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A Novel Method for Risk Assessment and Simulation of Collision Avoidance for Vessels based on AIS

ManhCuong Nguyen [1,2], Shufang Zhang [1] and Xiaoye Wang [1,*]

1 Information Science and Technology College, Dalian Maritime University, Dalian 116026, China; nguyenmanhcuong@vimaru.edu.vn (M.N.); sfzhang@dlmu.edu.cn (S.Z.)
2 Vietnam Maritime University, Haiphong 35000, Vietnam
* Correspondence: xywang1987@dlmu.edu.cn

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Abstract: The identification of risks associated with collision for vessels is an important element in maritime safety and management. A vessel collision avoidance system is a topic that has been deeply studied, and it is a specialization in navigation technology. The automatic identification system (AIS) has been used to support navigation, route estimation, collision prediction, and abnormal traffic detection. This article examined the main elements of ship collision, developed a mathematical model for the risk assessment, and simulated a collision assessment based on AIS information, thereby providing meaningful recommendations for crew training and a warning system, in conjunction with the AIS on board.

Keywords: collision avoidance; collision risk index; collision risk assessment; AIS

1. Introduction

Nowadays, the management of maritime safety, and pollution prevention of the marine environment is the central task of the international maritime industry [1–3]. Each collision caused by the manipulation of the crew not only causes material damage and threats to human life, but is also a great threat to the marine environment [4]. Thus, the International Regulation for preventing collisions at Sea (COLREGS) has been fully adhered to, combined with marine support systems to minimize crashes, such as the recommended use of automatic identification system (AIS) equipment and automatic radar plotting aids (ARPA) in practice [5,6].

However, COLREGS-72 regulations have few quantitative features, do not offer accurate or tailor-made maneuvers, are highly dependent on the sense and skills of the sailors, and they are even difficult to project or guess the vessels' cruise [7]. Therefore, in recent years, there have been a number of studies using AIS information to tackle maritime collisions that have achieved a number of accomplishments. Goerlandtand et al. built a common risk model and collision warning system [8]. Blaich et al. analyzed the use of AIS in automatic collision, incorporated ARPA, and an electronic chart display and information system (ECDIS) [9]. Rao and Balakrishnan designed a collision detection system by collecting global positioning system (GPS) and AIS information, and then issued alerts for fishing vessels via the Network Operations Center (NOC) [10].

Collision assessment is the basis of a crash detection and prevention system. It is very important to avoid collisions through the timely detection and immediate warning of the collision risk, thus ensuring maritime safety and avoiding casualties. This assessment is based on the development of a collision risk index (CRI) [11,12]. The value of the CRI is influenced by a variety of factors. The time to closest point of approach (TCPA), the distance at the closest point of approach (DCPA), the distance from the target vessel, and the relative bearing are the most significant influence factors. AIS devices on board use weighting methods, including DCPA and TCPA. This is the simplest method, but the results are not very accurate and not very high in some special situations. Furthermore, there are some methods for calculating the CRI through neural networks and fuzzy theory, which have the highest accuracy [11,13]. However, it is difficult to establish functions and to determine the initial conditions, which leads to limitations to the application of these methods in practice [14–16].

Different algorithms have been developed and used for navigation, guidance, and control (NGC) such as avoiding obstacles, and each method has its advantages and disadvantages [17–19]. In general, the issues related to avoiding collisions, warnings, motion control, and navigation guidance are divided into three basic groups: (a) Target point stabilization, which is setting the position of the ship in target ship to determine the collision capability, collision time, and collision location of the event [20–22]; (b) Collision avoidance processing, which implements the warning and proposed plan of collision avoidance by the combination of systems on board including the AIS, ARPA, ECDIS, very high frequency (VHF) equipment, and the warning signal [23,24]; and (c) Trajectory tracking, which includes navigation tracking the required ship moves in the reference curve according to route planning, and supporting the management of the volume of vessel traffic in the port [25,26].

