Application of Quantitative Obstacle Zone by Target (OZT) Method to Situation Awareness Assessment for Ship Collision Accidents

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Abstract: Ship collisions are frequently caused by human factors: improper ship operation and inadequate watchkeeping. In accident analysis, records from oral interviews are often used to investigate the cognitive status of ship operators. However, such subjective information is affected by various uncertainties and should be supported by objective evidence, such as physical historical data. The purpose of this study is to compare the physical state of a ship with the operator's subjective perception of collision possibilities. Ship-to-ship encounters can significantly impact the perception of operators. We first predicted and visualized potential collision points using ship trajectory data such as automatic identification system data. Subsequently, we quantified the area of potential collision points to assess the possibility of collision. We then compared the situational awareness of the operators with this quantified possibility to validate its accuracy. Specifically, we used two indicators developed in previous studies. The obstacle zone by target (OZT) represents encounter situations and provides positional information regarding the areas where the ship's course will be obstructed by the target ship. OZT on the course of a ship are considered to be more hazardous. Therefore, the authors propose an indicator to represent the impact of OZT: On-Course OZT Intensity (OCO Intensity). The relationship between the collision possibilities perceived by ship operators and OCO Intensity values has not been studied. In this study, the relationship between the two was analyzed based on accident investigation reports to objectively evaluate the subjective collision possibilities perceived by the operators. The results of this study are expected to improve the accuracy of collision possibility assessments using the OCO Intensity and aid accident investigation analyses.

Keywords: Ship Collision, Accident Analysis, Collision Possibility, Situation Awareness Assessment.

1. INTRODUCTION

The importance of maritime transportation has been increasing because of its highly efficient and environmentally friendly nature as well as labor shortages in other modes of transportation. Therefore, it is important to improve maritime traffic safety. Ship collisions account for the largest number of maritime accidents [1,2]. Half of these are believed to be caused by human factors such as inappropriate ship handling and inadequate watchkeeping [1]. Therefore, determining the human factors in collisions helps clarify the causes of many accidents. Thus, it is helpful to determine situations in which the operators recognize the possibility of a collision.

The Japan Transport Safety Board (JTSB), a government agency specializing in investigating transportation (aircraft, railways, and marine) accidents, publishes accident investigation reports, in which the JTSB analyzes the causes of accidents and sends safety recommendations, opinions or factual information notices. During the analyses of collisions, in most cases, the JTSB determines the timing of hazardous encounters and reports the reasons why operators perceived the collision possibilities from oral interviews conducted during the investigation as well as audio data recorded on board. However, because oral interviews and conversations recorded onboard are subjective, it is necessary to objectively and quantitatively evaluate hazardous encounters to clarify the situations in which the hazards occurred.

Several methods have been developed to assess ship-collision hazards. Szłapczyński et al. proposed a collision-avoidance decision support system comprising three stages: conflict detection, maneuver selection, and maneuver execution [3]. Montewka et al. [4] proposed a straightforward framework for assessing and monitoring the accident susceptibility of passenger ships, based on human performance heuristics and operational factors. Both incorporate hydrographic characteristics as variables in addition to information such as position and vessel speed obtained from the automatic identification system (AIS). These also incorporate subjective factors such as the navigator's individual preferences and the mental workload of the navigator onboard. Therefore, these include subjective elements and are not objective. However, indicators evaluated using only AIS data, such as collision judgment (CJ), blocking coefficient (BC), and obstacle zone by target (OZT), have been proposed. Because these indicators are calculated using AIS data, they are objective and can be analyzed separately from the subjective factors. Another benefit of using AIS data is the potential for handling many samples. Thus, with the JTSB, we developed a method by which AIS-based indicators can be used to assist accident investigations. During the development, a relationship was found between the subjective assessment of collision possibility and the values of CJ and BC. Moreover, guide values were identified for CJ and BC [5]. CJ is calculated using variables such as the relative heading, distance between two ships, and rates of change of them. However, this does not account for ship length. In BC, the ship length and relative speed are considered in the ship domain. Therefore, the ship domain used in BC is variable. OZT provides positional information about the area where its course will soon be intercepted by the target ship. It considers ship length in the calculation in a stable manner. That is, OZT indicates a specific course that should not be followed at any point in time; therefore, it has excellent clarity in terms of the course to take. We developed a method for converting the location information (OZT) into numbers [6]. This indicator is referred to as On-Course OZT (OCO) Intensity. This study aimed to compare the objective ship-to-ship encounter situations and operators' subjective assessment of collision possibilities during accidents.

2. ASSESSMENT METHODS FOR SHIP-TO-SHIP COLLISION POSSIBILITIES

2.1. OZT

An OZT shows the positions at which a ship cannot safely sail later owing to obstruction by other ships that are going straight ahead [7,8,9,10].

