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

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충돌 상황에서 운항자의 조종 특성과 안전성 사이의 관계

박정선

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요약문

해상 사고의 대부분이 인적 과실에서 비롯하고 있으며 특히, 항해 중 다른 선박과의 충돌 관계에 있어 사고 가능성은 항해 환경과 운항자의 선박 조종 능력에 따라 변화한다고 볼수 있다. 그러므로 선박간의 충돌 관계에 있어 인간이라는 요소는, 매우 중요한 역할을 하고 있고 이러한 운항자에 의한 수많은 사고 발생의 원인을 줄이고 안전을 도모하기 위해서 선행되어야 할 연구 대상이 된다.

그러나 인간이라는 존재는 상황에 따라 다양하게 변화하고 그 변화 역시 예측하기 힘든 불확실한 성질을 가지므로, 인간의 어떠한 요소들이 사고를 발생시키고 또한 그 가능성을 높게 하는지 구체적으로 밝히는 데에는 여러 가지 어려움이 있었다. 이와 같은 연구의 어려움으로 인하여 지금까지는 해상 사고와 관련된 인적 요소에 대하여 통계자료의 분석과 정성적인 연구만 수행되어 왔으나, 이 논문에서는 지금까지의 통계 자료와 정성적인 연구에서 나아가 인간의 행동과 안전성 사이의 관계에 대하여 공학적인 관점에서 접근함으로써 운항자들의 일반적인 행동 양상이 선박의 안전 운항에 미치는 영향을 정량적으로 나타내고자 하였다. 즉, 이러한 인간의 행위를 정량적으로 나타냄으로써 운항자들의 일반적인 조종 특성에 따른 충돌 위험 가능성을 구체적으로 밝히고자 하였다.

이 연구에서는 인간의 행위를 중심으로 안전성과의 관계를 분석하고 검토하기 위해서, 선박 조종 시뮬레이터를 이용한 BTM (Bridge Team Management) 훈련을 실시하였으며 또한 선장, 1 항사, 2 항사, 3 항사를 포함한 91 명의 운항자들을 대상으로 설문조사를 행하였다.

BTM 훈련에 있어서는 충돌 관계에서 상대 선박과의 위험한 상황을 인식하는 시간 및 피항을 취하는 시간 등과 같은 운항자들의 조종 특성을 조사하고, 이러한 요소들을 바탕으로 위험도의 측정 기준의 하나로 여겨지고 있는 최소 근접 거리(CPA)와의 상관관계를 구하였다. 그리고 운항자의 조종 능력과 충돌 가능성과의 관계를 그래프로 나타내고 인간의 행위에 따른 사고 발생 가능성의 예측 및 안전을 위한 운항 지침의 방향을 제시하였다.

또한 BTM 훈련과 더불어 운항자들을 대상으로 실시한 설문 조사를 바탕으로 항해 환경에 따른 조종 특성의 변화를 살펴보고 각각의 내용을 비교 분석하였다. 그리고 조종 특성의 변화의 주요 원인으로서 항행 수역의 선박 교통량에 의한 밀집도를 제시하고 그 관련성을 살펴보았다.

이와 같이 BTM 훈련과 설문조사의 내용을 분석한 결과로서, 항해 환경에 따른 운항자들의 조종 특성의 변화와 그 조종 특성의 변화에 따른 충돌 가능성의 변화를 나타내었다. 즉, 수역의 넓이, 복잡성, 상대 선박과의 피항 관계 등과 같은 항해 환경의 변화에 따라 운항자의 조종 특성이 변화하고 있으며 그 변화에 따라 안전성 또한 변하는 것이 밝혀졌다.

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1. Introduction

2. Relations between navigational environment and ship-handling

3. Relations between ship-handling ability and risk of collision

4. Variation of ship-handling characteristics

Chapter 1

Introduction

1.1 Purpose and background

It is widely said that there are many marine casualties are caused by human errors such as improper look-out, improper action, misunderstanding, etc. That is, we can say that the main cause of collision accident is human behavior and it has strong influence on the safety of navigation.

