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A Study on the Influence of Navigational Environment on Mariner's Behavior for Collision Avoidance

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Abstract : *The safety degree of navigation for collision avoidance is closely related with the combination between mariner's behavior and navigational environment. The condition of navigational environment is mainly decided by navigable waters, ship traffic, rule of road, sea state, weather and so on. Especially, the condition of navigable waters and ship traffic in navigational environment are ones of the important factors to attain safe navigation when mariners are underway and crossing, head on or overtaking situation. Thus this paper is to analyze the characteristics of mariner's behavior for collision avoidance caused by ship traffic and navigable waters by analyzing the contents of questionnaire and the results of international collaborative research. As a result, it can be concluded that the density of ship traffic and the area of navigable waters affect mariner's ship handling for collision avoidance.*

Key words : *Mariner's behavior, Ship handling, Collision avoidance, Detection, Recognition, Avoiding action, Navigational environment, Ship traffic, Navigable waters*

1. Introduction

The importance of human factors has been increasing in maritime field all over the world by the statistics that most of marine accidents are related with mariner's behavior (Lee et al., 2007; Yahei Hujii et al., 1981). Moreover, the statistics show that the collision between vessels is mostly related with mariner's behavior among various kinds of marine accidents (Korean Maritime Safety Tribunal, 1995~2004). Thus it has been considered that to reduce the accidents caused by human and to enhance the safety, it is necessary to study mariner's behavior and to develop the navigational environment considering the ability and limitation of mariners for safe navigation (Kobayashi H, 2002). And the variation of mariners' behavior in navigational environment and the influence of their behavior on the safety have been investigated in a previous study (Park et al., 2003). Consequently, it is obtained that mariner's behavior in detection process is related with the recognition and avoiding actions for collision avoidance, and such mariner's behavior is related with the safety in the situation of collision avoidance (Park et al., 2003). As a subsequent study, the aim of this study is to clarify how the characteristics of mariner's behavior change quantitatively by the navigational condition such as ship traffic and navigable waters.

Therefore the relation between the main behavior of mariners for collision avoidance and the navigational condition is discussed by applying the results of international collaborative research on human factors in ship handling and the contents of questionnaire. As a result, it can be concluded that the area of navigable waters and the volume of traffic ships around the own ship affect the mariner's behavior for collision avoidance to attain safe navigation.

2. Influence of Navigational Environment on Mariner's Behavior in Detection

The international collaborative research on human factors in ship handling was carried out and the mariner's behavior during the training using a full-mission ship handling simulator was measured by 8 institutes in 5 countries (Kobayashi H., 2005). And the situation of collision avoidance was selected because most of the collisions were caused by human behavior and the obtained data through the training was applied to analyze the standard behavior of mariners for collision avoidance.

In this section, the results of international collaborative research on human factors in ship handling are introduced to show the standard behavior of mariners in detection process on the relation between the detection distance to a target ship and navigational environment.

2.1 Condition of International Collaborative Research

IMO mentioned the importance of discussion on human factors in ship handling. However there have been few

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researches on human factors. Thus the international marine simulator forum (IMSF) carried out the international collaborative research on human factors to understand mariner's standard behavior in the situation of collision avoidance (Kobayashi H., 2005). During the training of ship handling simulator in each institute, the members of IMSF measured the important behavior of mariners in the situation of collision avoidance. The navigational condition of each scenarios is different depending on the objectives of the training in each institutes. Thus the results on mariner's behavior for various conditions are obtained. The analyzed items on mariner's behavior for collision avoidance in this study are as follows (Park et al., 2007a; Park et al., 2007b);

(i) The situation at the first detection of a target vessel
(ii) The situation at the first recognition of a target vessel considered as a danger
(iii) The situation at the start point of avoiding action for collision avoidance

2.2 Relation between Detection of a Target Ship and Navigational Condition

The safety degree of navigation is related with the combination between mariner's ship handling ability and navigational environment (Kobayashi H., 2006). In order to analyze the relation between mariner's behavior and navigational environment, the data when an own ship is a give way vessel for various conditions, which are obtained from the collaborative research, were applied. Especially, to detect the target ship in the process of collision avoidance is very important because it is related with subsequent works such as recognition and avoiding actions, and with the safety. The condition of navigational environment is mainly decided by navigable waters, ship traffic, rules of road, sea state, weather and so on. In this section, the influence of navigable waters and ship traffic conditions on the distance of target ships at the time of first detection when the visibility is fine is analyzed by using Pearson's Correlation Coefficient (Introductory Statistics, 2002).