Figure 1 illustrates an OZT diagram, in which the target ship is northeast of a faster-own ship in the north-up direction. The current position of the own ship was defined as point O, and the current position of the target ship was defined as point T. Then, a circle with a center at O and a safe radius distance r was drawn. In addition, two tangent lines l_1 and l_2 were drawn from point T to this circle centered at O. V_T is the absolute velocities of the target ship. The vector of length V_T was drawn from point T in the opposite direction. T' was denoted as the terminal point of this vector. V_O is the absolute velocities of the target ship. A circle was drawn with T' at its center and length of V_O as its radius. Drew lines connecting the intersection of this circle and l_1 or l_2 with point T'. These were the angles defined as the collision courses and moved parallel to point O. Proceeding between two collision courses means collision. Two collision courses, denoted by C_{O1} and C_{O2}, were obtained from Eqs. (1) and (2), where A_Z is the azimuth angle of the target ship from point O and α is the angle formed by the tangent line and line OT. Given that the distance between O and T is d, it is expressed by $\sin^{-1}\frac{r}{d}$. C_T is the course of the target ship.

$$C_{O1} = A_Z - \alpha - \sin^{-1}\left\{\frac{V_T}{V_O}\sin(A_Z - \alpha - C_T)\right\}. \tag{1}$$

$$C_{O2} = A_Z + \alpha - \sin^{-1}\left\{\frac{V_T}{V_O}\sin(A_Z + \alpha - C_T)\right\}. \tag{2}$$

Subsequently, we calculated the OZT using these collision courses. Two lines were drawn from point O at angles of C_{O1} and C_{O2}. These lines are denoted by l_1' and l_2'. Subsequently, a line extending the current course of the target ship was drawn. The intersection points of this line with l_1'and l_2'were Q_1 and Q_2, respectively. The line segment connecting Q_1 and Q_2 was the OZT. Because the own ship collided with the target ship upon entry into this zone, the OZT visually indicated the location of the collision. The OZT position changed continuously with the position and speed of the ships, and the course of the target ship changed.

In this study, the OZT was calculated at intervals of 10 s using ship information obtained from the AIS data. The lengths of the own and target ships are denoted as L_O and L_T, respectively, and r is defined as $((L_O^2+L_T^2)^{1/2})/2$.

2.2. OCO Intensity

An OZT represents location information and can occur in a variety of places regardless of the course of the own ship. An OCO Intensity quantifies the OZT and represents the degree of obstruction of the OZT ahead of the own ship. The closer the OZT is to the center of the ship's heading, the more likely a collision occurs,

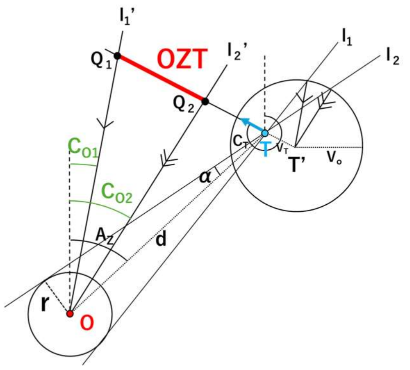


Figure 1. Diagram of the OZT Generated by a Target Ship

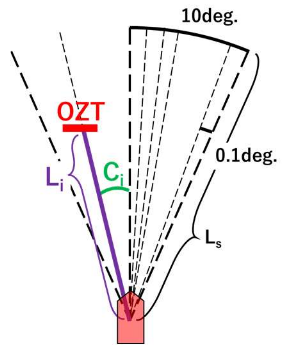


Figure 2. Conditions of OCO Intensity: OZT Generated on Course C_i from an Own Ship's Heading at Distance L_i

which may affect maneuvering. Avoidance is more difficult when the line segment of the OZT interferes with multiple courses. In addition, the shorter the distance to the OZT, that is, the shorter the time to collision, the more difficult it is to avoid a collision. The OCO Intensity was calculated using the following approach considering these factors.

Figure 2 shows an OCO Intensity diagram. The specific course width ahead of the own ship was divided into n parts using an arbitrary step size, and the i-th course is denoted by Ci. The distance to the OZT is Li. The safety margin distance is Ls, and the unsafe rate on course C_i, denoted by Ri, was calculated as $R_i = 1 - \frac{L_i}{L_s}$. Where Ri is a distance-dependent variable. In addition, the weighting factor, denoted by w_i and defined by each C_i, was calculated as exp($-a_c \cdot C_i$), where the a_c values were 0.019 and 0.026 for the right and left sides, respectively. This means that the closer C_i is to the center of the ship's heading, the larger the value of w_i. The OCO Intensity, denoted by b, was calculated as the weighted average of the unsafe rate, R_i. The OCO Intensity ranges from zero to one, with one indicating a collision [6].

$$b = \frac{\sum_i^n R_i \times w_i}{\sum_i^n w_i}. \quad (3)$$

In this study, OCO Intensities were calculated for a course width of 10° on each side ahead of the own ship, with a step size of 0.1°, resulting in n = 201. For L_S, a value 15 times that of L_O was used.

