

# Evaluation Method of Collision Risk by Using True Motion

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**ABSTRACT:** It is necessary to develop a useful application to use big data like as AIS for safety and efficiency of ship operation. AIS is very useful system to collect targets information, but this information is not effective use yet. The evaluation method of collision risk is one of the cause disturb. Usually the collision risk of ship is evaluated by the value of the Closest Point of Approach (CPA) which is related to a relative motion. So, it becomes difficult to find out a safety pass in a congested water. Here, Line of Predicted Collision (LOPC) and Obstacle Zone by Target (OZT) for evaluation of collision risk are introduced, these values are related to a true motion and it became visible of dangerous place, so it will make easy to find out a safety pass in a congested water.

## 1 DECISION MAKING PROCESS AND CONVENTIONAL EVALUATION METHOD OF COLLISION RISK

The subject of Decision Making for collision avoidance is strict requirements in terms of risk mitigation. There are three steps in the process of decision making. The first step is information collection, where various information like as AIS data, radar data, chart data and many other voyage related data used for ship operation are collecting. The second step is information processing, where all collected information would be processed and analyzed by the team on duty at bridge to recognize about the own ship current situation, for instance, encountering collision risk and the performance of own ship in a current navigation environment. The third step is the decision of own ship action, where captain and/or navigator select own ship action that satisfies safety, legality and efficiency. According to the near miss cause surveyed done in the past <sup>[1]</sup>, 43% of cause by the navigator themselves, 17% for

teamwork and 23% for supporter, so most of the cause of near miss exists in humans. So, there is need to review the function of decision making process. Improvement for the information collection has been made, such as loading AIS. And with appearance of GPS, it became easy to know the true motion of target. But nothing has been improved for the information processing and overall improvement of decision making has not progressed. Among the information processing, it is necessary to improve the evaluation method of collision risk. The conventional collision risk evaluation method use the Distance of Closest Point of Approach (DCPA) and Time to CPA (TCPA) of target which are related to relative motion (see Figure 1).

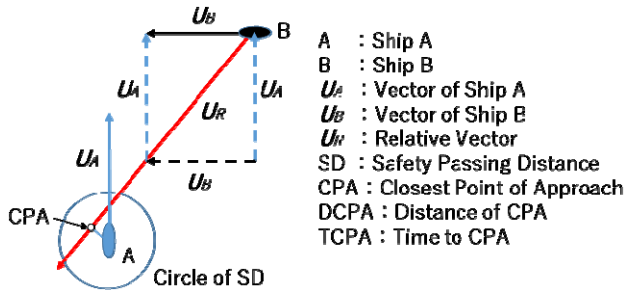


Figure 1. Collision risk evaluation method by using relative motion

This method has several problems for collision avoidance as follows;

- 1 It does not consider the ability for collision avoidance of own ship. The speed of own ship is deeply related to the ability to avoid collision.
- 2 It must set own ship action for evaluation in advance, even before decision making. So, this method is a trial and error method to find out safety action.
- 3 The base of this method evaluates strait line pass, but in congested area it is necessary to evaluate not only strait line pass but also broken line pass.
- 4 It is necessary to predict and respond quickly to the target's action change in a congested area. But there are many difficulties for predicting an effect of target's action change on the collision risk and planning pass.
- 5 It is not easy to compare the collision avoiding action with the chart data. It is necessary to convert numerical data to position data.

There are so many problems to use this evaluation method for collision avoidance in a congested area, so that the collision risk alarm equipped in ARPA has not been used so much, especially in a congested area, due to these reasons. For active use of big data such as AIS for collision avoidance, we need to improve the evaluation method of collision risk.

## 2 LINE OF PREDICTED COLLISION

There are two ways to express the process of collision between two dots. The first way, it is the closest point of approach (CPA) as shown in Figure 1, this value is related to the relative motion. The second way, two dots arrive at the same place at the same time from their own position. Here, the same place is named the Point of Predicted Collision (PPC), this is related to the true motion. Since, there are many problems in using the relative motion, so I will adopt PPC.

