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The Relation between Human Behavior and Safety in the Collision Avoidance Situation

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Abstract : *It can be said that the relationship between the maneuvering ability of operators and the navigational environment affects the safe degree of navigation in the collision avoidance situation. In order to reduce the occurrence probability of accident and to maintain the safety, it is necessary to clarify the relationship between human behavior and navigational environment. In this study, therefore, we analyzed and discussed the relationship between the maneuvering characteristics and the safety focused on human behavior as a fundamental factor of marine accidents using ship handling simulator and questionnaire. As a result, we concluded that navigational environment changes variously and the maneuvering ability of operators also varies with the navigational environment, and the ship handling characteristics strongly affect the occurrence probability of accident.*

Key words : *mariner's behavior, ship handling characteristics, collision risk, BTM (Bridge Team Management), questionnaire, crossing situation*

1. Introduction

The maneuvering ability of operators and navigational environment change variously during navigation, and the occurrence probability of collision also varies with the maneuvering ability of operators. Therefore, it is required to clarify the relationship between the condition of maneuvering ability and that of navigational environment in order to reduce many causes of marine accidents(Kobayashi H, 2002). In this paper, the relation of conditions between maneuvering ability and navigational environment is discussed by analyzing the results of BTM training and questionnaire.

In chapter 2, the relation between maneuvering ability and collision risk is shown based on BTM training using ship handling simulator. The BTM training was performed by 20 teams. On the basis of the results, the correlations between the factors such as recognition time, avoiding action time and *CPA* representing characteristics of avoidance behavior were calculated.

In chapter 3, the characteristics of ship handling affected by navigational environment are shown based on comparison between the questionnaire and the results of the BTM training.

2. The Relation between Maneuvering Ability and Collision Risk

The object of this study is to clarify the relation between mariners' behaviors and safety in crossing situation based on the results of BTM training. A team in the BTM training was organized with the captain who is commanding ship handling in bridge, 2nd and 3rd officers who take charge of the work such as lookout, VHF, radar and ships positioning measurement, and a quartermaster.

A scenario of training contains various cases which may happen in ship operation, and we selected and discussed two cases shown in Fig. 1 (a) and (b) among various cases of the scenario. The first case is that an own ship encounters a small high-speed vessel with the crossing situation in Singapore Strait. In the second case, the target ship has been an eastbound container vessel in the early stage, which slows down suddenly and proceeds toward the pilot station of the northern side. And then the risk of collision occurs between two vessels.

The results of the two cases were analyzed by Pearson's Correlation Coefficient(R) (Introductory Statistics).

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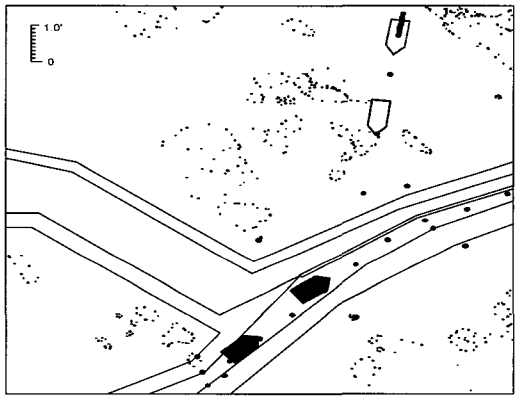
2.1 Case I : encountering a small high-speed vessel (when the own ship is the stand-on vessel)

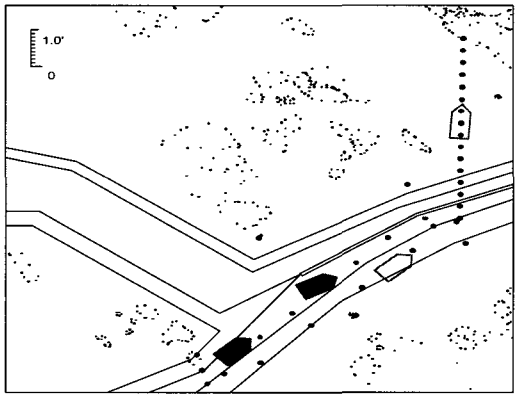
(1) The background and analysis items

In this section, a crossing situation as shown in Fig. 1 (a) is analyzed. The own ship is an eastbound VLCC in Singapore Strait. After passing the TAKONG, she encountered a small high-speed vessel on the crossing situation that sailed across the channel to south and the risk of collision has been increased as approaching the altering point. According to COLREG, the own ship is the stand-on vessel and the target is the give-way vessel (Marine Traffic Laws). However, the target ship does not take any action to avoid the collision and steadily approaches to the own ship. At the moment, mariners' behaviors in the course of coping with this dangerous situations were investigated. The contents of avoidance behavior were analyzed with the following items;