Fig. 1 shows the relation between the initial position and the detection distance of target ships during collision avoidance situation, which has a correlation coefficient (r) of 0.7734. It is shown that there is a strong correlation between the initial position and the detection distance. Thus it can be considered that when the initial distance becomes wider, the detection distance of the target ship can be bigger. In other words, the initial distance can affect the distance of the target ship at the first detection point. On the other hand, this result means that the detection distance can be affected by the area of navigable waters when the relative distance at initial position is assumed as the area of navigable waters. The relation between the initial distance of collision situation and the distance of the target ship at the first detection point can be expressed by equation (1) as shown in Fig. 1.

$$D_T = 7.0467 \times Log_e(D_I) - 8.5081$$
$$r = 0.7734 \qquad (1)$$

where

D_T : Distance of a target ship at the first detection,
D_I : Initial distance,
r : Correlation coefficient

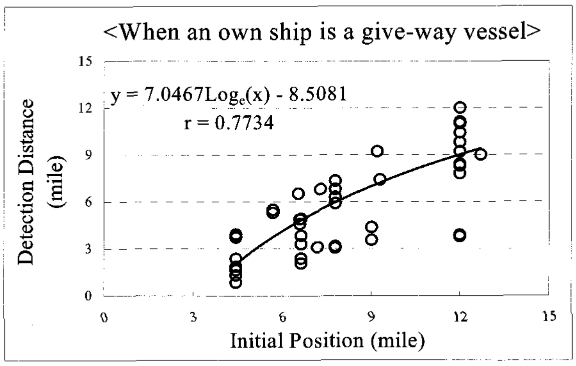

Fig. 1 Relation between detection points and initial position

Fig. 2 shows the relation between traffic density and the detection distance of target ships in the collision avoidance situation, which has a correlation coefficient (r) of 0.8044. It is shown that there is a strong correlation between the traffic density and the detection distance. In Fig. 2 and 3, the traffic density means the number of ships surrounding an own ship in the area of navigable waters, which can be calculated as follows.

$$DI_T = \frac{V_S}{A_I} = \frac{V_S}{3.14 \times D_I^2} \qquad (2)$$

where

DI_T: Traffic density, V_S: Volume of traffic ships,
D_I : Initial distance, A_I: Area of navigable waters

Thus it can be considered that the traffic density affects the distance of target ships at the first detection point. In other words, when the traffic density becomes higher, the detection distance can be smaller. That is, mariners can detect the target ship in collision situation later, as the volume of traffic ships in the navigable area becomes higher. The relation between the traffic density and the distance of a target ship at the first detection point can be expressed by equation (3) as shown in Fig. 2.

$$D_T = -1.7325 \times Log_e(D_{TS}) - 0.5185$$
$$r = 0.8044 \quad (3)$$

where

D_T : Distance of a target ship at the first detection,
D_{TS} : Traffic density,
r : Correlation coefficient