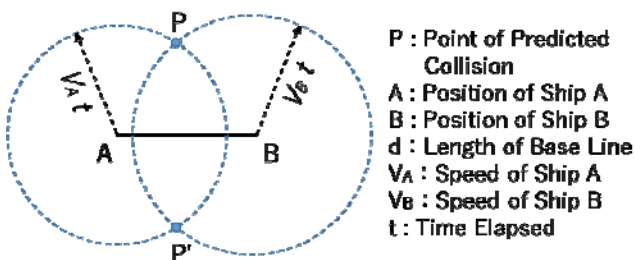


Figure 2. Point of Predicted Collision

Figure 2 shows where the PPC (P) looks from ship A and ship B. Length between AP and BP is proportion to their speed as follows,

$$AP : BP = V_A : V_B = V_A t : V_B t \quad (1)$$

$$t_{\min} = \frac{d}{V_A + V_B} \quad (2)$$

$$t_{\max} = \frac{d}{V_B - V_A}$$

Two PPC are determined every time elapsed (t) as shown in the figure.

Figure 3 shows the Line of Predicted Collision (LOPC) [2] that is formed by connecting PPC together. The LOPC change the shape according to the ratio of two ship's speed (N),

$$N = \frac{V_B}{V_A} \quad (3)$$

If two ship's speed are equal (N=1) then LOPC is the perpendicular bisector, and otherwise it is circular shape surrounding around low speed ship.

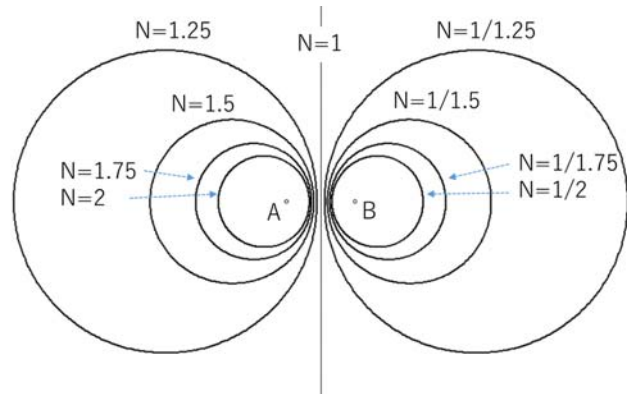
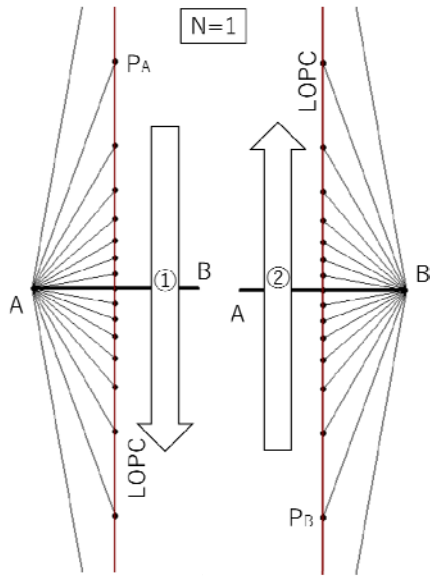


Figure 3. Line of Predicted Collision

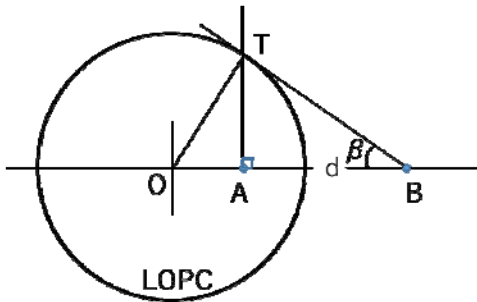
The PPC of the ship is an intersection of course line of the ship and LOPC. Left side of the Figure 4 shows PPC of ship A ( $P_A$ ) in each course of ship A, and right side shows PPC of ship B ( $P_B$ ) in each course of ship B respectively. If the ship changes course, then PPC move on LOPC according to the new course line. So, we can predict very easily which direction PPC will take. If  $P_A$  and  $P_B$  are same position, it means that two ship's destination is same, then they will collide at the PPC, and if their position are difference, two dots will not collide ( $DCPA > 0$ ).



**PA : Point of Predicted Collision by Ship A**  
**PB : Point of Predicted Collision by Ship B**

Figure 4. PPC and LOPC, the arrow represents movement of PPC when the ship has steered to starboard.