(i) The time when mariner recognizes the target vessel
(ii) The time when mariner takes avoiding action
(iii) Closest Point of Approach (*CPA*)



(a) Crossing with a small high-speed vessel



(b) Crossing with a container which proceeds toward the pilot station

Fig. 1 Two cases in scenario of Bridge Team Management (BTM)

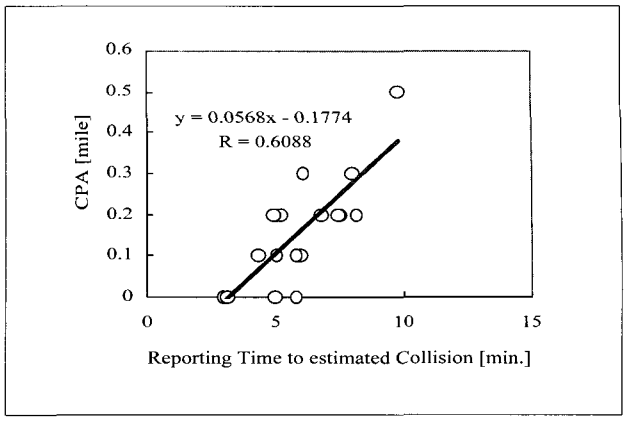


Fig. 2 Relation between CPA and Reporting Time

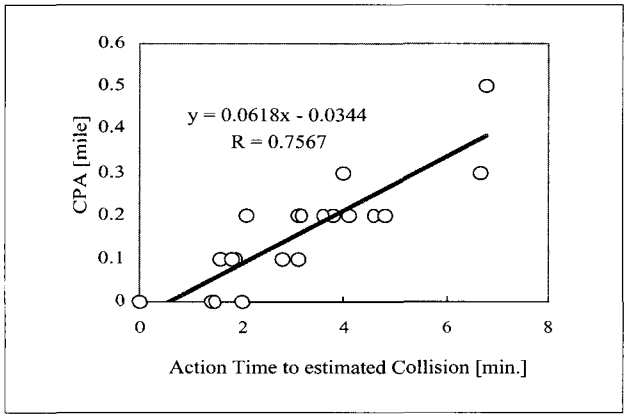


Fig. 3 Relation between CPA and Action Time

(2) The mariners' behaviors on ship handling

Tr : Reporting Time to estimated Collision when dangerous relation to target vessel is reported or recognized.
Ta : Avoiding Action Time to estimated Collision when the action to avoid target vessel is started.
CPA : Closest Point of Approach

1) The relation between *CPA* and *Tr*

Fig.2 shows the relation between *CPA* and recognition time (*Tr*) to estimated collision. The correlation coefficient (R) shows high value of 0.6088. It turns out that there is high correlation between *CPA* and recognition time to estimated collision. In other words, it means that *CPA* can change by the recognition time for the target vessel. Conversely, the time of recognizing the target vessel to secure safety can be decided. For example, it means that mariners must recognize the target vessel at least at the time of 7 minutes or more before collision in order to secure *CPA* of 2 cables as shown in Fig.2.

2) The relation between *CPA* and *Ta*

Fig.3 shows the relation between *CPA* and avoiding action time (*Ta*) to estimated collision. The correlation

coefficient (R) between *CPA* and *Ta* is 0.7567, which shows higher correlation than the one between *CPA* and *Tr*. It indicates that the action time has higher correlation to *CPA* than recognition time to target vessel and is more closely related to it.

3) The relation between *Tr* and *Ta*

Fig. 4 displays the relation between recognition time (*Tr*) and action time (*Ta*) to estimated collision. It is shown that the correlation coefficient (R) has high correlation of 0.6537 between *Tr* and *Ta*. It indicates that the avoiding action could be taken lately as it recognizes more lately for target ship. On the contrary, the avoiding action could be also taken quickly, the more it recognizes target ship early.

