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# Evaluation of the Risk of Collision Between Two Target Ships Based On Observation Data From A Third Party

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## Abstract

Detecting the risk of collision is a very important step to prevent marine accidents. For detecting the risk of collision, radar plotting is often used. Based on therelative position and motion of two ships, the risk of collision between them can be evaluated. However, the present radar equipmentis not supported to detect the risk of collision between two target ships from the observation data measured by a third party. This causes difficulties for officers of shore stations, when evaluating the marine traffic situation to maintain the safety of navigation.To solve this problem, it is necessary to develop a method to evaluate the risk of collision between two target ships from the observation data measured by the shore station radar (the third party). In this article, the development of such method is introduced..

**Keywords**: risk of collision, radar plotting, marine accident

## 1. Introduction

The collision between ship often causes huge loss of lives, properties, and damages to the environment. Preventing collision at sea and/or in the waterway is a very important duty of not only ship officers, but also port authorities. To prevent collision, the risk of collision should be evaluated in advance to achieve a sufficient amount of time for necessaryactions.

According to Rule 7d of the International Convention for Preventing Collision at Sea, ifthe risk of collision exists the following considerations shall be among those taken into account:

*(i) such risk shall be deemed to exist it the compass true bearing of an approaching vessel does not appreciably change;*

*(ii) such risk may sometimes exist even when an appreciable true bearing change is evident, particularly when approaching a very large vessel or a tow or when approaching a vessel at close range.*

To detect the risk of collision, radar is often used. Observation of radar plotting method isconducted to assess the risk of collision between own ship and target ships. By applying theradar plotting method, the risk of collision between own ship and target shipscan be deemed to exist when two below conditions are met:

- The value of closest point of approach (CPA) is smaller than $CPA_{min}$

- The value of time to the closest point of approach ($T_{CPA}$) is positive.

In marine practice, a ship's radar possesses the automatic radar plotting aids (ARPA) function which assists mariners to the values of CPA and $T_{CPA}$ automatically. This function allows for a faster detection of the risk of collision. However, this function does not allow for the detection the risk of collision between target ships.

The radar of shore stations faces the same situation relating tothis function, making it difficult to detect the risk of collision.To solve this problem, it is necessary to develop a method to evaluate the risk of collision between two target ships from the observation data measured by the shore station radar (the third party). This will assist officers of shore stations inevaluating the risk of collision between ships, thereby managing the traffic conditions more efficiently. In this article, the development of such method is introduced.

## 2. Development of a method to evaluate the risk of collision between two target ships from the observation data measured by the shore station radar

Collision risk between ships could be assessedusingmany methods. The method used in this paper is an analytical method, which assess collision risk directly by analytical expressions and ship movement parameters.When a ship is about to collide with another ship, collision risk should be evaluated before deciding the next movement of the ship. The CPA and TCPA are the most important factors when assessing the risk of collision between ships in a practical scenario.With the intention of simple, fast calculation and application, a method through which collision risk can be directly calculated byobservation data measured by the shore station radar wasproposed, including three steps.First, the positions of target ships will be obtained. The second step is the calculation of distance and true bearing between pairs of ships. Finally, the collision risk between these ships will be assessed by CPA.

### 2.1. Determination of target ships' positions from the shore station

For certain water area, there will be plenty of ships at the same time. To assess the collision risk between ships, the positions of ships are calculated by getting the inputs from radar. Initially, the true bearings and distances from shore station radar toships are recorded. The number of ships about which we can get information depends on the radar range.These ships consist of a ship set, denoted by set S:

S = {s|s = 1, 2, 3, ...,i}, where i is the total number of observed ships.

Given the position of the shore station radar:($\varphi_0$, $\lambda_0$), the first stage of our method is the calculation of thepositions of target ships.

The input data of ships observed from the shore station radar are true bearing and distance, which are denoted as$S_1(PT_{S1}, D_{S1})$, $S_2(PT_{S2}, D_{S2})$, …, $S_i(PT_{Si}, D_{Si})$.

A two-dimensional Cartesian coordinate system OXY in constructed with the vertical axis, with its positive direction representing North 0°, and the horizontal axis in the positive direction representing 90°.Due to the difference in ratio between longitude and latitude, the position in longitude and latitude is converted to OXY coordinates as follows:

$$\begin{cases} X = R\lambda\cos\varphi_{TG} \\ Y = R\varphi \end{cases} \tag{1}$$

where:

R is theradius of Earth(nautical miles)

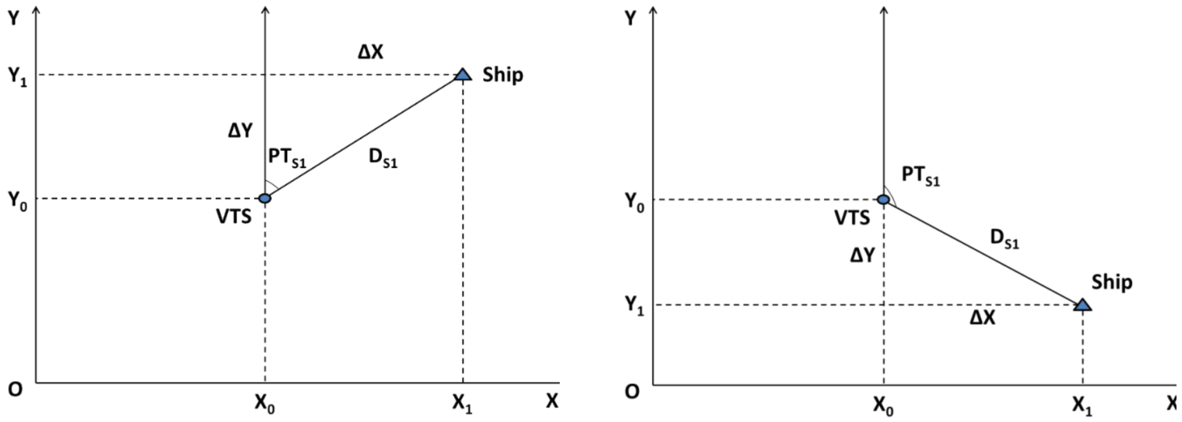
$\lambda$ is longitude (rad)

$\varphi$ is latitude (rad)