3. ANALYSIS METHOD

3.1. Overview

Because the operator's subjective assessments of collision possibility is perceived through subjective ship information, it is considered related to the OZT and OCO Intensities. In this study, we used accident investigation reports from the JTSB to obtain the records of operator's awareness of collision possibility assessment and ship maneuvering and then compared them to the OCO Intensity.

3.2. Analytical Procedure

In this study, the following procedure was performed:
1. Selection of accident investigation reports (18 reports were selected from 2008 to 2018),
2. Extraction of descriptions and times related to subjective of collision possibilities (57 cases),
3. Calculation of the OZT and OCO Intensities using AIS data,
4. Analysis of the relationship between the subjective of collision possibility and OZT and OCO Intensities.

This procedure was almost identical to that used in a previous study [5], and Steps 1 and 2 used datasets generated in a previous study [5]. The subjective awareness of collision possibilities extracted from the Reports were classified into three levels, based on the correspondence between the subjective possibility and the

Table 1. Relationship Between Subjective Collision Possibilities and Collision Avoidance Status [5]

SP Level	Subjective collision possibilities extracted from the Reports	
	Strength of subjective possibility	**Corresponding collision avoidance status**
SP Lv. 1	No collision possibility	-
SP Lv. 2	Collision possibility	During avoidance (more than a few minutes prior to the collision)
SP Lv. 3	Unavoidable collision possibility	Immediately before collision (including during continuous avoidance in a short time)

collision avoidance status defined in Table 1. Hereafter, the classified subjective collision possibilities are referred to as subjective possibility (SP) levels 1–3. In Step 3, the analysis used the period before the earliest time of the subjective collision possibility after the collision. In Step 4, the calculated OZT and OCO Intensities were visualized using maps and graphs, respectively.

The time corresponding to the subjective possibility extracted from the Reports was overlaid on an OCO Intensity graph. Using these visualizations, the relationship between the subjective collision possibility and transitions in the OZT and OCO Intensities was observed. Observations were conducted over short Periods separated by changes in the graph trend.

4. RESULTS AND DISCUSSION

In this section, an overview of the collisions is presented, along with the OZT map and OCO Intensity graph. Subsequently, the transition of the OCO Intensity was described based on observations of the visualizations. Finally, we examined the relationships subjective collision possibility and OCO Intensity. In this study, we focused on two collision cases, Case 1 and 2, that occur in cross-encounter situations. Except for a few time Periods in Case 2, the OCO Intensity increased as the ship approached the collision.

Here, the ship with the larger Gross Tonnage is referred to as Vessel A and the other is referred to as Vessel B. In both the OZT map and the OCO Intensity graph, Vessels A and B are depicted in red and light blue, respectively. The OZT maps show the positions of the ships as dots or ship shapes twice their actual sizes. They show the locations of the OZTs as line segments. For ease of visibility, one for each of the six AIS data was drawn as a ship shape and the five were dots. Red OZTs indicate that the course of Vessel A is obstructed by Vessel B. In the OCO Intensity graphs, the subjective collision possibilities extracted from the Reports were considered to have been recognized within a certain period [5], as indicated by black lines. Moreover, the peak OCO Intensity during this period was plotted with specific marks. The subjective collision possibilities were classified, as presented in Table 1.

4.1. Case 1: Collision Between a Cargo Ship and an Oil Tanker (29 September 2018, Kanmon Passage)

4.1.1 Collision Outline

According to an accident investigation report [11], a cargo ship (1,493 Gross Tonnage, Vessel A) proceeding northeast in the Wakamatsu Passage of Kanmon Port and an oil tanker (748 Gross Tonnage, Vessel B) proceeding southeast in the No. 2 Kanmon Passage of Kanmon Port collided at approximately 14:55 (local time, UTC+9 h). The JTSB concluded that the collision occurred because both operators thought that their target ship would avoid their own ship, and Vessel A attempted to pass the bow of Vessel B, while Vessel B maintained its course and speed.

4.1.2 Analysis

The OZT and OCO Intensities were analyzed for Case 1; Figures 3 and 4 show the results, respectively. Operators awareness extracted from the Report is noted in Table 2, adapted to the SP levels in Table 1. SP Levels corresponds to the marks shown in Figure 4.