4) The relation between avoiding methods and *Tr*, *Ta*, and *CPA*

The methods of avoiding action which are taken by operators can be divided into 3 categories;

① take an avoiding action using an engine or a steering wheel.

② give warning to the target ship using air horn.

③ communicate with target ship using VHF

Fig. 5 shows the correlation between *CPA* and *Ta* for each method of avoiding action. In case of ①, avoiding action is taken by own ship, and the values of *Ta* are mostly distributed in the range of 4 minutes or more. In case of ②, avoiding action is taken by the target ship, and the values of *Ta* are mostly distributed in the range of 4 minutes or less. In case of ③, avoiding action is taken by the own or target ship, and the values of *Ta* are mostly distributed in around 4 minutes.

It shows that there is tendency of avoiding by own ship when action time (*Ta*) to estimated collision is ample time. However, it shows that there is tendency of making the target ship take an avoiding action when action time (*Ta*) to estimated collision is small.

Considered *CPA*, the *CPA*s in case of ② are larger than those of ① when the *Ta* is the same value. It can be considered that the results are caused by the performance of the vessels. That is, movement of the small target ship is faster than the big own ship. From this point of view, we have to consider quick avoiding action for safety and ask target vessel's cooperation when the time to collision is short.

Fig.6 shows the correlation between *Tr* and *Ta* for each the method of avoiding action. The correlation coefficient is quite high when the avoiding action is taken by only own

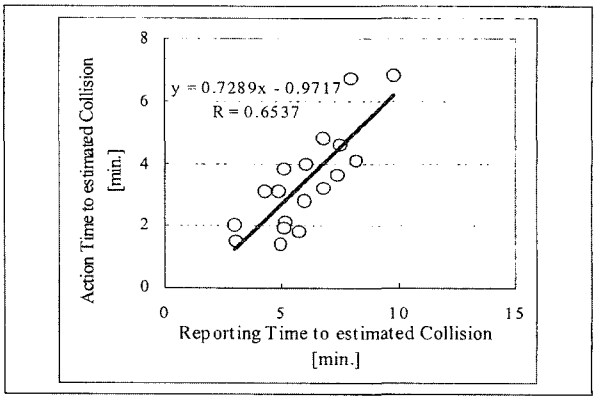


Fig. 4 Relation between Reporting Time and Action Time

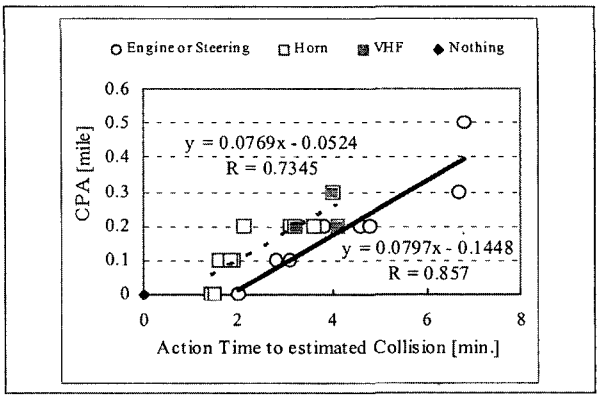


Fig. 5 Relation between CPA and Action Time for each Avoiding Method

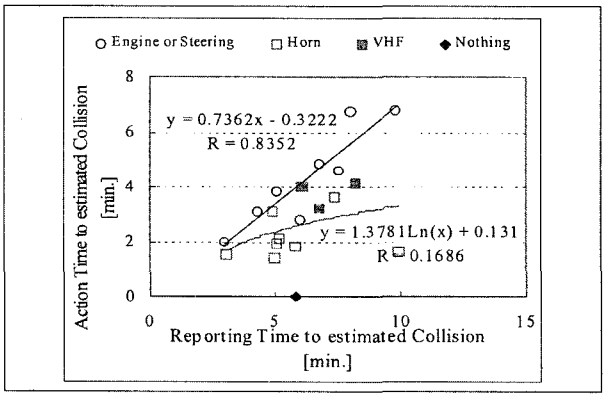


Fig. 6 Relation between Reporting Time and Action Time for each Avoiding Method

ship while it is very low when the action is taken by the target ship. The case ② are mostly distributed in the range of small values for *Ta* no matter how *Tr* is extended. It is also displayed that Horn was used abundantly when the time to collision is short, and VHF was used when there is a little time clearance. That is, it seems that there is the tendency of making the target vessel take avoiding action when time to collision is short.