However, as Jinfen Zhang et al. reported, many maritime accident investigations have shown that 75–96% of marine accidents are caused by human failure and collisions at sea involve the inaccuracy of the COLREGS rules in their implementation [27]. While engaging a seasoned crew will reduce the rate of accidents, crew costs currently account for approximately 35–68% of the daily operating costs [28]. Thus, this paper did not integrate the COLREGS rules into the collision avoidance techniques or propose a deterministic path planning algorithm to compute a practical and COLREGS-compliant navigation path. The focus of the process is the procedure for providing a warning to avoid collisions, that chooses the risk model, and that calculates the probability of collision [12,29]. In practice, small vessels and fishing vessels are not equipped with ARPA systems; collision assessment only uses the DCPA and TCPA parameters on the AIS system. These two parameters have major disadvantages when reflecting ships incorrectly moving into head-on situations and overtaking situations. Thus, this paper referred to a more general approach to calculate the CRI, which comprehends all situations for when a ship moves at sea. As the calculation method used in the article was not too complicated, elements of weather conditions were estimated through the factor of safety that was set at the highest level. The article also emphasized that the human factor was the most important; when the risk of collision becomes high, it will warning the crew to pay attention, and to take action to follow the prevention of COLREGS. Considering the practical requirements for collision avoidance, and based on information including the DCPA, TCPA, distance, and bearing, this paper developed a marine collision risk assessment model and built a simulation program to calculate the collision probability for cruise vessels on the sea, to provide a timely warning and auxiliary for collision avoidance. Next, the level of danger was fundamental to propose corresponding warnings to help sailors to keep attention, and to proceed to collision avoidance, based on the COLREGS-72 rules. This method is useful for small ships and fishing vessels that have limited equipment, and that are not fully equipped with RADAR ARPA, and ECDIS.

The ship domain is a well-known concept, defined by Goodwin (1975) as "the surrounding waters which a navigator of a ship wants to keep clear of other ships or fixed objects" [8]. Various mathematical domain models have been proposed, and empirical findings have confirmed the applicability of the concept. This evidence suggests that in similar navigational conditions, domains have similar shapes and sizes. Ships entering the domain of other vessels can be taken to deviate from a reference level, and thus, they present an elevated collision risk. Different domain geometries are found in different areas, but more research is needed to understand the situation-dependence of reference levels in different sea areas and in different weather conditions [8,30]. The application of a ship's domain in calculating collision is necessary. When the target ship is in the danger zone, it has many calculations to solve. When target ship is not in the danger zone, the collision calculations can be based on the ship's domain to determine the minimum safety distance.

The main contribution of this paper is that it provides a calculation of the CRI, where each weight is assigned, according to the danger level that is related to the collision situation by the analytic hierarchy process (AHP) algorithm [11]. AHP is a precise method for selecting decisions, which are believed to be useful for a developer. In the case where quantitative ratings are not available, AHP allows the programmer to still recognize whether one criterion is more important than another. The analytic hierarchy process (AHP) was developed by Saaty (1977, 1980, 1988, and 1995), and it is one of the best-known methods. The AHP approach is a subjective methodology where information and the priority weights of elements can be obtained from a system or user, and that designation is based on the assessment and assignment of the developer. It allows the programmer to assess the relative weights of multiple criteria in an intuitive manner. AHP makes the selection process very transparent. In addition, the AHP method provides a unique means of quantifying judgmental consistency.

This paper is organized as follows. Section 2 presents the necessary background and related work information regarding the risk assessment for maritime surveillance and the theory of a vessels' collision warning system. Section 3 introduces and describes the proposed ship encounters in relation to a collision at sea. Section 4 describes the collision avoidance algorithm. The results are discussed in Section 5. Finally, the conclusions and future work are given in Section 6.

2. A Theory of a Vessels Collision Warning System

The collision area is determined by the size of two ships, the position accuracy, and the deviation of the ship's movement in the operating space of each ship. There will be a collision when the distance of two ships is less than the radius of the collision area that is determined by taking a central ship. The location that is used for calculation is the location of the AIS antenna, and the radius of the collision area depends on the size of ship. Thus, we assume this is the application conditions are on the ocean surface. The length of the ship is more than 50 m, and the AIS equipment is located less than 50 m above sea level. The radius of the collision area is calculated as follows [23,31]:

$$R_1 = (L_0 + L_1) \times \left(1 + \sin 6^{\circ}\right) + (W_0 + W_1) / \cos 6^{\circ} + P_a \tag{1}$$

where L_0, L_1 represent the length of the ship and the target ship, respectively. W_0, W_1 are the width of the ship and the target ship, respectively. P_a is the location accuracy of the ships. During the crash avoidance study, the size and maneuverability of the vessel will be negligible when two vessels are far away. In this case, two ships will be considered as two moving points with a certain velocity vector. Thus, it can be placed in the geometric coordinate system, as shown in Figure 1 [12,28]:

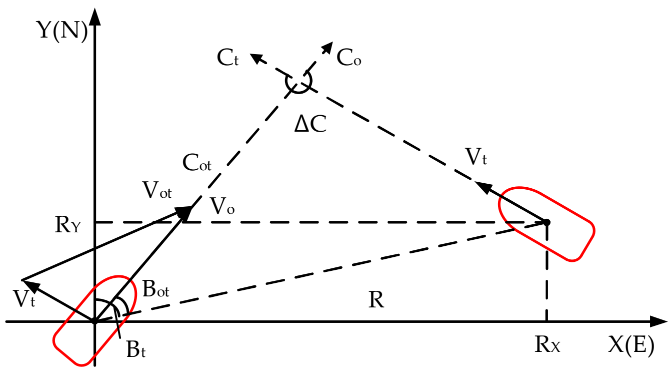

Figure 1. The moving vector diagram of encounter ships.

In Figure 1, the GPS position of the vessel is (λ_0, φ_0). The speed over ground (SOG), and the course over ground (COG) are V_o and C_o, respectively. The GPS position of the target vessel is (λ_T, φ_T). The SOG and COG of the target vessel are V_t and C_t, respectively. According to calculating the information of two ships, we can obtain the following results:

(1) (RX, RY) in the Descartes coordinate system.
(2) The relative distance, R.
(3) The relative speed with the target vessel, V_{ot}.
(4) The relative course with the target vessel, C_{ot}.
(5) The azimuth of the target vessel, B_t.
(6) The relative azimuth with this vessel—B_{ot}, $0° \leq B_{ot} \leq 180°$.

Then, the DCPA, and the time to the closest point of approach (TCPA) of encounter ships can be obtained. The magnitude value is expressed as follows:

$$DCPA = |R \sin(C_{ot} - B_t)| \quad (2)$$

$$TCPA = R \cos(C_{ot} - B_t)/V_{ot} \quad (3)$$

3. Intentional Collision Avoidance Rules

The rules of COLREGS related to lighting, warning signals, applicable principles, related definitions, etc., without mentioning the navigation plan and specific collision avoidance issues. Thus, situations encountered are divided in Figure 2 as follows [14,32]:

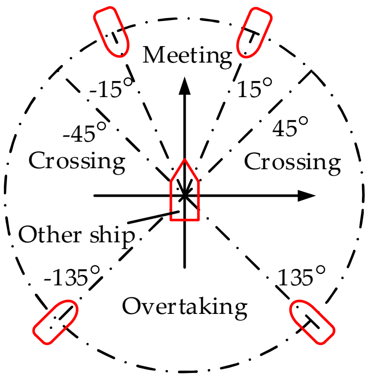

Figure 2. The encountered situations.

Meeting: When two ships navigate relative to each other, collision damage may occur. They are supposed to turn right, and then cruise through their own port, in order to avoid the risk of collision. The quantification is expressed as $5° \leq B_{ot}$ and $174° \leq \Delta C < 186°$ [33].

Crossing: When two ships cross through each other, one ship is on another ship's starboard side, so that the ship should make way and avoid navigating in front of another ship.

- Starboard crossing: Two ships head to cross, while the target ship is located on the starboard side. According to the encounter angle, the situation can be divided into a small crossing angle ($B_{ot} \leq 45°$ and $186° \leq \Delta C < 210°$) and a large crossing angle ($45° < B_{ot} \leq 125°$ and $210° \leq \Delta C < 360°$) [33].
- Board crossing: Two ships head to cross, while the target ship is located on the board side. According to the encounter angle, the situation can be divided into a small crossing angle ($B_{ot} \leq 45°$ and $150° \leq \Delta C < 174°$, and a large crossing angle ($B_{ot} \leq 125°$and $0° \leq \Delta C < 150°$) [33].