4.1.3 Comparison of the OZT Location and OCO Intensity

(i) 14:52:00–14:53:00

Figure 5(i) shows the position of each vessel and the OZT during this Period. During this Period, Vessel A generally completed its left turn at approximately 14:52:20 and then proceeded straight ahead with a gentle left turn, whereas Vessel B proceeded straight ahead the entire time. From the perspective of Vessel A, the OZT first appeared at 14:52:20 on a straight course. Thus, Vessel A turned left, resulting in a hazardous

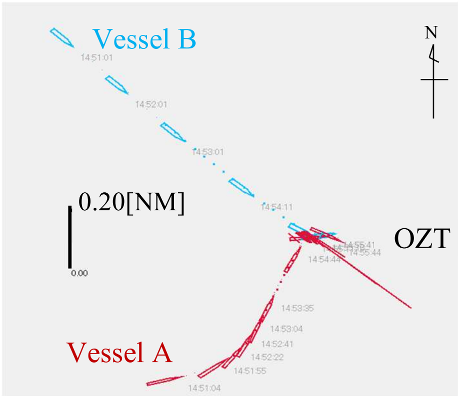


Figure 3. Position of Each Vessel and the OZT (14:51:00–14:56:00) in Case 1

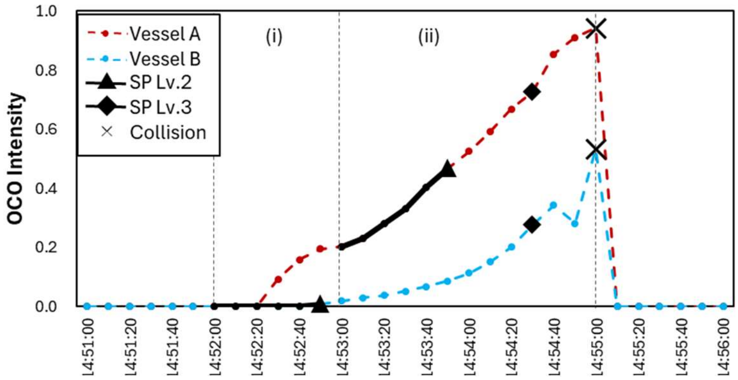


Figure 4. OCO Intensity for Case 1. Calculated using AIS data. The times were plotted corresponding to the operator's subjective collision possibility in Period
he investigation report.

Table 2. List of Subjective Collision Possibilities in Case 1

Time	Vessel	SP Lv.	Extracts from the Report
Approximately 14:52	B	Lv. 2	Recognized a fear of a collision
Approximately 14:53	A	Lv. 2	Recognized that a fear of a collision existed
14:54:30	A	Lv. 3	Felt a fear of collision, took hard to starboard, and stopped the main engine
14:54:30	B	Lv. 3	Recognized the risk of a collision, decreased ship speed, and stopped the main engine

encounter position. After Vessel A completely turned left, both vessels moved straight ahead. Therefore, the OZT remained at almost the same position. This resulted in a continued increase in OCO Intensity as the distance between the OZT and Vessel A decreased. From the perspective of Vessel B, the OZT first appeared at 14:52:50 on the left side of the straight course. This was because Vessel A turned left, resulting in a hazardous encounter position. The low OCO intensity in Period (i) was considered due to the OZT being located at the left edge of the calculated course (10 degrees), as well as the long distance between the OZT and Vessel B.