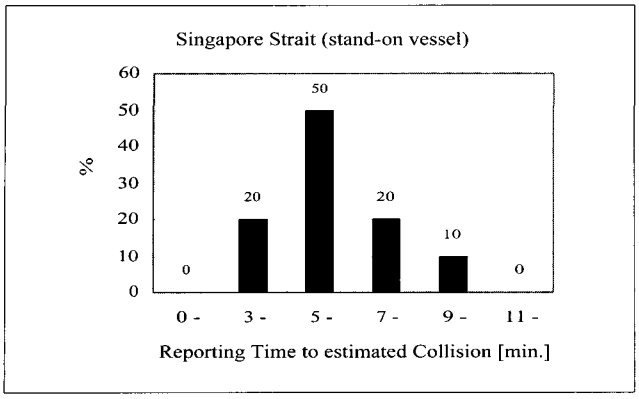


Fig. 7 Distribution of Reporting Time

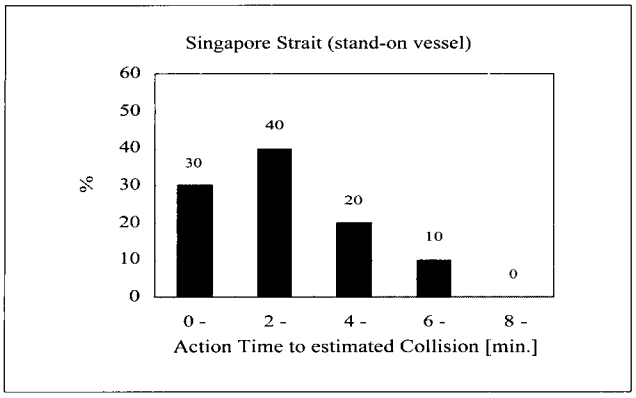


Fig. 8 Distribution of Action Time

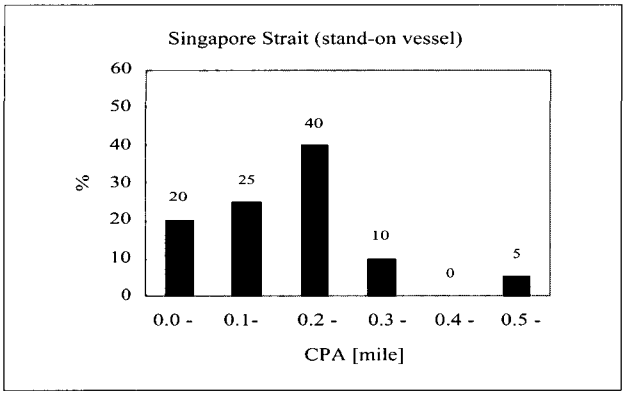


Fig. 9 Distribution of CPA

5) The fluctuation of maneuvering ability of mariners

The variation on characteristics of ship handling was analyzed.

Fig. 7 shows the distribution on recognition time to estimated collision for every 2 minutes. The data are concentrated between 5 minutes and 7 minutes. The average value of *Tr* is 6.2 minutes.

Fig. 8 shows the distribution on action time to estimated collision for every 2 minutes. The data is mostly distributed in the interval between 2 minutes and 4 minutes. It means that mariners usually start to take avoiding action at average 3.2 minutes before collision.

Fig. 9 displays the distribution of *CPA*. the 40 percent of total 20 teams correspond to the interval between 0.2 mile and 0.3 mile of *CPA* and 85 percent of them are gathered in less than 0.2 mile. That is, we can understand that small values of *CPA* are generally taken in restricted waters like Singapore Strait.

2.2 Case II : encountering a container vessel (when the own ship is the give-way vessel)

(1) The background and analysis items

The target ship has been the same eastbound vessel in the early stage, which proceeds toward the pilot station of northern side after slowing down suddenly and stopping the engine as shown in Fig.1 (b). And then the crossing situation was occurred suddenly and according to COLREG, an own ship is the give-way vessel and the target is the stand-on vessel. The behaviors of mariners to cope with this situation at the moment were analyzed. The analysis items are as follows;

(i) The time when mariner recognized the target vessel

(ii) The time when mariner started to perform avoiding action

(iii) Closest Point of Approach (*CPA*)

(2) The mariners' behaviors on ship handling

The correlation between the recognition time and action time to estimated collision, distribution of recognition time, action time and distribution of *CPA* are displayed in Figs. 10-14.

