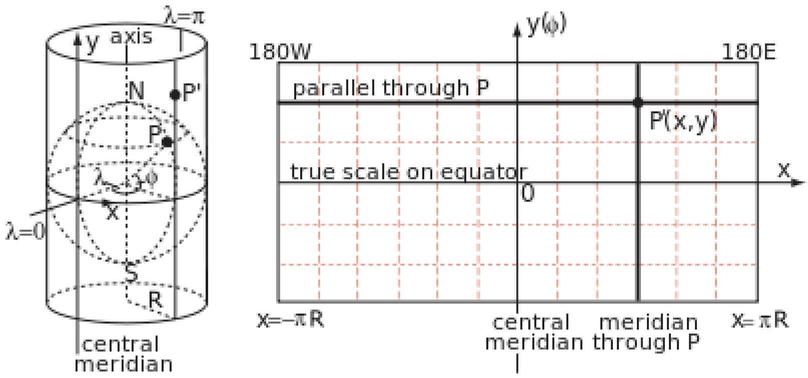

Figure 3.4 Basal principle of the Mercator projection [6]

As the calculation of OZT method is based on the projected coordinate system, and the AIS data is based on the geographic coordinate system, it is necessary to convert the coordinate system. With the advantage of rhumb lines, the Mercator projection is commonly used in the ships' positioning and heading determination.

3.3.1 Mercator Projection

$(lon,\ lat) \to (x,\ y)$, latitude of reference b0, origin of latitude 0, origin of longitude 0.

Mercator projection is a method to convert the (lon, lat) in the geographic coordinate system to (x, y) in the projected coordinate system. [12]

$$N = \frac{a}{\sqrt{(1-e^2*(sin(b0))^2)}}$$

$$R = N*cos(b0)$$

$$q = \ln\left(tan\left(\frac{\pi}{4}+\frac{lat}{2}\right)\right) - \ln\left(\frac{1+e*sin(lat)}{1-e*sin(lat)}\right)*\frac{e}{2}$$

$x = R*lon$

$y = R*q$

a -- Semi-major axis of the ellipsoid

b0 -- Latitude of reference

e -- First eccentricity

N -- Radius of curvature in prime vertical

R -- Radius of circle of latitude in latitude of reference

q -- Isometric latitude

x, y -- Orthogonal coordinates (in meters) in the Mercator projected coordinate system

lon, lat -- Longitude and latitude in the geographic coordinate system

3.3.2 Inverse Mercator Projection

$(x,\ y) \to (lon,\ lat)$, latitude of reference b0, origin of latitude 0, origin of longitude 0.

$$q = \ln\left(tan\left(\frac{\pi}{4}+\frac{lat}{2}\right)\right) - \ln\left(\frac{1+e*sin(lat)}{1-e*sin(lat)}\right)*\frac{e}{2}$$

$$lon = \frac{x}{R}$$

$$lat = 2\arctan(\exp(q)) - \frac{\pi}{2}$$

e -- First eccentricity

R -- Radius of circle of latitude in latitude of reference

q -- Isometric latitude

x, y -- Orthogonal coordinates (in meters) in the Mercator projected coordinate system

lon, lat -- Longitude and latitude in the geographic coordinate system

CHAPTER IV Ship Encounter Situations and Data Sieving

4.1 Ship Encounter Situations

Based on the COLREG-1972 (Regulations for Preventing Collisions at Sea 1972) [14], the ship encounter situations are categorized into three fundamental situations: Crossing, Head-on and Overtaking. In order to meet the requirement of collision avoidance decisions and considered the different characteristics of coming target ship bearing, here the ship encounter situations are classified into 6 situations: Head-on, Port crossing, Starboard crossing, Overtaking, Overtaken and Stationary.

(1) Head-on: the relative bearing is less than or equal to 6 degrees, the heading difference is between 174 degrees to 186 degrees.

(2) Port crossing: the relative bearing is equal or greater than 247.5 degrees but less than 292.5 degrees.

(3) Starboard crossing: the relative bearing is equal or greater than 6 degrees but less than 112.5 degrees.

(4) Overtaking: the own ship locates in the areas between the bearing of equal or greater than 112.5 degrees but less than 247.5 degrees of the target ship; $V_o \cos \Delta C > V_t$ (V_o and V_t denote the own ship velocity and target ship velocity, ΔC denotes the encounter angle).

(5) Overtaken: the target ship locates in the areas between the bearing of equal or greater than 112.5 degrees but less than 247.5 degrees of the own ship; $V_t \cos \Delta C > V_o$ (V_o and V_t denote the own ship velocity and target ship velocity, ΔC denotes the encounter angle).

(6) Stationary: the target ship keeps in a condition while velocity is less than or equal to 0.1 knots.

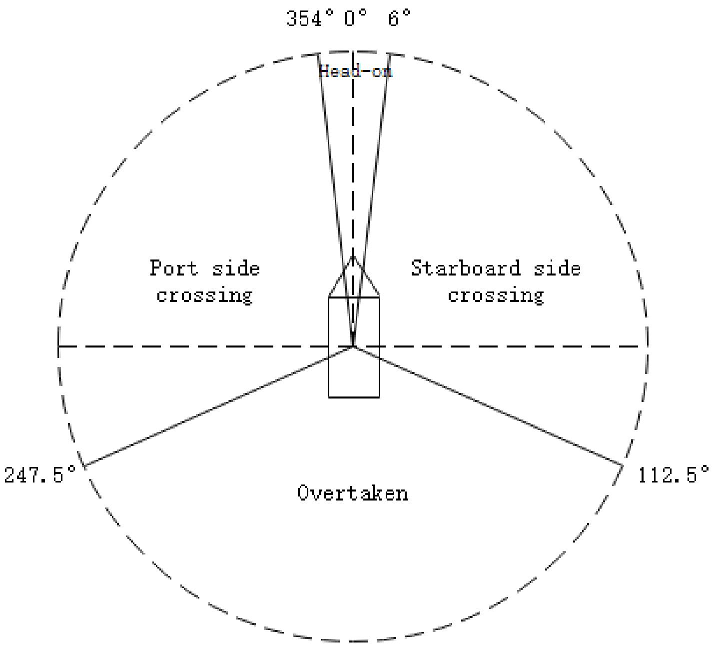

Figure 4.1 Ship encounter situations

4.2 AIS Data Sieving

4.2.1 The Choice of The Own Ship

In order to select the appropriate data, it is important to decide the own ship first. The training ship Shioji Maru of Tokyo University of Marine Science and Technology is an ideal own ship for research for two features: the relative fixed ship route and relative fixed schedule. As shown in Figure 4.2-4.6, the Shioji Maru has regular shipping line from Tateyama to Tokyo on every Thursday. The departure time is around 9 o'clock and the ETA is around 14 o'clock. Figure 4.2-4.6 shows the Shioji Maru shipping route April 27th, May 11th, May 25th, June 8th and June 15th in 2017. This paper selects the AIS data on April 27th, May 11th, May 25th, June 8th and June 15th in 2017.

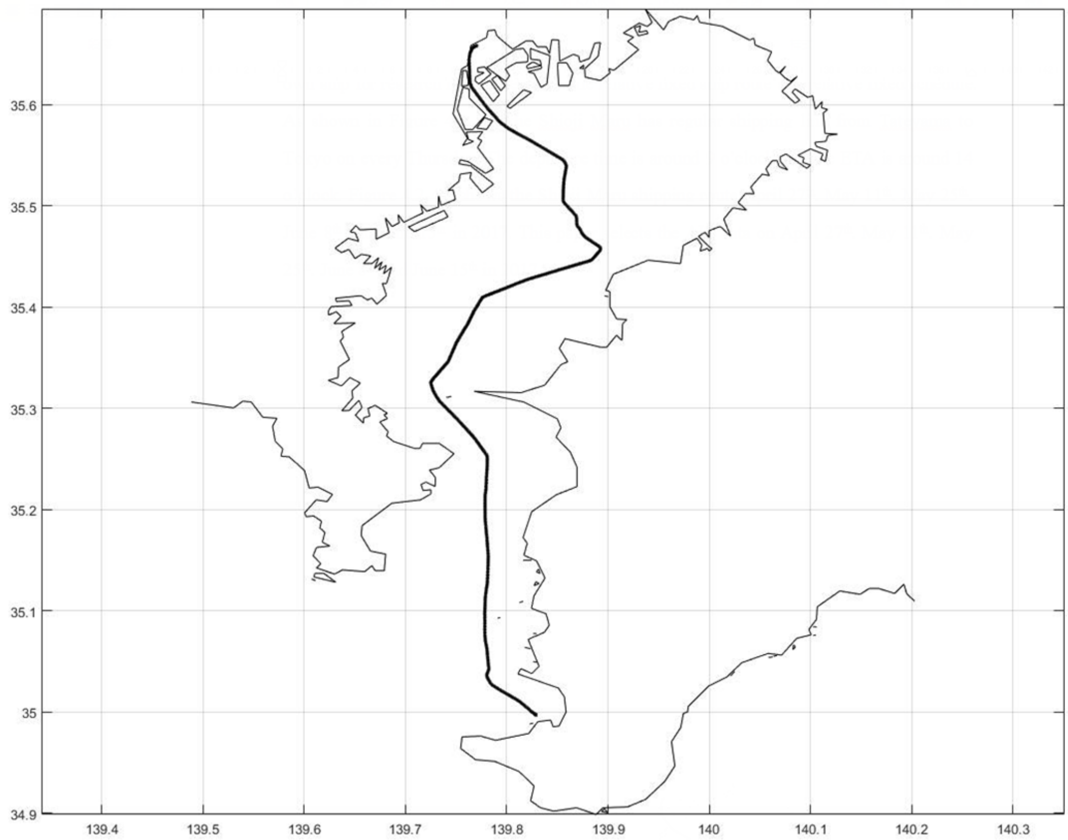

Figure 4.2 The Shioji Maru route on April 27th, 2017

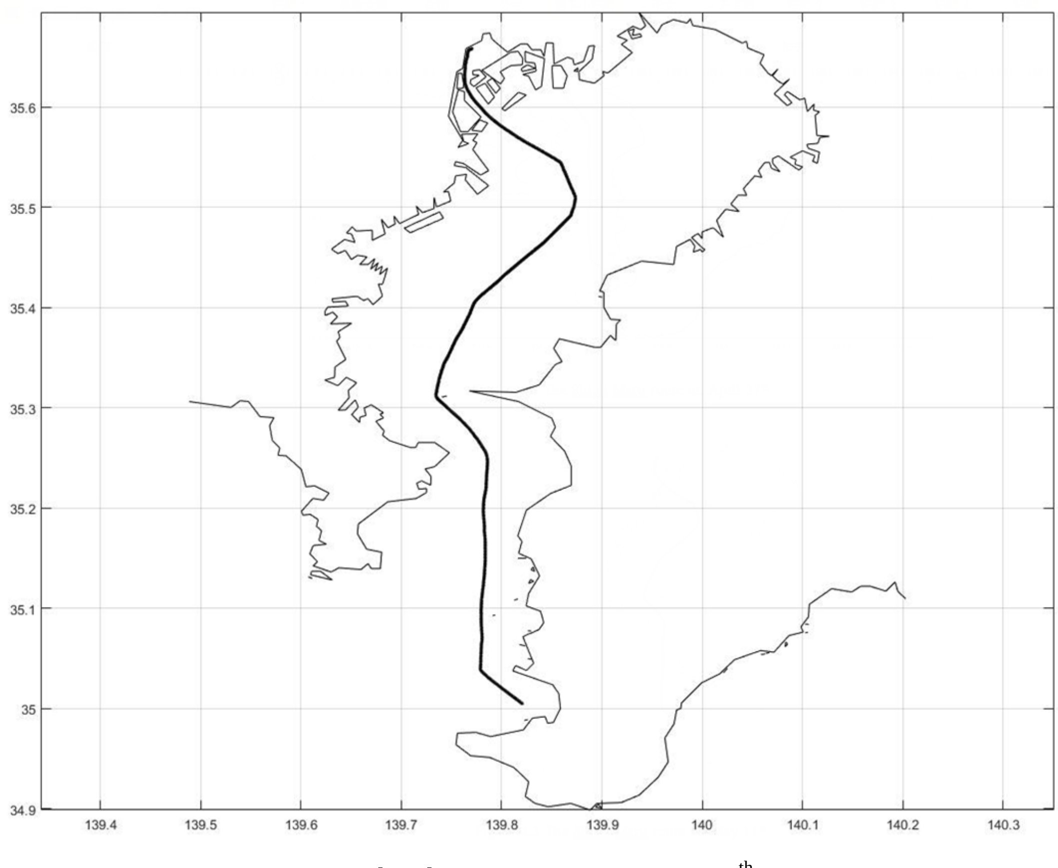

Figure 4.3 The Shioji Maru route on May 11th, 2017

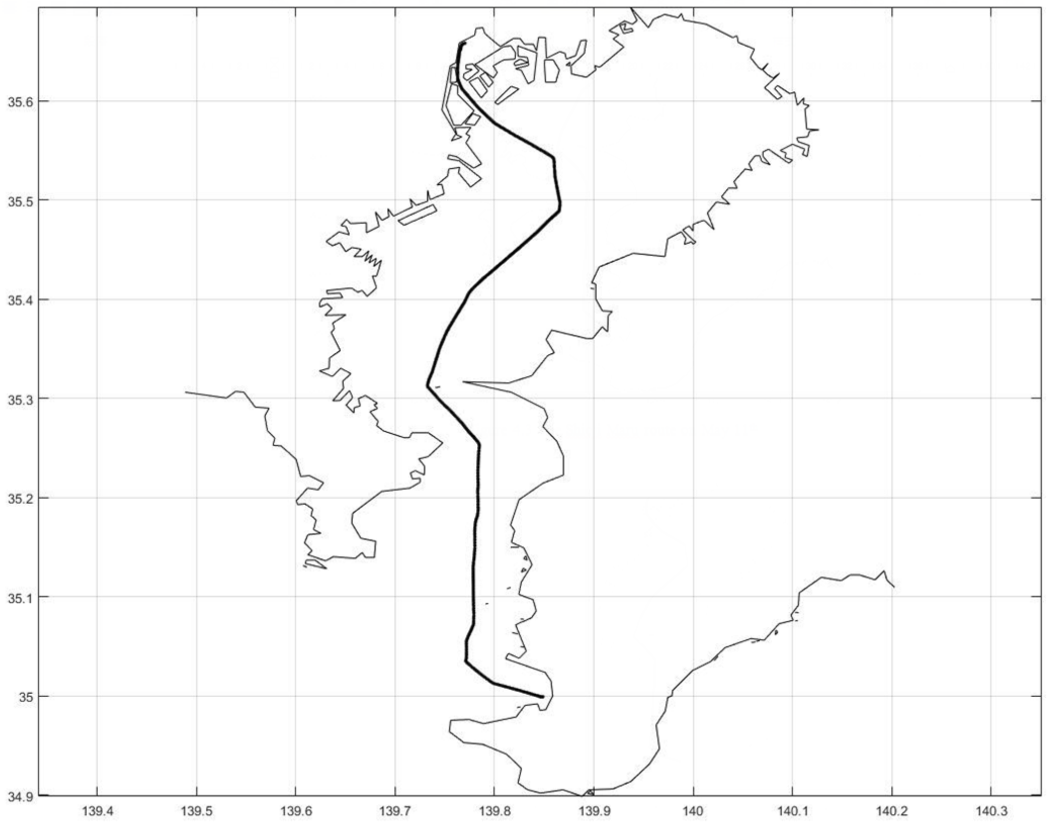

Figure 4.4 The Shioji Maru route on May 25th, 2017

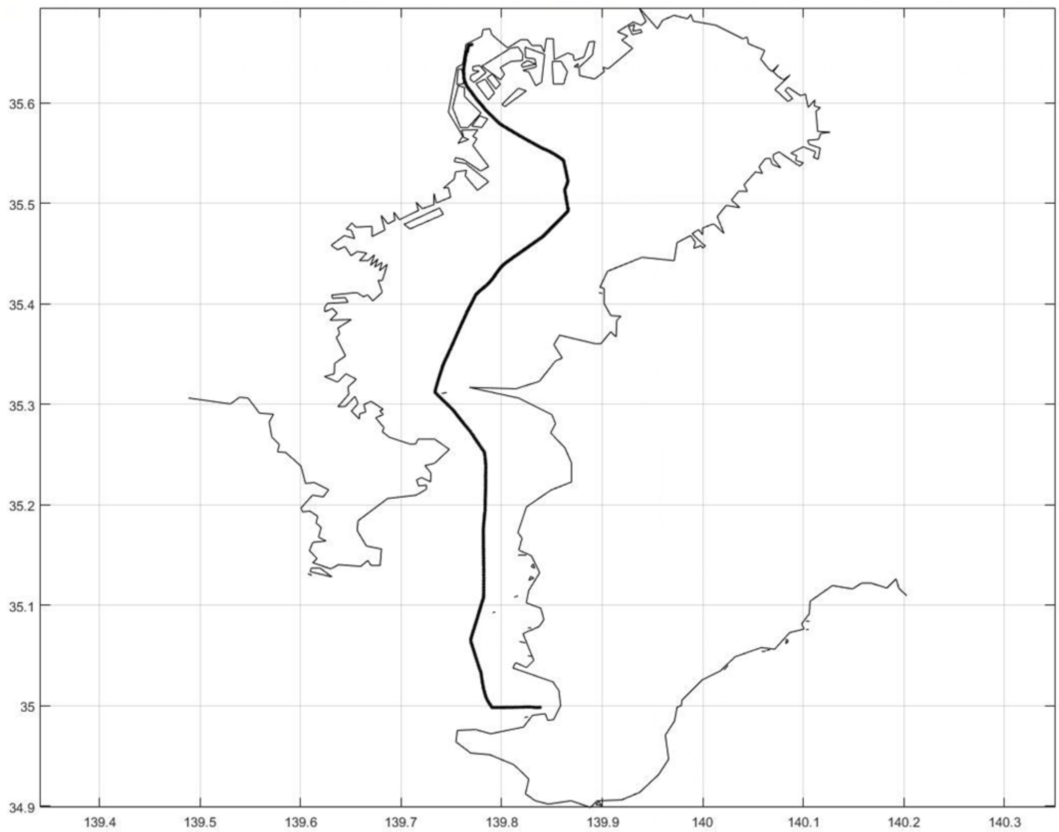

Figure 4.5 The Shioji Maru route on June 8th, 2017

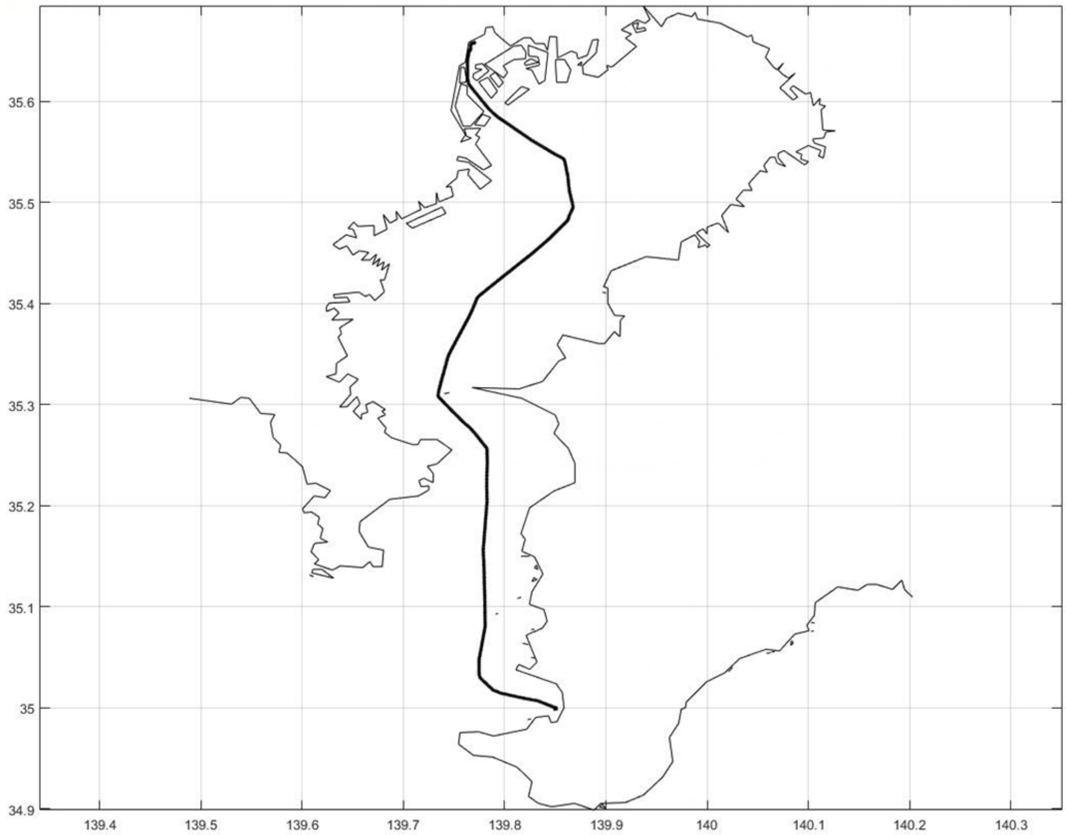

Figure 4.6 The Shioji Maru route on June 15th, 2017

4.2.2 Data Sieving Criterion

As the data are too large amount of that sieving data is essential, this paper sets a standard including four basic procedures to filter the data.

(1) Extract the AIS data of every 30 seconds;

(2) The distance between the own ship and the target ship is less than or equal to 3 nm;

(3) TCPA (Time to Closest Point of Approach) is less than or equal to 10 minutes;

(4) The OZT areas should be hunted between port 60 °to starboard 60 °of the own ship.

CHAPTER V Analysis

5.1 OZT Distribution Analysis

This paper picks up five days AIS data, April 27th, May 11th, May 25th, June 8th and June 15th in the Tokyo Bay in the year 2017, the traffic flow shows in the following figures.

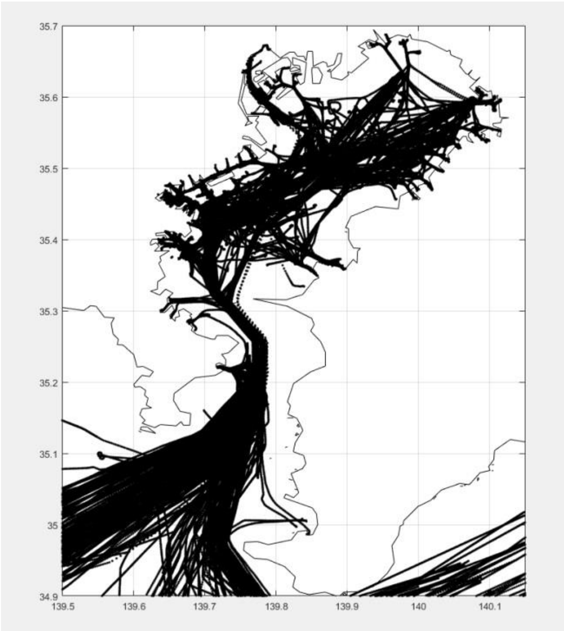

Figure 5.1 The traffic flow on April 27th, 2017

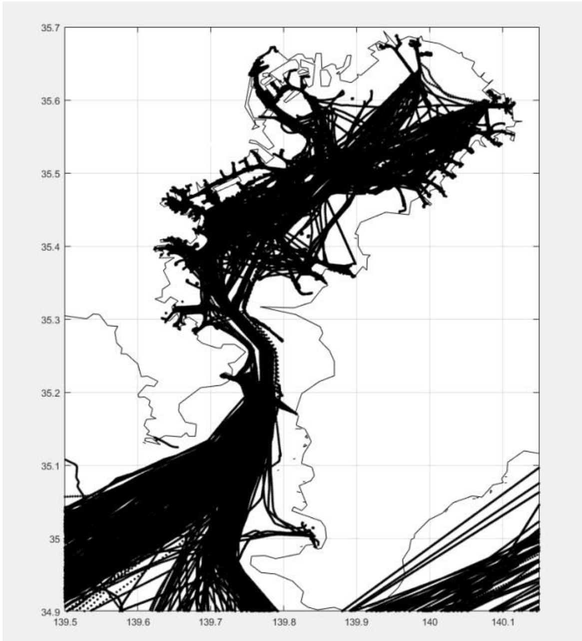

Figure 5.2 The traffic flow on May 11th, 2017

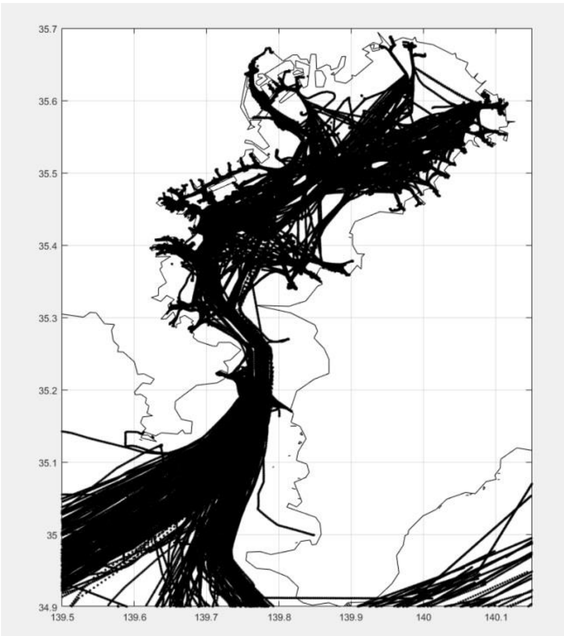

Figure 5.3 The traffic flow on May 25th, 2017

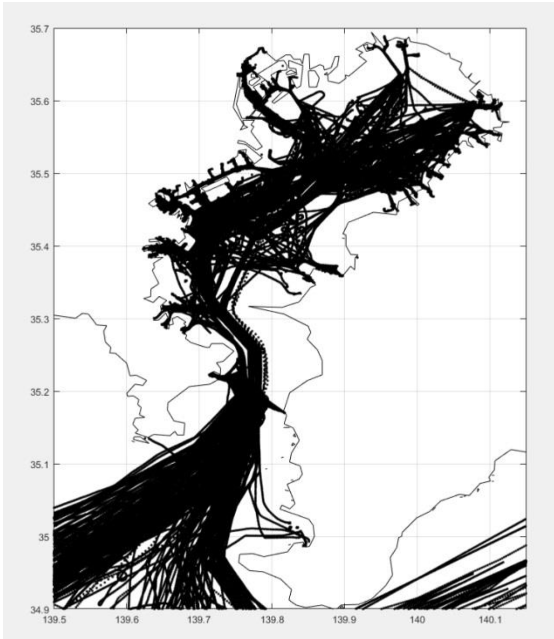

Figure 5.4 The traffic flow on June 8th, 2017

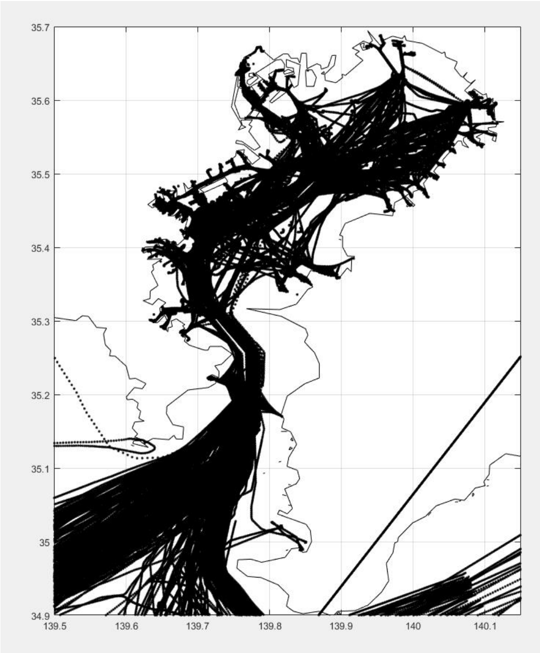

Figure 5.5 The traffic flow on June 15th, 2017

The relative authentic dangerous areas which the within 3 nm from the own ship, TCPA ≤10min, exist in Port 60°-Starboard 60° using the OZT theory are shown in the following figures.