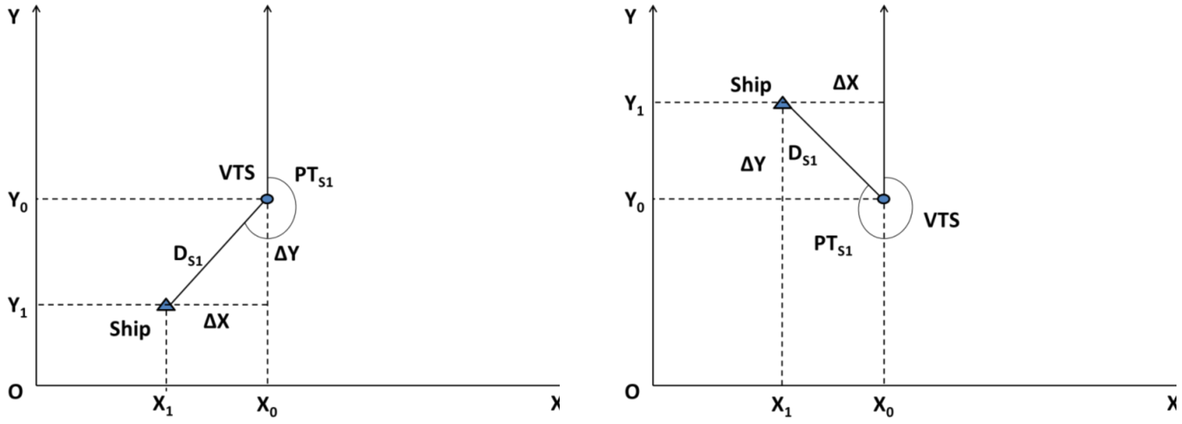
$\varphi_{TG}$is middle latitude (rad) (in this paper, the middle latitude is selected to be the latitude of the shore station $\varphi_0$)

After applying Equation (1) to the longitude $\lambda_0$ and latitude $\varphi_0$, the OXY coordinates of the shore station is($X_0$, $Y_0$).The area around the shore station is divided into four quarter I, II, III, IV, following a clockwise direction from North 0°.

Suppose that the target ship is $S_1$ with coordinate ($X_1$, $Y_1$) needed to be determined by applying geometry theory. $PT_{S1}$ and $D_{S1}$ are true bearing and thedistance measured to ship $S_1$ from the shore station respectively. The target ship could be in one of these four quarters, as demonstrated in Figure 1. The variation in latitude and longitude between ship $S_1$ and the shore station are denoted as $\Delta X$, $\Delta Y$.



(a) Target ship in quarter I (b) Target ship in quarter II



(c) Target ship in quarter III (d) Target ship in quarter IV

**Fig.1** Target ship observed from the shore station

In case target ship in the quarter I (Figure 1a), then $0^o \leq PT_{S1} \leq 90^o$, we have $X_1 > X_0$ and $Y_1 > Y_0$, the position of target ship $S_1$ can be obtained from the shore station as follows:

$$\begin{cases} \Delta X = X_1 - X_0 = D_{S1} sinPT_{S1} \\ \Delta Y = Y_1 - Y_0 = D_{S1} cosPT_{S1} \end{cases} \rightarrow \begin{cases} X_1 = X_0 + D_{S1} sinPT_{S1} \\ Y_1 = Y_0 + D_{S1} cosPT_{S1} \end{cases} \tag{2}$$

In case target ship in the quarter II (Figure 1b), then $90^o < PT_{S1} \leq 180^o$, we have $X_1 > X_0$ and $Y_1 < Y_0$, the position of target ship $S_1$ can be obtained from the shore station as follows:

$$\begin{cases} \Delta X = X_1 - X_0 = D_{S1} sinPT_{S1} \\ \Delta Y = Y_0 - Y_1 = -D_{S1} cosPT_{S1} \end{cases} \rightarrow \begin{cases} X_1 = X_0 + D_{S1} sinPT_{S1} \\ Y_1 = Y_0 + D_{S1} cosPT_{S1} \end{cases} \tag{3}$$

In case target ship in the quarter III (Figure 1c), then $180^o < PT_{S1} \leq 270^o$, we have $X_1 < X_0$ and $Y_1 < Y_0$, the position of target ship $S_1$ can be obtained from the shore station as follows:

$$\begin{cases} \Delta X = X_0 - X_1 = -D_{S1} sinPT_{S1} \\ \Delta Y = Y_0 - Y_1 = -D_{S1} cosPT_{S1} \end{cases} \rightarrow \begin{cases} X_1 = X_0 + D_{S1} sinPT_{S1} \\ Y_1 = Y_0 + D_{S1} cosPT_{S1} \end{cases} \tag{4}$$

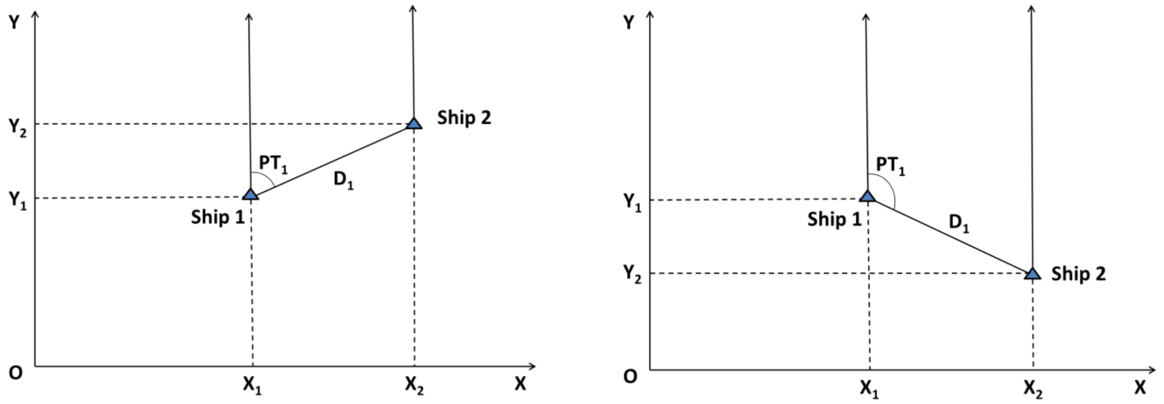
In case target ship in the quarter IV (Figure 1d), then $270^o < PT_{S1} \leq 360^o$, we have $X_1 < X_0$ and $Y_1 > Y_0$, the position of target ship $S_1$ can be obtained from the shore station as follows:

$$\begin{cases} \Delta X = X_0 - X_1 = -D_{S1} sinPT_{S1} \\ \Delta Y = Y_1 - Y_0 = D_{S1} cosPT_{S1} \end{cases} \rightarrow \begin{cases} X_1 = X_0 + D_{S1} sinPT_{S1} \\ Y_1 = Y_0 + D_{S1} cosPT_{S1} \end{cases} \tag{5}$$

Applying similar calculations with known data (true bearing and distance) for other target ships around the shore station, the positions of these ships can be obtained.