Fig. 10 displays the relation between recognition time and avoiding action time to estimated collision. It is shown that the correlation coefficient (R) has high correlation of 0.6565 between *Tr* and *Ta*. This value is similar with the case of a small high-speed vessel shown in Fig. 4.

Fig. 11 shows the relation between *Tr* and *Ta* for each the method of avoiding action as explained in previous section. It displays that VHF is mainly used for avoiding than Horn, and the correlation between *Tr* and *Ta* for only VHF is very high.

Fig. 12 and Fig. 13 show the distribution on recognition time and action time, respectively. The average value of *Tr* is 12.6 minutes, while the average value of *Ta* is 10 minutes. And it is found from the distribution of *CPA* in Fig. 14 that 65 percent of operators take action to avoid in the range of small values between 0.2 mile and 0.4 mile.

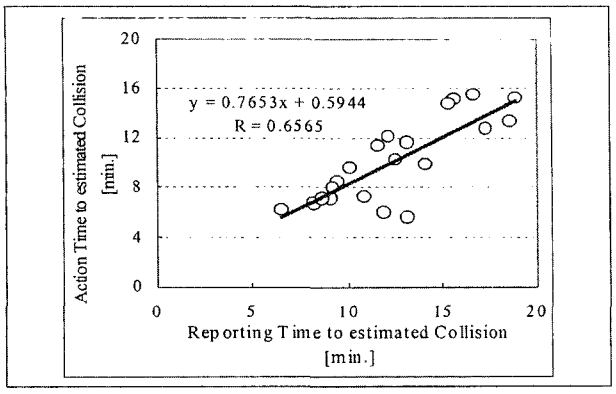


Fig. 10 Relation between Reporting Time and Action Time

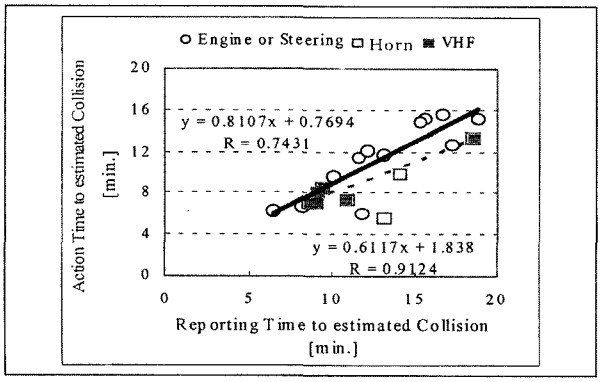


Fig. 11 Relation between Reporting Time and Action Time for each Avoiding Method

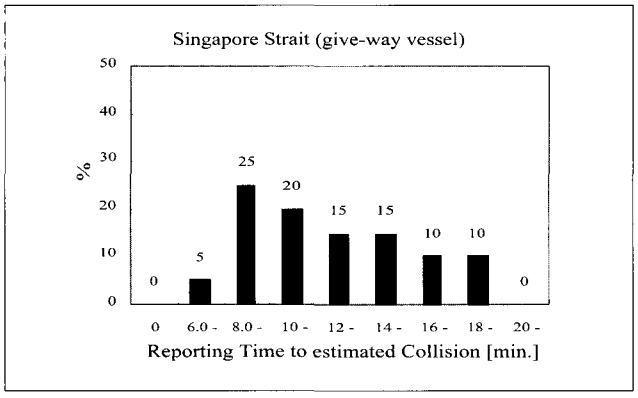


Fig. 12 Distribution of Reporting Time

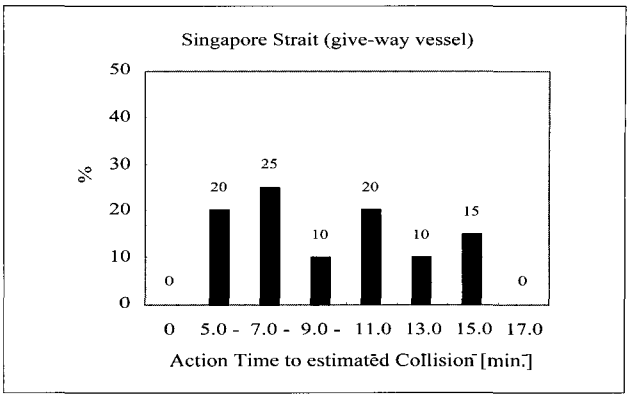


Fig. 13 Distribution of Action Time

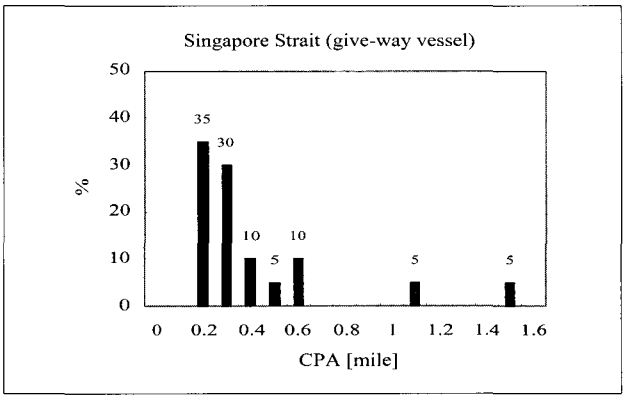