Overtaking: In a situation of a ship overtaking another ship, it is must be out of the way, and it should pass the ship from its port side.

- Being overtaken: Other ships should overtake from a direction more than 22.50° abaft of the beam of this ship. Quantification is expressed as $V_o < V_t$, $B_{ot} \geq 112.5°$, $0° \leq \Delta C < 90°$, or $270° \leq \Delta C < 360°$ [33].

- Overtaking: Quantification is expressed as $V_o > V_t$, $B_{ot} \leq \arcsin(0.924V_t/V_o)$, $0° \leq \Delta C < 90°$, or $270° \leq \Delta C < 360°$ [33].

The principle of avoiding ship collision is described, and ship encounters are described in relation to the collision in Figures 3 and 4, respectively.

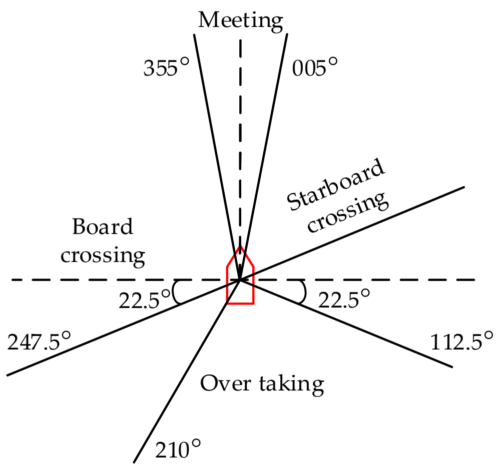

Figure 3. The ship collision-avoidance operation principle.

Different decisions of collision avoidance are made, according to different encounter types. The encounter situations and navigation rules are shown in Figure 4 [34]:

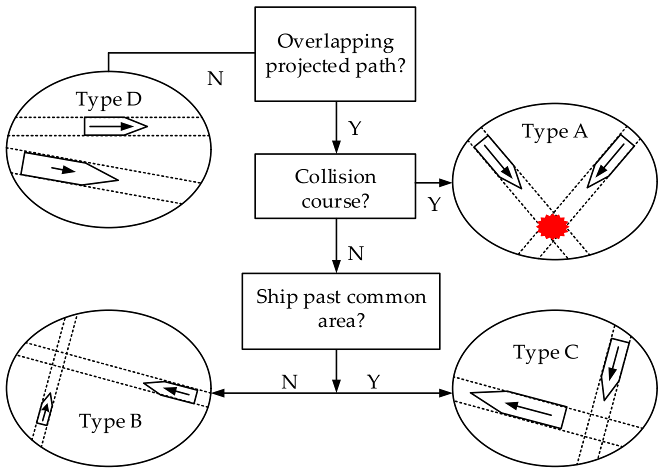

Figure 4. Model for classifying ship encounters in relation to the collision.

Figure 4 shows the encounters' relation to the collision at a particular moment, and may be classified into four types:

- Type A (collision situation). Two ships are on a collision course when two ships reach the common spatial zone simultaneously. They will collide if no evasive action is taken.
- Types B, C (crossing situation). Two ships move in overlapping paths, and the collision will be avoided when they pass through the common spatial zone at different times. In order to avoid collisions, one or two ships have to change their speed or course. They mean that this situation has to turn into a Type A situation first.
- Type D (non-crossing situation). The paths of two ships do not overlap in any way when two ships move in parallel in two adjacent lanes or when they have navigation courses. However, it does not mean that the collision risk is completely zero, as there may be some adjustment of the path by one or both ships.

Thus, all types of situations can be discussed to make sure the situation turns into a Type A before a collision happens. An algorithm can be developed to process these types.

4. Collision Avoidance Algorithm

In the collision avoidance algorithm, it is important to determine the movement parameters of the ship compared to the target vessel, which is the basis of the calculation type and case judgment [11]. The following is a series of ship motion calculations based on the Descartes coordinate system:

The speeds of the master and target ships on the axle component is [32]:

$$\begin{cases} v_{x_0} = v_0 \sin \varphi_0 \\ v_{y_0} = v_0 \cos \varphi_0 \end{cases} \begin{cases} v_{x_T} = v_T \sin \varphi_T \\ v_{y_T} = v_T \cos \varphi_T \end{cases}, \tag{4}$$

where (x_0, y_0) are the geographic coordinates of the ship with the velocity of v_0, and the direction of φ_0. (x_T, y_T) are the coordinates of the target vessel with a velocity of v_T, and a direction of φ_T.