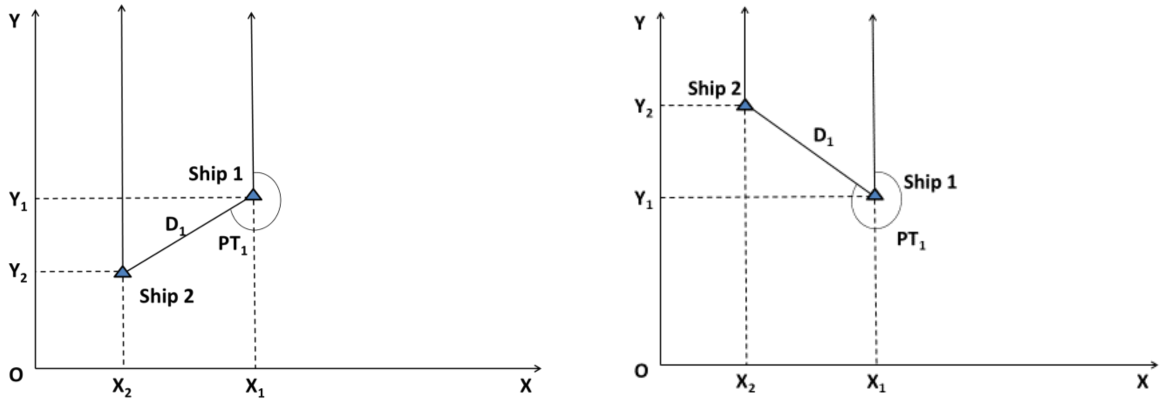
### 2.2. Determination of true bearing and distance between pairs of target ships

In Section 2.1, the positions of all ships observed from the shore station are obtained. To assess the collision risk between pairs of target ships, two parameters need to be specified:true bearing and thedistance between these ships. The distance is the radius that connects the ships intoan encounter cluster.Assuming that there are two ships: $S_1$ ($X_1$, $Y_1$) and $S_2$ ($X_2$, $Y_2$), the vicinity around ship $S_1$ can be similarly divided into four quarters, following a clockwise direction from North 0°. The distance and true bearing calculated from $S_1$ to $S_2$ are computed according to the position of ship $S_2$ in eachquarter of ship $S_1$, as shown in Figure 2.



(a) Ship 2 in quarter I of ship 1

(b) Ship 2 in quarter II of ship 1



(c) Ship 2 in quarter III of ship 1

(d) Ship 2 in quarter IV of ship 1

**Fig.2** Position of ship $S_2$ observed from $S_1$

The distance $D_1$ and true bearing $PT_1$ from ship $S_1$ to ship $S_2$ can be calculated by their coordinates ($X_1$, $Y_1$) and ($X_2$, $Y_2$) in four cases as follows:

Case 1: $X_2 > X_1$, $Y_2 > Y_1$ (in Figure 2a)

$$\begin{cases} D_1 = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \\ PT_1 = \arctan\left(\dfrac{X_2 - X_1}{Y_2 - Y_1}\right) \end{cases} with\ (0° \le PT_1 \le 90°) \qquad (6)$$

Case 2: $X_2 > X_1$, $Y_2 < Y_1$(in Figure 2b)

$$\begin{cases} D_1 = \sqrt{(X_2 - X_1)^2 + (Y_1 - Y_2)^2} \\ PT_1 = 180° - \arctan\left(\dfrac{X_2 - X_1}{Y_1 - Y_2}\right) \end{cases} with\ (90° < PT_1 \le 180°) \qquad (7)$$

Case 3: $X_2 < X_1$, $Y_2 < Y_1$(in Figure 2c)

$$\begin{cases} D_1 = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2} \\ PT_1 = 180° + \arctan\left(\dfrac{X_1 - X_2}{Y_1 - Y_2}\right) \end{cases} with\ (180° < PT_1 \le 270°) \qquad (8)$$

Case 4: $X_2 < X_1$, $Y_2 > Y_1$(in Figure 2d)

$$\begin{cases} D_1 = \sqrt{(X_1 - X_2)^2 + (Y_2 - Y_1)^2} \\ PT_1 = 360^\circ - \arctan\left(\dfrac{X_1 - X_2}{Y_1 - Y_2}\right) with\ (270^\circ < PT_1 < 360^\circ) \end{cases} \quad (9)$$

The collision risk between target ships will thenbe assessed in the following section.

### 2.3 Collision risk assessment between pair of target ships

There are many ships that sail within the scope of a maritime surveillance system from a third party. One desired function ofthis system is to evaluate and provide a ranked list of ships at risk. For that, the collisionrisk of ships could be continuously estimated andtracked automatically to monitor the surveilled sea areas. Then, the shore station can corporate and give instructions to ships in particularly highrisk, to initiate evasiveactions and trajectory to reduce the collision risk.

In the above sections, input parameters for collision risk assessment are collected. Let O be the ship and A, B bethe positions of target ships at time $t_1$, $t_2$ respectively.Let $PT_1$, $D_1$be the true bearing and distance from target ship $S_1$ to $S_2$ at time $t_1$respectively, and $PT_2$, $D_2$be the true bearing and distance from target ship $S_1$ to $S_2$ at time $t_2$ respectively.

According to the radar plotting for collision avoidance, therisk of collision is determined by two factors: CPA and DCPA.Based on these input data, the CPA and TCPA are calculated for thepair of ships in encounter.The CPA calculation method is widely adopted for collision avoidance research.A collision risk exists when CPA $<CPA_{min}$ and TCPA > 0, meaningthat two ships are coming closer and closer without change or with only little changes intrue bearing. The algorithm to compute CPA and TCPA is constructed as follow:

2.3.1. If there is no difference of true bearing between two observations, $PT_1 = PT_2$ then CPA = 0. In this case, one ship can keep the distance, move closer or further to another.

2.3.1.1 In case $D_1 = D_2$, it reveals that the relative position between two ships during the encounter is unchanged. Both the own ship and target ship are moving in the same direction with the same speed. The CPA and TCPA in this situation cannot be obtained and thecollision risk does not exist.

2.3.1.2 With the situation as in Figure 3, two ships are approaching to each other ($D_1 > D_2$). The extended trajectory of the marker of target ship is passing the own ship, therefore CPA = 0.