Fig. 14 Distribution of CPA

2.3 Summary

(i) The correlation between *CPA* and recognition time, and between *CPA* and action time indicated high value for the small high-speed vessel.

(ii) The correlation between action time and recognition time indicated high value for both a small high-speed vessel and a container vessel.

(iii) In the two cases of BTM training, the *CPA*s were mostly distributed in small values.

(iv) In the case of a small high-speed vessel, average recognition time (*Tr*) and action time (*Ta*) were 6.2

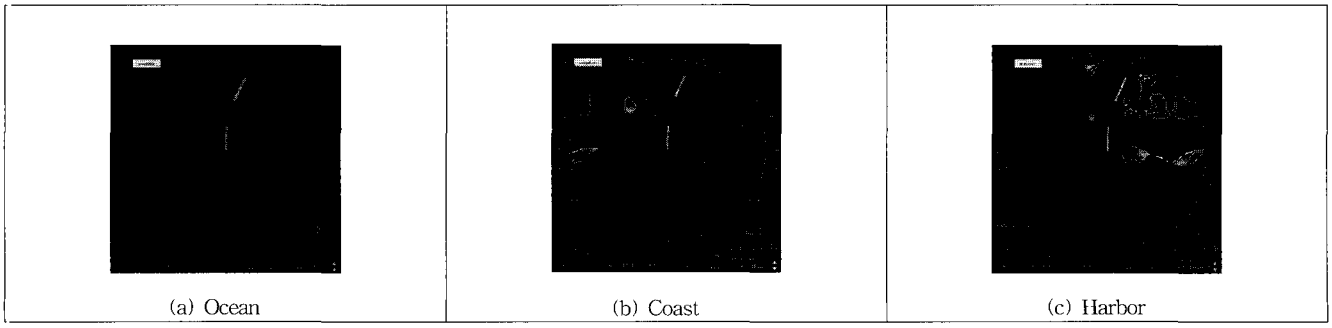


Fig. 15 Condition of Navigational Environment in the Questionnaire

minutes and 3.2 minutes respectively. And it was found that most operators took avoiding action in the range of average 0.16 mile.

(v) In the case of a container vessel, average recognition time (*Tr*) and action time (*Ta*) were 12.6 minutes and 10.2 minutes respectively. And it was found that most operators took avoiding action in the range of average 0.42 mile.

3. The Characteristics of ship handling caused by navigational environment

The characteristics of mariners for ship handling are analyzed with questionnaire in this chapter. The 91 mariners completed questionnaire form and the results are compared with the contents of the BTM training.