Figure 5 shows the shape of LOPC (N=2). Here T is the contact point of tangency drawn from ship B to the LOPC, where the angle of  $\angle TAB$  is  $90^\circ$ , and tangent angle of LOPC ( $\angle ABT$ ) is  $\beta$ .



**d : Base Line**    **T : Point of Tangency**  
 **$V_{LOW}$  : Speed of Low Speed Ship A**  
 **$V_{HIGH}$  : Speed of High Speed Ship B**  

$$\beta = \sin^{-1}(V_{LOW} / V_{HIGH})$$

Figure 5. Shape of LOPC (N=2)

The elements of LOPC can be obtained by the following equations

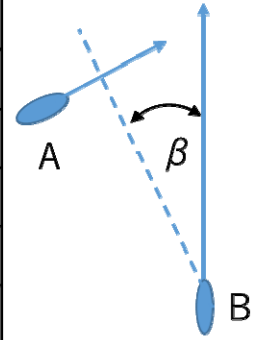
$$AO = \frac{d}{1 - N^2} \quad (4)$$

$$OT = N \times |AO|$$

So, the shape of LOPC change with speed ratio (N) and length of base line (d). The radius of LOPC (OT) tend to shorten when the speed ratio N departs from 1.0 as shown in the Figure 3. If high speed ship try to see low speed ship from the bow at an angle greater than  $\beta$ , then the course line of high speed ship does not cross the LOPC, so no collision occurs regardless of the course of low speed ship. Like this, high speed ship has capability to avoid collision by its own action. Several values of  $\beta$  are shown in Table 1.

Table 1. Sample of angle  $\beta$

N	$\beta$
1.00	90.0
1.25	53.1
1.50	41.8
1.75	34.8
2.00	30.0



### 3 OBSTACLE ZONE BY TARGET

However, ship is not a dot it has size and volume. So, we must take into consideration the safety passing distance (SD) between two ships. The course of ship A ( $C_A$ ) to keep the SD between the ship B can be obtained by using next method which all navigator knows well (see Figure 6).

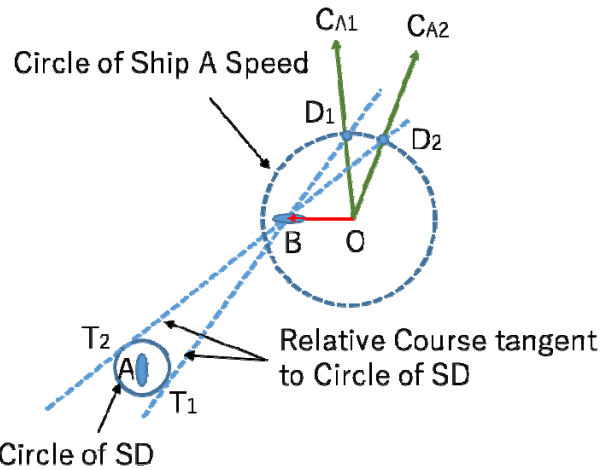


Figure 6. Obtaining method of Collision Course, where collision course is  $CA1 \sim CA2$

- 1 First, draw a circle of radius SD centered on ship A, as indicate "Circle of SD" in the figure.
- 2 Draw tangent lines to this circle from ship B, and contact points are set as T1 and T2.
- 3 Draw the motion vector of ship B behind ship B, as indicate "OB" in the figure.
- 4 Draw a circle of radius of ship A speed centered on point O, as indicate "circle of ship A speed" in the figure.
- 5 D1 and D2 are intersections of tangent lines and circle of ship A speed. The direction of line connecting O and D1 ( $CA1$ ) and O and D2 ( $CA2$ ) become collision courses to be obtained.