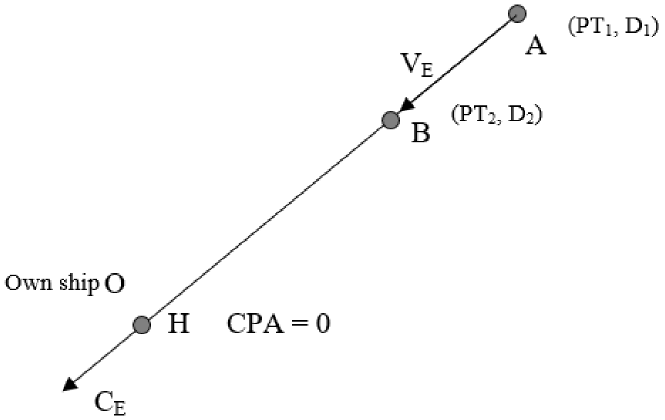


**Fig.3** Two ships are approaching without change of true bearing

The initial speed $V_E$ and initial course $C_E$ of the marker of target ship will be calculated as follows:

$$\begin{cases} V_E = \dfrac{D_1 - D_2}{t_2 - t_1} \\ C_E = PT_2 + 180^\circ \end{cases} \quad (10)$$

Due to the need for the course tobe in range from 0° to 360°, if $C_E > 360^\circ$, only the value of $(C_E - 360^\circ)$ will be utilized.

The TCPA is computed as:

$$TCPA = \frac{D_2}{V_E} \tag{11}$$

Without anychange in true bearing and a decrease of distance, the CPA = 0 and TCPA > 0, thus, there will be collision risk between thetwo ships.

2.3.1.3 When two ships are moving far away ($D_1 < D_2$), the CPA = 0 and a similar calculation for $V_E$, $C_E$ is carried out (in Figure 4).

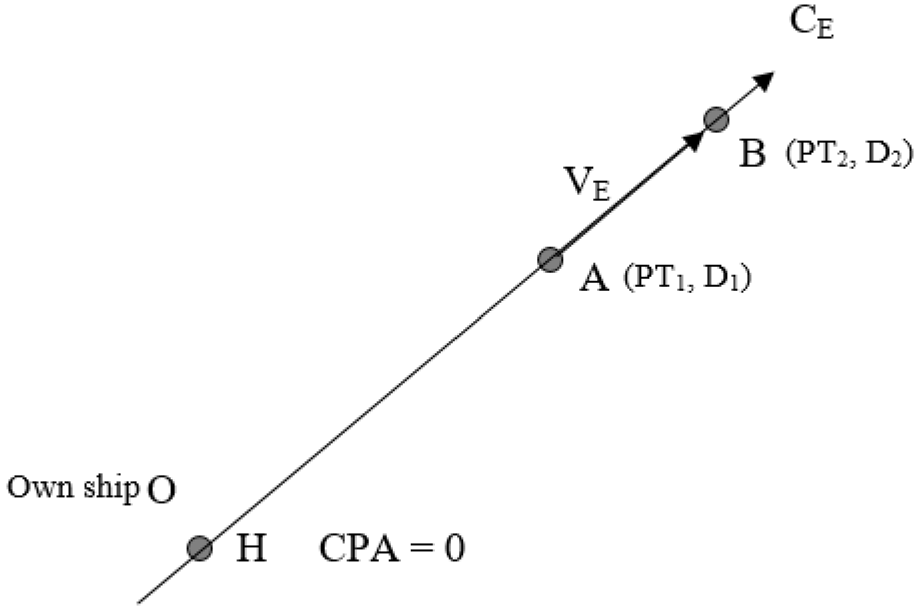


**Fig.4** Two ships are moving far away without change of true bearing

Because the target ship hasalready crossed the closest point of approach, therefore $V_E < 0$; it leads to TCPA < 0. Hence, in case of a ship moving further from each other, aconflict will not occur.

2.3.2 A ship may change or intend to change the course when approaching. The true bearing of the the target ship at two observations will thereforevary ($PT_1 \neq PT_2$).

If the target ship is changing the course, its trajectory will be a curved trajectory rather than a straight line. Theapproaching situationthereforesignificantly differs compared to the previous situation.

2.3.2.1When two ships are moving closer ($D_1 > D_2$), the distance observed of the marker of the target ship is as:

$$AB = \sqrt{D_1^2 + D_2^2 - 2D_1D_2\cos\left(PT_1 - PT_2\right)} \tag{12}$$

In triangle OAH, we know that:

$$\widehat{OAH} = arcos\left(\frac{D_1^2 + AB^2 - D_2^2}{2AB.D_1}\right) \tag{13}$$

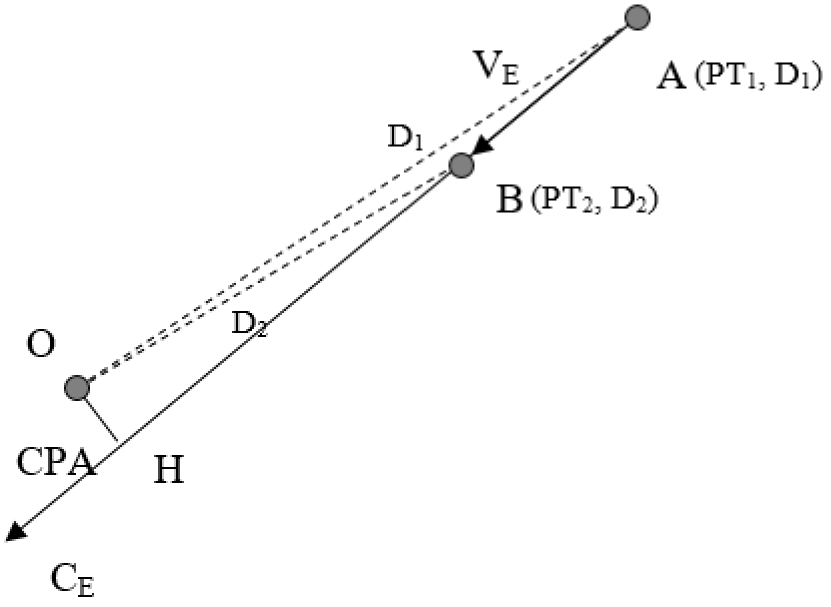


**Fig.5** Two ships are moving closer with change of true bearing

CPA and TCPA can be calculated as follow:

$$\begin{cases} CPA = D_1 sin\widehat{OAH} \\ TCPA = \dfrac{D_1 sin\widehat{OAH} - AB}{V_E} \end{cases} \tag{14}$$