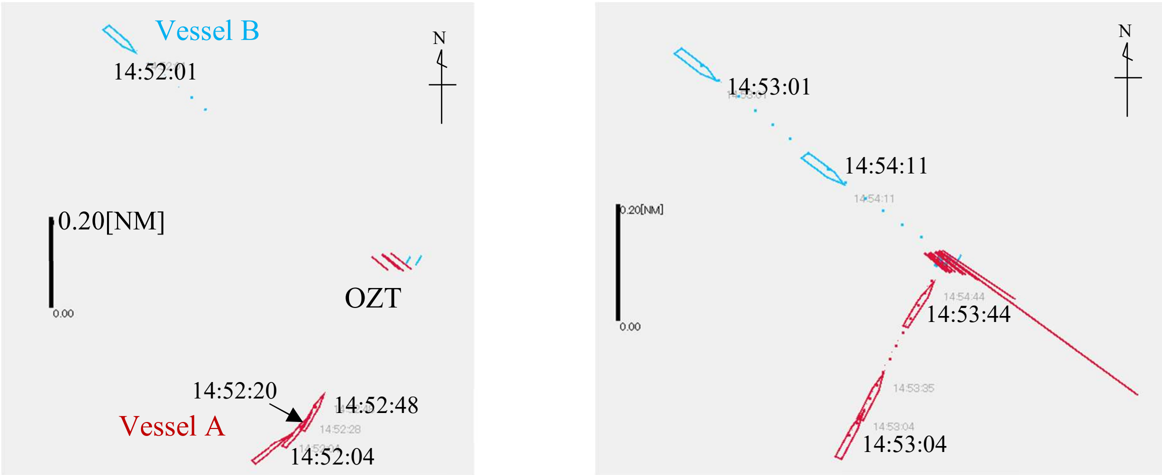
(ii) 14:53:00–14:55:00

Figure 5(ii) shows the position of each vessel and the OZT during this Period. During this Period, Vessel A proceeded straight ahead with a gentle left turn and Vessel B proceeded straight ahead. As both vessels proceeded straight ahead, from the perspective of Vessel A, the OZT remained in almost the same position. Thus, the increase in OCO Intensity continued as the distance decreased. The OZT at 14:54:40 and 14:54:50 extended beyond the calculated course range (10°), and the portion outside this range does not affect the OCO Intensity. From the perspective of Vessel B, because Vessel A proceeded straight ahead with a gentle left turn, the OZT slid toward the heading of Vessel B. Thus, it is considered that the OCO Intensity increased as the distance decreased and that the OZT interfered with more courses. At 14:54:50, the OCO Intensity decreased slightly owing to the change in heading caused by the left rudder of Vessel B; however, there was no significant change in the OZT.

<u>4.1.4 Discussion</u>

First, we reviewed the OCO Intensity when ship operator's subjective collision possibilities, classified as SP Lv. 2. Referring to Figures 4 and 5(i), the operator of Vessel B recognized fear when the OZT was first observed, and the OCO Intensity began to increase. This is an effect of the completion of the left turn of Vessel A. Thus, there is a relationship between OCO Intensity and subjective awareness. Referring to Figure 4(ii), the operator of Vessel A recognized that fear of collision existed when the OCO Intensity increased. Therefore, there is a relationship between OCO Intensity and subjective awareness.

Subsequently, we reviewed the OCO Intensity when ship operators perceived subjective collision possibilities, classified as SP Lv. 3. According to the Report [11], the operators of both vessels urgently avoided



(i) 14:52:00–14:53:00 (ii) 14:53:00–14:55:00

Figure 5. Position of Each Vessel and the OZT at Each Time Period in Case 1

operations when they thought that a collision was unavoidable at 14:54:30. As shown in Figure 4(ii), these occurred at the timing just before the peak of the OCO Intensity, and the OCO Intensities were higher than those of SP Lv. 2. Thus, the OCO Intensity was related to subjective awareness and had higher values when the operator sensed a higher possibility of collision. This means that OCO Intensity is related to subjective awareness, as it was higher at SP Lv. 3 than at SP Lv. 2.

Thus, in this case, the OCO Intensity increased for collisions, and there was a relationship between OCO Intensity and subjective awareness. However, the OCO Intensity of Vessel B was lower than that of Vessel A for the entire duration. It is possible that the OCO Intensity was lower because the OZT segment was shorter. Therefore, fewer courses must be intercepted. Moreover, the shorter the OZT, the lower was the chance of the OZT appearing on the heading. In this case, the main reason for the shorter OZT of Vessel B was that Vessel A was slower. Therefore, it is difficult to consider that the possibility of collision with Vessel A from the perspective of B was significantly lower than that of perspective of Vessel A.

4.2. Case 2: Collision Between Two Container Ships (7 June 2016, Hanshin Port)

4.2.1 Outline

According to an accident investigation report [12], a container ship (170,794 Gross Tonnage, Vessel A) proceeded north in the Kobe Section of Hanshin Port, and another container ship (9,948 Gross Tonnage, Vessel B) proceeded west-northwest in the Kobe section. The ships collided near the south entrance of Kobe Chuo Passage at approximately 7:08:54. The JTSB concluded that Vessel A continued to proceed, whereas Vessel B increased in speed. This was because, the operator of Vessel A thought that Vessel A would be given precedence when entering the Passage, and the operator of Vessel B thought that Vessel A would navigate astern of Vessel B.

4.2.2 Analysis

Figure 8(i) shows the po The OZT and OCO Intensities were analyzed for Case 2; Figures 6 and 7 show the results, respectively. Operators' awareness extracted from the Report is noted in Table 3, adapted to the SP levels in Table 1. SP Levels correspond to the marks shown in Figure 7.

4.2.3 Comparison of the OZT Location and OCO Intensity

(i) 6:54:00–6:56:00

Figure 8(i) shows the position of each vessel and the OZT during this Period. During this Period, Vessel A slowly turned left, whereas Vessel B proceeded straight ahead. From the perspective of Vessel A, the OZT first appeared at 6:54:20, positioned to the right of a straight course. Vessel A turned to the left, resulting in a hazardous encounter situation and OZT. However, OCO Intensity increased only slightly, owing to the long distance between the OZT and Vessel A. From the perspective of Vessel B, the OZT first appeared at 6:55:20, which was positioned on a straight course. Vessel A turned left, resulting in a hazardous encounter and