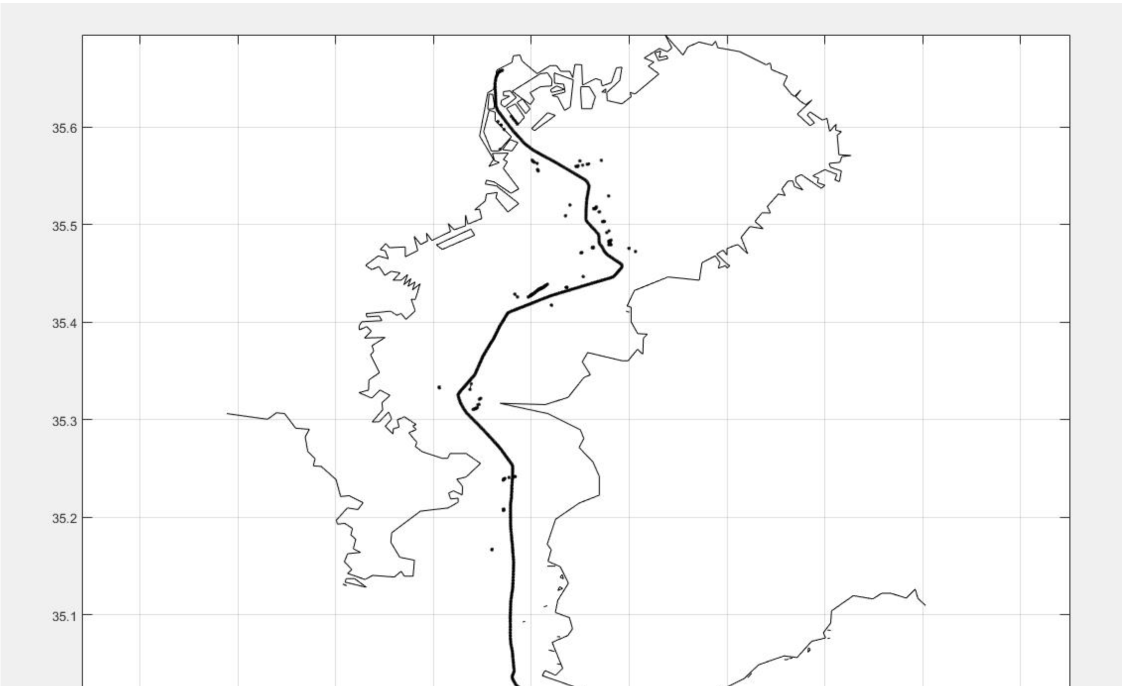

Figure 5.6 The authentic dangerous area for the Shioji Maru on April 27th, 2017

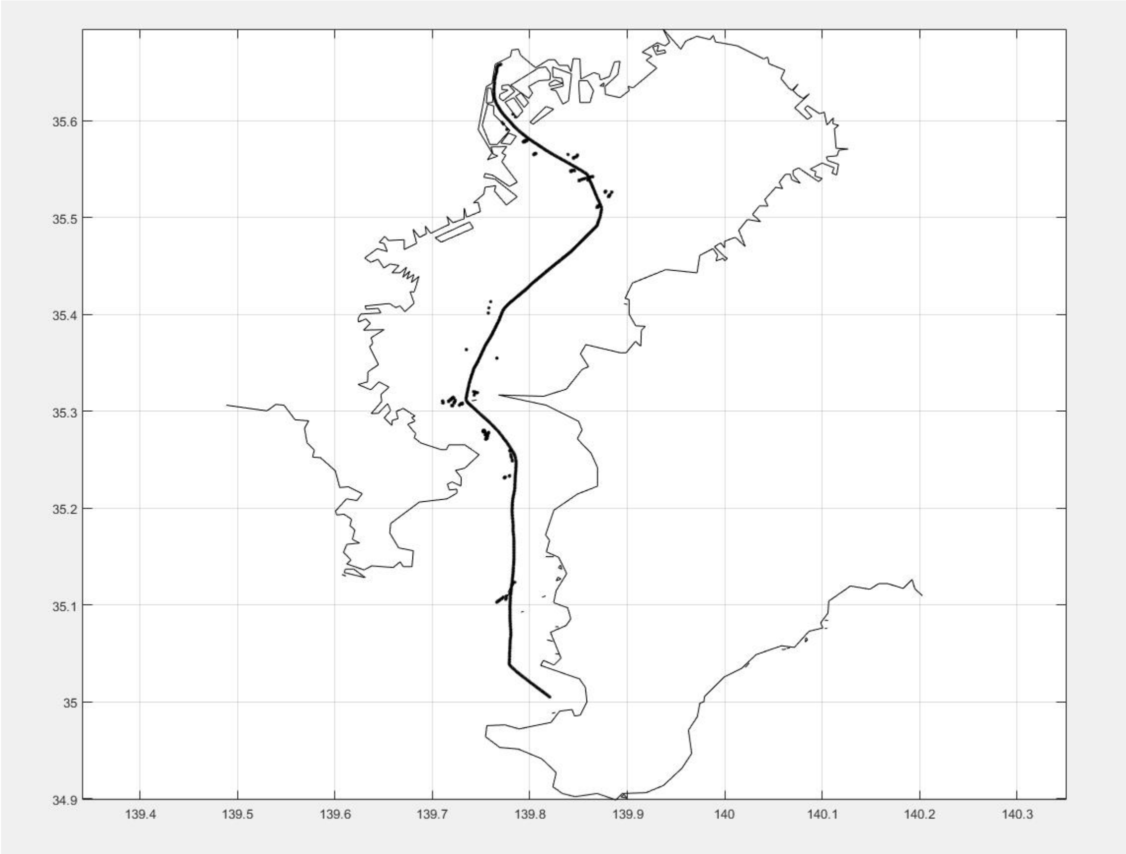

Figure 5.7 The authentic dangerous area for the Shioji Maru on May 11th, 2017

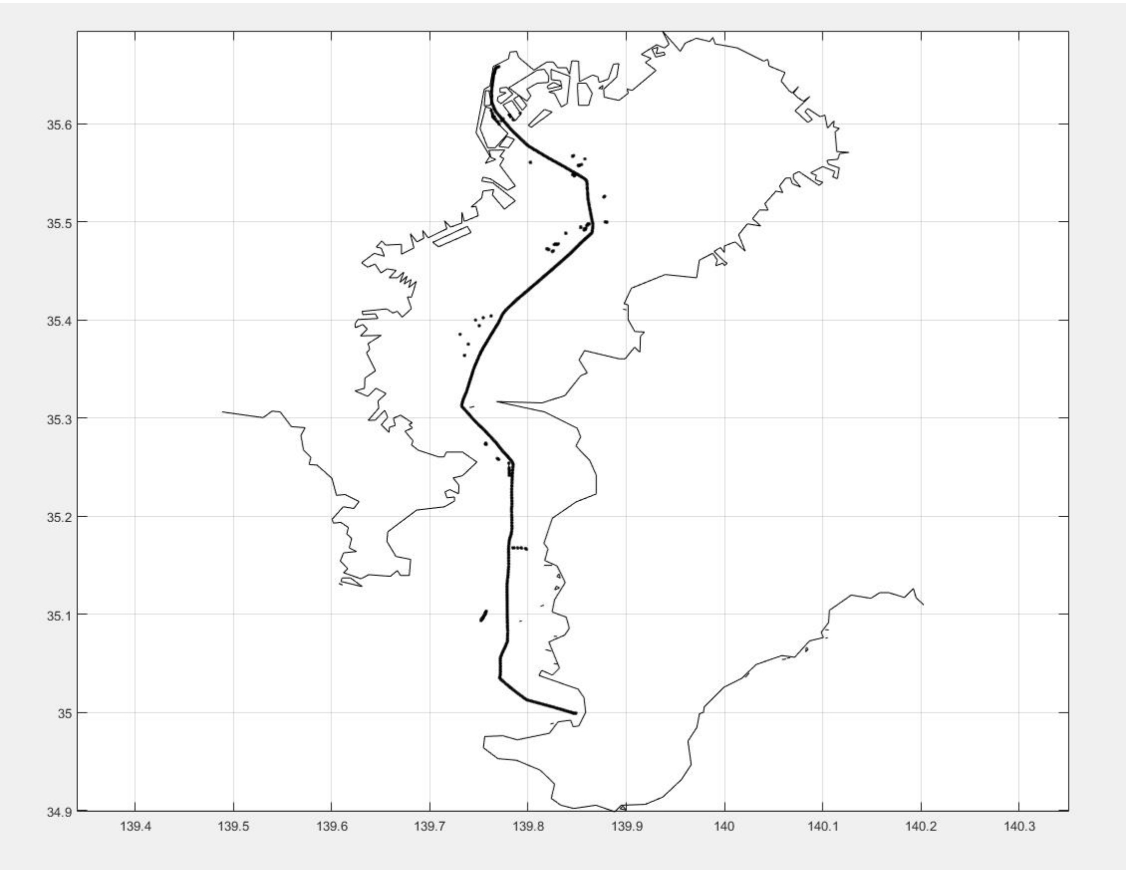

Figure 5.8 The authentic dangerous area for the Shioji Maru on May 25th, 2017

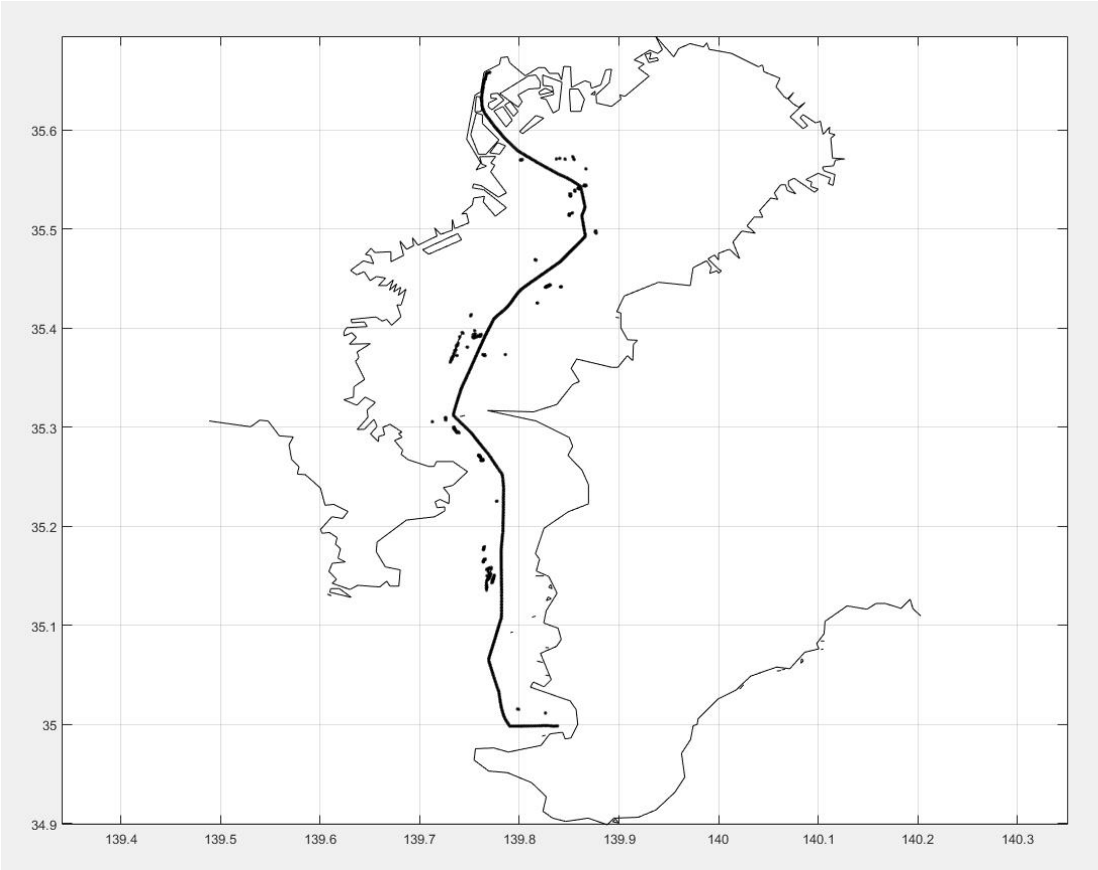

Figure 5.9 The authentic dangerous area for the Shioji Maru on June 8th, 2017

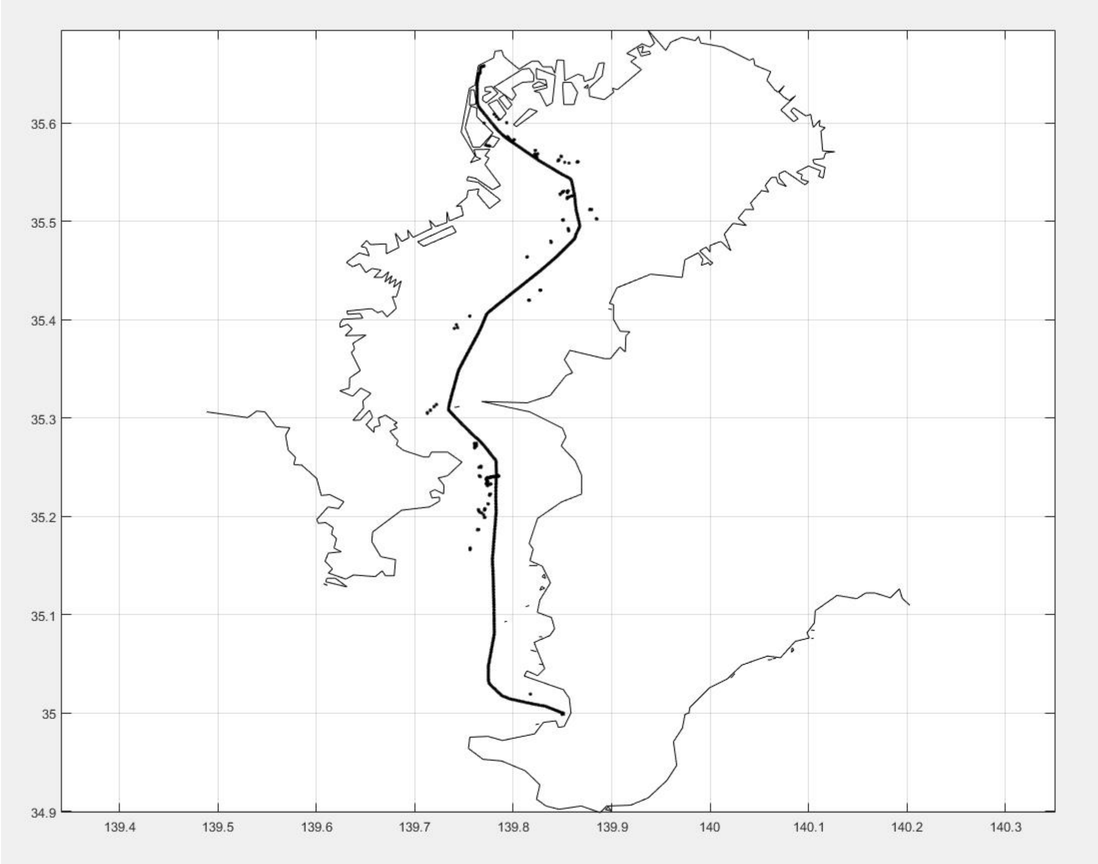

Figure 5.10 The authentic dangerous area for the Shioji Maru on June 15th, 2017

In Figure 5.6-5.10, the black line indicates the own ship route, while the black dots nearby the black line indicate the OZT areas in the five different days.

The five days OZT data on April 27th, May 11th, May 25th, June 8th and June 15th with and without the Shioji Maru ship route are as shown in the following Figure 5.11 and Figure 5.12. Different colors indicate different OZT areas from different dates. The OZT areas on April 27th, May 11th, May 25th, June 8th and June 15th are shown in blue, green, cyan, yellow and red respectively.

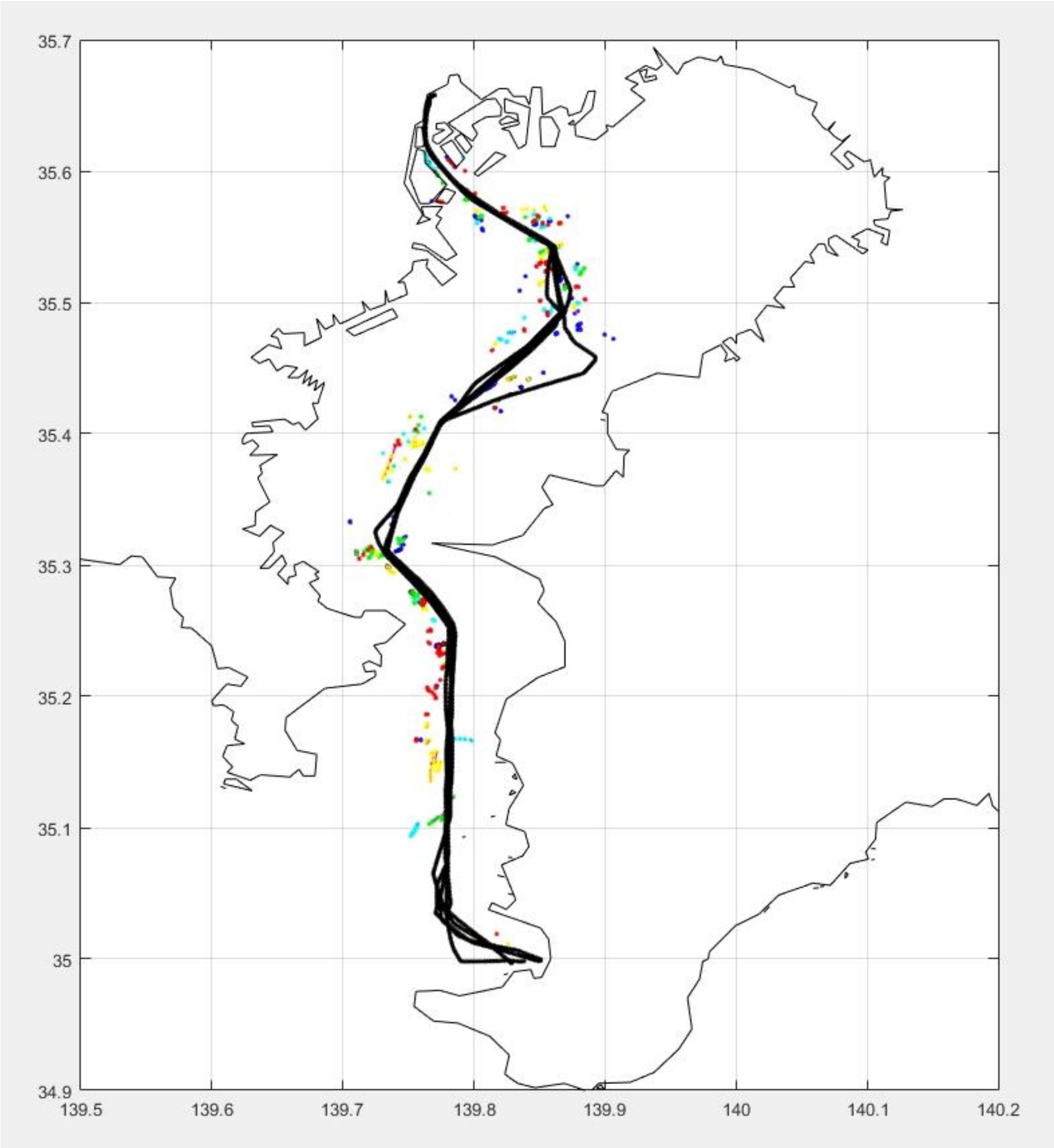

Figure 5.11 The superimposed five days authentic dangerous area for the Shioji Maru with own ship route

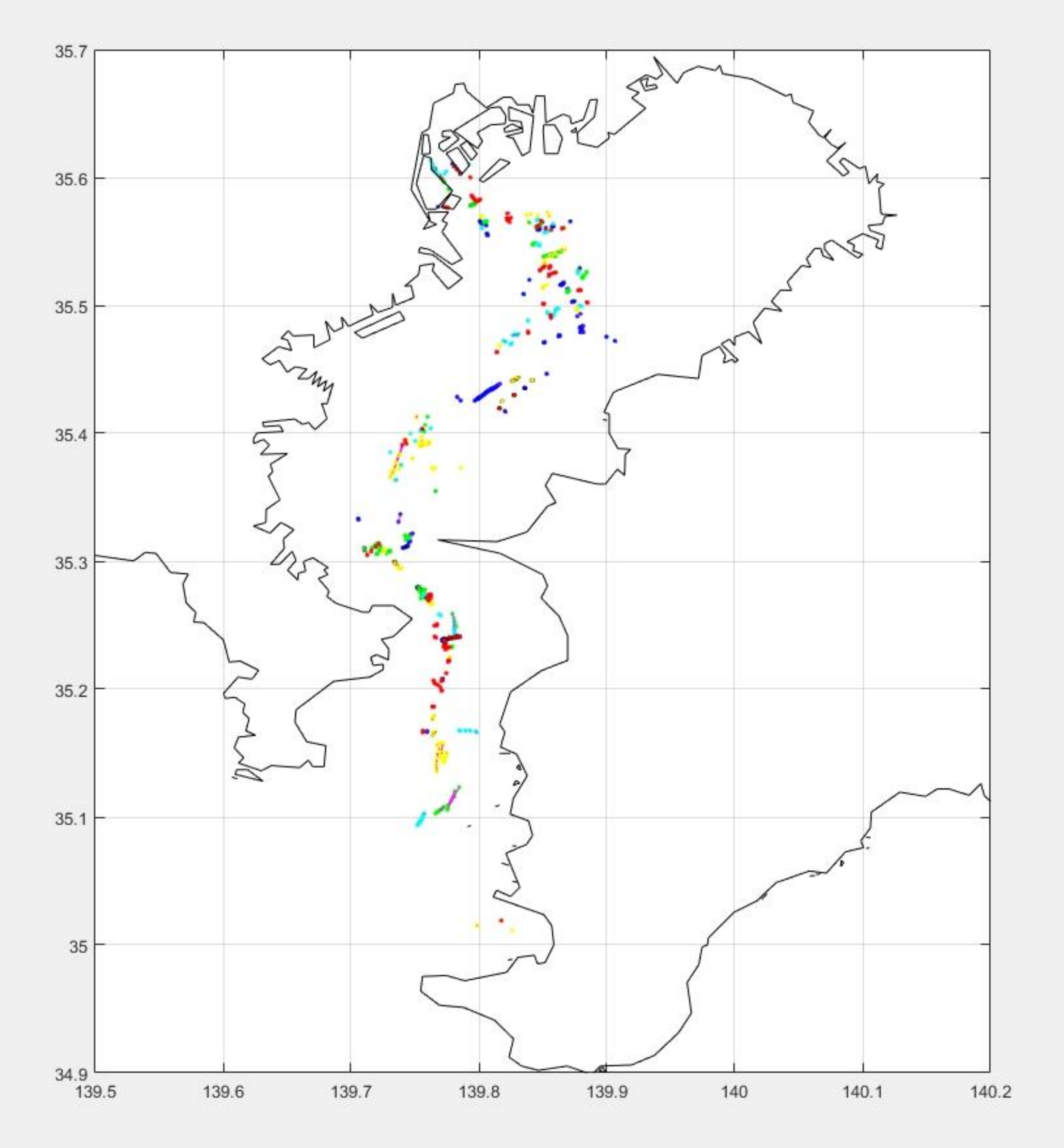

Figure 5.12 The superimposed five days authentic dangerous area for the Shioji Maru

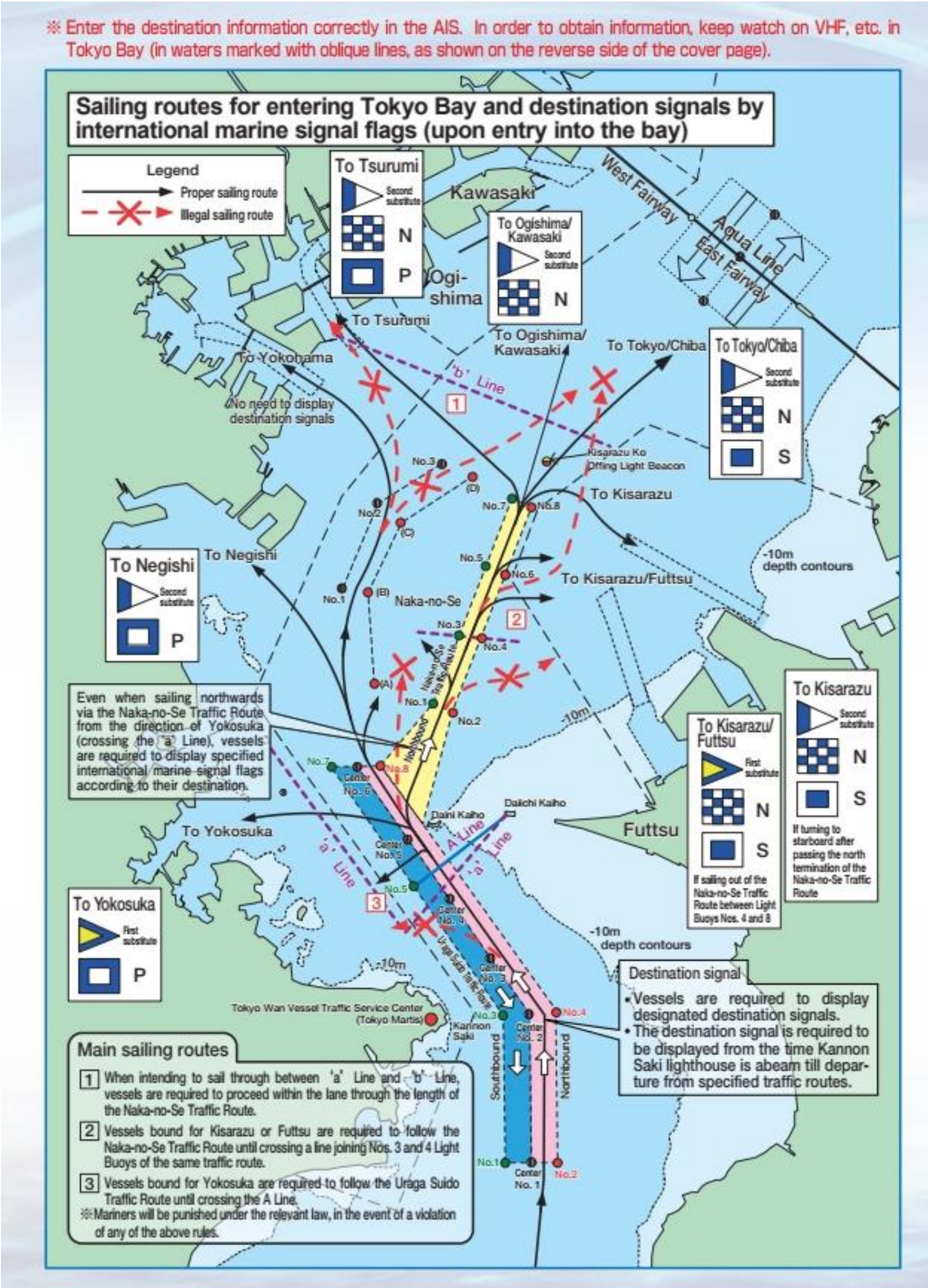

Figure 5.13 Sailing route in Tokyo Bay [13]

Without regard to the already existed traffic control area in Tokyo Bay for navigation safety (Figure 5.13), there are two densely-distributed OZT areas. From the five days data as shown in Figure 5.14, the two densely-distributed OZT areas are mainly in Area D and Area E, which are 139.81°E-139.86°E, 35.41°N-35.49°N and 139.83°E-139.89°E, 35.47°N-35.58°N. The safety area is mainly in Area F as shown in Figure 5.14, with the range of 139.75°E-139.81°E, 34.98°N-35.09°N. From the own ship route's respect, when the Shioji

Maru reaches the areas in 139.845°E-139.870°E, 35.538°N-35.557°N and 139.850°E-139.880°E, 35.480°N-35.518°N as shown in Figure 5.16, the own ship has maximum probability estimation to meet with relative dangerous ship encounter situations. Figure 5.15 shows the OZT emerge area on own ship route from five days data, with red areas indicate the own ship position when OZT data emerge and blue areas indicate no OZT data have been found from the own ship perspective.