The relative velocities of the two ships on the x and y axes are given by [32]:

$$\begin{cases} v_{x_R} = v_{x_T} - v_{x_0} \\ v_{y_R} = v_{y_T} - v_{y_0} \end{cases} \tag{5}$$

The magnitude of the relative speed is [32]:

$$v_R = \sqrt{{v_{x_R}}^2 + {v_{y_R}}^2} \tag{6}$$

The relative direction is [32]:

$$\varphi_R = \arctan\frac{v_{x_R}}{v_{y_R}} + \alpha, \tag{7}$$

where:

$$\alpha = \begin{cases} 0 & v_{x_R} \geq 0, \ v_{y_R} \geq 0 \\ \pi & v_{x_R} < 0, \ v_{y_R} < 0 \\ \pi & v_{x_R} \geq 0, \ v_{y_R} < 0 \\ 2\pi & v_{x_R} < 0, \ v_{y_R} \geq 0 \end{cases} \tag{8}$$

The relative distance between the two ships is [32]:

$$R = \sqrt{(x_T - x_0)^2 + (y_T - y_0)^2} \tag{9}$$

The bearing direction of the master ship with the target vessel is [32]:

$$\alpha_0 = \arctan\frac{x_0 - x_T}{y_0 - y_T} + \alpha \tag{10}$$

The DCPA between the two ships is [12,32]:

$$DCPA = |R \sin(\varphi_R - \alpha_T - \pi)| \tag{11}$$

The TCPA between the two ships is [12,32]:

$$TCPA = \left| \frac{R \cos(\varphi_R - \alpha_T - \pi)}{v_R} \right| \tag{12}$$

The azimuth between the ship and the target ship can be expressed as [12,32]:

$$\Delta B = B_t - B_o, \tag{13}$$

where $B_o = C_o$. The speed factor is given by [12,32]:

$$K = \frac{V_o}{V_t} \quad (14)$$

When the TCPA is less than or equal to zero, it means that the two vessels have passed the closest approach, which is defined as the presence of a collision. $DCPA$, $TCPA$, R, ΔB and K, are components of the mathematical model of collision risk assessment. R and $DCPA$ represent the collision space, $TCPA$ represents the collision time, and K represents the difficulty of the collision avoidance. The values of ΔB and K affect the avoidance behavior when they are considered to be at a high or low risk of collision. These parameters in the mathematical model and the simulation program of crash risk are called functional functions [33].

The functional function of DCPA is [33]:

$$U_{DCPA} = \begin{cases} 1 & DCPA \leq d_1 \\ \frac{1}{2} - \frac{1}{2}\sin[\frac{\pi}{d_2 - d_1}(DCPA - \frac{d_1+d_2}{2})] & d_1 < DCPA \leq d_2 \\ 0 & d_2 < DCPA \end{cases} \quad (15)$$

where d_1 is the minimum safe pass distance, and d_2 is the safe encounter distance. d_1 and d_2 can be expressed as [33]:

$$\begin{aligned} d_1 &= SDA \times N \\ d_2 &= K \times d_1 \end{aligned} \quad (16)$$

where the ship safe distance of approach (SDA) is the fuzzy distance when the sailor operates. N is the relative value representing the instantaneous visibility, for the AIS system, N = 1. In addition, the SDA is calculated according to the Goodwin model as follows [8,12]:

$$SDA = D(\Delta B) + K_1 + K_2 \quad (17)$$

where K_1 is the systemic sensitivity effect to SDA, and K_1 = 0 for AIS. K_2 is the effect of the maritime area to SDA. The weight is small, and it can be considered equal to 0. The values of $D(\Delta B)$ corresponds to the following [33]:

$$D(\Delta B) = \begin{cases} 1.1 - 0.2\frac{\Delta B}{180^0} & 0^0 \leq \Delta B \leq 112.5^0 \\ 1.0 - 0.4\frac{\Delta B}{180^0} & 112.5^0 < \Delta B \leq 180^0 \\ 1.0 - 0.4\frac{360^0 - \Delta B}{180^0} & 180^0 < \Delta B \leq 247.5^0 \\ 1.1 - 0.4\frac{360^0 - \Delta B}{180^0} & 247.5^0 < \Delta B \leq 360^0 \end{cases} \quad (18)$$