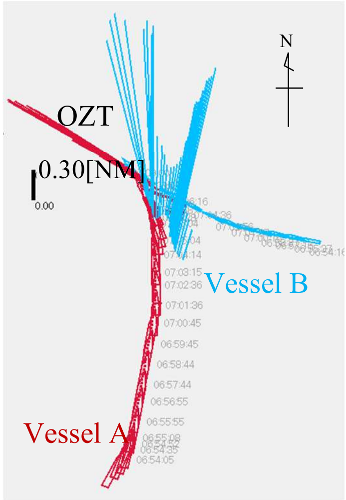


Figure 6. Position of Each Vessel and the OZT in Case 2 from 6:54:00–7:09:30

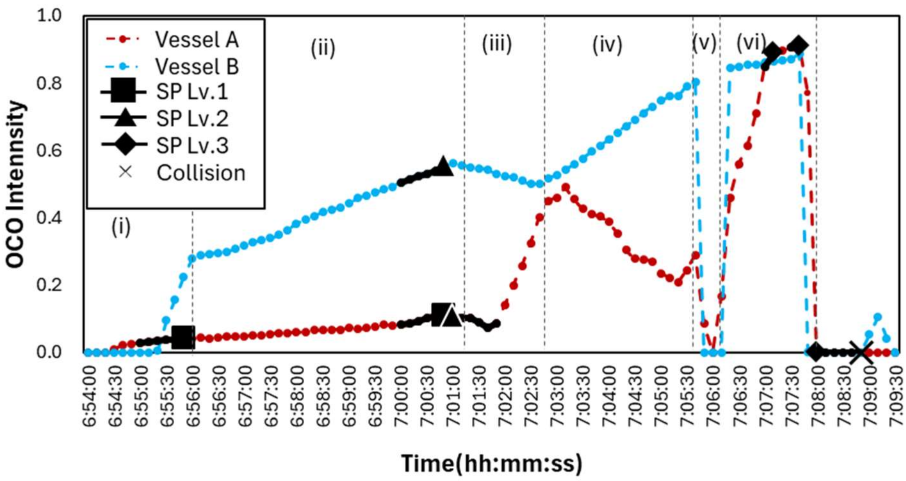


Figure 7. OCO Intensity for Case 2. Calculated using AIS data. The times corresponding to the operator's subjective collision possibility in the investigation report were plotted.

Table 3. List of Subjective Collision Possibilities in Case 2

Time	Vessel	SP Lv.	Extracts from the Report
Approximately 6:55	A	Lv. 1	Focusing attention on Vessel B and one other vessel
Approximately 7:00	A	Lv. 1	Noticed Vessel B
Approximately 7:00	B	Lv. 2	Sensed a risk of a collision with Vessel A
Approximately 7:01	A	Lv. 2	Sensed a risk of a collision
7:07:04	A	Lv. 3	Stopped the main engine
7:07:35	A	Lv. 3	Instructed slow astern followed by full astern
Approximately 7:08	B	Lv. 3	Set the main engine to half ahead

occurred OZT. The heading change in Vessel A caused the OZT to slide toward the heading of Vessel B. Therefore, the OCO Intensity increased continuously because the OZT gradually interfered with more courses.

(ii) 6:56:00–7:01:30

Figure 8(ii) shows the position of each vessel and the OZT during this Period. During this Period, Vessel A slowed while turning left and moved almost straight ahead, whereas Vessel B proceeded straight ahead. From the perspective of Vessel A, Vessel B moved straight ahead, and the OZT was continuously observed in the same position. Because the OZT was positioned to the right of the straight course and Vessel A faced slightly left, the OCO Intensity increased slightly. From the perspective of Vessel B, the OZT became shorter and moved away from Vessel B but continuously obstructed Vessel B's course. Because the OZT had backed off a little, the increase in the OCO Intensity was slow.

(iii) 7:01:30–7:03:00

Figure 8(iii) shows the position of each vessel and the OZT during this Period. During this Period, Vessel A turned left, whereas Vessel B continued to move straight in an increased speed. From the perspective of Vessel A, as Vessel B accelerated, the OZT lengthened. Moreover, the OZT obstructed Vessel A's heading direction. This caused a significant increase in the OCO Intensity. From the perspective of Vessel B, the OZT position slid away when Vessel A turned left. Thus, Vessel B approached the OTZ; however, the OCO Intensity decreased as the OZT backs off.

(iv) 7:03:00–7:05:45

Figure 8(iv) shows the position of each vessel and the OZT during this Period. During this Period, Vessel A stopped turning left and moved straight ahead, whereas Vessel B continued to go straight and further increased its speed. From the perspective of Vessel A, the trends of the OZT lengthening and sliding described in Period (iii) continued. Consequently, the position of the OZT moved to the left of Vessel A's heading. The OZT is long but out of the calculation area. Thus, the OCO Intensity decreased. From the perspective of Vessel B, the