The course between  $CA1$  and  $CA2$  would be that the DCPA is less than SD, so that this course is called collision courses. But, in case of a congested area, collision courses per each target will be overlap and not easy to find out safe passage route by using these collision courses. So, I add the following action,

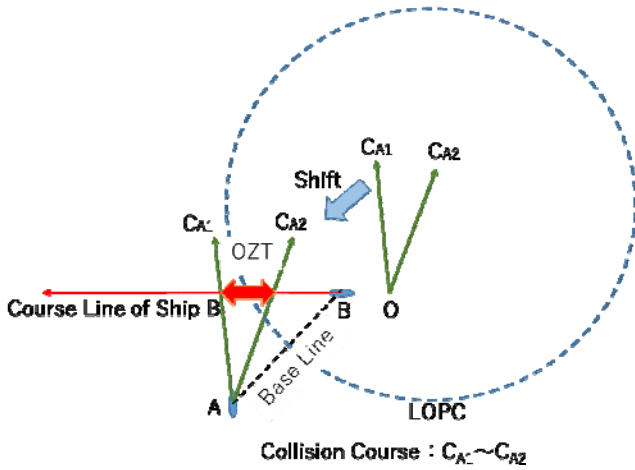
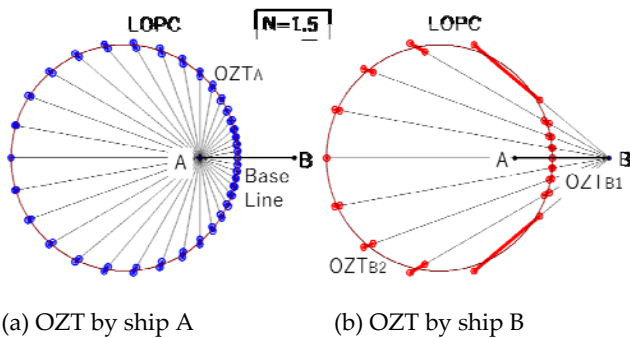


Figure 7. Obtaining the Obstacle Zone by Target

- 1 Shift the collision courses (CA1 and CA2) to ship A as shown in the Figure 7.
- 2 And find the zone which part of the course line of ship B cut out by these collision courses. This zone is named the Obstacle Zone by Target (OZT)[3][4][5].

Since ship A will collide with ship B when passing through this zone, which means that the collision course can be converted to the information of collision place.



(a) OZT by ship A (b) OZT by ship B  
Figure 8. The Course Line of each ship and OZT, where  $N=1.5$

Figure 8 shows the OZT in case of  $N=1.5$ . Left side of the figure shows the OZT in each course of low speed ship A ( $OZT_A$ ), since ship A is inside of the LOPC, every course line of ship A cross the LOPC and generate  $OZT_A$  at the intersection as shown in the figure. Right side figure shows the OZT in each course of high speed ship B ( $OZT_B$ ), since ship B is outside of the LOPC, basically two OZT ( $OZT_{B1}$  and  $OZT_{B2}$ ) are generated when the course line of ship B cross the LOPC, and when the course line is close to the contact point, one long  $OZT_B$  is generated. OZT has following advantages,

- It can be visualized the collision risk as danger place.
- OZT is on the LOPC as shown in the Figure 8. So, position of OZT will move on the LOPC according with target action change. It becomes easy to predict the new position of OZT with target's action change by using LOPC.
- OZT will be displayed on the course line of each target individually, so it is easy to identify which ship's OZT is, and it make easy to find out safety place to pass in a congested area.

- OZT shows location, so it can be superimposed on the chart and it is useful for preventing grounding at same time.

So, the perspective should be changed to true motion from relative motion, then the collision risk will change from the numerical form like TCPA and DCPA to visualized information, so it can be easy to use even in a congested area.

The collision course  $C_A$  is obtained by the following equation.

$$C_A = A_Z \pm \alpha - \sin^{-1}\{N \sin(A_Z \pm \alpha - C_B)\} \quad (5)$$

where  $A_Z$  is the azimuth angle of ship B,  $C_B$  is the course of ship B and  $\alpha$  is  $\angle ABT$  in the Figure 6.

#### 4 LOPC AND OZT

Figure 9 shows how LOPC and OZT change with a speed ratio  $N$ . Here, the speed ratio  $N$  is 1.5, 1.25 and 1 respectively. The OZT by ship A ( $OZT_A$ ) and the OZT by ship B ( $OZT_B$ ) occurs at the intersection of LOPC and course line of ship respectively. The length of  $OZT_B$  becomes longest in a point of tangency of LOPC, see  $OZT_{B1}$  in the figure.