The functional function of R is [33]:

$$U_R = \begin{cases} 1 & R \leq r_1 \\ \frac{1}{2} - \frac{1}{2}\sin[\frac{\pi}{r_2 - r_1}(R - \frac{r_1+r_2}{2})] & r_1 < R \leq r_2 \\ 0 & R > r_2 \end{cases} \quad (19)$$

where r_1 = distance for latest actions (DLA) indicates the collision distance of the vessels and the latest action to avoid collision. This distance is not fixed, which depends on the size, speed, type of the ship, the weather condition, the operational ability of officers, and so on. In fact, the traveled distance is safe in the range of 0.4 to 1 nautical mile. In simulation calculations, the article selects r_1 = 1. r_2 indicates the distance from the ship to the target ship in the danger zone. If r_2 is not in the safe range, it can be considered to be safe. So, $r_2 = r_1 + d_2$.

The functional function of TCPA is [33]:

$$U_{TCPA} = \begin{cases} 1 & TCPA \leq t_1 \\ \left|\frac{t_2 - TCPA}{t_2}\right| & t_1 < TCPA \leq t_2 \\ 0 & t_2 < TCPA \end{cases} \tag{20}$$

where t_1 is the time of arrival to the collision. t_2 is the time of arrival to the destination. Normally, 6–8 nautical miles between ships is usually considered the auto driving stage when using autopilot. For the sake of safety, this article set 8 nautical miles as the distance between ships beginning to form a collision situation. Then, we set the time required to sail from 8 nautical miles between ships to the closest point of approach as t_2. Next, the TCPA was set to correspond to t_2. t_1 and t_2 are given by [33]:

$$t_1 = \begin{cases} \frac{\sqrt{DLA^2 - DCPA^2}}{V_{ot}} & DCPA \leq DLA \\ \frac{DCPA - DLA}{V_{ot}} & DCPA > DLA \end{cases} \tag{21}$$

$$t_2 = \frac{\sqrt{8^2 + DCPA^2}}{V_{ot}} \tag{22}$$

The functional function of ΔB is [11,33,35]:

$$U_{\Delta B} = \frac{1}{2}[\cos(\Delta B - 19^0) + \sqrt{\frac{440}{289} + \cos^2(\Delta B - 19^0)}] - \frac{5}{17} \tag{23}$$

So, the algorithm of collision avoidance, namely the collision-risk index (CRI), is calculated as follows:

$$CRI = \alpha_{DCPA} U_{DCPA} + \alpha_{TCPA} U_{TCPA} + \alpha_R U_R + \alpha_{\Delta B} U_{\Delta B} \tag{24}$$

where U_{DCPA}, U_{TCPA}, U_R, and $U_{\Delta B}$ are membership functions that represent the distance at the closest point of approach, the time to the closest point of approach, and the distance and the azimuth of the ship and target ship, respectively. Each factor has different effects on the collision risk. The numbers α_{DCPA}, α_{TCPA}, α_R, $\alpha_{\Delta B}$ are the weights ranging from 0 to 1, and they have a total of 1, which indicates the effects to collision capability of each membership function to the collision risk. The specific calculation process and the value ranges of the above parameters are given in Section 5.

5. Building a Simulation Program

The algorithm test data of the simulation program comes from assuming that the vessel is moving in the open sea with good visibility, as the data of ship encounter status are from the AIS. The ship length is 50 m, and the ship height is 15 m. The weather conditions, wind speed, wave intensity, and sea current are normal. The vision of the watching sailor is good. The weight given to each parameter was set to be the AHP algorithm in the case that the quantitative ratings were not available. Among the factors that affect collisions, TCPA is the most important, and so we set α_{TCPA} = 0.5. The distance between the two ships was also a major influencing factor, especially in the area with a large crossing of boats; thus, we set α_R = 0.3. DCPA has an influence on the size of the ship, so we set α_{DCPA} = 0.1. The azimuth between the two ships affects the reverse ability of the ship, and changes the direction of the ship; thus, we set $\alpha_{\Delta B}$ = 0.1.