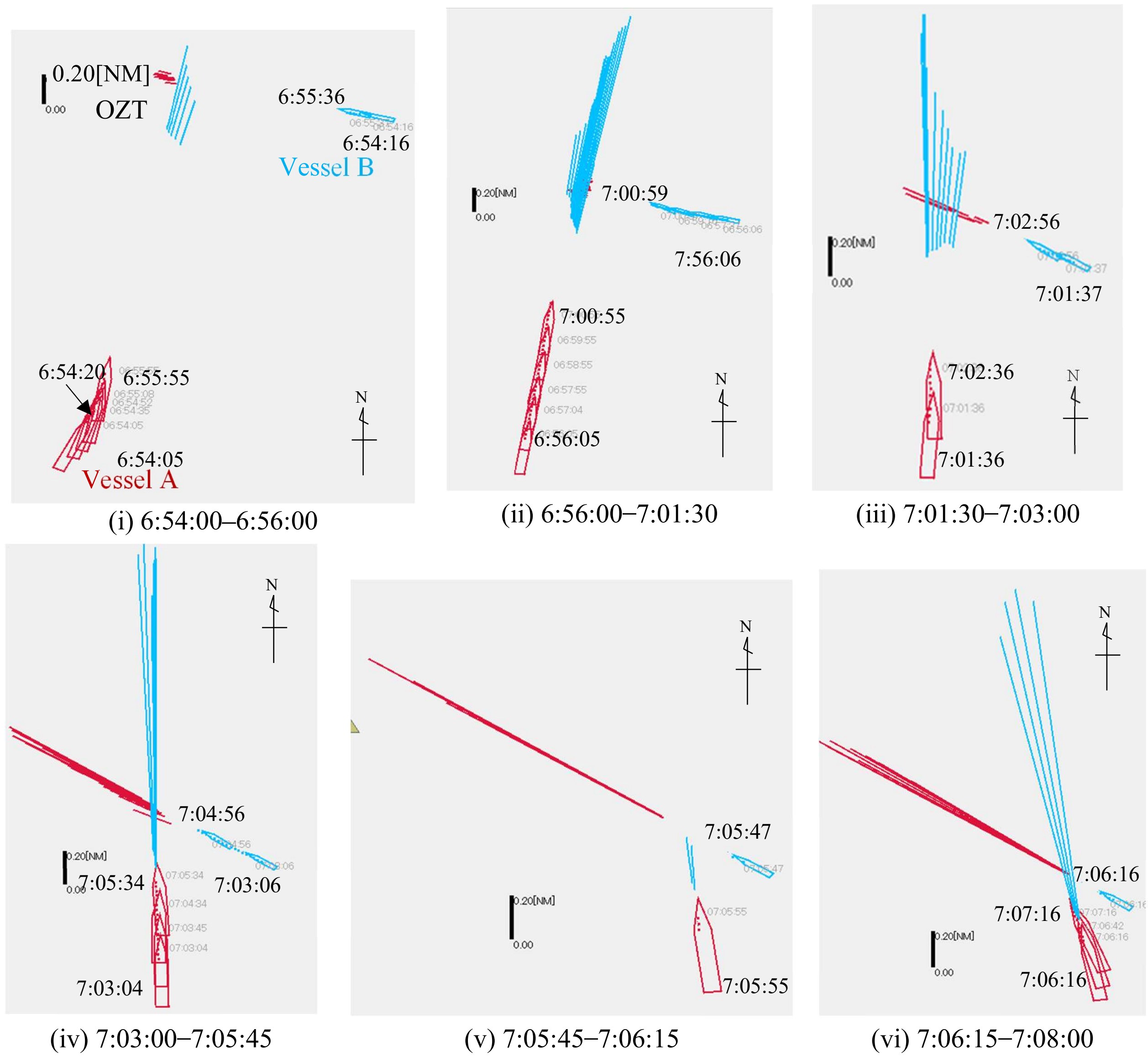


Figure 8. Position of Each Vessel and the OZT during each time Period in Case 2

OZT continued to appear in almost the same location. The OCO Intensity increased during this Period as the distance between Vessel B and the OZT decreased.

(v) 7:05:45–7:06:15

Figure 8(v) shows the position of each vessel and the OZT during this Period. During this Period, Vessel A slowed and turned left again, whereas Vessel B proceeded straight ahead at a low speed. From the perspective of Vessel A, the trends of the OZT lengthening and sliding described in Periods (iii) and (iv) continued. Thus, the OZT moved to the left outside of the calculated course, and the OCO Intensity decreased significantly. From the perspective of Vessel B, because Vessel A increased its speed and turned left, the OZT shortened and moved to the left outside of the calculated courses, reducing the OCO Intensity. The OCO Intensities were zero. This implies that Vessel B could cross in front of Vessel A temporarily based on this calculation.

(vi) 7:06:15–7:08:00

Figure 8(vi) shows the position of each vessel and the OZT during this Period. During this Period, Vessel A turned hard left, whereas Vessel B proceeded straight ahead at a low speed. From the perspective of Vessel A, the OZT position was again in a hazardous encounter situation, as described in Period (iv). However, the OZT position did not slide because Vessel B did not accelerate. Therefore, the OCO Intensity increased as the distance decreased. From the perspective of Vessel B, the OZT position was again in a hazardous encounter situation, similar to that described in Period (iv). Thus, the OCO Intensity increased as the distance decreased.