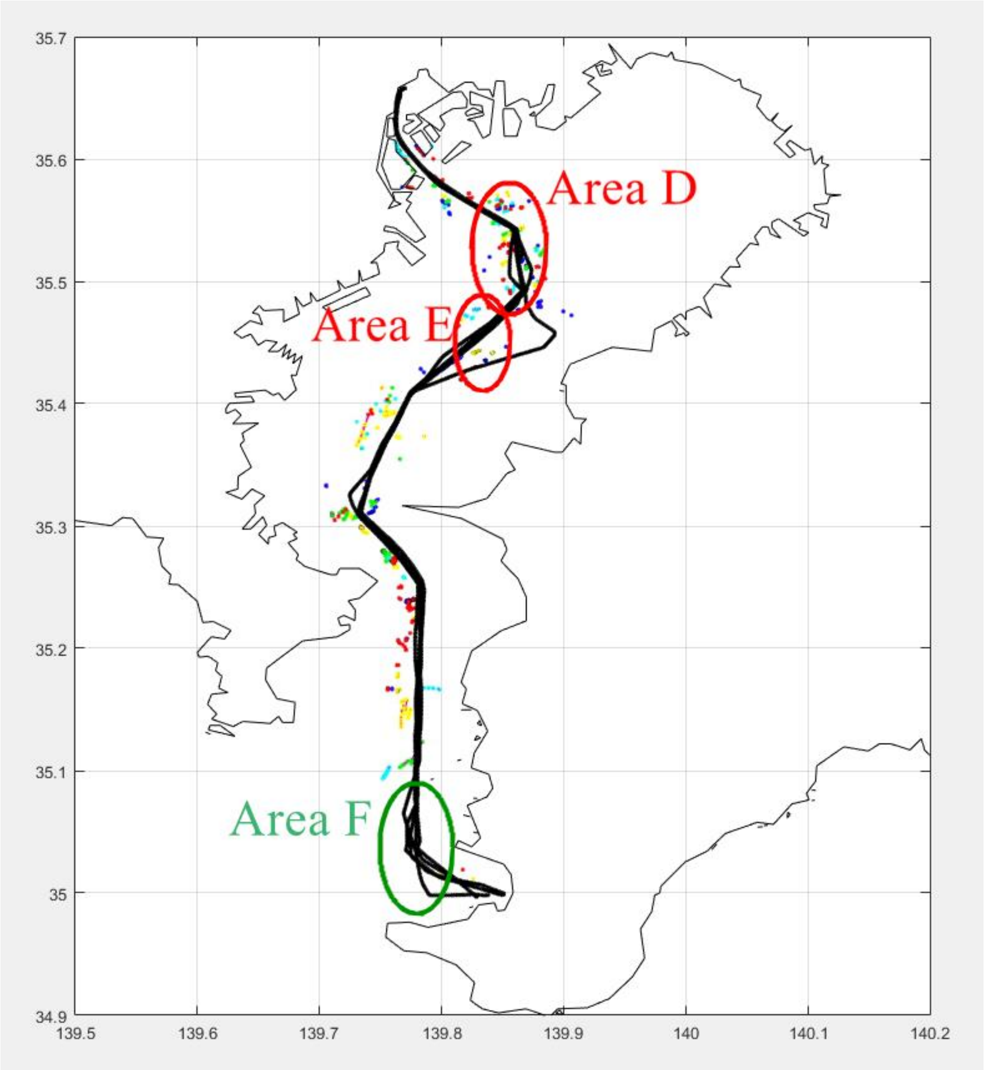

Figure 5.14 The densely-distributed OZT areas from five days data

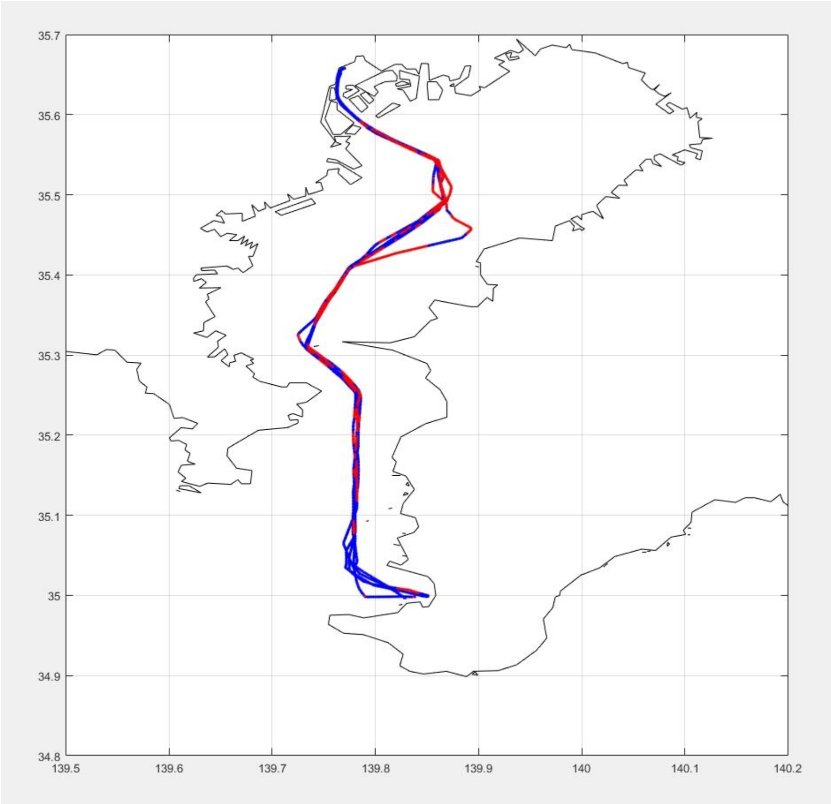

Figure 5.15 The OZT emerge area on own ship route from five days data

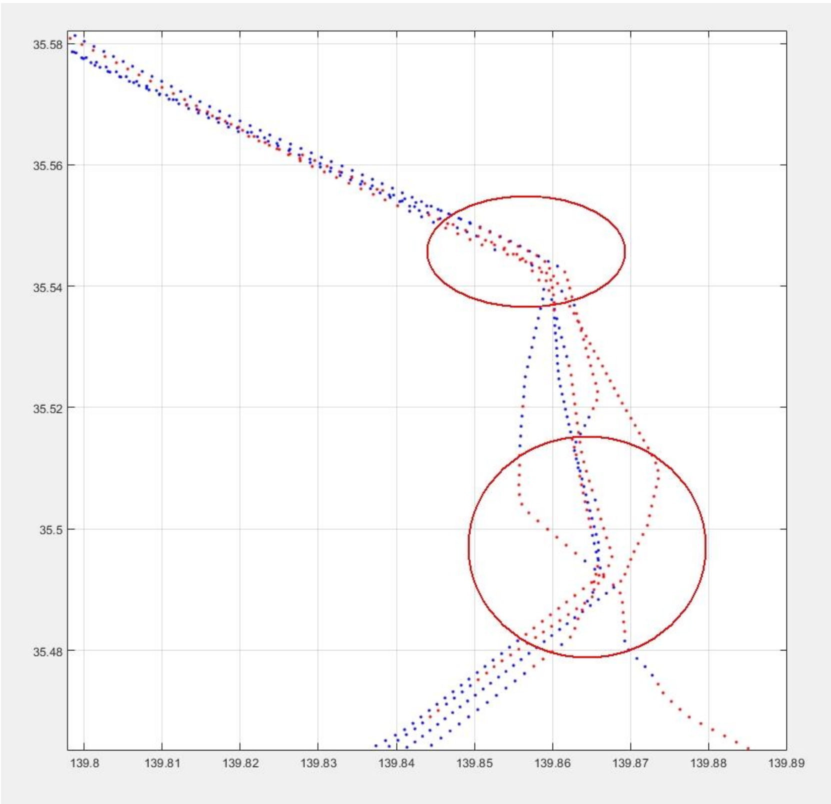

Figure 5.16 The densely-distributed OZT emerge area on own ship route from five days data

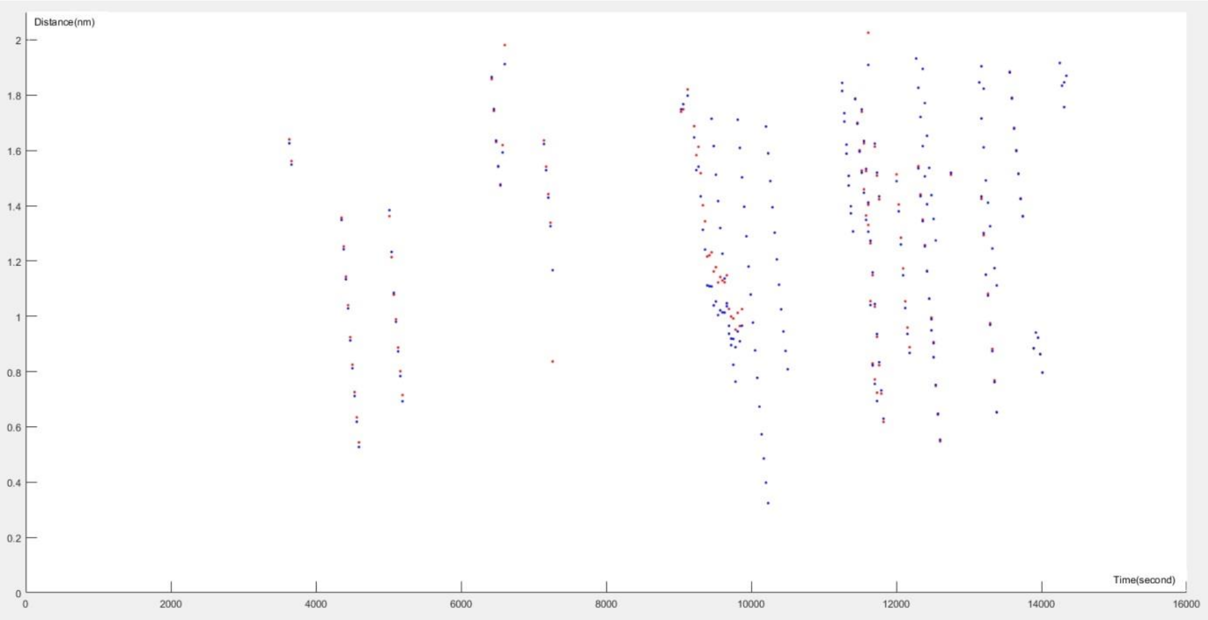

Figure 5.17 The OZT distance distribution diagram on April 27th, 2017

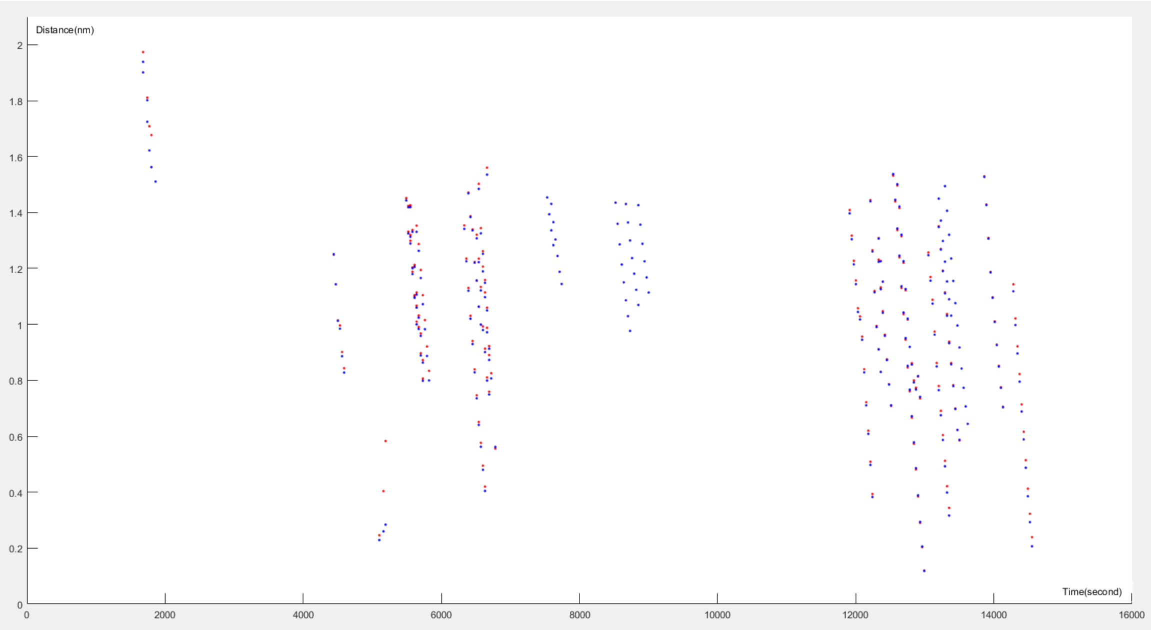

Figure 5.18 The OZT distance distribution diagram on May 11th, 2017

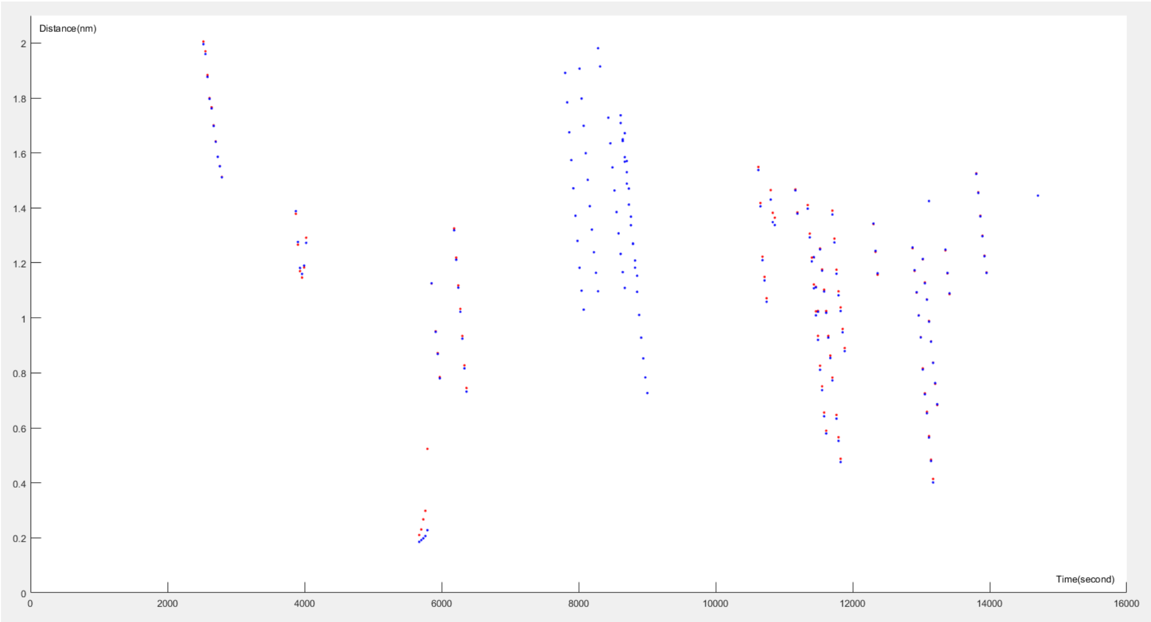

Figure 5.19 The OZT distance distribution diagram on May 25th, 2017

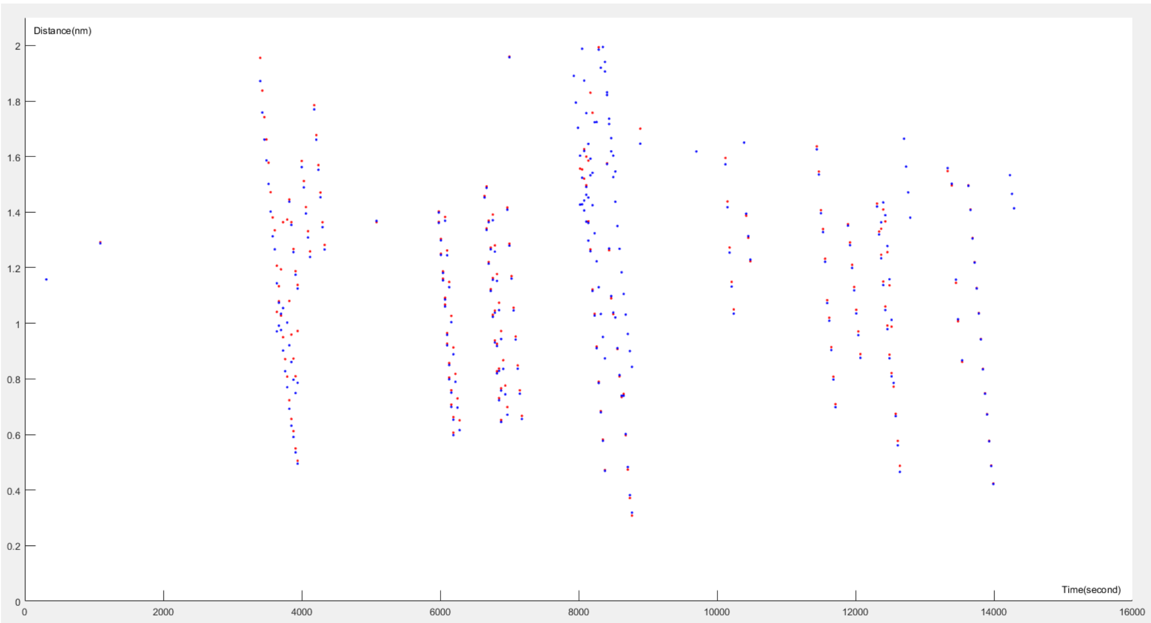

Figure 5.20 The OZT distance distribution diagram on June 8th, 2017

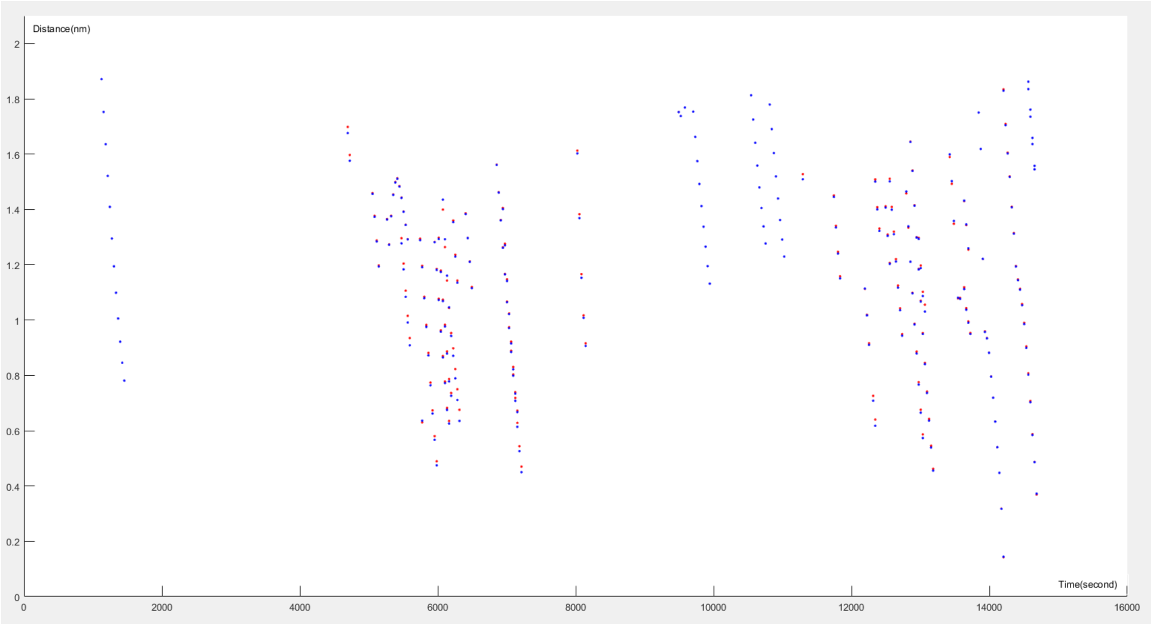

Figure 5.21 The OZT distance distribution diagram on June 15th, 2017

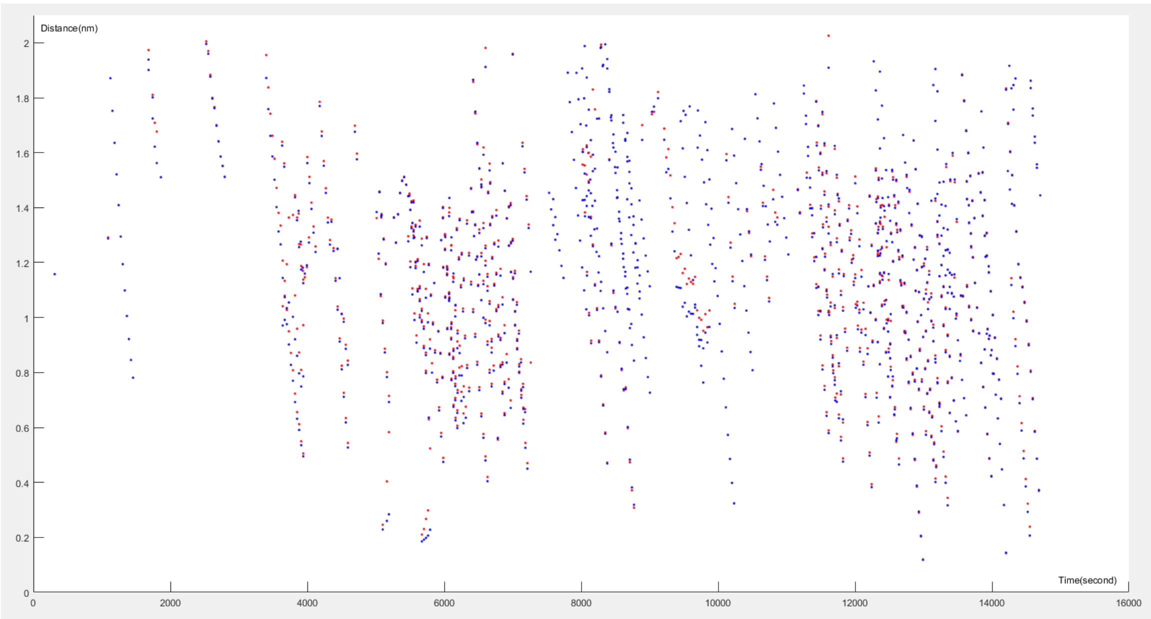

Figure 5.22 The five days superimposed OZT distance distribution diagram

In order to study the dangerous areas for ship collision avoidance, we eliminate the OZT areas which denote the docking ships when entering the harbor, so OZT areas which exist in the north of 35.58°N are removed. From Figure 5.17-5.21, the distance between the own ship and the OZT areas is mainly distributed in from 0.8 nm to 1.7 nm on April 27th, from 0.4 nm to 1.4 nm on May 11th, from 0.7 nm to 1.5 nm on May 25th, from 0.7 nm to 1.5 nm on June 8th, from 0.6 nm to 1.5 nm on June 15th. The generally distributed distance between the own ship and the OZT areas is from 0.6 nm to 1.5 nm as shown in Figure 5.22.