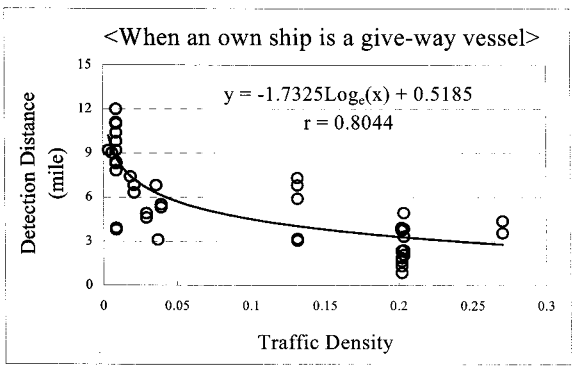

Fig. 2 Relation between detection points and traffic density

Fig. 3 shows the relation between traffic density, relative speed and the detection distance of target ships in the collision avoidance situation, which has a correlation coefficient (r) of 0.8238. It is shown that there is a strong correlation among the traffic density, the relative speed between the own and a target ship, and the detection distance. Thus it can be considered that when the traffic density becomes higher and the relative speed becomes faster, the detection distance can be smaller. In other words, the traffic density and the speed of the own ship and target ships can affect the detection distance of a target ship at the first detection point. That is, mariners can detect the target vessel in collision situation in a closer distance, as the volume of traffic ships in the navigable area becomes higher and the relative speed between the two ships becomes bigger. The relation between the traffic density, the relative speed between the two ships and the distance of the target ship at the first detection point can be expressed by equation (4) as shown in Fig. 3.

$$D_T = -1.4153 \times Log_e\left(\frac{D_{TS}}{V_R}\right) - 2.6131$$
$$r = 0.8238 \quad (4)$$

where

D_T : Distance of a target ship at the first detection,
D_{TS} : Traffic density, V_R: Relative speed,
r : Correlation coefficient

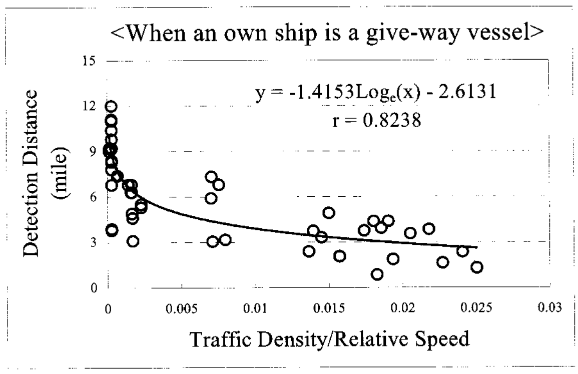

Fig. 3 Relation between detection points, traffic density and relative speed

As shown in Figs. 1~3, therefore, it can be concluded that the area of navigable waters, the traffic ships surrounding the own ship and the speed of ships have an influence on the mariner's behavior in ship handling for collision avoidance.

3. Influence of Navigational Environment on Mariner's Behavior in Recognition and Action

It is obtained that mariner's detection behavior is related with the recognition and avoiding actions, and the mariner's behavior is related with the safety in the situation of collision avoidance (Park et al., 2003). And furthermore, we considered the volume of traffic ship within the detection distance of the target ship from the own ship, which indicates the traffic density surrounding the own ship. In this section, the relation between the traffic density and the characteristics of mariner's behavior in the recognition of risk and the avoiding action for collision avoidance is discussed with the contents of questionnaire.

3.1 Influence of Traffic Density on Mariner's Behavior

(1) Contents of questionnaire

In order to find the characteristics of mariner's ship handling for each navigational condition and comprehend their knowhow to keep safe navigation, a questionnaire was carried out. The 91 mariners including captains, 1st officers, 2nd officers and 3rd officers completed a questionnaire form.

