Research on Stage Division in the Ship Collision Avoidance Process

Yanning Hao*, YuelinZhao*

School of navigation, Dalian Maritime University, Dalian, China

*Corresponding author e-mail: sin50@sina.com, *13304289000@163.com

Abstract. On the basis of analyzing the ship's encounter, the meaning of the collision risk and the various stages of the ship's collision avoidance are qualitatively and quantitatively analyzed, and the relevant recommendations for the division of the ship's handling and collision avoidance phase based on DLMA are proposed. Provide a reference for the division of collision responsibility and ship maneuvering actions.

1. Introduction
The provisions and terminology of the Rules\(^1\) are mostly abstract, but the judgments and actions taken by seafarers in complying with the Rules are specific and precise. Therefore, under normal circumstances, it is not feasible to just explain the Rules qualitatively. Since the Rules have the dual attributes of legal norms and technical specifications, some terms need to be embodied in the application of the Rules. The quantification of the four stages of ship collision avoidance belongs to this category of problems.

2. Division of stages in the process of ship collision
In the process of ship collision accidents, from the formation of collision danger to the occurrence of collision, it has experienced the process of involving risk of collision, risk of collision exists, close-quarters situation is developing, results in a close-quarters situation, immediate danger, and finally collision, as shown in Figure 1 [1].

There is a different understanding of how much the likelihood of a collision increases to what it can be called a "Risk of collision". "Risk of collision" is a possibility of collision. The most important basis for judging is the DCPA (Distance of Closest Point of Approaching) and TCPA (Time to Closest Point of Approaching). It is generally believed that when the DCPA<safety encounter distance and the TCPA is small, the two ships should be considered to be in the risk of collision. [1]

After the two ships involve risk of collision, although they have the possibility of collision, if each can abide by the Rules and related special rules (hereinafter referred to as the "Rules"), take appropriate action(s), they will pass at a safe distance, in other words, collision will not occur. On the contrary, if each of them fails to act in accordance with the Rules, close-quarters situation might form. The term "close-quarters situation" first appeared in the 1960 Rules. In addition to this article, the 1972 Rules also mentioned the close-quarters situation in Article 19, paragraph 4/5, but in the rules, there is no clear definition of “close-quarters situation” [2]. Experts and scholars from

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\(^1\)International Regulations for Prevention Collision at Sea, 1972
maritime circles in different countries have different opinions in qualitative and quantitative interpretation of the close-quarters situation. British captain F. Wylie believes that in close-quarters situation, the danger can be understood as the actual collision risk already exists. [3] US Captain R.A. Cahill said: "In close-quarters situation, around an area of the ship, if other ship suddenly takes an unexpectedly large-scale turn to the action, then own-ship alone can't avoid collision. [4]" However, the maritime community in China generally believes that the "close-quarter situation" refers to the situation in which two vessels approach a certain level, when only one takes action, they cannot pass at safe distance.

After the close-quarter situation formed, if neither party has it, or if only one party takes immediate action, they would further pose an immediate danger that collision cannot be avoided by the action taken by a single ship. At this time, only two vessels immediately take the action that is most helpful to avoid collision, and the actions of the two ships are coordinated, the collision would be avoided. Otherwise the collision would occur. Moreover, even if the collision is unavoidable, the correctness of the emergency action taken will be directly related to the degree of damage caused by the collision.

Through the above analysis of the entire collision process, there are many conditions for collision accidents and collision damage, and the causal size of each condition in collision accidents and damage is different.

![Figure 1. Ship collision process.](image)

3. Quantification of ship collision avoidance phase division

The ship's speed, maneuverability, encounter situation and sea state must be taken into account in the process of quantification of the ship’s collision stages. In the case of mutual observation and poor visibility, as well as in different sea areas (narrow waterways, traffic separation, wide waters), the collision avoidance phase should be treated differently.

3.1. Quantification of ship collision avoidance phase in sight of one another

When two vessels are in sight of one another, it can be divided by the requirements of collision avoidance of give-way and stand-on vessel, as shown in Figure 2.

1) When they are far apart, two vessels may take free actions before the danger of collision exists.
2) So as to involving risk of collision, the give-way vessel shall take significant action in a timely manner to ensure that both parties pass at a safe distance. At this time, the stand-on vessel shall be keep course and speed.
3) When the give-way vessel apparently fails to take collision avoidance actions in accordance with the Rules, the stand-on vessel required by the Rules shall sound the whistle in accordance with the slogan
specified in Article 34, paragraph 4 of these Rules, and the stand-on vessel can take appropriate actions to avoid collisions in compliance with Rules, but the stand-on vessel in the crossing situation should not alter course to port for a vessel on her own port side.

(4) When, from any cause, the vessel required to keep her course and speed finds herself so close that collision cannot be avoided by the action of the given-way vessel alone, she shall take such action as will best aid to avoid collision.

Figure 2. The four stages of collision avoidance procedure in sight of one another.

Many scholars believe that when the two ships on the sea are close to 6 n mile, if the DCPA of the two ships is smaller than the safety DCPA, it is considered that the risk of collision is forming; if the both do not take any action and continue to approach 3 n mile, it is considered that a close-quarter situation is forming; If they continue to approach 1 n mile, then an immediate danger is emerging. The basis for its judgment is mainly determined by the Rules on the luminous range of the ship's lighting. For the two motor vessels in the Crossing situation on the sea, the guide to the Rules for maritime collision avoidance suggests that the boundary value of the collision risk stage may be 5-8 n mile, and the close-quarters situation may take 2-3 n mile [5].