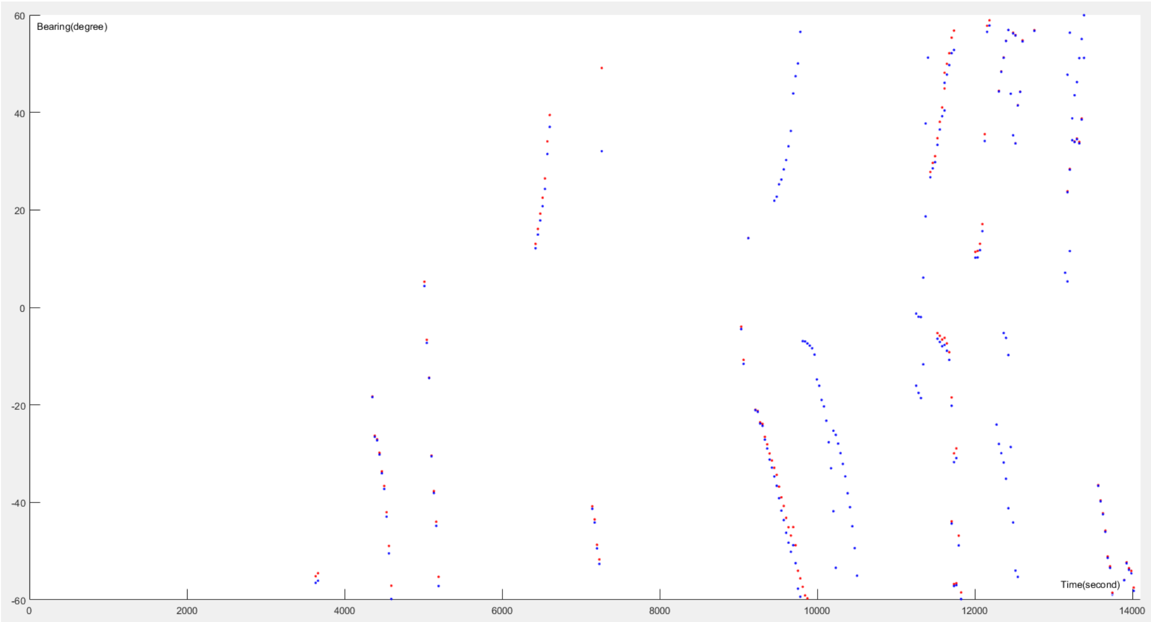

Figure 5.23 The OZT bearing distribution diagram on April 27th, 2017

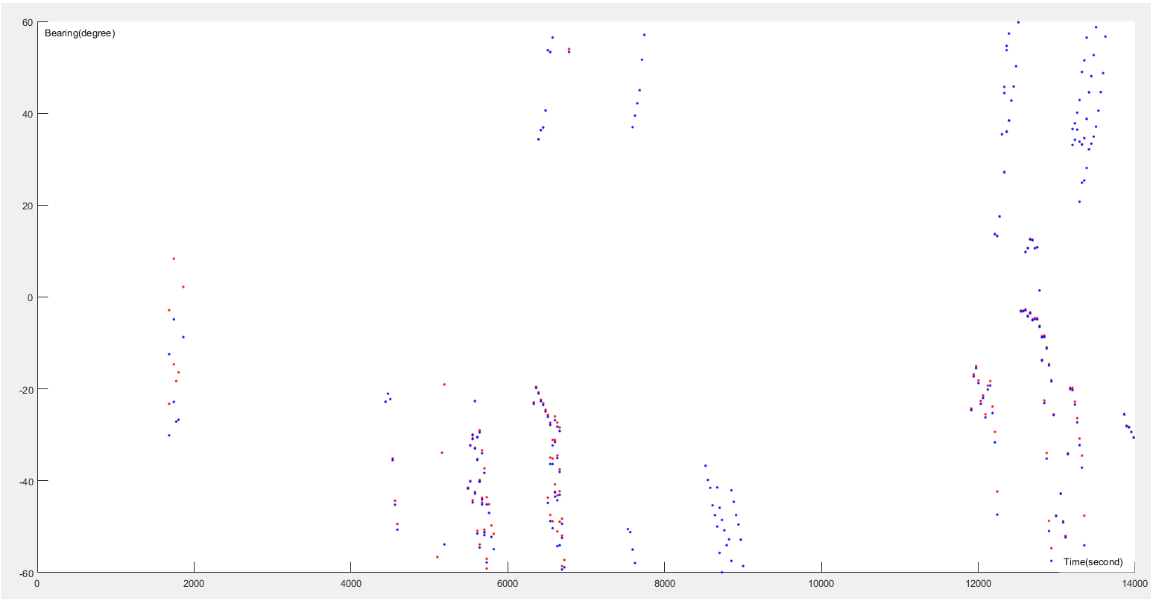

Figure 5.24 The OZT bearing distribution diagram on May 11th, 2017

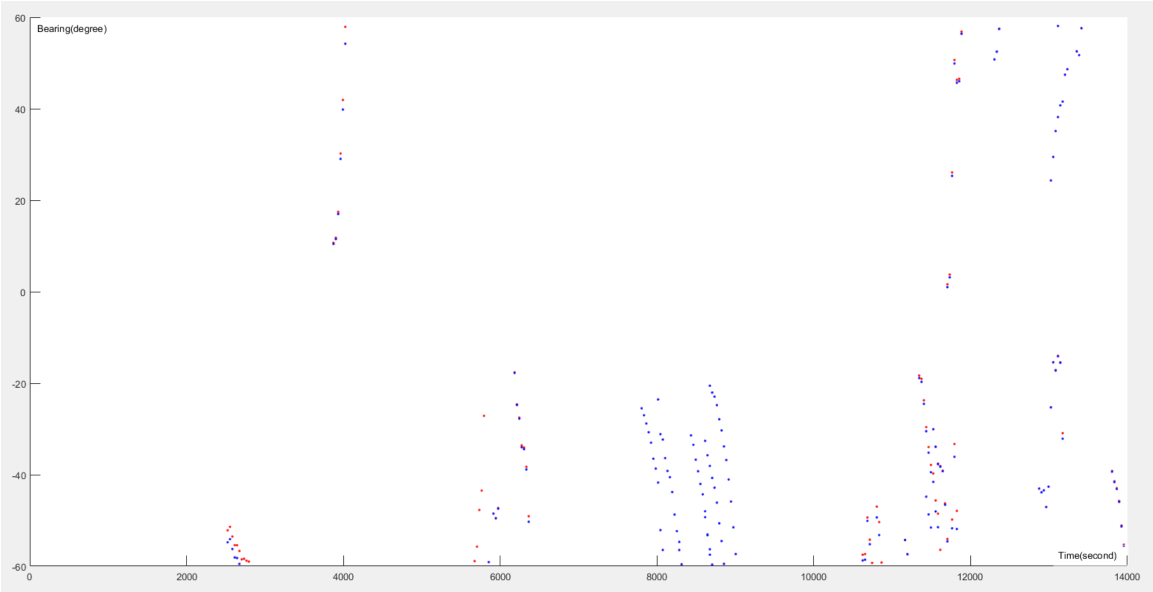

Figure 5.25 The OZT bearing distribution diagram on May 25th, 2017

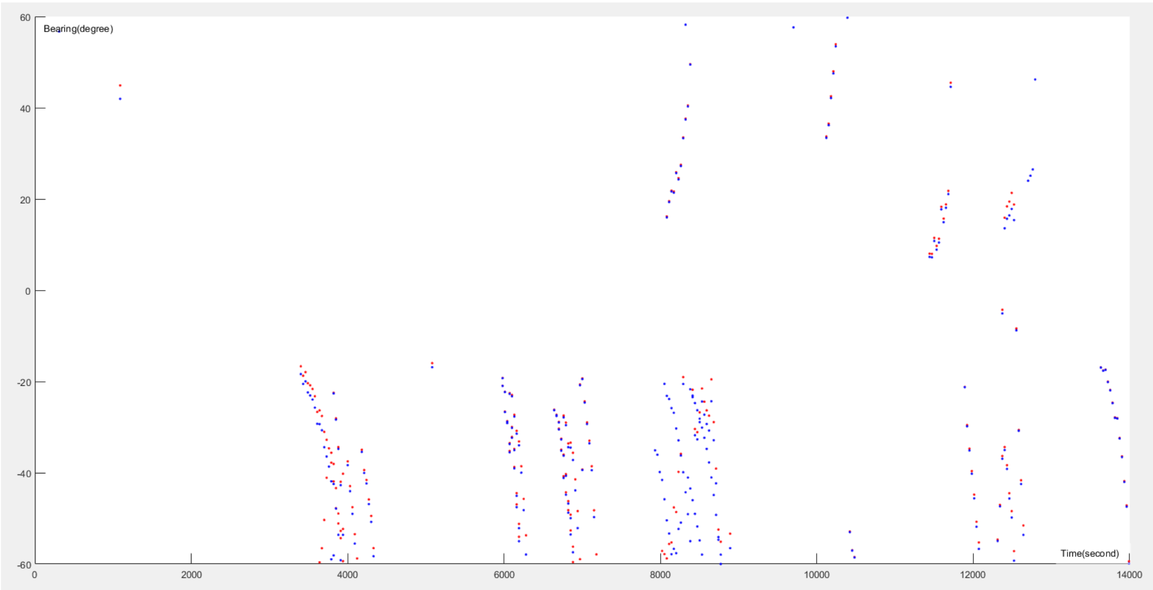

Figure 5.26 The OZT bearing distribution diagram on June 8th, 2017

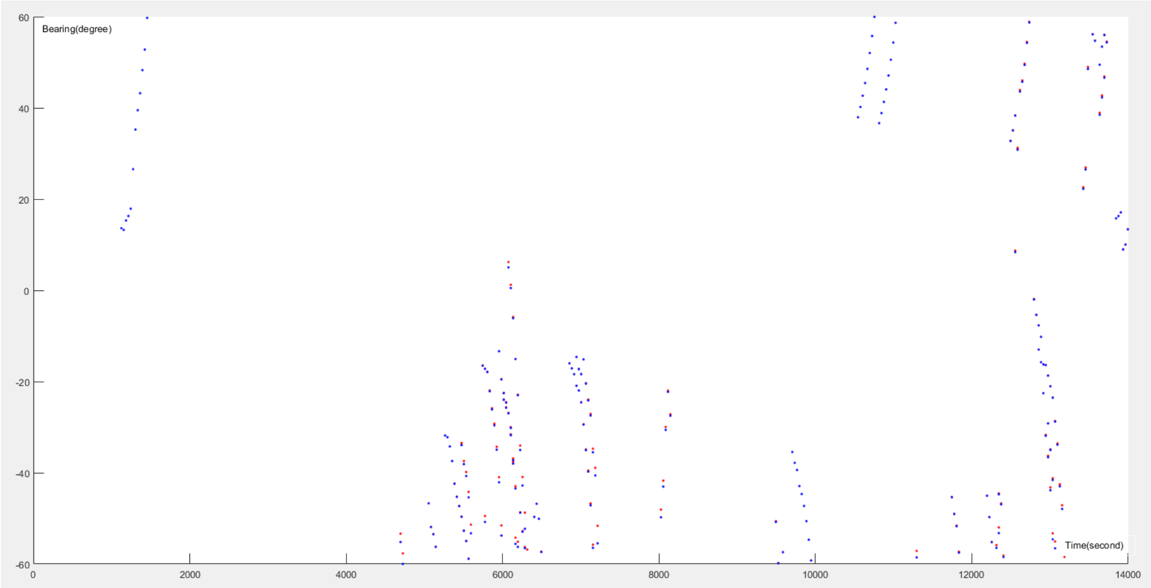

Figure 5.27 The OZT bearing distribution diagram on June 15^{th}, 2017

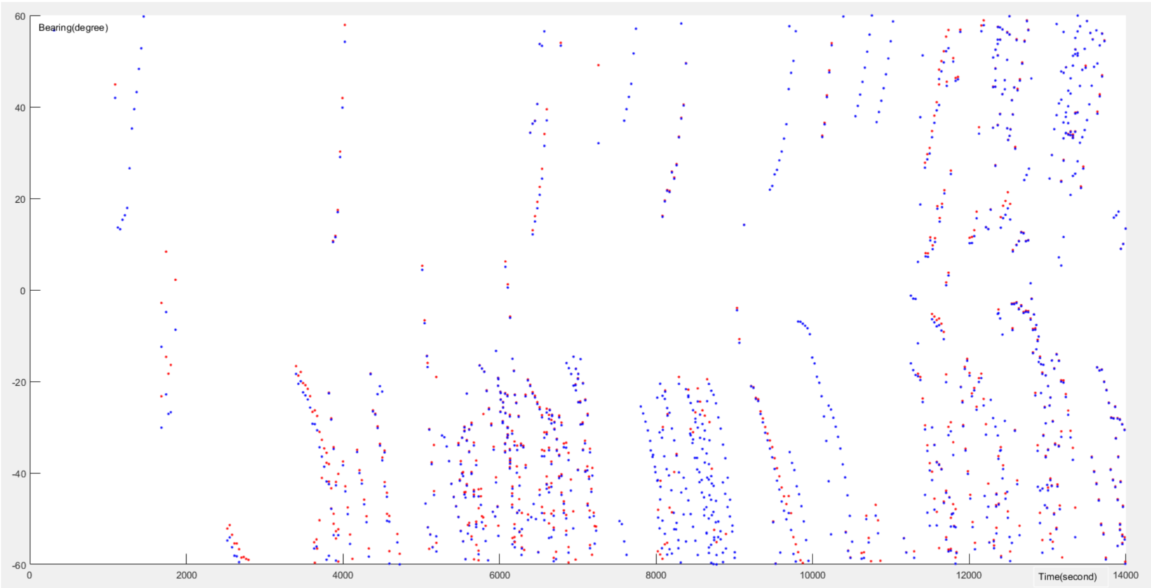

Figure 5.28 The five days superimposed OZT bearing distribution diagram

From Figure 5.23-5.27, the relative bearing between the own ship and the OZT areas is mainly distributed in Port 20°-60° and Starboard 20°-60° on April 27^{th}, Port 20°-60° and Starboard 30°-60° on May 11^{th}, Port 20°-60° and Starboard 20°-60° on May 25^{th}, Port 20°-60° and Starboard 20°-60° on June 8^{th}, Port 20°-60° and Starboard 30°-60° on June 15^{th}. The generally distributed relative bearing between the own ship and the OZT areas is Port 20°-60° and Starboard 20°-60° as shown in Figure 5.28.

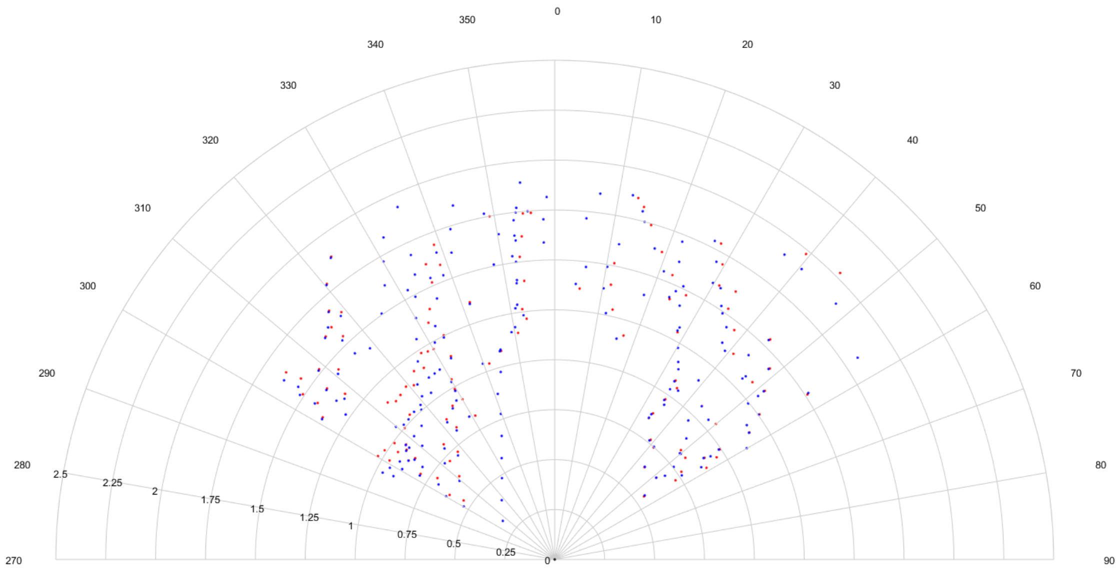

Figure 5.29 The OZT distribution diagram on April 27th, 2017

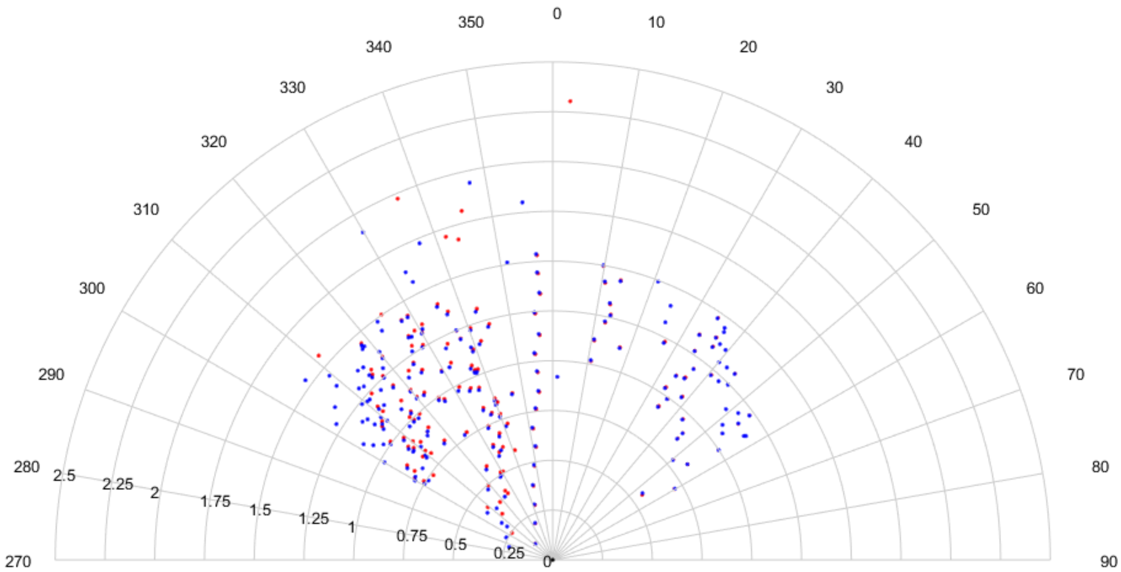

Figure 5.30 The OZT distribution diagram on May 11th, 2017

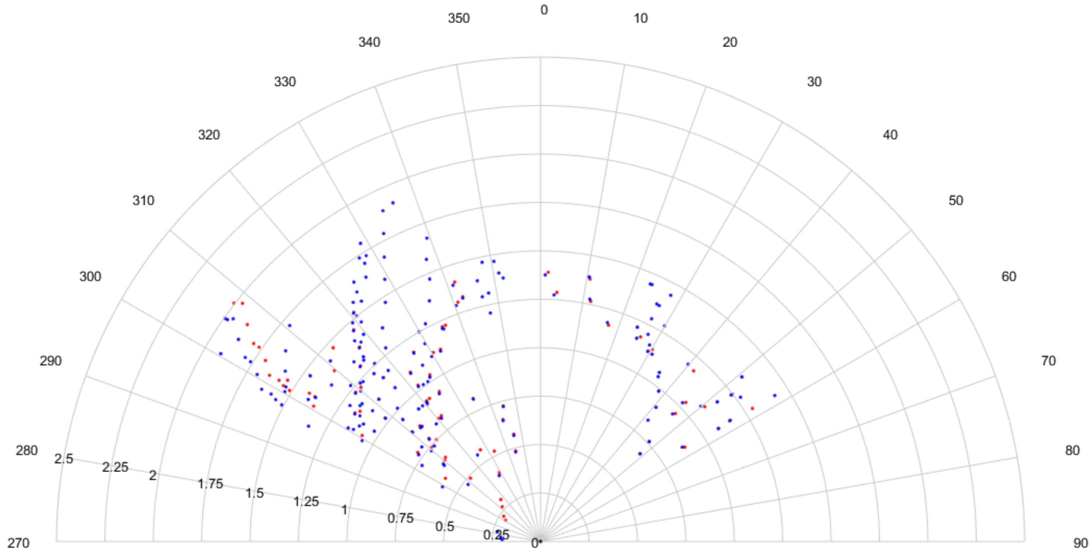

Figure 5.31 The OZT distribution diagram on May25th, 2017

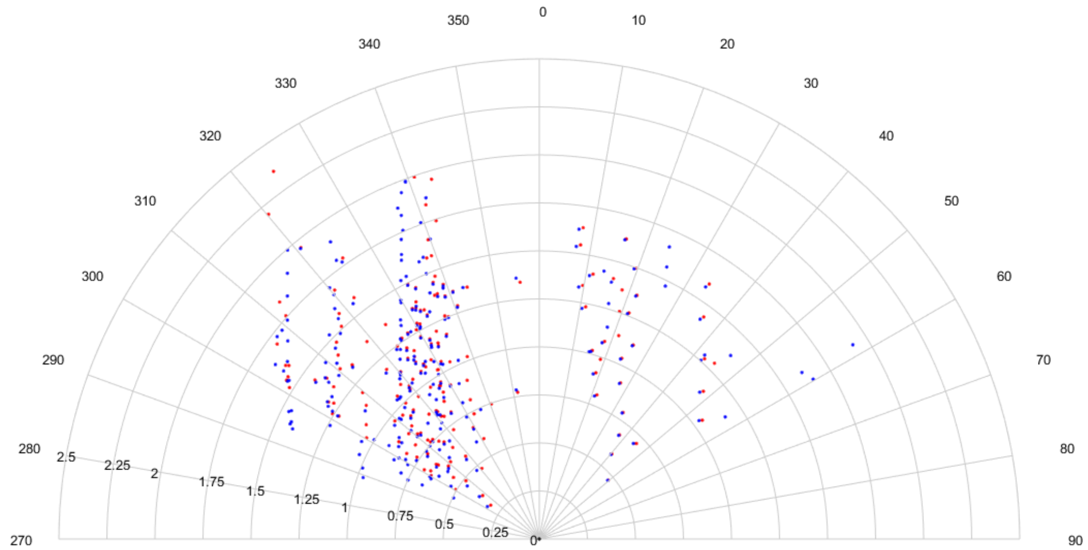

Figure 5.32 The OZT distribution diagram on June 8th, 2017

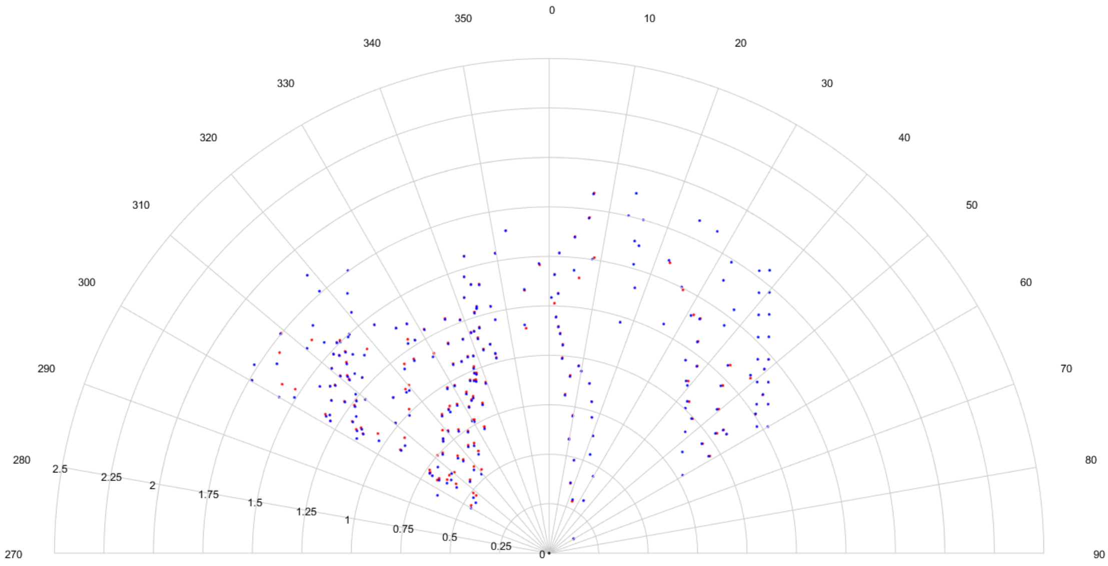

Figure 5.33 The OZT distribution diagram on June 15th, 2017

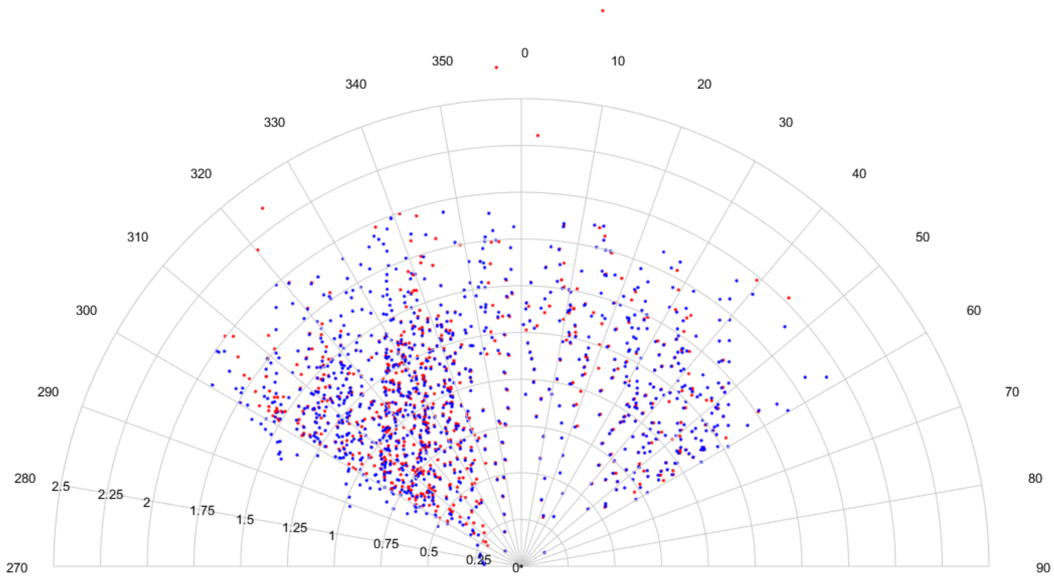

Figure 5.34 The five days superimposed OZT distribution diagram

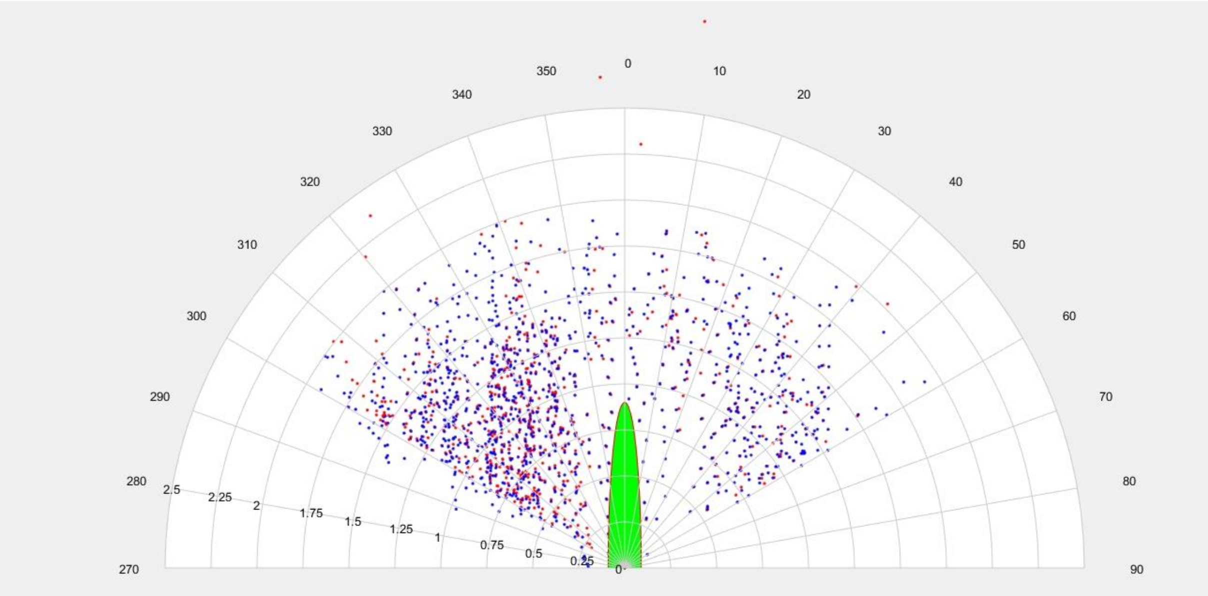

Figure 5.35 The five days superimposed OZT distribution diagram with safety area

From the Figure 5.29 to Figure 5.34, we build a safety area that there is no OZT data intrudes into this area in five days. As shown in Figure 5.35, the green area is what we believe a safety area. This safety area is an ellipse, with the major semi-axis is 0.9 nm and minor semi-axis is 0.09 nm.

5.2 Ship Encounter Situations Statistic

Based on the ship encounter situations categorizes we built on Chapter 4.1, here we make a classified statistic of ship encounter situations of the Shioji Maru in relative dangerous conditions.

Table 5.1 The relative dangerous ship encounter situation statistic

Situation / Date	Head-on (Number of Cases)	Port crossing (Number of Cases)	Starboard crossing (Number of Cases)	Overtaking (Number of Cases)	Overtaken (Number of Cases)	Stationary (Number of Cases)	Total (Number of Cases)
0427	0	7	5	2	0	8	22
0511	0	10	5	0	1	7	23
0525	0	8	5	1	1	14	29
0608	0	8	2	0	1	6	17
0615	0	19	5	1	0	5	30

Table 5.2 Ship encounter situation statistic in two areas

Date	Situation	Total (Number of Cases)	Traffic Controlled area (Number of Cases)	Percentage (%)	Dangerous area (Number of Cases)	Percentage (%)	Total percentage (%)
0427	Port crossing	7	2	28.57	3	42.86	71.43
	Starboard crossing	5	1	20.00	1	20.00	40.00
	Stationary	8	0	0.00	5	62.50	62.50
	Overtaking	2	1	50.00	0	0.00	50.00
0511	Port crossing	10	6	60.00	2	20.00	80.00
	Starboard crossing	5	1	20.00	4	80.00	100.00
	Stationary	7	5	71.43	2	28.57	100.00
	Overtaken	1	1	100.00	0	0.00	100.00
0525	Port crossing	8	2	25.00	4	50.00	75.00
	Starboard crossing	5	0	0.00	5	100.00	100.00
	Stationary	14	7	50.00	1	7.14	57.14
	Overtaking	1	1	100.00	0	0.00	100.00
	Overtaken	1	1	100.00	0	0.00	100.00
0608	Port crossing	8	4	50.00	3	37.50	87.50
	Starboard crossing	2	1	50.00	1	50.00	100.00
	Stationary	6	4	66.67	1	16.67	83.33
	Overtaken	1	1	100.00	0	0.00	100.00
0615	Port crossing	19	8	42.11	6	31.58	73.68
	Starboard crossing	5	0	0.00	5	100.00	100.00
	Stationary	5	1	20.00	0	0.00	20.00
	Overtaking	1	0	0.00	0	0.00	0.00

On account of Chapter 5.1 Figure 5.14, here we count the relative dangerous ship encounter situations occur in the Tokyo Bay traffic controlled area and the dangerous area we proposed, from the Table 5.2, most of the relative dangerous ship encounter situations occurs in those two areas.