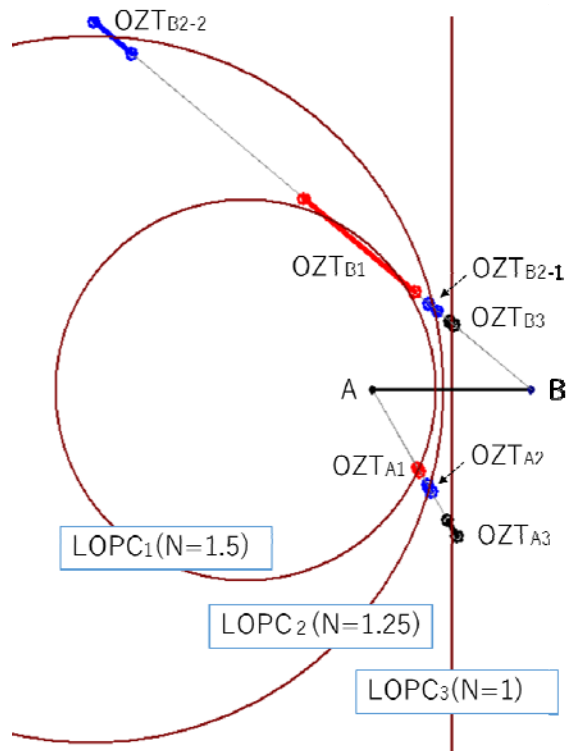


Figure 9. Change of Speed and OZT

Figure 10 shows the  $OZT_A$  and the  $OZT_B$  in case of both ship's destination is a point of tangency.

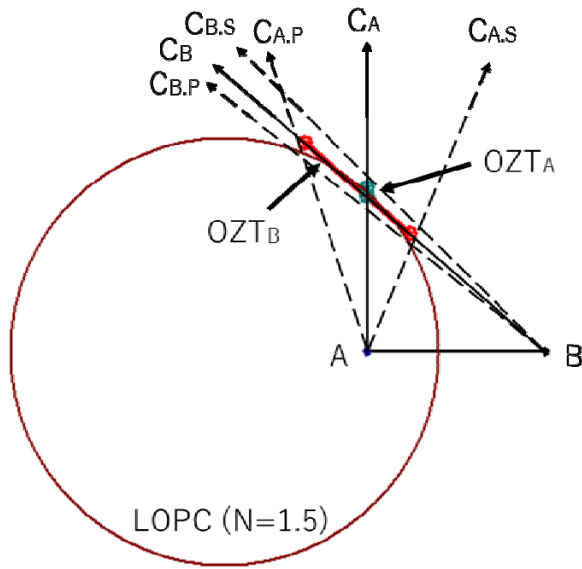


Figure 10. Difference of  $OZT_A$  and  $OZT_B$  at the point of tangency of LOPC

There is a big difference between  $OZT_A$  and  $OZT_B$ . For ship A to avoid passing through  $OZT_B$ , it is necessary to take large angle course change, for instance where starboard side from  $C_A$  to  $C_{A.S}$ , or port side case from  $C_A$  to  $C_{A.P}$ . On the other hand, if ship B avoid passing through  $OZT_A$ , it is sufficient to take small angle course change, where starboard side from  $C_B$  to  $C_{B.S}$  or port side from  $C_B$  to  $C_{B.P}$  respectively. This difference leads to gap in the start time of the avoidance action by each ship.

## 5 DISTRIBUTION OF OZT IN A CONGESTED AREA

Figure 11 is an example of OZT distribution in a congested area, it shows OZT by the target ship. On the screen, there are 21 target ships at same time, it is quite congested but OZT in the angle range of 10 points ( $112.5^\circ$ ) on each side from the bow of ship A are only 10 places, Z1 to Z10 as shown in the figure, these OZT will obstruct the passage of ship A. The target ship forming the OZT can be easily identified, so you can identify the target ships that need attention. From the OZT distribution shown in the figure, it is easy to find a safety route which is straight line or broken line avoiding through these OZT. Thinking about behavioral conditions like as safety, legality and efficiency, we will select route of own ship, among those safety routes candidate. There are four OZT (Z5, Z6, Z7 and Z9) near the course line of ship A. If ship A passes through these four OZT, it is difficult to get enough space between each OZT, and since the ship A will becomes an overtaking ship against the target forming Z5, the ship A will be necessary to take avoiding action against this target before reaching Z5.