The marine collision risk assessment model is applied by simulating the parameters of the host and target vessels, and by using the C++ and Qt tools. The criteria for calculating the CRI and issuing a warning are as follows: when $CRI \geq 0.6667$, there is a high probability of collision, so the vessel needs to take immediate action to avoid the collision. When $0.3333 \leq CRI < 0.6667$, it is likely to collide, and so the vessel needs to be noted. When $CRI <$ 0.3333, there is a low probability of collision, so the vessel needs to be tracked.

The general procedure for the proposed approach is shown in Figure 5, and the information from the AIS was calculated. If the collision probability of the ship and the target ship is high, the system will issue a warning and ask the crew to consider the situation, then the crew needs to take action to avoid the collision, referring to the requirements stated in Chapter 2 of the "Convention on International Regulation for the preventing Collision at Sea (1972)".

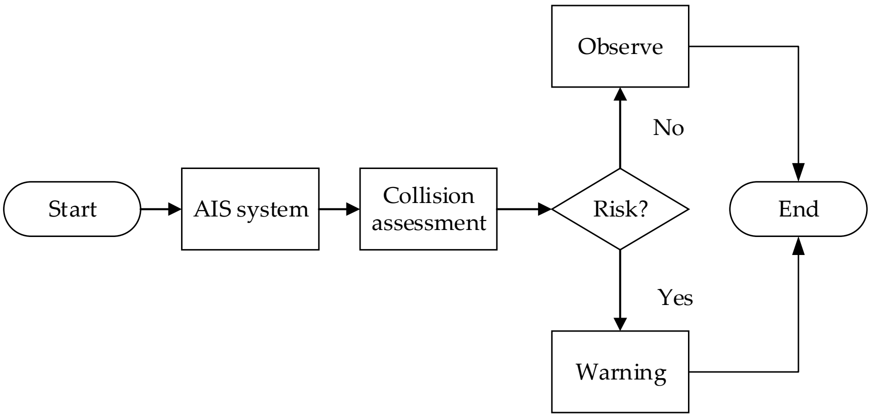

Figure 5. The general procedure for the proposed approach.

The applications of some specific cases are summarized in Table 1.

Table 1. Summary of some specific cases.

No.	Situation	Course (°)	Azimuth (°)	Speed (kn)	Distance (miles)	DCPA (miles)	TCPA (hr)	CRI
1	Head-on	175	3	12	5	0.6959	0.4126	0.2925
2	Head-on	180	5	15	5	0.4358	0.3321	0.3286
3	Starboard	275	30	15	8	7.2505	0.2254	0.5325
4	Starboard	200	25	13	10	0.8716	0.7663	0.1968
5	Board	162	33	15	12	9.3258	0.5035	0.5395
6	Board	130	110	6	11	3.7622	1.7228	0.0001
7	Overtaking	0	356	8	3	0.2093	0.3741	0.4266
8	Overtaking	280	15	10	5	4.9810	0.0436	0.6077
9	Being overtaken	8	150	14	2	1.2313	0.1126	0.7363
10	Being overtaken	11	170	13	1.5	0.5376	0.1077	0.8736

In Table 1, 10 cases corresponded to the situations encountered in Figure 4. The collision capability was assessed by the CRI, which increases with a decrease in the distance between the two ships, and an increase of the speed between the two ships. CRI is usually large in the case of two ships in head-on, overtaken, and being overtaken situations. CRI is usually small in the case of two ships in board and starboard. The CRI reflects the collision more accurately than when only observing the TCPA and DCPA.

Simulation results are shown in Figure 6:

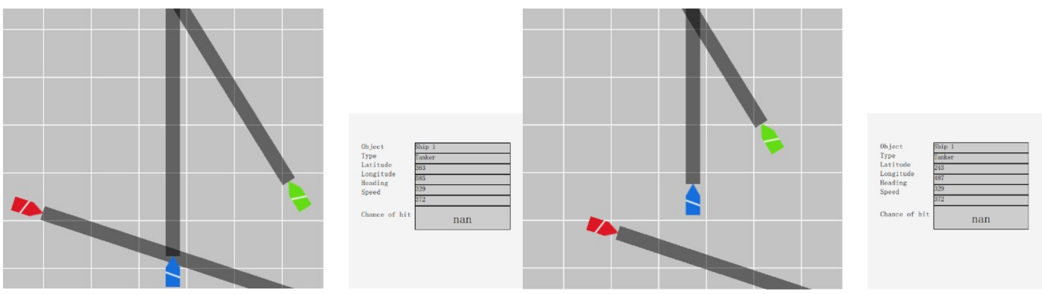

Figure 6. Image simulation.