In triangle OBH:

$$\widehat{OBH} = arsin(\frac{CPA}{D_2}) \tag{15}$$

The opposite bearing between two ships PTN$_1$ and PTN$_2$ in each observation can be calculated as follows:

$$\begin{array}{l} If\ PT_1 + 180° < 360°\ then\ PTN_1 = PT_1 + 180° \\ If\ PT_1 + 180° > 360°\ then\ PTN_1 = (PT_1 + 180°) - 360° \\ If\ PT_2 + 180° < 360°\ then\ PTN_2 = PT_2 + 180° \\ If\ PT_2 + 180° > 360°\ then\ PTN_2 = (PT_2 + 180°) - 360° \end{array} \tag{16}$$

Similarly, the relative bearing between two ships GM$_1$ and GM$_2$ in each observation can be calculated,and therelative position of ships can be obtainedas follow:

$$\begin{array}{ll} If\ 0° \le PT_1 - C_0 \le 180°\ then\ GM_1 = PT_1 - C_0 & (in\ starboard) \\ If\ PT_1 - C_0 \le -180° then\ GM_1 = 360° - (PT_1 - C_0) & (in\ starboard) \\ If\ PT_1 - C_0 > 180° then\ GM_1 = (PT_1 - C_0) - 360° & (in\ port) \\ If - 180° < PT_1 - C_0 < 180° then\ GM_1 = (PT_1 - C_0) - 360° & (in\ port) \\ If\ 0° \le PT_2 - C_0 \le 180°\ then\ GM_2 = PT_2 - C_0 & (in\ starboard) \\ If\ PT_2 - C_0 \le -180° then\ GM_2 = 360° - (PT_2 - C_0) & (in\ starboard) \\ If\ PT_2 - C_0 > 180° then\ GM_2 = (PT_2 - C_0) - 360° & (in\ port) \\ If - 180° < PT_2 - C_0 < 180° then\ GM_2 = (PT_2 - C_0) - 360° & (in\ port) \end{array} \tag{17}$$

where C$_0$ is the initial course of the own ship.

The speed of the marker of the target ship can be calculated as follow:

$$V_E = \frac{AB}{t_2 - t_1} \tag{18}$$

The course of the marker of the target ship can be calculated based on the relative position between two ships as follow:

```
$If\ 0° < GM_1\ and\ GM_2 < 180°\ (in\ starboard)$
$then\ if\ GM_1 > GM_2\ (the\ targetship\ crossing\ the\ bow)$
    $then\ C_E = PTN_2 + \widehat{OBH}$
    $if\ GM_1 < GM_2 (the\ targetship\ crossing\ the\ stern)$
    $then\ C_E = PTN_2 - \widehat{OBH}$
$If\ -180° < GM_1\ and\ GM_2 < 0°\ (in\ port)$
$then\ if\ GM_1 > GM_2\ (the\ targetship\ crossing\ the\ stern)$
    $then\ C_E = PTN_2 + \widehat{OBH}$
    $if\ GM_1 < GM_2 (the\ targetship\ crossing\ the\ bow)$
    $then\ C_E = PTN_2 - \widehat{OBH}$                                        (19)
$If\ -90° \le GM_1 \le 0°\ and\ 0° \le GM_2 \le 90°\ (the\ targetship\ crossing\ the\ bow)$
$then\ C_E = PTN_2 - \widehat{OBH}$
$If\ 0° < GM_1 \le 90°\ and -90° \le GM_1 < 0°\ (the\ targetship\ crossing\ the\ bow)$
$then\ C_E = PTN_2 + \widehat{OBH}$
$If\ 90° < GM_1 \le 180°\ and -180° \le GM_2 \le -90°\ (the\ targetship\ crossing\ the\ stern)$
$then\ C_E = PTN_2 + \widehat{OBH}$
$If\ -180° \le GM_1 < -90°\ and\ 90° < GM_2 \le 180°\ (the\ targetship\ crossing\ the\ stern)$
$then\ C_E = PTN_2 - \widehat{OBH}$
```

If $C_E$> 360°, only the value of ($C_E$ – 360°) will be used.

In this case, two ships are moving closer, then TCPA > 0. To evaluate the risk of collision, CPA needs to be compared with $CPA_{min}$. If CPA <$CPA_{min}$, we can conclude that the collision risk exists.

2.3.2.2In contrast to the above situation, if $D_1$< $D_2$, two ships are moving far from each other (in Figure 6)

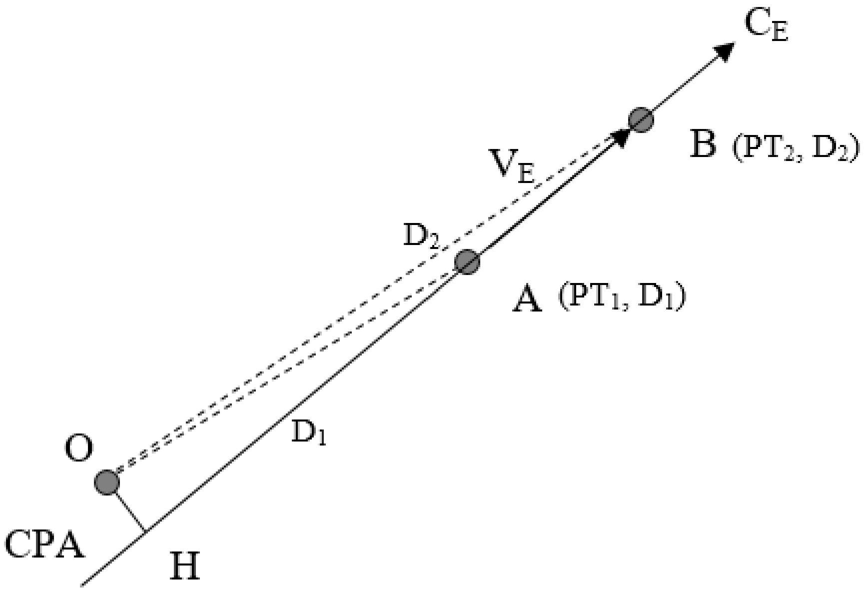


**Fig.6** Two ships are moving far away with change of true bearing

Using equations (12) – (17), CPA, TCPA, opposite bearing and relative bearing can be calculated. However, there are differences in thecalculation of speed and thecourse of the marker of the target ship:

$$V_E = -\frac{AB}{t_2 - t_1} \tag{20}$$

$$\begin{array}{l}
\qquad\qquad If\ 0° < GM_1\ and\ GM_2 < 180°\ (in\ starboard) \\
then\ if\ GM_1 > GM_2\ (the\ targetship\ crossing\ the\ bow) \\
\quad then\ C_E = PTN_2 + 180° - \widehat{OBH} \\
\quad if\ GM_1 < GM_2 (the\ targetship\ crossing\ the\ stern) \\
\quad then\ C_E = PTN_2 - 180° + \widehat{OBH} \\
\qquad\qquad If\ -180° < GM_1\ and\ GM_2 < 0°\ (in\ port) \\
then\ if\ GM_1 > GM_2\ (the\ targetship\ crossing\ the\ stern) \\
\quad then\ C_E = PTN_2 + 180° + \widehat{OBH} \\
\quad if\ GM_1 < GM_2 (the\ targetship\ crossing\ the\ bow) \\
\quad then\ C_E = PTN_2 - 180° - \widehat{OBH} \\
\qquad If\ -90° \le GM_1 \le 0°\ and\ 0° \le GM_2 \le 90°\ (the\ targetship\ crossing\ the\ bow) \\
then\ C_E = PTN_2 - 180° + \widehat{OBH} \\
\qquad If\ 0° < GM_1 \le 90°\ and -90° \le GM_1 < 0°\ (the\ targetship\ crossing\ the\ bow) \\
then\ C_E = PTN_2 + 180° - \widehat{OBH} \\
\qquad If\ 90° < GM_1 \le 180°\ and -180° \le GM_2 \le -90°\ (the\ targetship\ crossing\ the\ stern) \\
then\ C_E = PTN_2 - 180° + \widehat{OBH} \\
\qquad If\ -180° \le GM_1 < -90°\ and\ 90° < GM_2 \le 180°\ (the\ targetship\ crossing\ the\ stern) \\
then\ C_E = PTN_2 + 180° - \widehat{OBH}
\end{array} \tag{21}$$

If $C_E$> 360°, only the value of ($C_E$ – 360°) will be used.

Because of two ships moving further and further, there is no collision risk.

## 3. Evaluation of the accuracy of thecalculations of CPA, TCPA from the observation data measured by the shore station radar

In theprevious part, the method to evaluate the risk of collision is introduced. Toexamine this method, the experiments were carried out using ship handling simulator in Vietnam Maritime University. Thissimulator was designed by Transas. It was approved by Det Norske Veritas.

To evaluate the accuracy of thecalculation of CPA, TCPA introduced in part 2, a scenario of crossing situation of 2 bulk carriers was set in calm condition. Both were requested to maintain their course and speed during theexperiments. Their positions, course, andspeed were recorded. From our own ship, by using ARPA function, the CPA, TCPA of target ship were acquired and recorded.

From the bulk carriers' data of position, we set 4 virtual VTS in positions as following:

**Table 3.1**. Positions of virtual VTS

| | | |
|---|---|---|
| VTS 1 | 20.71074N | 107.0212E |
| VTS 2 | 20.60344N | 106.9787E |
| VTS 3 | 20.59573N | 106.7909E |
| VTS 4 | 20.66689N | 106.8162E |

The arrangements of bulk carriers and 4 virtual VTSs are shown in Fig.7:

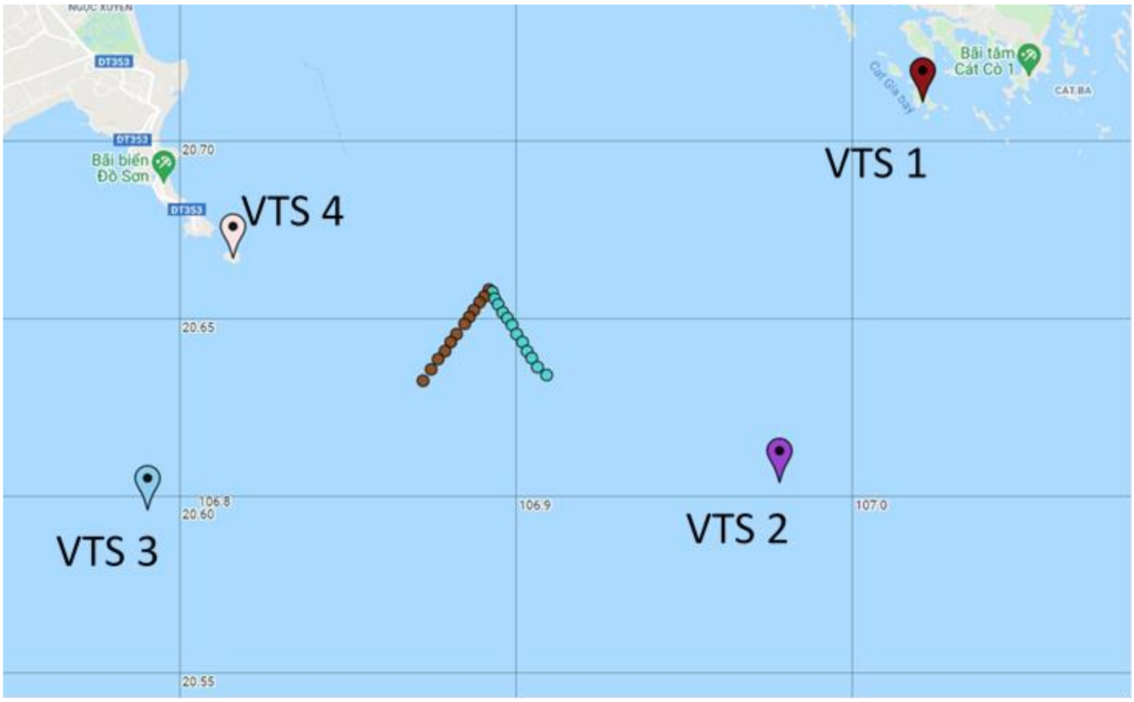


**Fig.7.** Arragement of bulk carriers and 4 virtual VTSs

The data collected fromtheexperiment isshown in Table 3.2

**Table 3.2**. data of experiment

| *Own ship (OS)* | | | | *Target ship (TS)* | | | | *CPA* | *TCPA* | *Time* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Lattitude* | | *Longitude* | | *Lattitude* | | *Longitude* | | | | | |
| *20* | *37.946* | *106* | *52.359* | *20* | *38.05* | *106* | *54.57* | *0.1* | *10* | *12:02:33* | *t1* |
| *20* | *38.142* | *106* | *52.507* | *20* | *38.17* | *106* | *54.37* | *0.1* | *9.4* | *12:03:49* | *t2* |
| *20* | *38.307* | *106* | *52.633* | *20* | *38.32* | *106* | *54.27* | *0.1* | *8.4* | *12:04:55* | *t3* |
| *20* | *38.449* | *106* | *52.739* | *20* | *38.48* | *106* | *54.18* | *0.1* | *7.4* | *12:05:56* | *t4* |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 38.6 | 106 | 52.853 | 20 | 38.61 | 106 | 54.11 | 0.1 | 6.4 | 12:06:56 | t5 |
| 20 | 38.745 | 106 | 52.963 | 20 | 38.74 | 106 | 54.01 | 0.1 | 5.4 | 12:07:58 | t6 |
| 20 | 38.912 | 106 | 53.09 | 20 | 38.89 | 106 | 53.95 | 0.1 | 4.3 | 12:09:03 | t7 |
| 20 | 39.026 | 106 | 53.176 | 20 | 39.01 | 106 | 53.86 | 0.1 | 3.5 | 12:09:52 | t8 |
| 20 | 39.144 | 106 | 53.266 | 20 | 39.13 | 106 | 53.8 | 0.1 | 2.6 | 12:10:43 | t9 |
| 20 | 39.283 | 106 | 53.373 | 20 | 39.25 | 106 | 53.72 | 0 | 1.7 | 12:11:41 | t10 |
| 20 | 39.378 | 106 | 53.448 | 20 | 39.34 | 106 | 53.67 | 0 | 1 | 12:12:20 | t11 |
| 20 | 39.492 | 106 | 53.535 | 20 | 39.44 | 106 | 53.61 | 0 | 0.3 | 12:13:03 | t12 |

The virtual bearings and distances from 4 VTSs to own ship and target ship are shown in Table 3.3, 3.4, 3.5, 3.6:

**Table 3.3**.Virtual bearings and distances from VTS1 to OS and TS

| Time | | OS | | | | TS | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | D(OS) | PT(OS) | Lat | Long | D(OS) | PT(OS) | Lat | Long |
| t1 | 12:02:33 | 17.739 | 240.63 | 20.63243 | 106.8727 | 14.407 | 233.8 | 20.63417 | 106.9095 |
| t2 | 12:03:49 | 17.338 | 241.26 | 20.6357 | 106.8751 | 14.531 | 235.25 | 20.63617 | 106.9065 |
| t3 | 12:04:55 | 17 | 241.81 | 20.63845 | 106.8772 | 14.504 | 236.53 | 20.63867 | 106.9049 |
| t4 | 12:05:56 | 16.714 | 242.31 | 20.64082 | 106.879 | 14.51 | 237.69 | 20.64133 | 106.9034 |
| t5 | 12:06:56 | 16.41 | 242.85 | 20.64333 | 106.8809 | 14.493 | 238.88 | 20.6435 | 106.902 |
| t6 | 12:07:58 | 16.118 | 243.39 | 20.64575 | 106.8827 | 14.505 | 240.06 | 20.64567 | 106.9004 |
| t7 | 12:09:03 | 15.783 | 244.04 | 20.64853 | 106.8848 | 14.491 | 241.36 | 20.64817 | 106.899 |
| t8 | 12:09:52 | 15.557 | 244.49 | 20.65043 | 106.8863 | 14.515 | 242.31 | 20.65017 | 106.8977 |
| t9 | 12:10:43 | 15.323 | 244.98 | 20.6524 | 106.8878 | 14.546 | 243.29 | 20.65217 | 106.8963 |
| t10 | 12:11:41 | 15.046 | 245.57 | 20.65472 | 106.8896 | 14.564 | 244.41 | 20.65417 | 106.895 |
| t11 | 12:12:20 | 14.855 | 245.98 | 20.6563 | 106.8908 | 14.583 | 245.18 | 20.65567 | 106.894 |
| t12 | 12:13:03 | 14.632 | 246.49 | 20.6582 | 106.8923 | 14.581 | 246.13 | 20.65733 | 106.8931 |

**Table 3.4.**Virtual bearings and distances from VTS2 to OS and TS

| Time | | OS | | | | TS | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | D(OS) | PT(OS) | Lat | Long | D(OS) | PT(OS) | Lat | Long |
| t1 | 12:02:33 | 11.493 | 286.31 | 20.63243 | 106.8727 | 7.966 | 295.41 | 20.63417 | 106.9095 |
| t2 | 12:03:49 | 11.356 | 288.43 | 20.6357 | 106.8751 | 8.349 | 295.89 | 20.63617 | 106.9065 |
| t3 | 12:04:55 | 11.251 | 290.26 | 20.63845 | 106.8772 | 8.618 | 297.13 | 20.63867 | 106.9049 |
| t4 | 12:05:56 | 11.173 | 291.85 | 20.64082 | 106.879 | 8.875 | 298.03 | 20.64133 | 106.9034 |
| t5 | 12:06:56 | 11.099 | 293.57 | 20.64333 | 106.8809 | 9.13 | 299.08 | 20.6435 | 106.902 |
| t6 | 12:07:58 | 11.036 | 295.25 | 20.64575 | 106.8827 | 9.393 | 299.93 | 20.64567 | 106.9004 |
| t7 | 12:09:03 | 10.975 | 297.2 | 20.64853 | 106.8848 | 9.672 | 301 | 20.64817 | 106.899 |
| t8 | 12:09:52 | 10.942 | 298.54 | 20.65043 | 106.8863 | 9.889 | 301.6 | 20.65017 | 106.8977 |
| t9 | 12:10:43 | 10.912 | 299.94 | 20.6524 | 106.8878 | 10.118 | 302.17 | 20.65217 | 106.8963 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *t10* | *12:11:41* | *10.884* | *301.6* | *20.65472* | *106.8896* | *10.371* | *302.92* | *20.65417* | *106.895* |
| *t11* | *12:12:20* | *10.868* | *302.75* | *20.6563* | *106.8908* | *10.548* | *303.39* | *20.65567* | *106.894* |
| *t12* | *12:13:03* | *10.858* | *304.12* | *20.6582* | *106.8923* | *10.753* | *304.09* | *20.65733* | *106.8931* |