Based on the Distance of Last-minute action of turning (DLMA), Hu Changping² takes a series of parameters considering the conditions of the two ships, the ship's scale, and the speed of the ship. Simplify, divide the collision avoidance phase of the ship, and draw the boundary values of the four phases:

Outer areas of immediate danger:

\[ DLMA = 5L \times \sqrt{1 + K^2 - 2K \times \cos \Delta H} \]  

Outside the region of the close-quarters situation:

\[ D_2 = 15L \times \sqrt{1 + K^2 - 2K \times \cos \Delta H} \]  

The outside of the risk of collision zone:

\[ D_3 = 25L \times \sqrt{1 + K^2 - 2K \times \cos \Delta H} \]

Where: \( L \) is the length of the ship; \( K \) is the ratio of the ship's speed; \( \Delta H \) is the heading angle between the ships.

²Hu Changping. "The division and quantification of the collision avoidance phase during the ship encounter." China Navigation 2 (2001). The specific simplification process can be found in the article.
Taking the HARVEST and JINKUN case as example, the three-stage boundary value is 1.11 n mile, 3.33 n mile, and 5.56 n mile, which is not much different from the critical value proposed in the Rules. It is generally believed that the reference thresholds of 1 n mile, 3 n mile, and 6 n mile are basically consistent and can be quantified as a phase division when vessels in sight of one another.

3.2. Quantification of ship collision avoidance phase in restricted visibility

In general, many scholars believe that in the case of restricted visibility, the corresponding distances of 6 n mile, 3 n mile, and 1 n mile should be increased to 8 n mile, 4 n mile, and 2 n mile.

First of all, let's look at the study of the close-quarters situation model (the inner boundary of the close-quarters situation is also the outer boundary of the immediate danger situation). Wang Fengchen [6] believes that when the visibility is restricted, the rule 19, paragraph 5 stipulates: "every vessel which hears apparently forward of her beam the fog signal of another vessel, or which cannot avoid a close-quarters situation with another vessel forward of her beam, shall reduce her speed to the minimum at which she can be kept on her course". According to the regulations, the distance at which the close-quarters situation is formed is equivalent to the distance when hearing the whistle of other ship. Equivalent, while the large ship has an audible distance of 2 n mile, so 2 n mile is used as the distance between two ships after the formation of a close-quarters situation in the case of restricted visibility, and it is considered that in the case of restricted visibility or crowded waters less than 2 n mile is enough when slowing down. “In the sea, the scope of the initial application of the close-quarters situation in the case of poor visibility is 2-3 nautical miles for the outer boundary”, Luo Shimin said in the revision of the Rules for avoiding collisions at sea [7]. Sometimes 1 nautical mile is acceptable for each other.

From the external model research in the close-quarters situation, the external research is mostly the safety distance + DLMA based quantitative research. That is, the distance model of the two ships in the close-quarters situation is:

\[
D = d_1 + d_2
\]  

\[
d_1 = \frac{D_s \sin \left( \arctg \frac{\sin q + \sin (90-q)}{\cos(90-q) + \sqrt{k^2 - \sin^2 q}} \right) }{\sin q} \]  

\[
d_2 = \frac{V_0 (t_1 + t_{90}) \sin(\arcsin k \sin q + q)}{k \sin q} \]

In the formula: \(D_s\) is safe distance; \(q\) is relative bearing of the encounter ship; \(k = \frac{V_0}{V_i}\); \(t_1\) is the time required from the command of full rudder to the rudder angle of 35 degrees; \(t_{90}\) is time required after the rudder is full and the bow is rotated 90 degrees; \(d_1\) is relative distance of movement required to maintain a safe distance; \(d_2\) is relative movement distance of own-ship turning 90 degrees to the right.

4. Safe distance

The risk of collision and the close-quarters situation stage all involve the discussion of safety distance. Therefore, the value of safety distance is especially important when quantifying. Sun Licheng [8] counts the average distance of avoidance safety distance for different encounter situations through the research on the close-quarters situation model. See Table 1.below.
Table 1. Statistical of safe distance.

| Encounter Situation         | Mean safe distance(n mile) |
|----------------------------|---------------------------|
| Head-on situation          | 1.07                      |
| Starboard to starboard     | 0.74                      |
| Port side to port side     | 0.625                     |
| Crossing situation         | 1.0                       |
| Overtaking situation       | 0.65                      |
| Restricted visibility      | 1.76                      |

Luo Shimin's description of the safety distance is 0.5 n mile for good visibility in the wide waters, 2 n mile for restricted visibility, and 0.5 n mile for the traffic separation. In the principle of ship collision avoidance [9], the safety distance statistics of different encountering situations in different environments can be seen that the difference between the safe distance between the daytime narrow channels and the daytime ocean is about 0.3 n mile. In the fog, the safety distance on the ocean is about 1 nautical mile larger than when the visibility is good.

According to Table 1 and the above scholars' discussion on the safety distance in different environments, it can be concluded that the mean value of the safety distance difference is about 1 n mile in good and poor visibility. The safety distance difference between narrow waterway, traffic separation and wide waters, the mean is around 0.2 n mile. Taking the extreme situation of the same speed and the speed of the two ships as the safest quantitative reference, the difference between the close-quarters situation is about 1.2 n mile and 0.28 n mile according to formula (4) (5). Therefore, by quantifying the safety distance in different environments and taking into account the knowledge of most scholars, based on the stage division method proposed by Hu Changping, this paper considers that the reference value of the broad waters with poor visibility is D good +1.2 n mile, when the visibility is good. The narrow waterway or traffic separation is Dgood+0.28 n mile.

5. Conclusion
Based on the full consideration of ship encounter situation, ship scale, speed, sea state and visibility, this paper discusses the value of safety distance and puts forward suggestions for the collision avoidance stage. It has been verified to be reasonable and can provide reference for the division and analysis of ship collision responsibility, the risk assessment and maneuvering action of ship encounters.

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