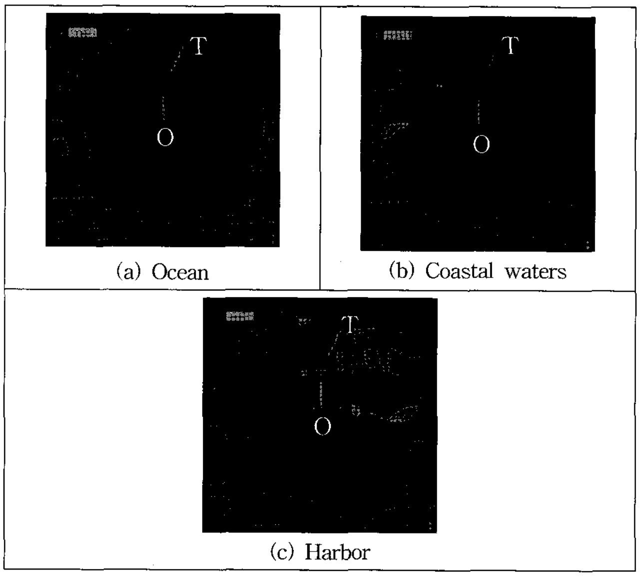

Fig. 4 The condition of navigational environment in the questionnaire

In the questionnaire, the situations of collision in each navigational condition are shown with the photos of radar screen in the questionnaire form. On the photos, an own ship starts from the origin of the radar screen and a target ship is indicated differently depending on situations. That is, an own ship is denoted by symbol 'O', and a target ship is denoted by symbol 'T'. In the screen, the own ship is a give-way vessel at the center and the target ship is a stand-on vessel toward the own ship according to the rules of CORLEG (Marine Traffic Laws, 1992). The detailed condition of the questionnaire is shown in Table 1. Fig. 4 shows the conditions of navigational environment where mariners encounter the target ship in the situation of collision avoidance in ocean, coastal waters and harbor respectively.

Table 1 The condition of questionnaire

Subject	91 mariners (captains, 1st officers, 2nd officers and 3rd officers)
Type of own ship	Container (speed 16kt, length 280m)
Type of target ship	Container (speed 16kt, length 280m)
Fairway condition	- Fine visibility - No aids to navigation - No other vessels
Navigable waters	- Ocean, coastal waters and harbor
Relation of collision	- Own ship is a give-way vessel - Target ship is a stand-on vessel
Items of question	- Distance to detect a target vessel - Time to recognize the risk of a target vessel - Time to start to take avoiding action

(2) Relation between traffic density and mariner's behavior in recognition and action process

The distance of target ships at the first detection point was applied to calculate the density of traffic existing between the own ship and target ships as shown in equation (5). And the relations between the mariner's recognition on collision risk, avoiding actions for collision avoidance and the traffic density calculated by the number of traffic ships existing within the area between the own ship and the target ship were analyzed.

Fig. 5 shows the relation between the recognition timing on collision risk and traffic density in each navigational condition, which are given from the results of the international collaborative research and the questionnaire mentioned above. The symbol (○) denotes the average value of the experimental results of IMSF, whereas the symbols (□), (▲) and (x) indicate the average values of harbor, coastal waters and ocean in the questionnaire respectively. In Fig. 5 and Fig. 6, the traffic density means the number of traffic ships existing within the area of the detection distance of the target ship, which can be calculated as follows.

$$DD_T = \frac{V_S}{A_d} = \frac{V_S}{3.14 \times D_d^2} \qquad (5)$$

where

DD_T : Traffic density, V_S: Volume of traffic ships,
D_d : Detection distance, A_d: Area of detection distance

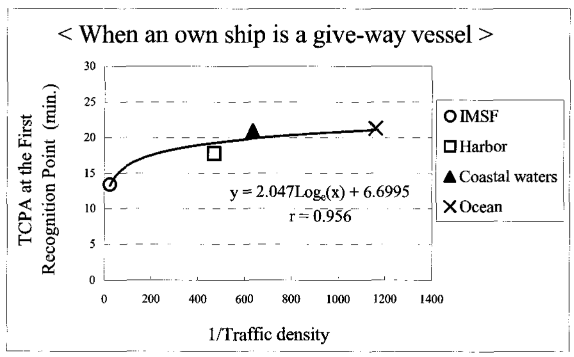

Fig. 5 Relation between recognition timing and traffic density

In Fig. 5, the correlation between the recognition timing on collision risk and traffic density is very high (0.956). It means that the recognition timing of mariners has a strong relation on the number of ships around and the area of navigable waters. That is, when the traffic volume increases and the area of navigable waters becomes narrower, mariners can generally recognize the risk of collision to the target ship later.