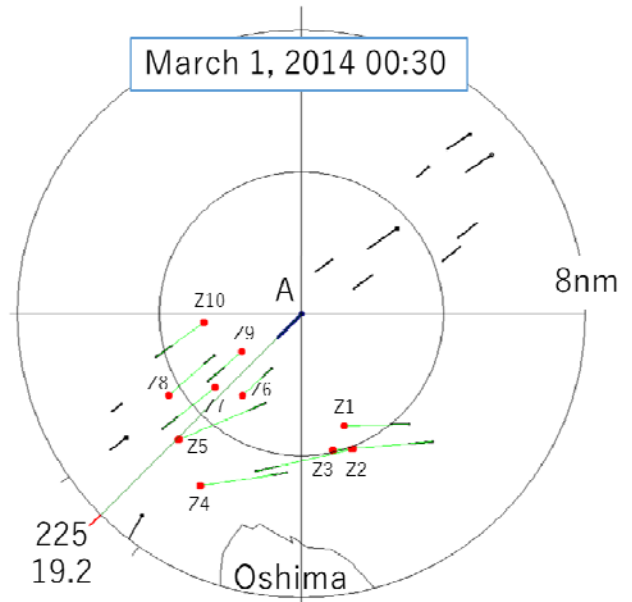


Figure 11. Sample of OZT distribution

Figure 12 shows a similar route adopted by ship A. First, ship A changed its course to port 20 degree to avoid congestion, and go straight about 3nm (10 minutes). After passing Z6, ship A put the course back and took starboard 20 degree. This route and OZT can be superimposed on the chart as shown in the figure. So, at the same time it can be used to prevent the grounding.

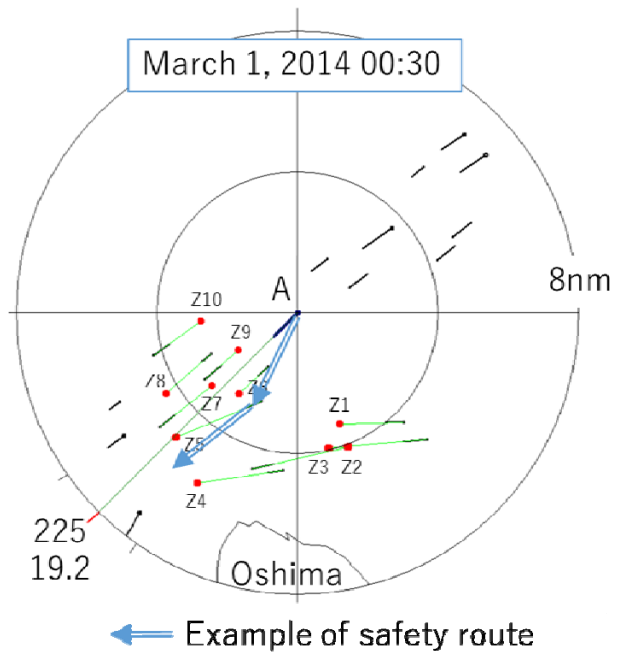


Figure 12. Safety route planning

## 6 CONCLUSIONS

After this study, it appears that the evaluation of collision risk using true motion has many advantages as follows;

- 1 In this method, the ability for collision avoidance of own ship has been considered. There is a strong relation between the ability of collision avoidance

and LOPC. The ability for collision avoidance is high when the ship locates outside LOPC.

- 2 It is easy to find out safety route and action for collision avoidance by using the distribution of OZT around own ship.
- 3 The influence by target's action change can be regarded as sifting position of OZT. And new position of OZT by target's action change can be easily predicted by using LOPC.
- 4 It is easy to compare the planning pass obtained by decision making with chart data.

And, LOPC can be regarded as a model in the case where  $SD=0$  in OZT. Therefore, all the two ships encounter condition can be explained by using LOPC. So, it become possible to evaluate collision risk quickly per the target's dynamic information.

Since this theme is fundamental to ship safety operation, it can be utilized all matters related to ship safety operation, like as ship traffic flow analysis and design of ship traffic flow etc.

The standard of collision avoidance action by using LOPC and OZT will be made in future work.

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