3.1 The contents of questionnaire

① Subject	91 Mariners (Captain, 1st officer, 2nd officer and 3rd officer)
② Own ship	Container (Speed 16kt, Length 280m)
③ Target ship	Container (Speed 16kt, Length 280m)
④ Fairway condition	Fine visibility, no aids to navigation, no other vessels
⑤ Navigational waters	Ocean, Coast and Harbor
⑥ Relation of collision	- own ship is the stand-on vessel - own ship is the give-way vessel
⑦ Items of question	- Time to report target vessel - Time to start to take avoiding action

Table 1 Comparison for condition between the BTM training and questionnaire when the own is a stand-on vessel

	Small high-speed vessel in the BTM training	Questionnaire
Type of target vessel	Small cargo	Container
Navigational environment	With buoys, altering points and other vessels. Restricted waters is applied	No aids to navigation, no other vessels. Open sea
Own ship	Stand-on vessel	Stand-on vessel

3.2 The comparison between questionnaire and BTM training in the case of small high-speed vessel

The each average values of *Tr* and *Ta* for ocean, coast and harbor in the questionnaire and for small high-speed vessel in Singapore Strait are shown respectively in Fig. 16 and Fig. 17.

In the questionnaire, there are no buoys, no altering points and no other vessels in the around, and the target ship is same kind of large vessel as the own ship.

In the BTM training, on the contrary, there are many buoys, altering points and other vessels and traffic separation zone is applied. The conditions for the case I in the BTM training and questionnaire when the own ship is the stand-on vessel are shown in Table 1. The results of this comparison indicated various differences from ocean to Singapore Strait.

Fig.16 shows mean values on *Tr* caused by various navigational waters. *Tr* of ocean displays the most large value and then coast, harbor, and Singapore Strait in that large order. It can be considered that it is caused by not only characteristic of the waters but also complex factors such as many buoys, altering points, high traffic density and traffic separation.

Fig.17 shows mean values on *Ta* caused by various navigational waters. It indicates large gap between the case I and questionnaire while values of *Ta* for ocean, coast and harbor in the questionnaire are similar. It means that it is the *Ta* strongly is affected by complex factors such as high traffic density, traffic separation and etc. It is also confirmed that *Tr* and *Ta* become smaller as condition of navigational environment become difficult. That is, it turns out that characteristics of ship handling can be varied with various conditions of navigational environment.

3.3 The comparison between questionnaire and BTM training in the case of container vessel

The average values of *Tr* and *Ta* for container vessel and ocean, coast, harbor in questionnaire are shown in Fig. 18 and Fig. 19.

In the questionnaire, the target ship is same kind of large container vessel, and there are no buoys, no altering points and no other vessels in the around. In the BTM training, the target ship is large container vessel, too. However, there are many buoys, altering points and other vessels in the around and traffic separation is applied. The conditions for the case II and questionnaire when the own ship is the give-way vessel are indicated in Table 2. With these conditions, we displayed and analyzed each mean values of *Tr* and *Ta* for ocean, coast, harbor and Singapore Strait.

In Fig.18, the gap for values of *Tr* between the case II and questionnaire is smaller than that in Fig.16.