**Table 3.5**.Virtual bearings and distances from VTS3 to OS and TS

| *Time* | | *OS* | | | | *TS* | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *D(OS)* | *PT(OS)* | *Lat* | *Long* | *D(OS)* | *PT(OS)* | *Lat* | *Long* |
| *t1* | *12:02:33* | *9.439* | *64.37* | *20.63243* | *106.8727* | *13.064* | *70.89* | *20.63417* | *106.9095* |
| *t2* | *12:03:49* | *9.83* | *63.11* | *20.6357* | *106.8751* | *12.845* | *69.47* | *20.63617* | *106.9065* |
| *t3* | *12:04:55* | *10.164* | *62.13* | *20.63845* | *106.8772* | *12.799* | *68.03* | *20.63867* | *106.9049* |
| *t4* | *12:05:56* | *10.451* | *61.32* | *20.64082* | *106.879* | *12.74* | *66.75* | *20.64133* | *106.9034* |
| *t5* | *12:06:56* | *10.759* | *60.52* | *20.64333* | *106.8809* | *12.716* | *65.38* | *20.6435* | *106.902* |
| *t6* | *12:07:58* | *11.058* | *59.79* | *20.64575* | *106.8827* | *12.676* | *64.06* | *20.64567* | *106.9004* |
| *t7* | *12:09:03* | *11.405* | *59* | *20.64853* | *106.8848* | *12.674* | *62.56* | *20.64817* | *106.899* |
| *t8* | *12:09:52* | *11.642* | *58.49* | *20.65043* | *106.8863* | *12.65* | *61.48* | *20.65017* | *106.8977* |
| *t9* | *12:10:43* | *11.89* | *57.98* | *20.6524* | *106.8878* | *12.627* | *60.35* | *20.65217* | *106.8963* |
| *t10* | *12:11:41* | *12.185* | *57.42* | *20.65472* | *106.8896* | *12.629* | *59.05* | *20.65417* | *106.895* |
| *t11* | *12:12:20* | *12.389* | *57.06* | *20.6563* | *106.8908* | *12.631* | *58.16* | *20.65567* | *106.894* |
| *t12* | *12:13:03* | *12.631* | *56.62* | *20.6582* | *106.8923* | *12.666* | *57.07* | *20.65733* | *106.8931* |

**Table 3.6.**Virtual bearings and distances from VTS4 to OS and TS

| *Time* | | *OS* | | | | *TS* | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *D(OS)* | *PT(OS)* | *Lat* | *Long* | *D(OS)* | *PT(OS)* | *Lat* | *Long* |
| *t1* | *12:02:33* | *7.014* | *123.1* | *20.63243* | *106.8727* | *10.368* | *110.53* | *20.63417* | *106.9095* |
| *t2* | *12:03:49* | *7.044* | *119.48* | *20.6357* | *106.8751* | *9.994* | *109.94* | *20.63617* | *106.9065* |
| *t3* | *12:04:55* | *7.094* | *116.46* | *20.63845* | *106.8772* | *9.749* | *108.69* | *20.63867* | *106.9049* |
| *t4* | *12:05:56* | *7.148* | *113.91* | *20.64082* | *106.879* | *9.518* | *107.63* | *20.64133* | *106.9034* |
| *t5* | *12:06:56* | *7.223* | *111.25* | *20.64333* | *106.8809* | *9.302* | *106.34* | *20.6435* | *106.902* |
| *t6* | *12:07:58* | *7.31* | *108.74* | *20.64575* | *106.8827* | *9.078* | *105.12* | *20.64567* | *106.9004* |
| *t7* | *12:09:03* | *7.428* | *105.94* | *20.64853* | *106.8848* | *8.86* | *103.53* | *20.64817* | *106.899* |
| *t8* | *12:09:52* | *7.517* | *104.07* | *20.65043* | *106.8863* | *8.685* | *102.46* | *20.65017* | *106.8977* |
| *t9* | *12:10:43* | *7.619* | *102.19* | *20.6524* | *106.8878* | *8.505* | *101.3* | *20.65217* | *106.8963* |
| *t10* | *12:11:41* | *7.752* | *100.04* | *20.65472* | *106.8896* | *8.319* | *99.82* | *20.65417* | *106.895* |
| *t11* | *12:12:20* | *7.851* | *98.61* | *20.6563* | *106.8908* | *8.193* | *98.78* | *20.65567* | *106.894* |
| *t12* | *12:13:03* | *7.792* | *96.95* | *20.6582* | *106.8923* | *8.063* | *97.32* | *20.65733* | *106.8931* |

The comparision between calculated data of CPA and TCPA using above method and indicating data of CPA and TCPA on radar screen are shown in Table 3.7.

**Table 3.7.** Calculated data of CPA and TCPA using above method and indicating data of CPA and TCPA on radar screen

| *Time* | | *Δt* | *PT12 (0)* | *PT21 (0)* | *VE* | *Tínhtoán* | | *ARPA* | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *TCPA (m)* | *CPA (NM)* | *TCPA (m)* | *CPA (NM)* |
| *t1* | *12:02:33* | | *88.8* | *267.13* | | | *0.1* | *10* | *0.1* |
| *t2* | *12:03:49* | *0.021111* | *89* | *269.09* | *11.27368* | *9.38* | *0.1* | *9.4* | *0.1* |
| *t3* | *12:04:55* | *0.018333* | *89.3* | *269.52* | *11.12727* | *8.40* | *0.1* | *8.4* | *0.1* |
| *t4* | *12:05:56* | *0.016944* | *89.7* | *268.69* | *11.09508* | *7.41* | *0.1* | *7.4* | *0.1* |
| *t5* | *12:06:56* | *0.016667* | *90* | *269.52* | *11.1* | *6.41* | *0.1* | *6.4* | *0.1* |
| *t6* | *12:07:58* | *0.017222* | *90.6* | *270.3* | *11.03226* | *5.41* | *0.1* | *5.4* | *0.1* |
| *t7* | *12:09:03* | *0.018056* | *91.3* | *271.57* | *11.07692* | *4.31* | *0.1* | *4.3* | *0.1* |
| *t8* | *12:09:52* | *0.013611* | *92.2* | *271.43* | *11.16735* | *3.45* | *0.1* | *3.5* | *0.1* |
| *t9* | *12:10:43* | *0.014167* | *93.7* | *271.61* | *11.29412* | *2.57* | *0.1* | *2.6* | *0.1* |
| *t10* | *12:11:41* | *0.016111* | *96.8* | *275.8* | *10.92414* | *1.69* | *0* | *1.7* | *0* |
| *t11* | *12:12:20* | *0.010833* | *102.6* | *280.37* | *11.26154* | *0.99* | *0* | *1* | *0* |
| *t12* | *12:13:03* | *0.011944* | *127.1* | *306.54* | *10.71628* | *0.32* | *0* | *0.3* | *0* |

From Table 3.7, we found that the values of CPA are coincided.Despitesome differences among the values of TCPA, these are small enough to be ignored. These differences are caused by the round function of ARPA in the indication. This is proved that the formulas in part 2 are reliable in calculating CPA and TCPA for evaluating the risk of collision between 2 target vessel from VTS radar.

## 4. Conclusion

A new method to evaluate the risk of collision between two target ships from observation data measured by the shore station radar is introduced and the accuracy of calculation is confirmed. By using this method, we can develop and practice the applicationor tools to calculate CPA, TCPA between target ships quickly. Then, the risk of collision can be evaluated. It is very useful for VTS officers in managing traffic ships, to maintain the safety of navigation.

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