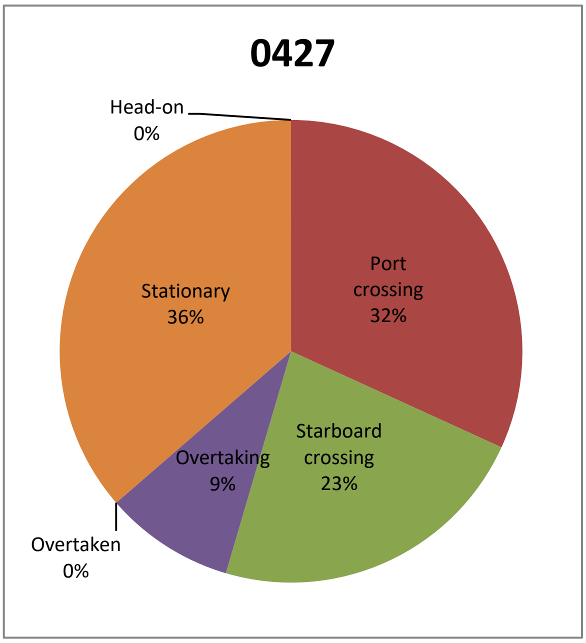

Figure 5.36 The relative dangerous continuous ship encounter situation on April 27th, 2017

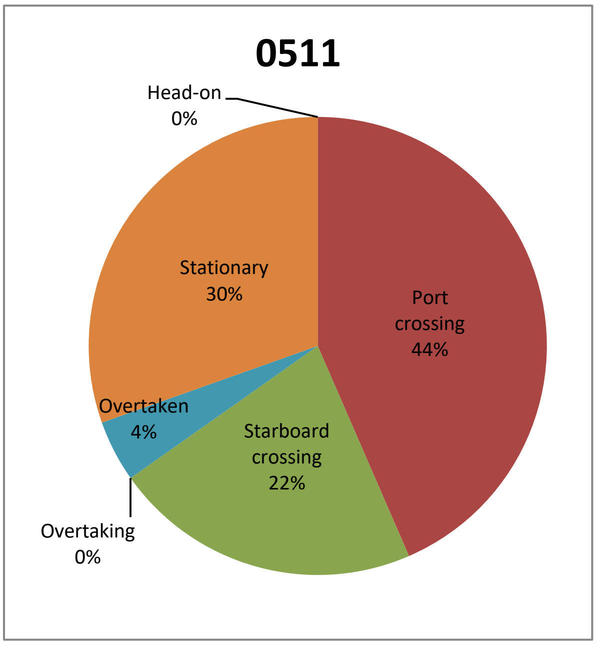

Figure 5.37 The relative dangerous continuous ship encounter situation on May 11th, 2017

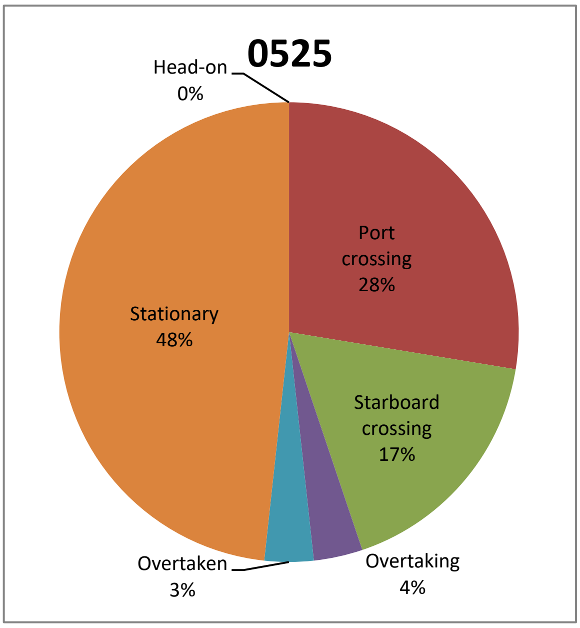

Figure 5.38 The relative dangerous continuous ship encounter situation on May25th, 2017

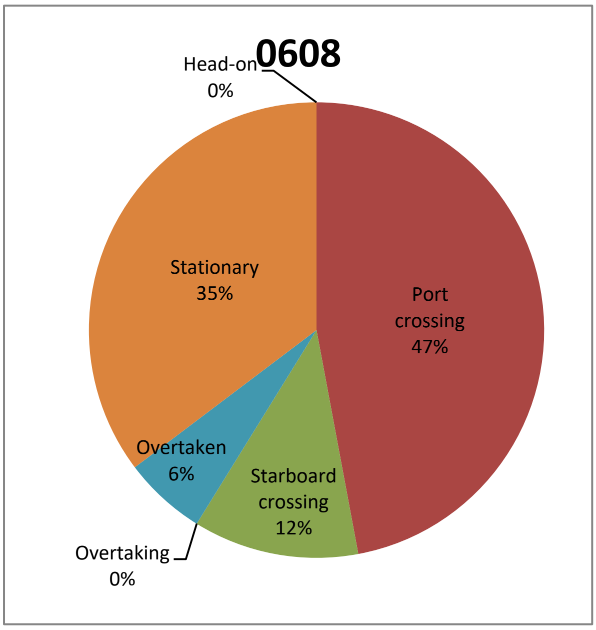

Figure 5.39 The relative dangerous continuous ship encounter situation on June 8th, 2017

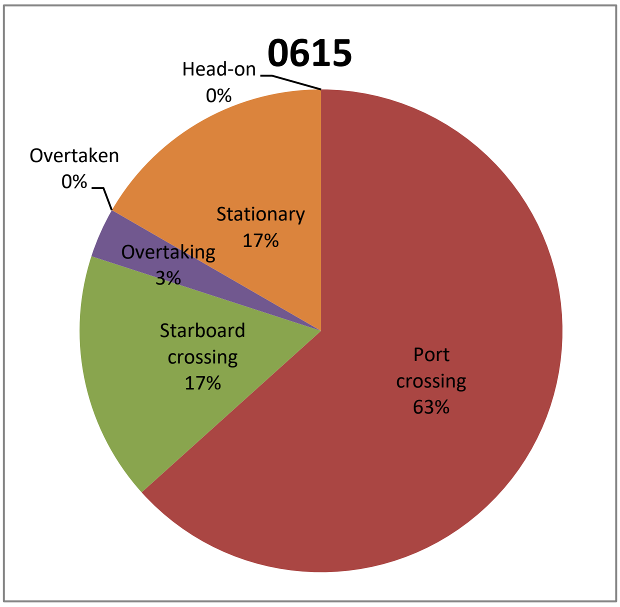

Figure 5.40 The relative dangerous continuous ship encounter situation on June 15th, 2017

From the statistic of relative dangerous ship encounter situation, the port crossing account for a much greater portion, while there is no continuous dangerous head-on situation appears from these five days data statistics. The navigator of the Shioji Maru either takes the collision avoidance actions earlier and finds a safety route to ensure navigation safety or changes the original dangerous head-on situation to crossing situation, those are the reasons no continuous dangerous head-on situation appears. For the higher proportion of port crossing, 50 percent of the continuous dangerous port crossing situations occur in the traffic control areas in Tokyo Bay when the Shioji Maru enters the port.

Here, we propose a simple indicator κ for navigation safety evaluation

$$\kappa = \frac{Time\ of\ Appear\ OZT}{Total\ Navigation\ Time}$$

While the smaller the κ is, the less time for the own ship encountered the dangerous situation, in other words, the relative navigation safety it presents.

Table 5.3 The navigation safety indicator

Date \ κ	κ
0427	0.2955
0511	0.2562
0525	0.2647
0608	0.3149
0615	0.3632

On June 15th, the $\kappa = 0.3632$, which indicates the navigator spends longer time on collision avoidance handling compared to May 11th, while the $\kappa = 0.2562$.

5.3 Navigation Characteristics Analysis

As no continuous head-on collision avoidance encounter situation is witnessed in these five days, we select five kinds of representative ship encounter situations and analyze navigation characteristics using the OZT theory. The five representative ship encounter situations are: Port crossing, Starboard crossing, Overtaking, Overtaken and complex situation. The red and black dots indicate the own ship (Shioji Maru) position, denote the own ship position whether the own ship witnesses the OZT data or not respectively. The asterisk marks indicate the positions of target ships, with different colors represent different target ships. The lilac and ondine circles represent the OZT areas. The time shown in the figures is described by second. For example, 00:00:30 UTC is converted into 30 second.

(1) Port crossing.

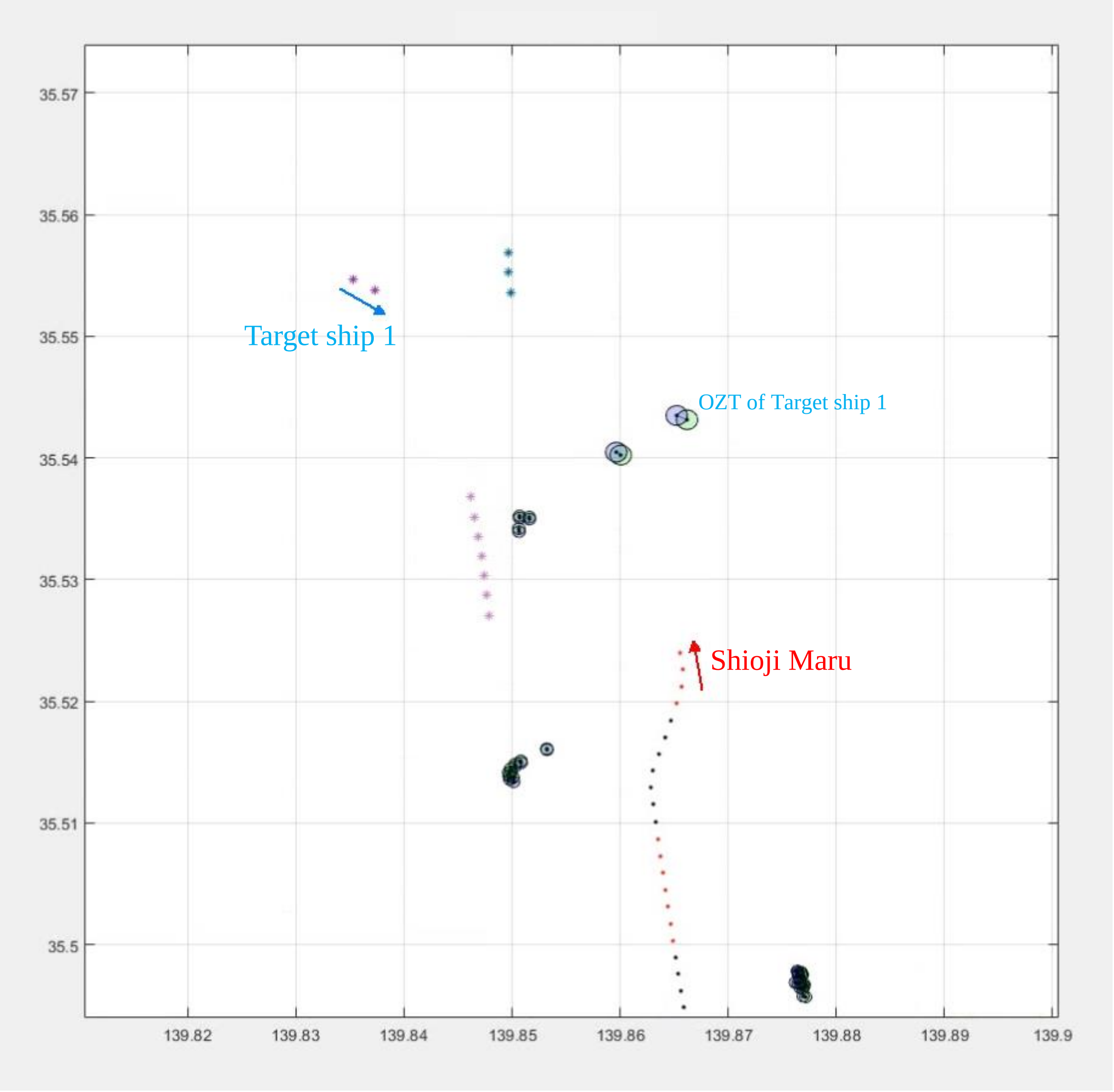

Figure 5.41 Ship encounter situations analysis (Time=12401)

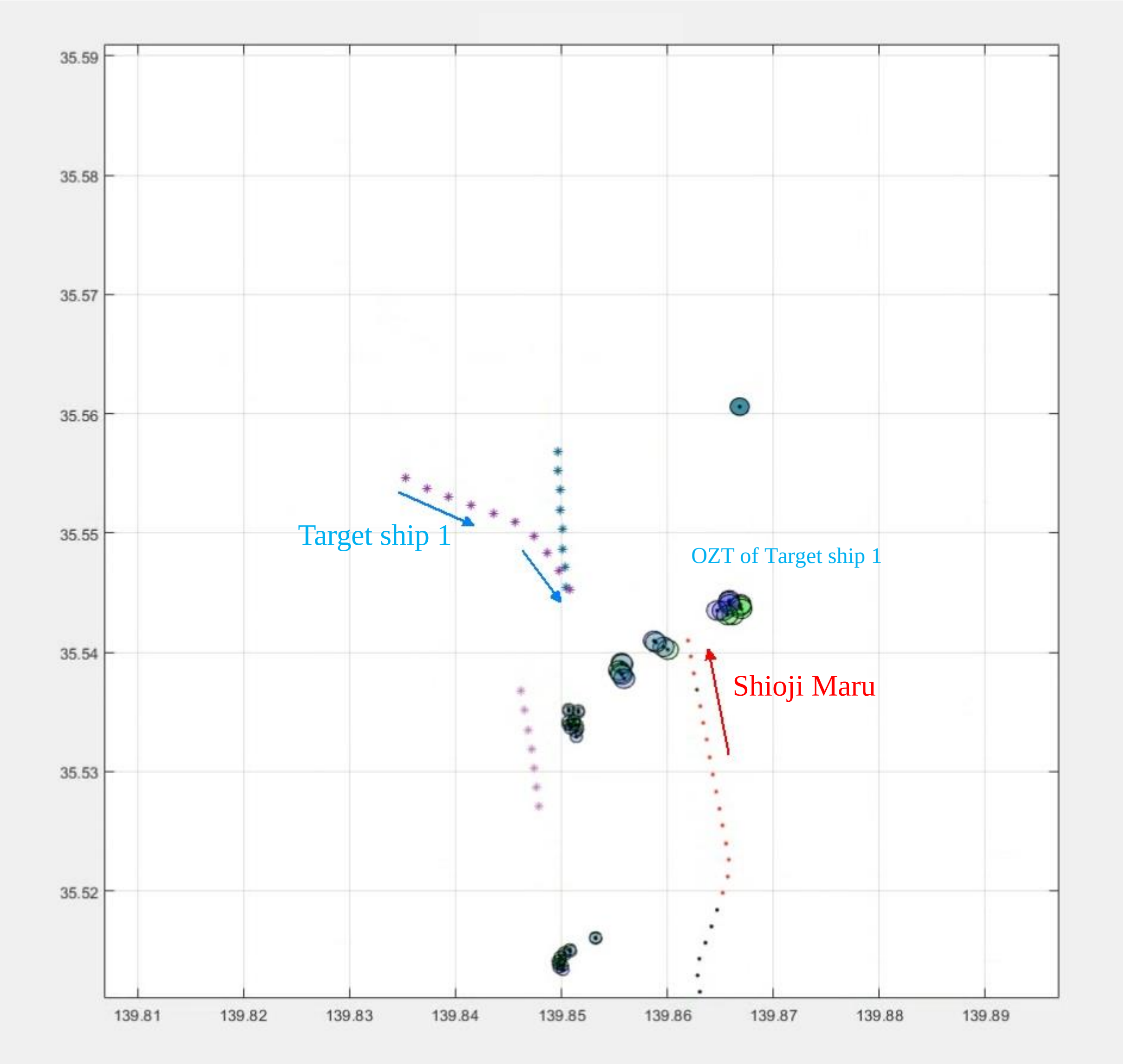

Figure 5.42 Ship encounter situations analysis (Time=12761)

Table 5.4 The own ship information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
12341	10.40526	35.52119	139.8657	11.26316	7.473684
12371	10.13333	35.52262	139.8658	356	349.3333
12401	10.2	35.52397	139.8655	349.3333	345.6667
12431	10.39091	35.52549	139.8652	349	345.9091
12461	10.5	35.52688	139.8649	349.9	346
12491	10.40909	35.52831	139.8646	349.0909	345.9091
12521	10.41	35.52975	139.8643	349.1	346
12551	10.5	35.53119	139.864	349.0526	345.0526
12581	10.5	35.53268	139.8637	349.1	345.1
12611	10.30909	35.53408	139.8634	349.8182	345.9091
12641	10.2	35.53548	139.8631	350.1	345.1
12671	10.00909	35.53686	139.8628	348.0909	343.9091
12701	10	35.53823	139.8625	349.1	345
12731	10	35.53966	139.8622	351	345.0909
12761	10.09	35.54099	139.862	350	345

Table 5.5 The target ship 1 information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
12341	13.5	35.55581	139.8334	127.4333	130
12371	13.6	35.55464	139.8352	125.42	128.4
12401	13.41111	35.55373	139.8373	114.2	116.3333
12431	13.2	35.55305	139.8393	111.84	115
12461	13.38889	35.55237	139.8414	112.1889	116
12491	13.5	35.55165	139.8436	112.68	116
12521	13.51111	35.55089	139.8457	115.3778	119.6667
12551	12.76667	35.54979	139.8474	133.6667	139.6667
12581	12.56667	35.54833	139.8487	148.2	153
12611	12.88	35.54683	139.8498	150.82	154
12641	13.1	35.54523	139.8508	150.7	153
12671	13.38	35.54357	139.852	150.66	153.2
12701	13.58889	35.54189	139.8531	150.5222	154
12731	13.61111	35.54027	139.8542	152.9667	156.7778
12761	13.8	35.53851	139.8552	154.8778	158

At time 12341, the own ship witnesses the OZT area along its course, but the own ship is the stand-on ship according to the COLREG-1972, the target ship 1 is the crossing give-way ship, so the target ship 1 turns to starboard to avoid collision. But the target ship 1 turns to port from time 12401 (as shown in Figure 5.41) and then realizes the collision risk from time 12521 so that it turns to starboard to avoid collision, but this action is relative not timely.

Until time 12761(shown in Figure 5.42), no OZT area is witnessed along the course of the own ship, so collision avoidance actions are completed.

(2) Starboard crossing.

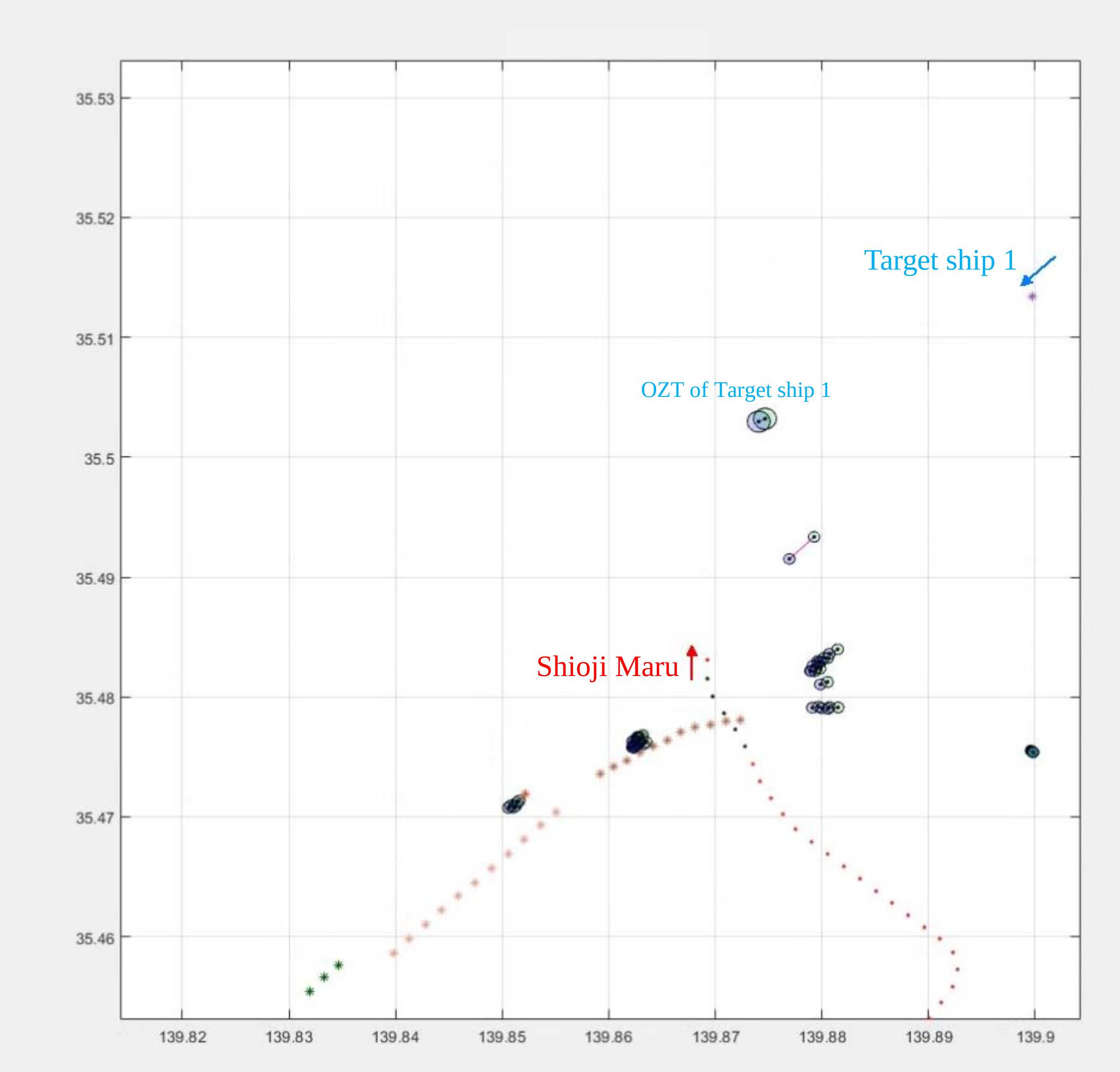

Figure 5.43 Ship encounter situations analysis (Time=12003)

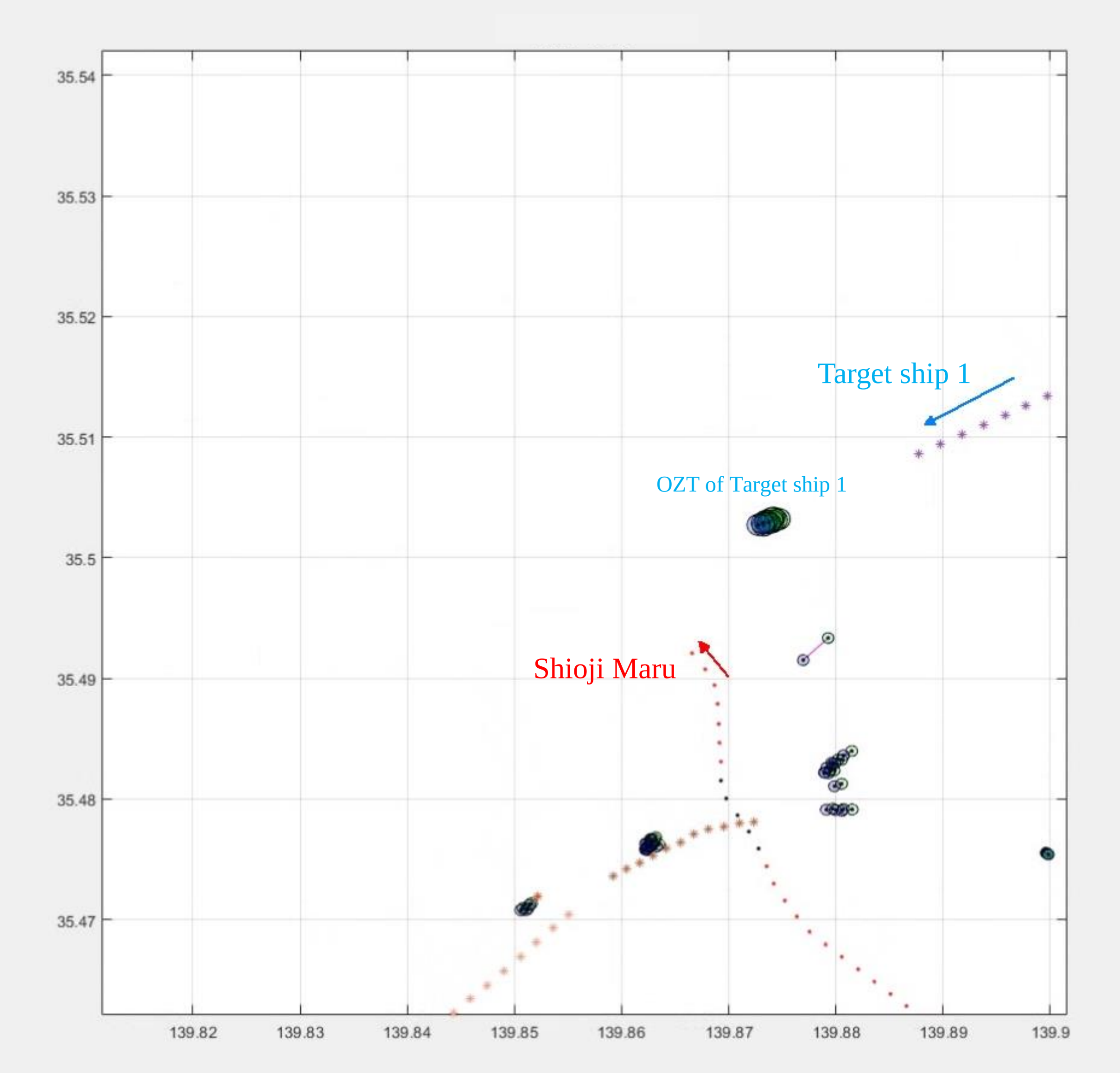

Figure 5.44 Ship encounter situations analysis (Time=12183)

Table 5.6 The own ship information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
12003	11.4	35.48309	139.8693	0	1
12033	11.3	35.48466	139.8691	356.2	0.9
12063	11.3	35.48622	139.8691	358	1.363636
12093	11.3	35.48787	139.869	355.3	358
12123	11.24286	35.48943	139.8687	343.1429	342.1429
12153	11.3	35.49076	139.8678	324	324
12183	11.6	35.49208	139.8666	324.8571	327.7143

Table 5.7 The target ship 1 information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
12003	12.9	35.51339	139.8997	243.5111	242.1111
12033	12.9	35.51261	139.8977	244.19	242
12063	12.91111	35.51183	139.8958	243.5556	243
12093	13	35.51106	139.8938	244.27	242
12123	13	35.51023	139.8917	243.7667	242
12153	13.01	35.50942	139.8897	243.44	243
12183	13	35.50864	139.8877	244.1667	241

As shown in Figure 5.43, at time 12003, the OZT area is witnessed along the own ship course. According to the COLREG-1972, the own ship is the crossing give-way ship, so the own ship turns to port to avoid collision. As the target ship 1 is the crossing stand-on ship, it keeps its course in this period.

(3) Overtaking.