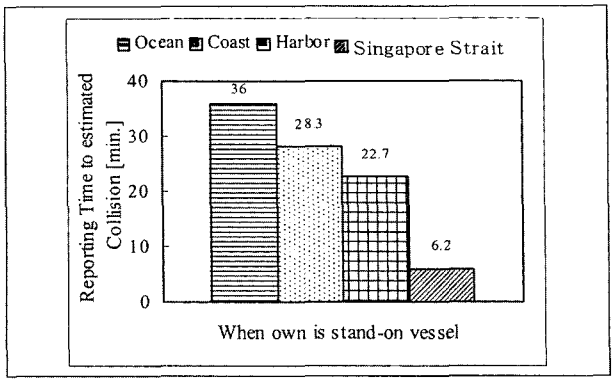


Fig. 16 Comparison with Reporting Time

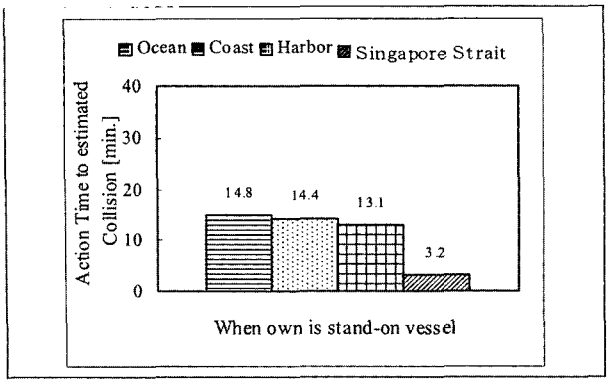


Fig. 17 Comparison with Action Time

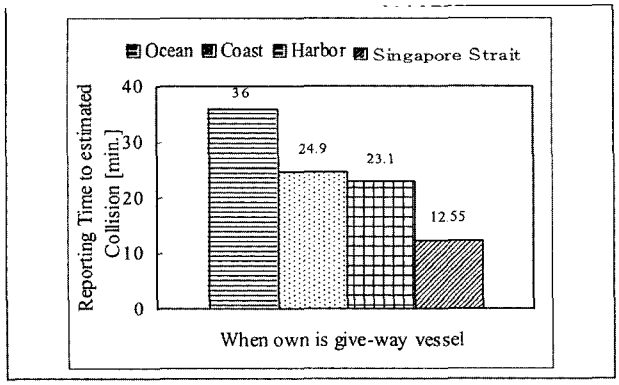


Fig. 18 Comparison with Reporting Time

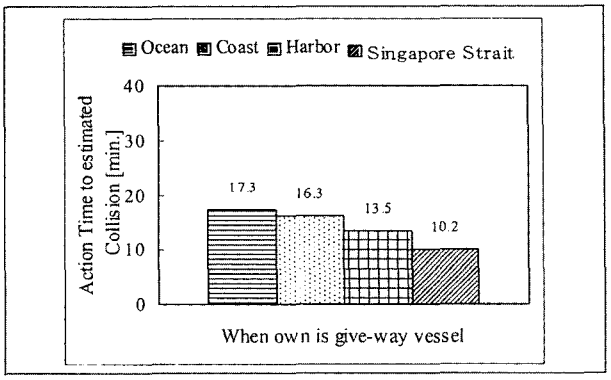


Fig. 19 Comparison with Action Time

Table 2 Comparison on condition between the BTM training and questionnaire when the own is the give-way vessel

	Container vessel in the BTM training	Questionnaire
Type of target vessel	Container	Container
Navigational environment	With buoys, altering points and other vessels. Restricted waters is applied	No aids to navigation, no other vessels. Open sea
Own ship	Give-way vessel	Give-way vessel

Fig.19 displays on values of *Ta* which from the case II of BTM training is much larger than that in Fig.17.

Thus, we can understand that there is tendency to take avoiding action earlier when an own ship is a give-way vessel than a stand-on vessel, and to give much care for look out when a target ship is a large vessel than a small one. That is, we can conclude that characteristics of ship handling change by various factors such as navigational environment, own ship's position in crossing situation, and a type of target ship.

3.4 Summary

The results from comparison with questionnaire and BTM training are summarized as follows;

(i) It indicated that recognition time, action time representing characteristics of ship handling can change by the condition of navigational environment.

(ii) It indicated that recognition time, action time can change by type or performance of target vessel. That is, it can be considered that there is tendency to give much care for look out or to take earlier avoiding action for a large vessel than a small one.

(iii) It indicated that specially, action time can change by own ship's status in crossing situation. In other words, we can understand that when an own ship is a give-way vessel, mariners have tendency to take earlier avoiding action.

4. Conclusion

Firstly, we found from two cases of BTM training that recognition time (*Tr*) is strongly related with *CPA* and action time (*Ta*), and the majority of mariners take small *CPA* of considerable danger in restricted waters like Singapore Strait, especially.

Thus, we can understand that although most mariners take small *CPA* in same difficult environment, it is important for safety to recognize target vessel as early as possible since it affects to *CPA* and action time (*Ta*). Otherwise, it is easy to occur *CPA* of considerable danger in congested waters. In other words, there is high probability for mariners with usual ability to make collision in difficult navigational environment.

Secondly, we obtained from the comparison between questionnaire and BTM training that ship handling characteristics can change by various factors such as condition of navigational environment, a type or performance of target ship and own ship's status in the crossing situation.

To sum up the results of the BTM training and the questionnaire we have studied thus far, it can be concluded that the characteristics of ship handling vary with factors such as the condition of navigational waters, own ship's status in crossing situation and the performance of target vessel as mentioned above, and the probability of collision could be higher when the majority of operators encounter target vessel with crossing situation in difficult environment.

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