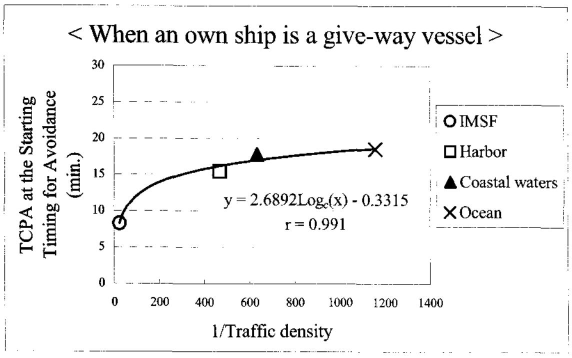

Fig. 6 Relation between start timing of avoiding action and traffic density

Fig. 6 shows the relation between the start timing of avoiding action and traffic density for each navigational condition, which are given in the international collaborative research and questionnaire mentioned above. The correlation between the recognition timing on collision risk and traffic density is very high (0.991). It means that the start timing of avoiding action of mariners has a strong relation on the number of ships around and the area of navigable waters. That is, when the traffic volume increases and the area of navigable waters becomes narrower, mariners can generally take an avoiding action later. Consequently, it can be considered that the traffic volume and the detection distance of the target ship have a strong influence on the mariner's behavior such as recognition timing of collision risk and start timing of an avoiding action. That is, when the traffic volume surrounding the own ship increases and the detection distance of a target ship becomes narrower, they can generally recognize the risk of collision later and take an avoiding action later.

As shown in Fig. 5 and Fig. 6, therefore, it is confirmed that the navigational condition such as the traffic volume and navigable waters is very important factor to affect the safety as well as mariner's behavior when we consider mariner's behavior is related with the safety (Park et al., 2003).

4. Conclusion

The influence of navigational environment on the standard behavior of mariner in ship handling for collision avoidance was analyzed based on the results of the international collaborative research and the questionnaire in this paper.

As a result, it is obtained that the area of navigable waters and the volume of traffic ship affect the detection distance of a target ship from the results for the influence of navigational environment on the mariner's detection behavior in section 2. That is, when the area of navigable waters becomes narrower and the volume of traffic ship in the navigable area becomes larger, mariners can detect the target ship in a closer distance. In addition to that, the speed of traffic ship affects the distance of target ships to the own ship at the first detection point. In other words, when the traffic density and the relative speed between the ships becomes higher, mariners can detect the target vessel in collision situation lately.

And moreover, it is confirmed that the detection distance of a target ship and the traffic volume surrounding the own ship affect mariner's recognition timing of collision risk and start timing of avoiding actions for collision avoidance. Consequently, it can be concluded that the traffic volume and the area of navigable waters in navigational environment are important factors for safety in the situation of collision avoidance when mariners are underway, crossing or head on.

Therefore we can expect that the obtained results will be a good guideline for developing the necessary condition of navigational environment based on human factors and the enhancement of safety of navigation in maritime field.

References

[1] Kobayashi H. (2002), "The Condition on Occurrence of Maritime Accidents and Bridge Team Management", Proceedings of 2nd JAPAN-KOREA Workshop on Marine Simulator Research, pp. 1-8.

[2] Kobayashi H. (2005), "Report of International Collaborative Research on Human Factor in Ship Handling", International Marine Simulator Forum, Memorial University of Newfoundland, Canada.

[3] Kobayashi H. (2006), "Mariner's Function for Safe Navigation", Proceeding of 6th Asian Conference on Marine Simulator and Simulation Research, pp. 1-12.

[4] Korean Maritime Safety Tribunal (1995~2004), "The statistics of marine accidents"

[5] Lee O. Y., Grewal D., and Cahoon S. (2007), "A Study on the Practical Means to Prevent Collision at Sea", International Journal of Korean Navigation and Port Research, Vol. 31, No. 4, pp. 295-307.

[6] Mann and Prem S. (2002), "Introductory Statistics", Wiley.

[7] Park, J. S., Kobayashi H., and Yea, B. D. (2003), "The

Relation between Human Behavior and Safety in the Collision Avoidance Situation", International Journal of Korean Navigation and Port Research, Vol. 27, No. 6, pp. 611-618.

[8] Park, J. S., Kobayashi, H., and Yea, B. D. (2007a), "A study on Mariners' Standard Behavior (1)", International Journal of Korean Navigation and Port Research, Vol. 31, No. 4, pp. 281-287.

[9] Park, J. S., Kobayashi, H., and Yea, B. D. (2007b), "A study on Mariners' Standard Behavior (2)", International Journal of Korean Navigation and Port Research, Vol. 31, No. 4, pp. 309-315.

[10] Park, Y. S. (1992), "Marine Traffic Laws", Hyung-seul publishing co.

[11] Yahei, H., Tsutomu, M., and Kiyoshi, H. (1981), "Maritime Traffic Engineering"

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