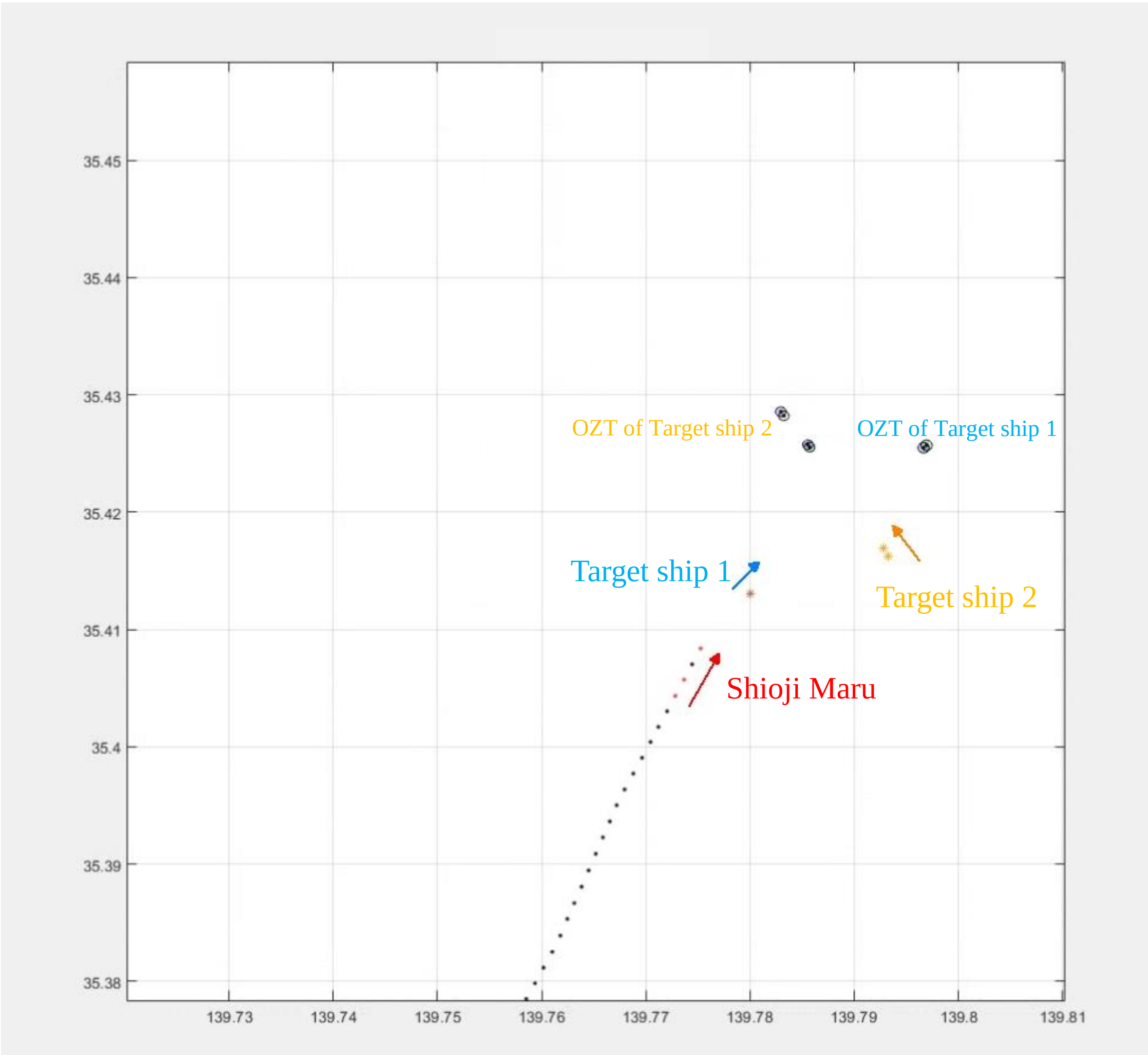

Figure 5.45 Ship encounter situations analysis (Time=9123)

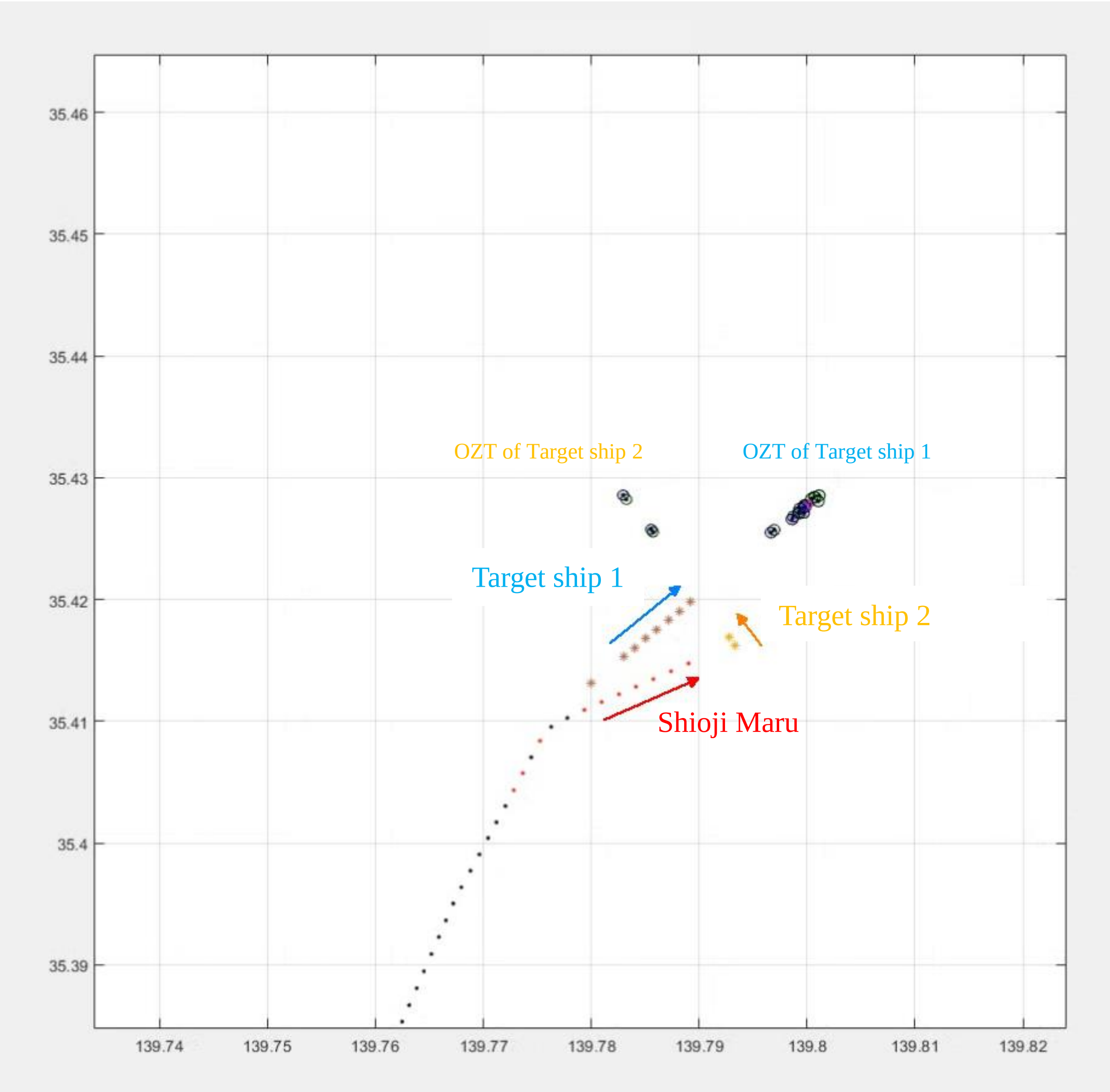

Figure 5.46 Ship encounter situations analysis (Time=9393)

Table 5.8 The own ship information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
9123	10.7625	35.40839	139.7753	25.375	31.5
9153	10.1	35.40954	139.7763	51	61
9183	10.3	35.41026	139.7778	61.5	65.5
9213	10.4	35.41092	139.7794	63.4	66
9243	10.4	35.41157	139.781	64	65.3
9273	10.44	35.4122	139.7826	64	66
9303	10.4	35.41282	139.7841	63.7	65
9333	10.4	35.41345	139.7858	64	65.55556
9363	10.5	35.4141	139.7874	64	66
9393	10.5	35.41474	139.789	64.44444	66.44444

Table 5.9 The target ship 1 information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
9123	8.14	35.4131	139.78	47.82	58
9153	8.1	35.41381	139.781	47.63333	57
9183	8	35.41456	139.782	48.46	57.7
9213	8.036842	35.41531	139.783	48.2	57.63158
9243	8	35.41605	139.784	48.59	57
9273	8.177778	35.41678	139.7851	47.68889	57
9303	8.1	35.41752	139.7861	47.83333	57.66667
9333	8	35.41826	139.7871	47.39	57
9363	8.1	35.41902	139.7881	48.13	57
9393	8	35.41976	139.7892	49.55	58

As shown in Figure 5.45, at time 9123, the own ship witnesses the OZT area along its course, but the own ship is the overtaking ship according to the COLREG-1972 for the target ship 1, and the crossing give-way ship for the target ship 2, so the own ship turns to starboard instead of turning to port to overtake the target ship 1 and avoid collision for the target ship 2. Till time 9393 (shown in Figure 5.46), the encounter situation is not overtaking any more.

(4) Overtaken.

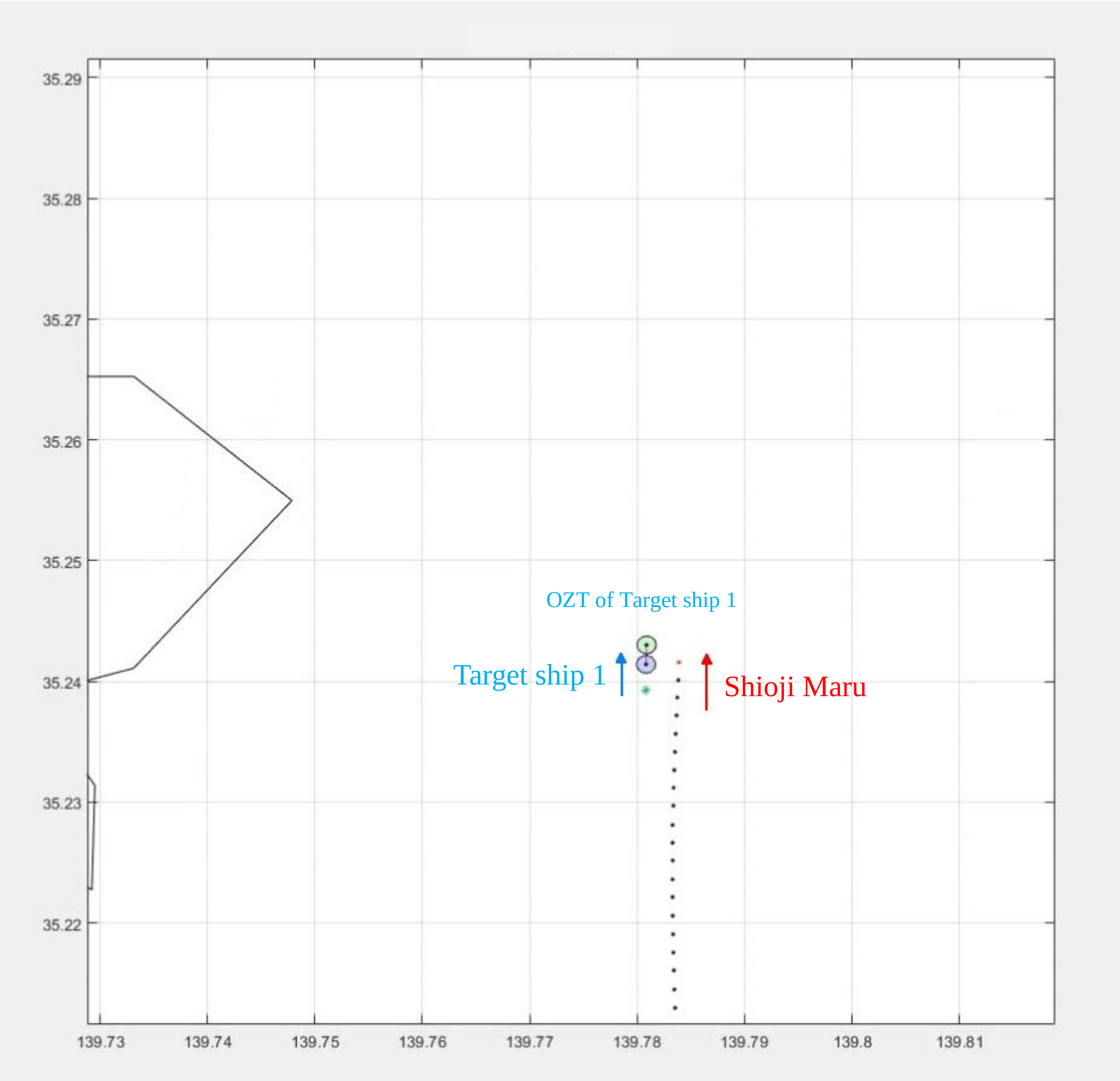

Figure 5.47 Ship encounter situations analysis (Time=5674)

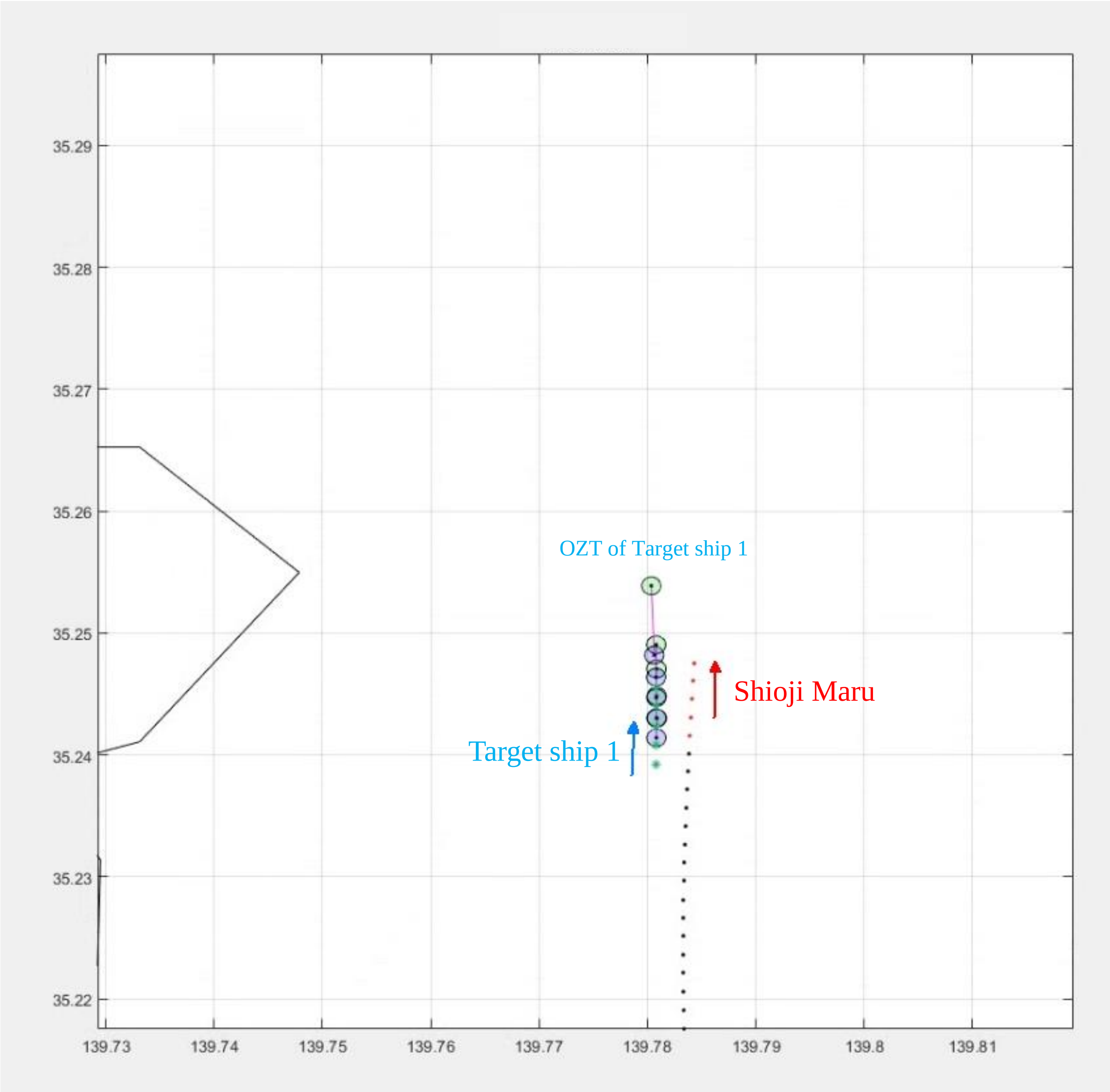

Figure 5.48 Ship encounter situations analysis (Time=5794)

Table 5.10 The own ship information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
5644	10.6	35.24009	139.7838	2	359
5674	10.6	35.24158	139.7839	2	359
5704	10.8	35.24307	139.784	3	0
5734	10.6	35.2446	139.7841	3	0
5764	10.8	35.24609	139.7842	3	0
5794	10.8	35.24752	139.7843	4	0

Table 5.11 The target ship 1 information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
5644	11.46	35.23762	139.7807	2.08	0
5674	11.45	35.23922	139.7808	1.5	358.5
5704	11.44	35.24081	139.7808	0.58	358
5734	11.5	35.24236	139.7808	0.15	358
5764	11.5	35.24397	139.7808	0.02	356.6
5794	11.5	35.24551	139.7808	357.75	355.5

As shown in Figure 5.47, at time 5674, the target ship 1 aims to overtake the own ship meanwhile the distance of two ships are quite short. The target ship 1 turns to port while the own ship turns to starboard a little to keep the two routes apart far enough from each other.

(5) Complex situation I.

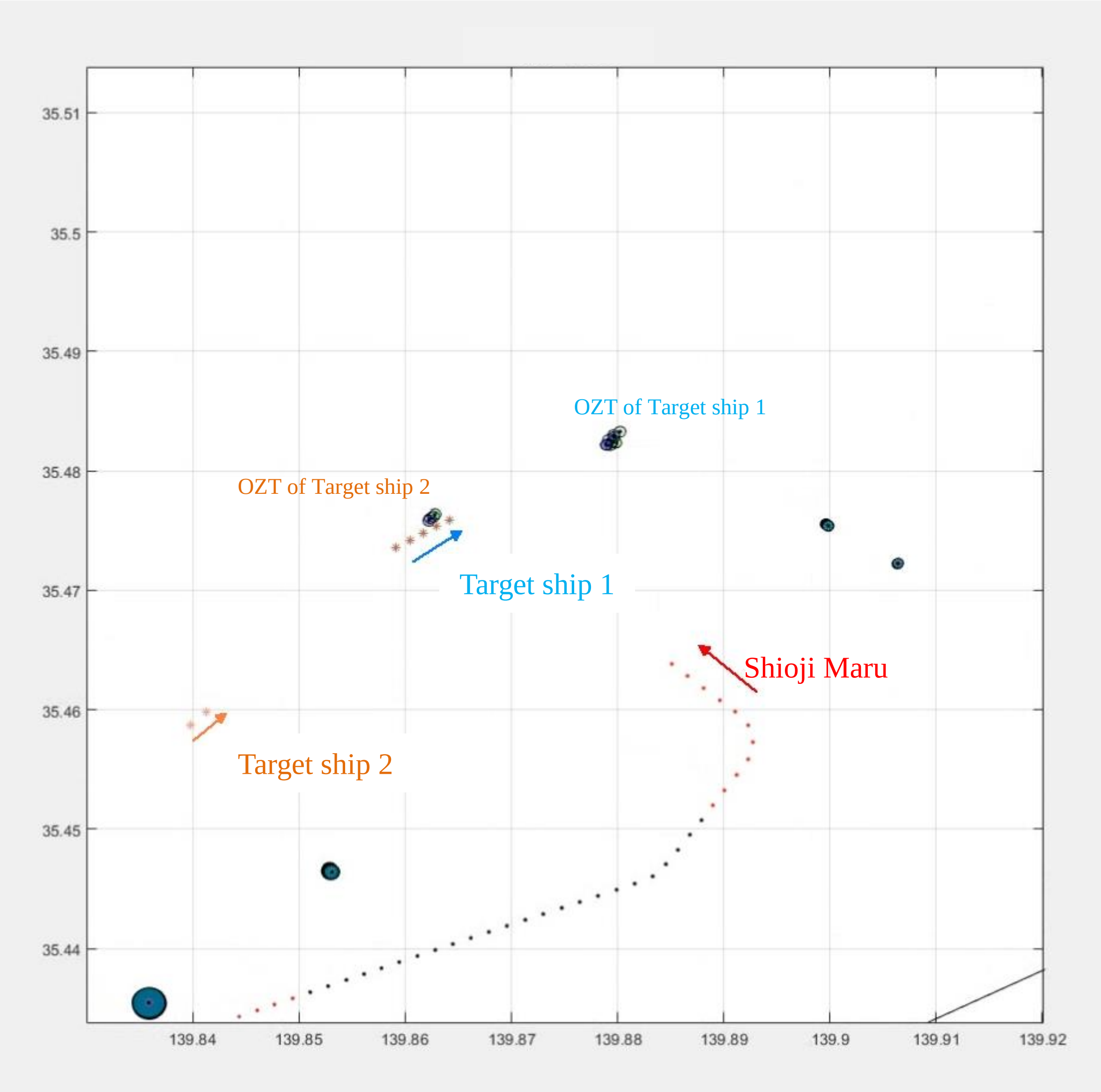

Figure 5.49 Ship encounter situations analysis (Time=11553)

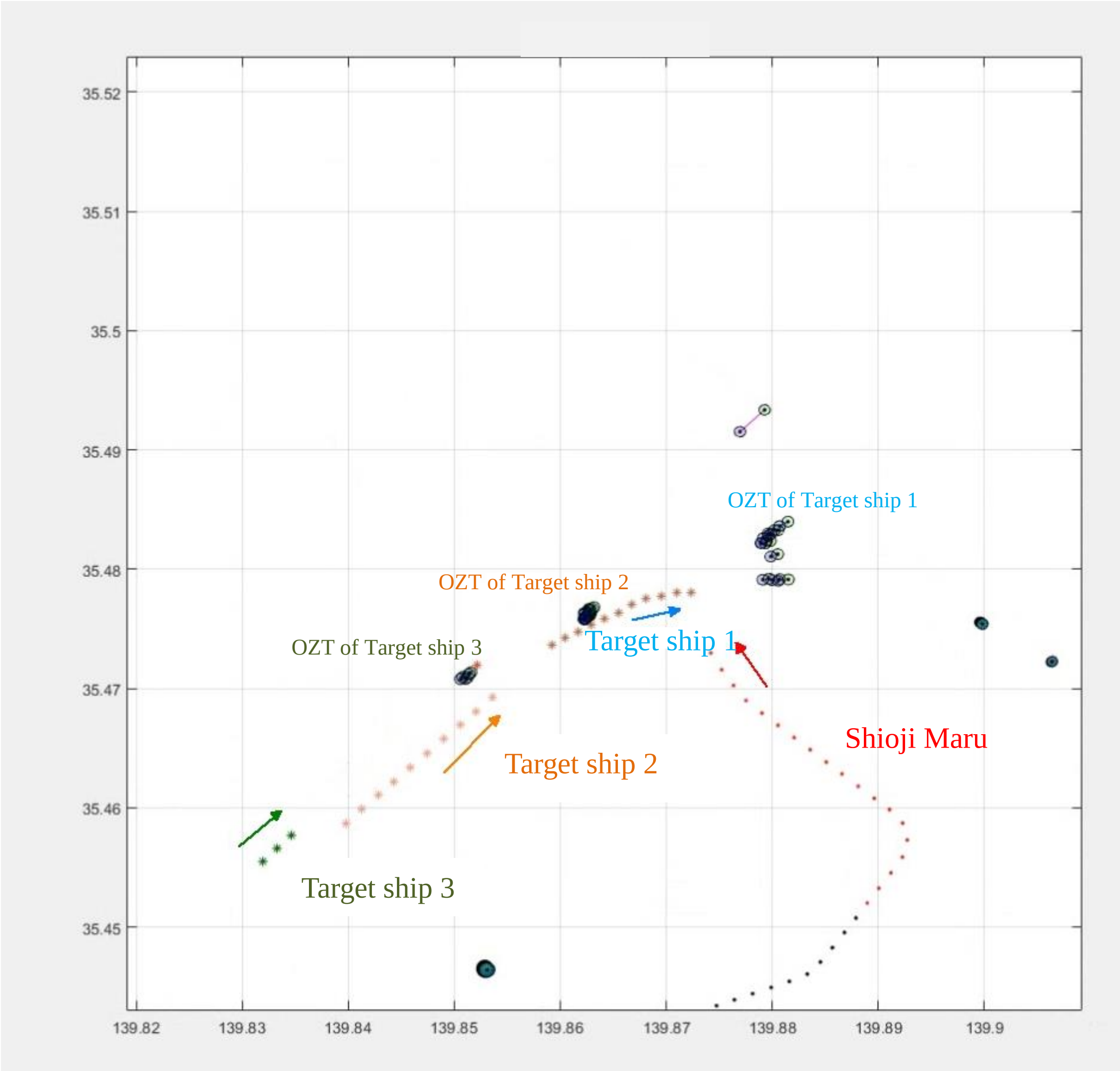

Figure 5.50 Ship encounter situations analysis (Time=11793)

Table 5.12 The own ship information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
11523	11.5	35.46283	139.8866	309.0909	309.5455
11553	11.5	35.46382	139.8851	309.6364	310.3636
11583	11.5	35.46485	139.8836	309.3	311.3
11613	11.5	35.46588	139.8821	309.3333	310.3333
11643	11.5	35.4669	139.8805	309	310
11673	11.6	35.46792	139.879	309	310.6364
11703	11.53	35.46899	139.8776	314.6	319
11733	11.5	35.47024	139.8764	325.3	328.7
11763	11.45455	35.47157	139.8753	324.0909	325.9091
11793	11.37	35.47297	139.8742	334.5	339.9

Table 5.13 The target ship 1 formation

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
11523	8.522222	35.47535	139.8629	61.37778	70.77778
11553	8.6	35.47588	139.8642	60.60909	70
11583	8.6	35.47638	139.8655	60.86	70
11613	8.666667	35.47706	139.8668	60.1	72.66667
11643	8.5	35.4775	139.8681	69.7	84.75
11673	8.5	35.47772	139.8695	80	89
11703	8.6	35.478	139.871	81.72	90
11733	8.6	35.47806	139.8723	81.86667	88.66667
11763	8.6	35.47833	139.8738	80.42	88
11793	8.6	35.4785	139.8753	80.53333	88

Table 5.14 The target ship 2 formation

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
11523	12.3	35.45867	139.8398	46.98182	48
11553	12.4	35.45983	139.8413	46.84	48
11583	12.33	35.46103	139.8428	46.15	47
11613	12.36	35.46219	139.8443	46.32	48
11643	12.4	35.46339	139.8459	47.3	48
11673	12.4	35.46455	139.8474	47.36364	48
11703	12.3	35.46573	139.849	47.2	48
11733	12.3	35.46692	139.8505	47.00909	47.36364
11763	12.4	35.46809	139.852	46.46667	47
11793	12.3	35.46929	139.8536	46.30909	47.36364

As shown in Figure 5.49 and Figure 5.50, the own ship encounters the OZT area near its course. From three target ships, in each condition the own ship is the crossing stand-on ship. The target ship 1 turns to starboard, but the target ship 2 takes no actions although collision risk exists the OZT area displaying along the course. The own ship turns to starboard and finds a safety route to avoid collision.

(6) Complex situation II.