4.2.4 Discussion

First, we reviewed the OCO Intensity when ship operators perceive subjective collision possibilities, which are classified as SP Lv.1. Referring to Figure 7 Period (i) and (ii), the operator of Vessel A focused on or noticed Vessel B when the OCO Intensity was at a low value. At those time, the operator did not recognize the possibility of collision. Thus, when the SP level was low, the OCO Intensity was also low. Therefore, the OCO Intensity was related to subjective awareness and had a low value when the operator did not sense the possibility of collision.

Subsequently, we reviewed the OCO Intensity when ship operators sensed subjective collision possibilities, classified as SP Lv. 2. Figure 7(ii) shows that the operator of Vessel A sensed the risk of collision when the OCO Intensity remained constant at a low value and the OZT position remained unchanged. The operator of Vessel A might have sensed the possibility of a collision because of the shortened time margin. However, it appeared that the decrease in distance was not reflected in the OCO Intensity owing to the offset caused by the Vessel A's heading. The operator of Vessel A might have sensed the possibility of a collision when the OCO Intensity began to increase, as indicated in Figure 7(iii). Similarly, the operator of Vessel B sensed the risk of collision when the OCO Intensity remained constant. At that time, the distance was offset by a change in the heading of Vessel A. Moreover, we could not exclude the possibility that the operator of Vessel B sensed the risk when the OCO Intensity began to increase. This was because the Report did not mention any perceptions at earlier time points. Thus, the OCO Intensity corresponding to SP Lv. 2 for both operators in Case 2 remained almost constant despite the expected increase. Thus, it is unclear whether the OCO Intensity is related to subjective awareness.

Finally, we reviewed the OCO Intensity when ship operators sensed subjective collision possibilities, classified as SP Lv. 3. Figures 7 and 8(vi) show that at 7:07:04 and 7:07:35, in which the operator of Vessel A urgently avoided operations, the OZT was close to Vessel A. This shows that the OCO Intensity was related to subjective awareness in these instances. In addition, Figure 7 shows that the operator of Vessel B performed an urgent avoidance operation at approximately 7:08, after the OCO Intensity peaked and then dropped. This drop was possibly caused by the nature of the OZT such as effect by the antenna position and safe passing distance. Another possible reason for the decrease in the OCO Intensity was that the OZT slid outward owing to the strong influence of the avoidance operation of Vessel A. Moreover, because we could not confirm the accuracy of the operator's memory or time written in the Report, the actual timing may be a few dozen seconds earlier, when the OCO Intensity was high. The OCO Intensity corresponding to SP Lv. 3 for Vessel B in Case 2 was low despite the expected high value. Thus, it was unclear whether the OCO Intensity was related to subjective awareness.

In Case 2, the OCO Intensity appeared to increase as the collision approached, suggesting a correlation between OCO Intensity and subjective awareness. However, several challenges remain unaddressed. First, as shown in Figure 7, during Periods (i)–(iii), the OCO Intensity of Vessel A was lower than that of Vessel B. This Period was a hazardous encounter. However, the OCO Intensity was low because the heading of Vessel A was slightly outside the OZT position. Therefore, it is difficult to assess a future hazardous situation solely based on the current heading while the course is changing. Moreover, Figure 7(iv) shows that the OCO Intensities of both vessels decreased. The accident investigation report did not describe the operator awareness during this time. As noted in Section 4.2.3(iv), this occurred because the OZT temporarily slid outside the calculated course. However, if the distance is sufficiently small, it is considered dangerous even if the OZT is off the heading course. Moreover, the operator of Vessel B performed an urgent avoidance operation after the OCO Intensity decreased. This could be caused by the area within which the OZT was evaluated. A challenge for studies using accident investigation reports is the accuracy of the time written in Reports. For example, the solution is to treat a particular avoidance maneuver as a result of an operator's awareness of an accident. Overcoming these challenges will provide a better understanding of the relationship between the indicators and awareness, which will be useful for future investigations.

5. CONCLUSION

This study aimed to compare the objective ship-to-ship encounter situations and subjective operator awareness during ship collisions. First, the collision possibilities of the encounter situations were quantified using OZT and OCO Intensity. Subsequently, the transitions in the OZT and OCO Intensities were compared with the collision possibilities perceived by the operators. This awareness was obtained from accident investigation reports.

Transitions of the OCO Intensity during a collision exhibited an increasing trend as the collision approached. The factors affecting the OCO Intensities were discussed by examining the position and length of the OZT at each time. The OCO Intensity tends to increase as a ship approaches a collision point, reflecting changes in course and speed. Hence, despite its challenges remain, OCO Intensity is a promising indicator for evaluating collision possibilities.

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