Figure 6 shows a simulation program that calculates the possibility of collision between ships while traveling around other ships. The possibility of collision depends on the location, the direction of travel, the speed, and the distance between ships with a corresponding CRI.

6. Conclusions and Further Work

In the method using the DCPA and TCPA to calculate the collision capability, it is clear that when two ships are in the same lane, the DCPA is always zero, which means that collision will be immediate, no matter how far away the two ships are. Furthermore, when the ship moves in the same lane and moves slower than the target ship, the possibility of collision is not present, which is not accurate. A comparison of Cases 3 and 4 in Table 1 serves as an illustrative example of the superiority of the method used in this article. Case 4 seems more dangerous than Case 3, because the distance to the point of collision was 0.8716 nautical miles closer than 7.2505 nautical miles. However, in Case 3, the distance between the two ships was actually smaller than that in case 4: 8 nautical miles smaller than 10 nautical miles, and the speeds were faster: 15kn and 13kn. Along with the influence of the different course and azimuth, the time approach to the point of collision of Case 3 was 0.2254 hour when the time approach to the point of collision of Case 4 was 0.7663 hour. Additionally, in the combination of factors to calculate the CRI, that Case 3 was more dangerous than Case 4 was accurate.

The CRI indicates the collision risk of the two ships; the higher the value of the TCPA, the closer the distance between the two ships, and the greater the speed of the ship and the angle of the ship. This index is especially useful with a high density of boats in cruising areas, when the distance between the ships is not too far, and the weather conditions are not favorable. Dynamic visualization results showed that the collision risk assessment model can be applied in practice.

Avoiding operations are widely applied by the operational officer, who observes the target ships for 3 to 6 minutes, then determines the parameters of the target ship, and explains the collision risk. This model can be integrated into the AIS to help the sailor to quickly and accurately assess the collision risk, thereby applying the COLREGS-72 collision avoidance principle to handle the situation.

A small-size embedded system with the collision risk assessment model can be installed on-board for navigation, and equipped on small vessels and fishing vessels to avoid collision without an ARPA system. This collision risk assessment model can also be used at the base station, VTS centers, and NoC, to monitor, manage, and issue hazard warnings for vessels in the operating area of stations.

The limitations of this paper are the effects of ship size, ship type, weather condition, and the dynamic activity of the target ship on safety, which were not been researched here, as they were beyond the scope of this study. The calculation collision capability is based on information from the AIS system. Therefore, the speed and course used in the article were the SOG and COG, and not the actual speed of the ship through the water surface. This will be affected in complex weather conditions and high-flow sea currents, especially in the case of head-on situations. The number of DLA is one of the parameters involved that was set at one nautical mile to calculate the CRI. In future study, when the ship target is in a danger zone, for the number of DLA required to calculate the details to fit the type of ship, we will use the ship's domain to calculate the CRI in more detail. The application of the proposed method is necessary to enhance the capability of risk assessment by collecting more encountered conditions in practice. Furthermore, the authors will continue with this research and develop a hardware device to improve the AIS system.

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Abbreviations

AHP	Analytic Hierarchy Process
AIS	Automatic Identification System
ARPA	Automatic Radar Plotting Aid
COG	Course Over Ground
COLREGS	Convention on International Regulation for Preventing Collisions at Sea
CRI	Collision Risk Index
DCPA	Distance at Closest Point of Approach
DLA	Distance for Latest Actions
ECDIS	Electronic Chart Display and Information System
GPS	Global Positioning System
NGC	Navigation, Guidance and Control
NOC	Network Operations Center
RADAR	Radio Detection and Ranging
SDA	Safe Distance of Approach
SOG	Speed Over Ground
TCPA	Time to Closest Point of Approach
VHF	Very High Frequency

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