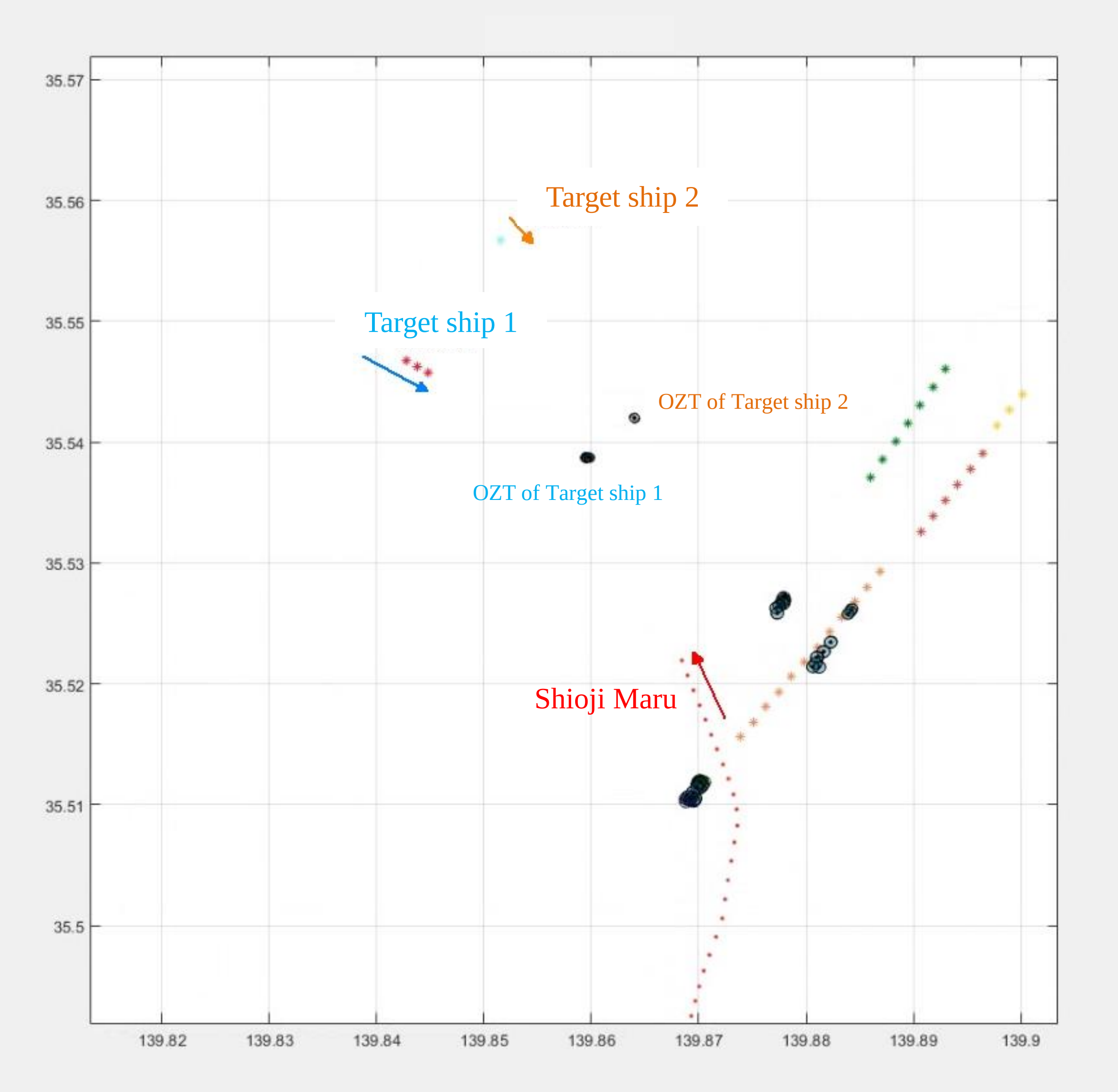

Figure 5.51 Ship encounter situations analysis (Time=12602)

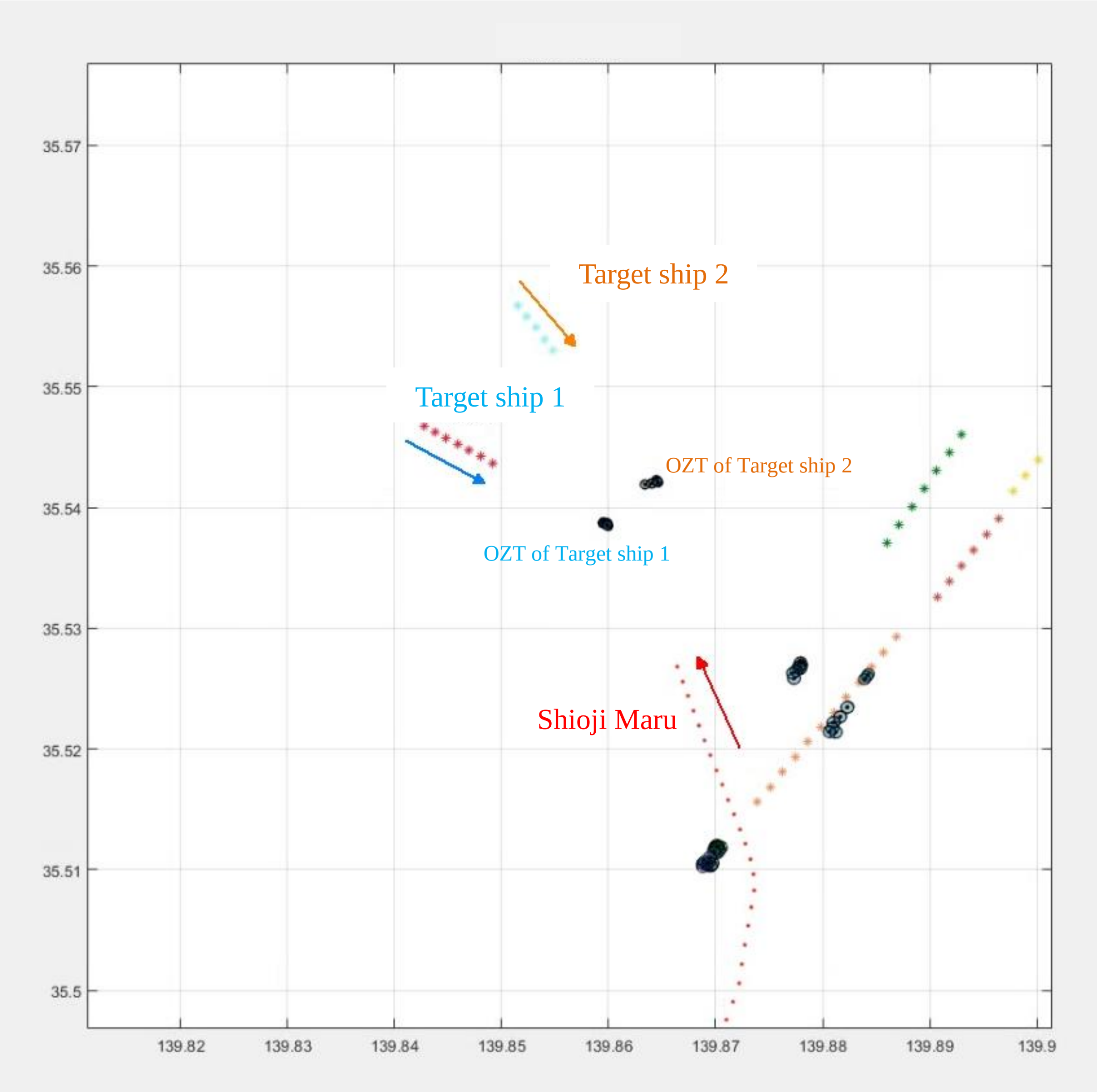

Figure 5.52 Ship encounter situations analysis (Time=12722)

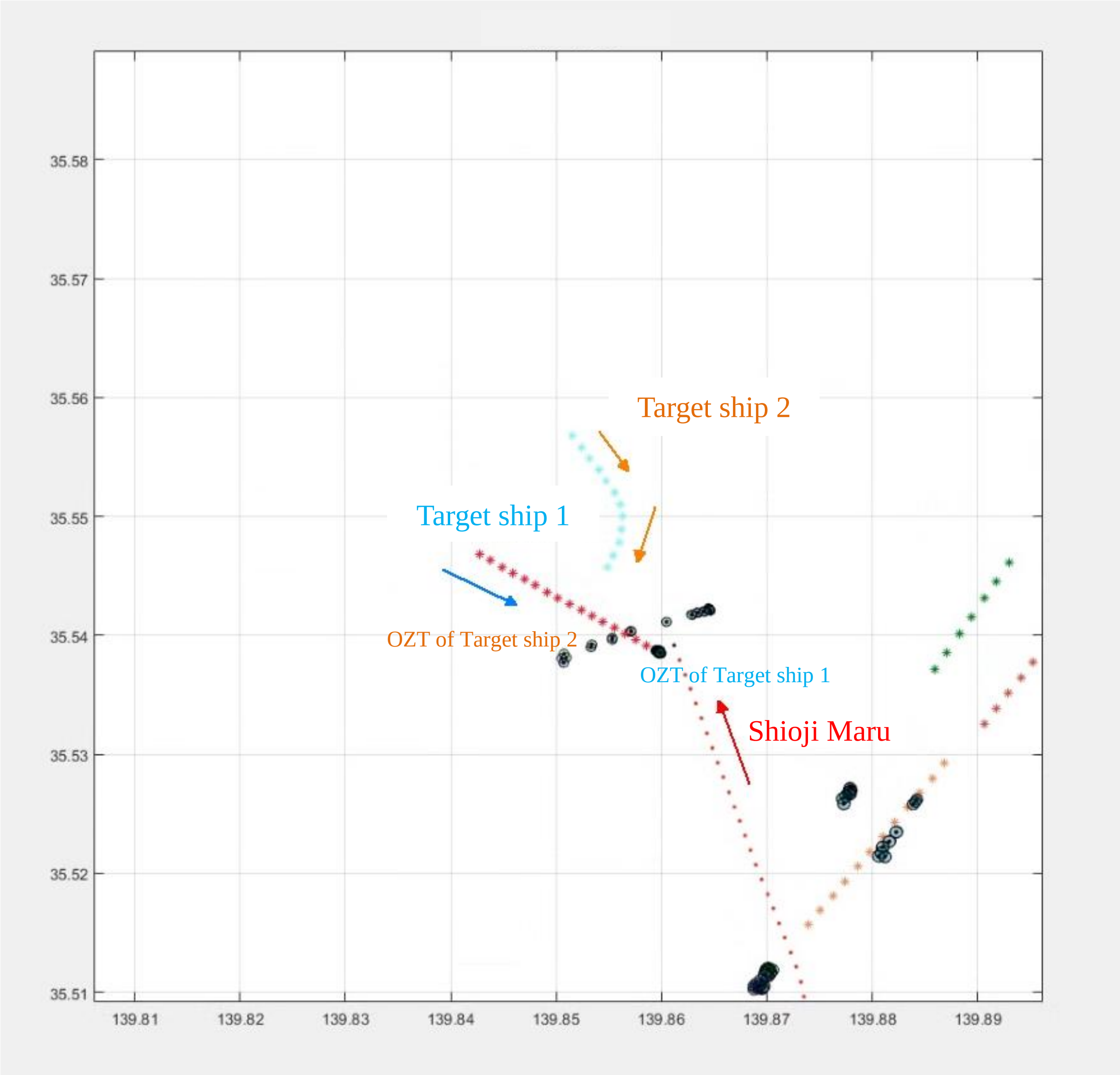

Figure 5.53 Ship encounter situations analysis (Time=13022)

Table 5.15 The own ship information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
12512	9.3	35.51822	139.8701	338	338
12542	9.3	35.51948	139.8695	339	340
12572	9.4	35.5207	139.869	340	340
12602	9.3	35.52193	139.8684	340	340
12632	9.4	35.52316	139.8679	341	341
12662	9.3	35.52439	139.8674	340	340
12692	9.3	35.52558	139.8669	341	341
12722	9.4	35.52682	139.8664	341.0909	340.0909
12752	9.4	35.52809	139.8659	339	339
12782	9.4	35.52928	139.8653	341	340
12812	9.4	35.53052	139.8648	341	341
12842	9.3	35.53176	139.8643	341	340
12872	9.5	35.53304	139.8638	340	340
12902	9.4	35.53427	139.8633	341	341
12932	9.3	35.5355	139.8628	340	340
12962	9.4	35.53668	139.8622	340	339
12992	9.4	35.53792	139.8617	341	340.0909
13022	9.5	35.53916	139.8612	341	341
13052	9.390909	35.54045	139.8607	340	339

Table 5.16 The target ship 1 information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
12512	7.1	35.54729	139.8417	120.19	119.7
12542	7.1	35.54677	139.8427	120.5364	119.2727
12572	7.17	35.54628	139.8437	120.18	119.7
12602	7.2	35.54576	139.8448	119.8556	119
12632	7.3	35.54525	139.8459	119.9364	118.7273
12662	7.388889	35.54472	139.847	120.3556	119.1111
12692	7.4	35.54421	139.848	120.5091	120
12722	7.4	35.54367	139.8491	120.3444	119.1111
12752	7.4	35.54316	139.8502	120.94	120
12782	7.211111	35.54263	139.8513	120.5	120
12812	7.2	35.54213	139.8523	120.6455	120
12842	7.1	35.54162	139.8534	119.9167	120
12872	7.1	35.54113	139.8544	120	120
12902	7.1	35.54063	139.8555	120.1333	119
12932	7.1	35.54013	139.8565	120.1	119
12962	7.1	35.53965	139.8576	120.34	118.2
12992	7.1	35.53915	139.8586	120.3182	119
13022	7	35.53866	139.8597	118.5778	116.8889

13052	7.1	35.53821	139.8607	117.5455	116

Table 5.17 The target ship 2 information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
12512	8.1	35.55965	139.8493	149.6095	152
12542	8.2	35.55867	139.85	150.76	152
12572	8.2	35.5577	139.8507	147.4111	150
12602	8.2	35.55677	139.8515	145.3	147
12632	8.2	35.55584	139.8523	143.7889	148
12662	8.2	35.55491	139.8532	143.7818	147.8182
12692	8.2	35.55395	139.854	143.9111	149.7778
12722	8.1	35.55302	139.8548	147.5091	151.8182
12752	8.111111	35.55204	139.8555	149.6889	156.7778
12782	7.925	35.55103	139.8561	159.975	172.25
12812	7.766667	35.54997	139.8563	175.8667	181.6667
12842	7.9	35.54887	139.8562	184.52	190.6
12872	8.088889	35.54778	139.8559	193.6556	197.5556
12902	7.933333	35.54675	139.8554	204.7333	203
12932	7.9	35.54577	139.8549	202.78	199.8
12962	8.09	35.54472	139.8544	202.86	199.1
12992	8	35.5437	139.8539	200.98	198.8
13022	8.1	35.54263	139.8533	200.99	198
13052	8	35.54158	139.8529	199.4	196.8

As shown in Figure 5.51, at time 12602, two OZT areas appear on port and starboard sides of the own ship. As for the encounter situation of the own ship and the target ship 2, it is the near head-on situation, but not head-on and not crossing. Both the own ship and the target ship 2 should take collision avoidance actions. The target ship 2 turns to starboard to avoid collision. Then it is relative safe for the own ship. For the target ship 1, the target ship 1 is the crossing give-way ship, but it does not take any collision avoidance actions which is not good. From the result of time 13022 (Figure 5.53), the distance of the own ship and the target ship 1 is quite close.

(7) Complex situation III.

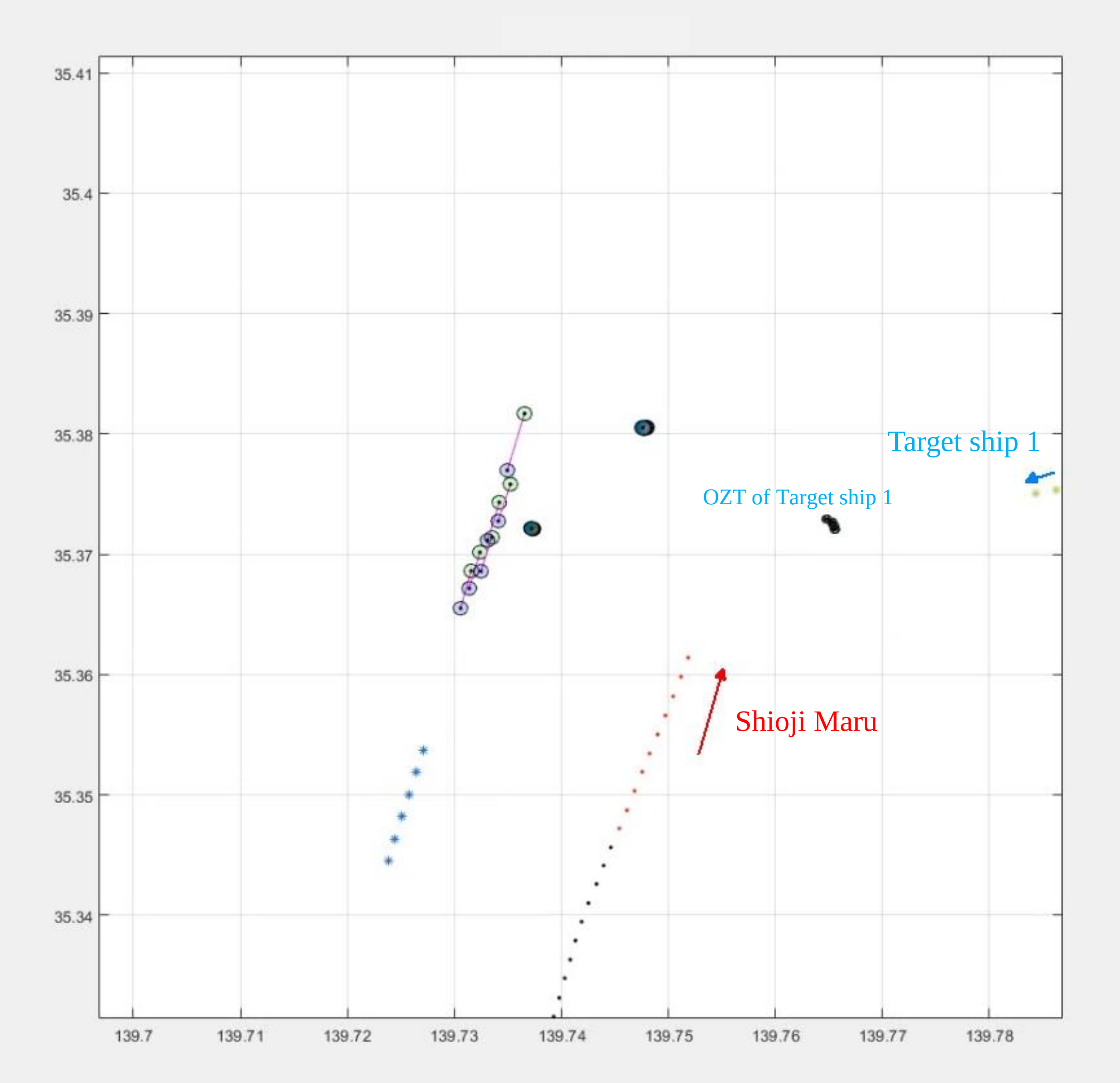

Figure 5.54 Ship encounter situations analysis (Time=8201)

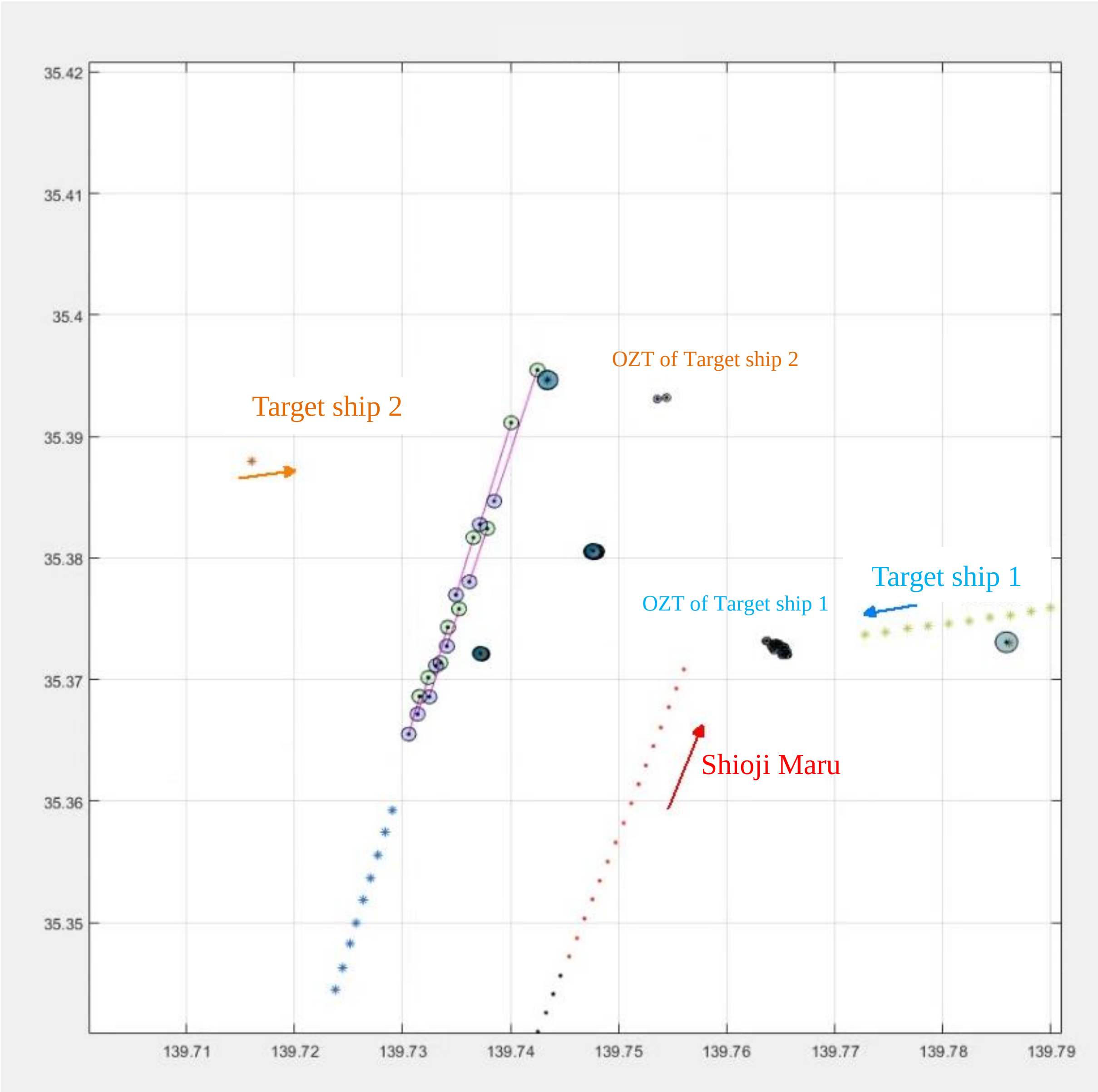

Figure 5.55 Ship encounter situations analysis (Time=8381)

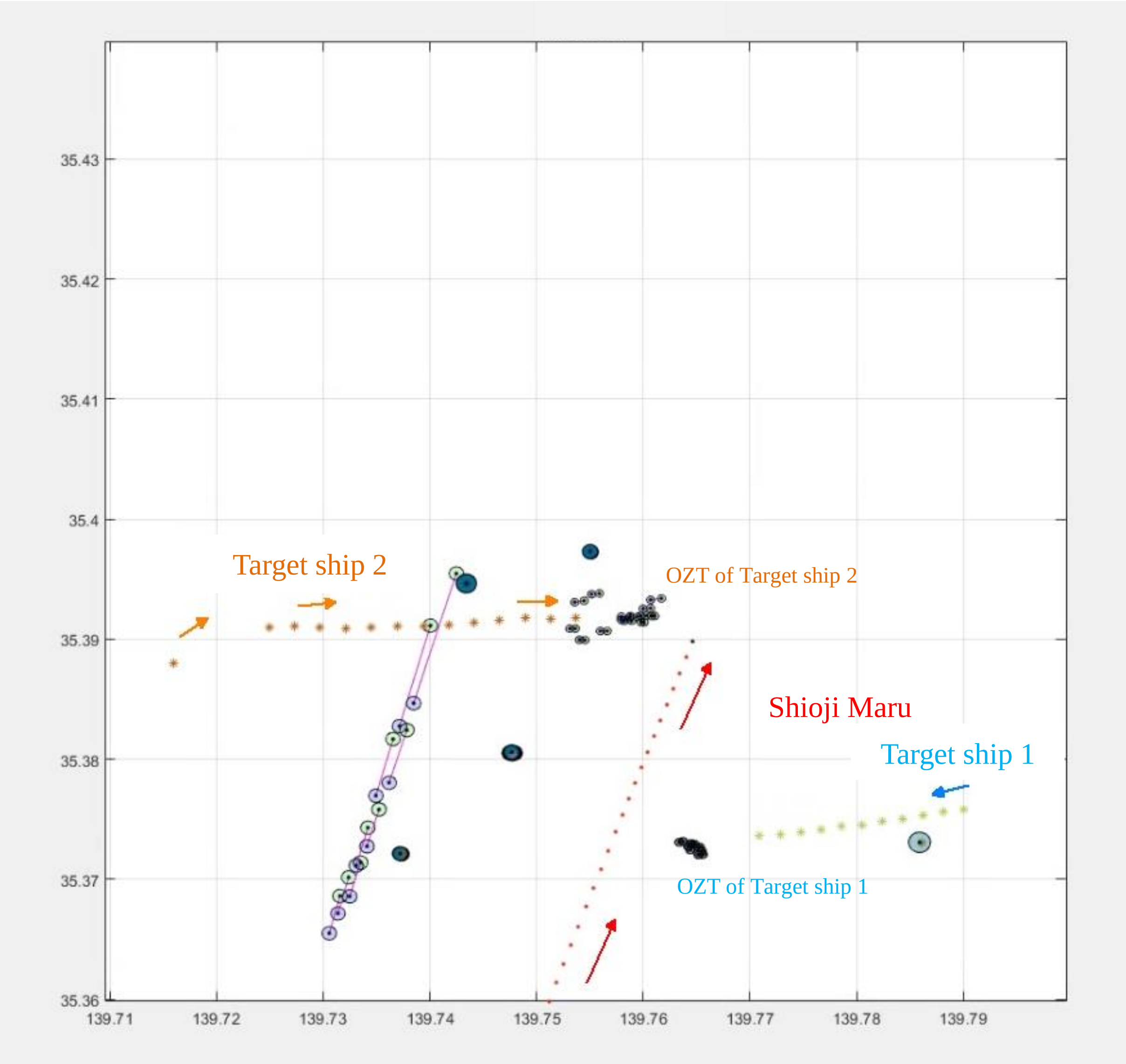

Figure 5.56 Ship encounter situations analysis (Time=8801)

Table 5.18 The own ship information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
8141	12.2	35.35818	139.7505	20	20
8171	12.1	35.35981	139.7512	17.2	18.9
8201	12.1	35.3614	139.7518	19	20
8231	12.1	35.36293	139.7525	19.1	19.9
8261	12.1	35.36452	139.7532	20	20
8291	12	35.36605	139.7539	20	20
8321	12.1	35.36773	139.7547	19	20
8351	12.1	35.36927	139.7553	20	20
8381	12	35.37084	139.756	19	20
8411	12	35.37236	139.7567	20	20
8441	11.4	35.37396	139.7574	20	20
8471	10.41818	35.37536	139.7581	19	19.90909
8501	10.11818	35.3767	139.7587	20	20
8531	10.1	35.37801	139.7592	20	20
8561	10.08182	35.37932	139.7598	20	20
8591	10	35.38059	139.7604	20	20
8621	10	35.38194	139.761	20	20
8651	10.1	35.38324	139.7616	20	20
8681	10.1	35.38455	139.7622	20	20
8711	10.1	35.38587	139.7628	20	20
8741	10.1	35.38715	139.7634	20	20
8771	10.1	35.38851	139.764	20	20
8801	10.1	35.38981	139.7646	20	19.81818

Table 5.19 The target ship 1 information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
8141	11.3	35.37533	139.7862	259	257
8171	11.38182	35.37507	139.7844	262.3455	259.8182
8201	11.4	35.37481	139.7824	258.9	257
8231	11.4	35.37457	139.7805	263.1182	261
8261	11.4	35.37438	139.7786	262.9909	260.0909
8291	11.4	35.37416	139.7767	260.3182	257.3636
8321	11.3	35.37389	139.7747	262.3	260
8351	11.5	35.37373	139.7728	265.7	263
8381	11.5	35.37363	139.7708	264.9	262

Table 5.20 The target ship 2 information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
8291	13.96667	35.38798	139.716	80.56667	76.33333
8321	14.4	35.38872	139.7183	63.9	65
8351	14.36	35.3897	139.7204	59.24	59
8381	14.2	35.39059	139.7225	70.9	74.5
8411	14.1	35.39101	139.7249	83.68571	87.14286
8441	14.1	35.39107	139.7273	90.48571	92.57143
8471	14.1	35.39099	139.7297	93	95
8501	14.2	35.39093	139.7321	90.72857	92.42857
8531	14.2	35.39099	139.7345	87.35	90
8561	14.2	35.39106	139.737	88.11111	89.55556
8591	14.2	35.39113	139.7394	88.53077	91
8621	14.1	35.39118	139.7418	87.3	88.66667
8651	14.1	35.39137	139.7441	82	84.5
8681	14.04286	35.39161	139.7465	85.21429	87.57143
8711	14.1	35.39175	139.7489	88.65	90.5
8741	14	35.39171	139.7513	92.3	93.5
8771	14.07692	35.39175	139.7537	88.15385	91.23077
8801	14.05	35.3918	139.7561	88.85	92.5

As shown in Figure 5.54, at time 8201, the OZT area appears near the own ship route but relative still safety. At time 8381 (Figure 5.55) another OZT area from the target ship 2 emerges on the other side of the ship route. For the own ship, the target ship 2 is the crossing give-way ship, it turns to port and starboard in this period, which is not good for collision avoidance. The own ship slows down which is also relatively not good for collision avoidance in this situation.

(8) Complex situation IV.

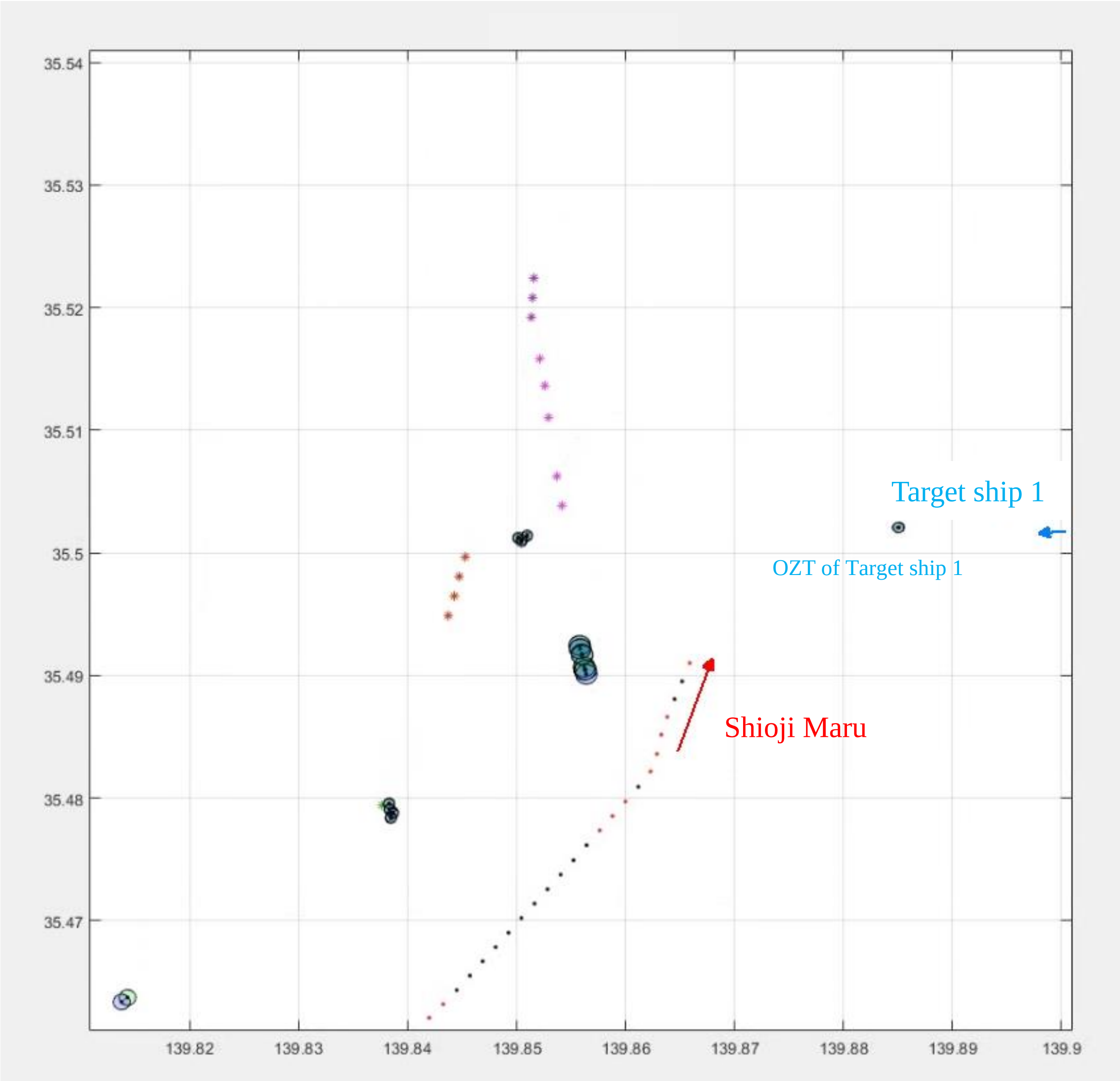

Figure 5.57 Ship encounter situations analysis (Time=12495)

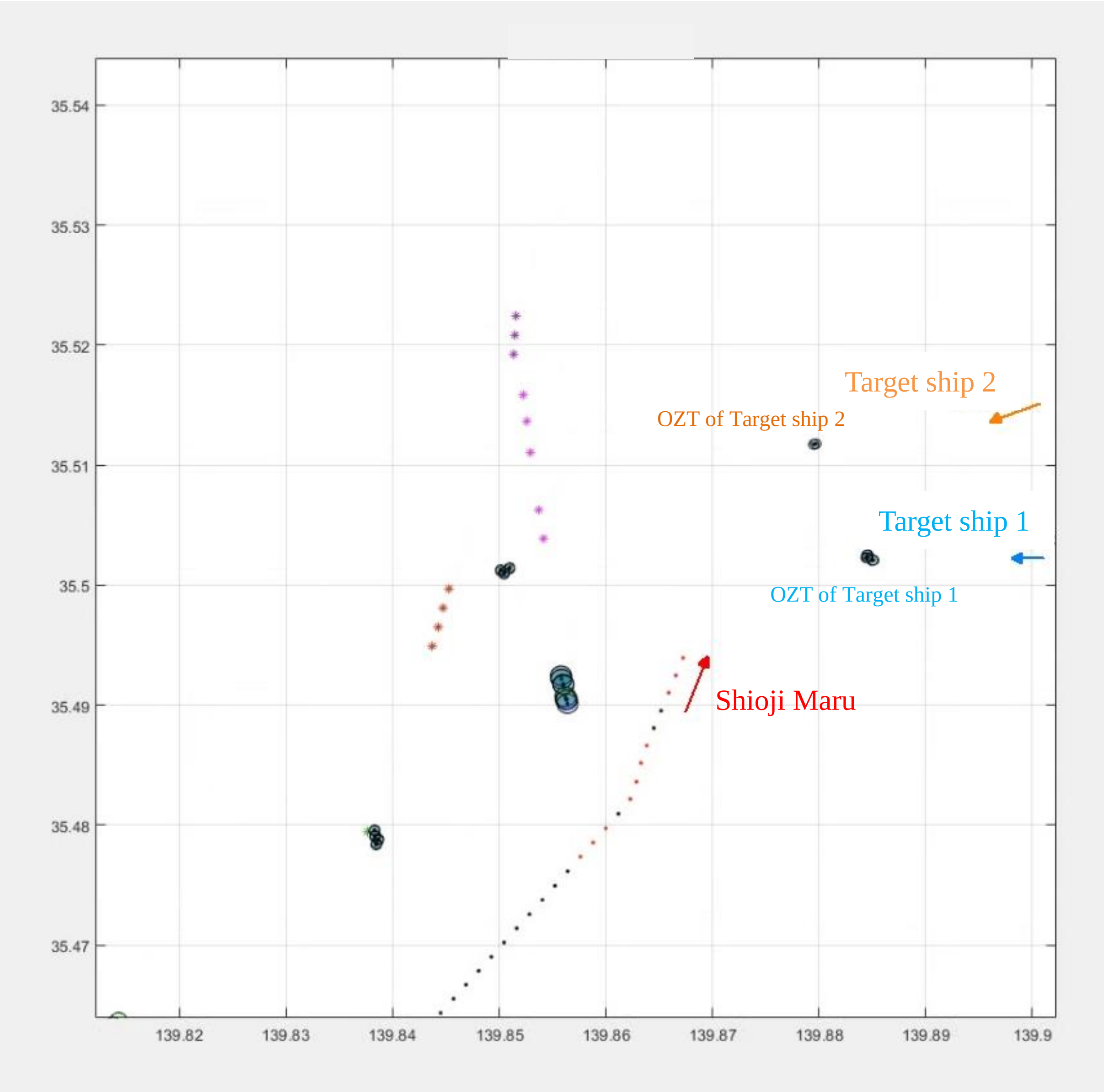

Figure 5.58 Ship encounter situations analysis (Time=12555)

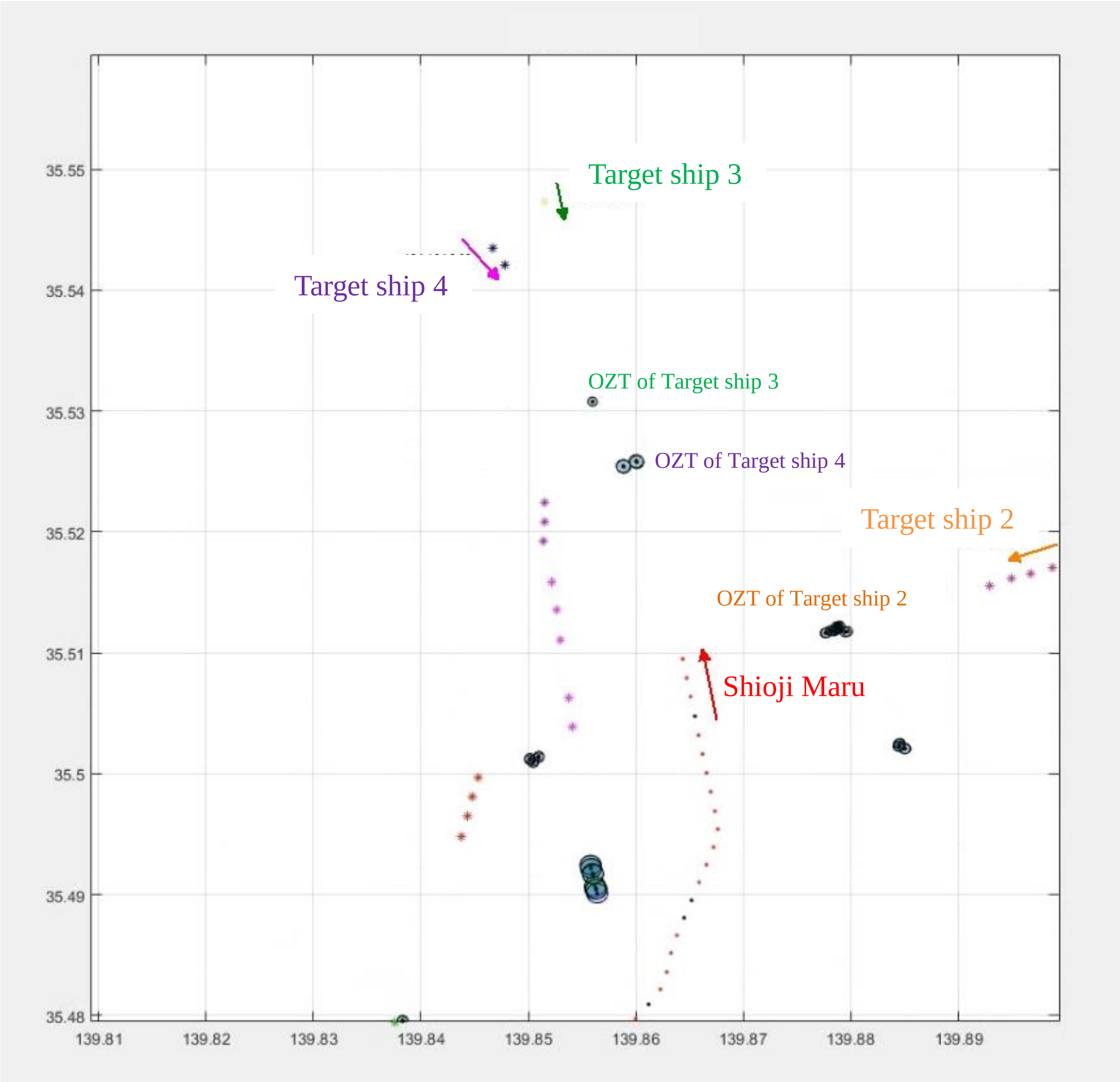

Figure 5.59 Ship encounter situations analysis (Time=12855)

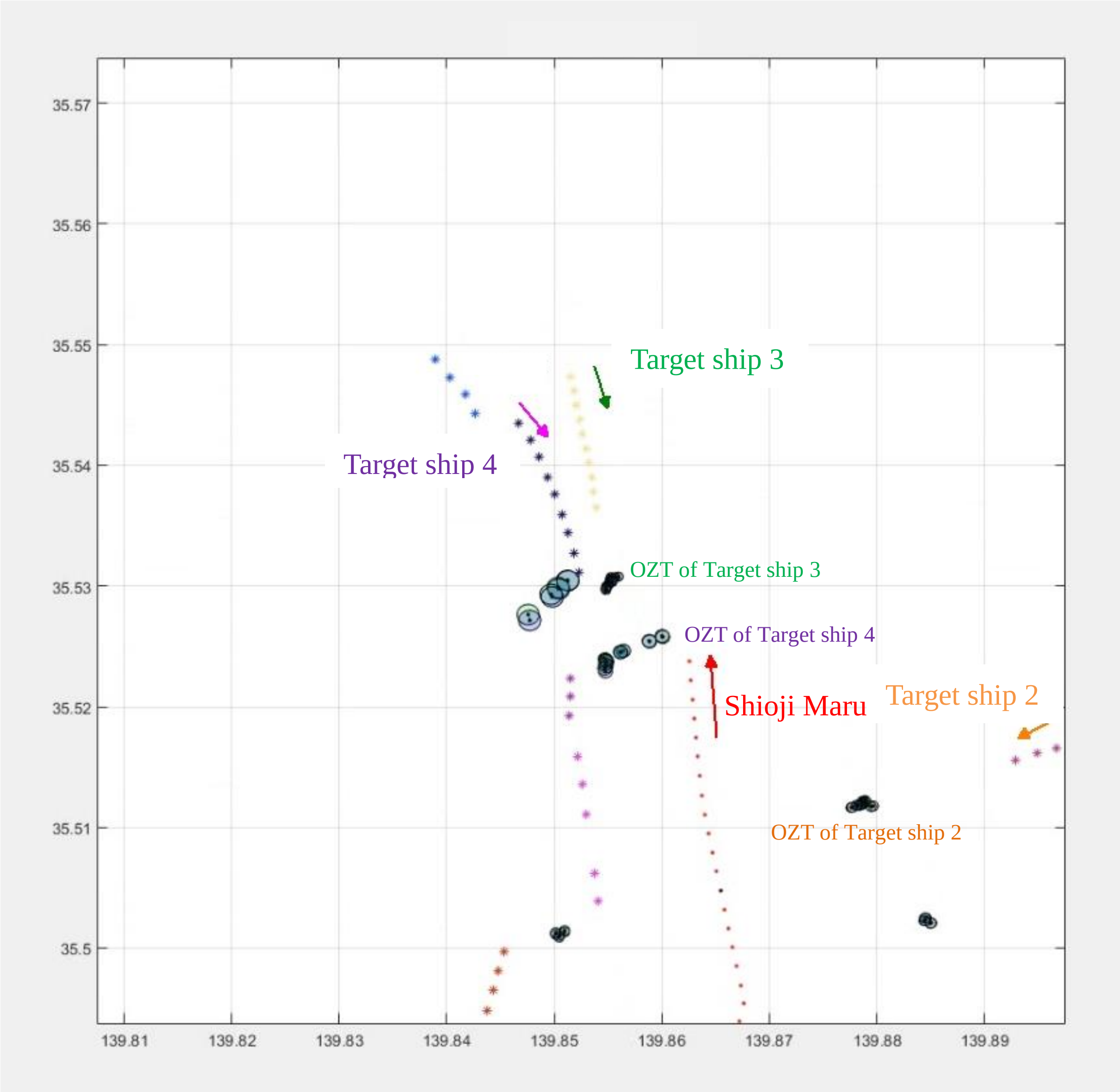

Figure 5.60 Ship encounter situations analysis (Time=13125)

Table 5.21 The own ship information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
12495	11.3	35.49101	139.8659	21	22
12525	11.3	35.49247	139.8666	19.6	20.6
12555	11.3	35.49392	139.8672	20.8	21
12585	11.05	35.49542	139.8676	1.5	357.5
12615	11.28	35.4969	139.8674	347.2	348
12645	11.4	35.49852	139.867	348	349.7
12675	11.4	35.50007	139.8666	348.3636	350
12705	11.53333	35.50162	139.8662	348.3333	349.3333
12735	11.6	35.50318	139.8658	349	350
12765	11.5	35.50475	139.8655	349	350
12795	11.5	35.50637	139.8651	348.6	350
12825	11.5	35.5079	139.8647	349	350
12855	11.54	35.50949	139.8644	348.4	349.8
12885	11.57273	35.51103	139.864	349.2727	350.2727
12915	11.54	35.51264	139.8637	353.4	355
12945	11.52727	35.51427	139.8635	354	355
12975	11.5	35.51589	139.8634	354.6	355
13005	11.5	35.51743	139.8632	355	354.7273
13035	11.46	35.51902	139.863	355	354.6
13065	11.3	35.52057	139.8629	354.2727	354.5455
13095	11.3	35.52219	139.8627	355	354
13125	11.4	35.52376	139.8626	355.3333	356

Table 5.22 The target ship 3 information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
12855	8.781818	35.5474	139.8515	167.6	165.1818
12885	8.7	35.54621	139.8518	169.54	167.8
12915	8.8	35.545	139.8521	169.8444	167.1111
12945	8.72	35.54381	139.8523	168.28	168
12975	8.71	35.54261	139.8526	169.13	167.1
13005	8.816667	35.54141	139.8529	169.8167	168
13035	8.89	35.54021	139.8532	169.79	167.9
13065	8.9	35.539	139.8535	172.0333	170
13095	8.9	35.53777	139.8537	172.92	172
13125	9	35.53654	139.8538	173.35	171.1667

Table 5.23 The target ship 4 information

Time(sec)	SOG(knots)	Latitude(°)	Longitude(°)	COG(°)	Heading(°)
12855	12.1	35.54066	139.8486	158.16	159.7
12885	12.08	35.53905	139.8493	159	160
12915	12.02727	35.53756	139.8501	159.0455	162.1818
12945	12	35.53594	139.8507	164.7	165.8
12975	12.1	35.53437	139.8512	164.3545	165.7273
13005	12.1	35.53271	139.8518	165.1	166
13035	12.1	35.53113	139.8523	166.1182	166
13065	12.1	35.52949	139.8528	165.54	166
13095	12.02727	35.52787	139.8533	165.2273	166
13125	12	35.52623	139.8538	165.7	166

From Figure 5.57, at time 12495, the OZT area of the target ship 1appears near the own ship route, the own ship begins to turn to port. After taking action for the target ship 1, at time 12555 (Figure 5.58), another OZT area of the target ship 2 appears along the own ship route. Consequently the own ship turns to port severely. However, at time 12855 (Figure 5.59), two OZT areas appear near the own ship route, from the target ship 3 and the target ship 4. Comparatively speaking, the OZT area from the target ship 4 has collision risk if takes no actions. The own ship and both the target ships turn to starboard to avoid collision. At time 13125 (Figure 5.60), all the ships pass safely.

CHAPTER VI Conclusions

(1) From the five days data, the two densely-distributed OZT areas are mainly in 139.81°E-139.86°E, 35.41°N-35.49°N and 139.83°E-139.89°E, 35.47°N-35.58°N. The safety area is mainly in 139.75°E-139.81°E, 34.98°N-35.09°N.

(2) The dangerous area proposed along with the Tokyo Bay traffic controlled area can cover most of the relative dangerous ship encounter situations of the Shioji Maru.

(3) From the own ship route's respect, when the Shioji Maru reaches the areas in 139.845°E-139.870°E, 35.538°N-35.557°N and 139.850°E-139.880°E, 35.480°N-35.518°N, the own ship has maximum probability estimation to meet with relative dangerous ship encounter situations.

(4) The distance between the own ship and the OZT areas is mainly distributed in from 0.8 nm to 1.7 nm on April 27th, from 0.4 nm to 1.4 nm on May 11th, from 0.7 nm to 1.5 nm on May 25th, from 0.7 nm to 1.5 nm on June 8th, from 0.6 nm to 1.5 nm on June 15th. The generally distributed distance between the own ship and the OZT areas is from 0.6 nm to 1.5 nm.

(5) The relative bearing between the own ship and the OZT areas is mainly distributed in Port 20°-60° and Starboard 20°-60° on April 27th, Port 20°-60° and Starboard 30°-60° on May 11th, Port 20°-60° and Starboard 20°-60° on May 25th, Port 20°-60° and Starboard 20°-60° on June 8th, Port 20°-60° and Starboard 30°-60° on June 15th. The generally distributed relative bearing between the own ship and the OZT areas is Port 20°-60° and Starboard 20°-60°.

(6) The safety area of the Shioji Maru which no OZT data intrudes into in five days is an ellipse, with the major semi-axis is 0.9 nm and minor semi-axis is 0.09 nm.

(7) From the statistic of relative dangerous ship encounter situation, the port crossing account for a much greater portion, while there is no continuous dangerous head-on situation appears from these five days data statistics. The navigator of the Shioji Maru either takes the collision avoidance actions earlier and finds a safety route to ensure navigation safety or

changes the original dangerous head-on situation to crossing situation, those are the reasons no continuous dangerous head-on situation appears. For the higher proportion of port crossing, 50 percent of the continuous dangerous port crossing situations occur in the traffic control areas in Tokyo Bay when the Shioji Maru enters the port.

(8) From the navigation characteristics analysis using the OZT theory, the navigator of the Shioji Maru takes the good collision avoidance actions in almost all cases. The navigator of the Shioji Maru is of good maneuvering and ship operation behaviors.

(9) In conclusion, the OZT theory is an effective way for ship collision avoidance and the OZT theory can help the navigators to be aware of collision risks as well as improve the navigators' collision avoidance maneuvering.

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BIBLIOGRAPHY

[1] AIS CLASS A SHIP STATIC AND VOYAGE RELATED DATA. Retrieved June 29, 2017, from: https://www.navcen.uscg.gov/?pageName=AISMessagesAStatic.

[2] AIS - AUTOMATIC IDENTIFICATION SYSTEM. Retrieved June 29, 2017, from: http://www.bluebird-electric.net/AIS_automatic_satellite_ship_identification_system.htm.

[3] J-Marine GIS Implementation Example. Retrieved June 29, 2017, from: http://www.jrc.co.jp/eng/casestudy/case0002/index.html.

[4] R. Shoji, F. Kitazawa and H. Nishiyama, "Construction of Advanced Navigation System," 2012 Fifth International Conference on Emerging Trends in Engineering and Technology, Himeji, 2012, pp. 276-280.

[5] H. Imazu. Computation of OZT by using Collision Course. Japan Institute of Navigation (188):2014.4. 78-81 ISSN 0919-9985.

[6] Mercator projection. Retrieved June 29, 2017, from: https://en.wikipedia.org/wiki/Mercator_projection.

[7] W. Zhe. The Research on Automatic Collision Avoidance for Unmanned Surface Vessel (2013). Dalian Maritime University.

[8] K. Hasegawa, J. Fukuto, R. Miyake, M. Yamazaki: An Intelligent Ship Handling Simulator with Automatic Collision Avoidance Function of Target Ships, Proc. International Navigation Simulator Lecturers Conference, (INSL17), pp.F23-1-10, Rostock, Germany, Sep. 3-7, 2012.

[9] J. Fukuto, H. Imazu, New collision alarm algorithm using obstacle zone by target (OZT), IFAC Proceedings Volumes, Volume 46, Issue 33, 2013, Pages 91-96, ISSN 1474-6670.

[10] K. Kumagai, T. Mochida, Y. Tanaka and J. Kayano, "Basic Study on Analyzing of Maneuvering for Avoiding Collision in the Congested Sea Area where Many Ships are Crossing by Using OZT," 2012 Fifth International Conference on Emerging Trends in Engineering and Technology, Himeji, 2012, pp. 270-275.

[11] AIS stands for Automatic Identification System. Retrieved June 29, 2017, from: https://www.easyais.com/en/ais-information/what-is-ais/.

[12] X. Yixing, HU Li, ZHOU Hong, WANG Leyu. Research on arithmetic of coordinates transformation in ECDIS. Journal of Engineering Design, 2003, 10(5):299-302.

[13] Safety Tokyo Bay. Retrieved June 29, 2017, from: http://www6.kaiho.mlit.go.jp/tokyowan/info/stb/stbEng.pdf.

[14] COLREGs Course. Retrieved June 29, 2017, from: http://www.ecolregs.com/index.php?option=com_k2&view=item&layout=item&id=109&Itemid=359&lang=en.

[15] TYPES OF AUTOMATIC IDENTIFICATION SYSTEMS. Retrieved June 29, 2017, from: https://www.navcen.uscg.gov/?pageName=typesAIS.

[16] CLASS A AIS POSITION REPORT. Retrieved June 29, 2017, from: https://www.navcen.uscg.gov/?pageName=AISMessagesA.

[17] H. Imazu. Evaluation Method of Collision Risk by Using True Motion. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, Vol. 11, No. 1, pp. 65-70, 2017.

[18] J. Kayano and H. Imazu, "A study of a collision avoidance support system," 2009 IEEE International Conference on Systems, Man and Cybernetics, San Antonio, TX, 2009, pp. 244-249.

[19] J. Kayano, H. Imazu, C. Nishizaki and K. Murai, "A study on analysis of characteristics of ships navigators' look-out by using OZT," 2015 10th System of Systems Engineering Conference (SoSE), San Antonio, TX, 2015, pp. 274-279.

[20] H. Imazu, J. Fukuto and M. Numano, "Obstacle Zone by Target and its Expression", Journal of Japan Institute of Navigation, Vol. 107, pp. 191-197, 2002.