In order to reduce the occurrence probability of accidents resulted from human error and to maintain the safety, it is necessary to clarify relations between human error and the risk of collision. Furthermore, we require studies for the efficient balance of roles between human characteristics and automatic system, for the development of onboard bridge system to support operators, for the reference of BTM (Bridge Team Management) training which is conducted worldwide for crew members, etc.

However there have not been sufficient researches for human errors with regard to the collision and, especially, the researches quantitatively clarifying relations between human behavior and safety in the collision avoidance situation.

In this study, therefore, we aim to clarify relations between mariners' behavior and the risk of collision under the given navigational environment.

We performed a questionnaire for mariners and BTM training using a ship-handling simulator. The relations between the condition of maneuvering ability and that of navigational environment focused on human behavior as a main factor of marine accidents is examined and clarified by analyzing the results from BTM training and questionnaire.

1.2 Composition of this thesis

This thesis consists of five chapters. After this introductory Chapter 1, the contents and conditions of the questionnaire are shown in Chapter 2.

In Chapter 3, the contents of BTM training performed by twenty teams are displayed and the probability of collision depending on ship-handling characteristics is discussed using correlation coefficient (r).

In Chapter 4, the characteristics of ship-handling affected by navigational environment are shown based on comparison between the results of the questionnaire and those of the BTM training.

The final chapter summarizes and discusses the obtained results from the preceding chapters.

Chapter 2

Relations between Navigational Environment and Ship-Handling

2.1 Introduction

We performed a questionnaire, which was completed by 91 mariners (including captains, chief officers, 2nd officers and 3rd officers) in order to investigate the characteristics of mariners for ship-handling in various navigational waters.

In this chapter, we displayed and explained the variation of ship-handling characteristics with results of the questionnaire.

2.1.1 Conditions of the questionnaire

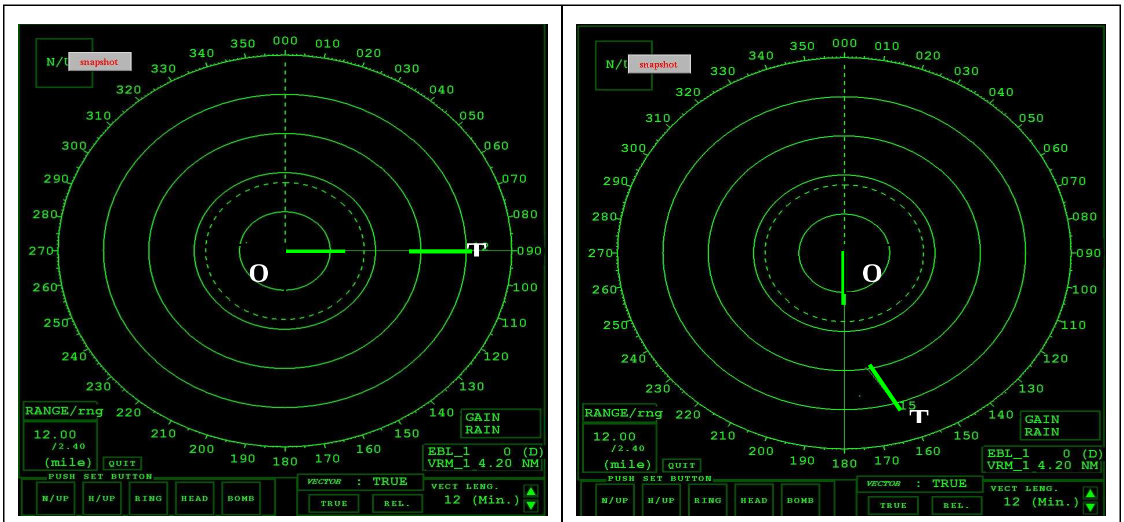
Subject	Mariners (Captains, Chief officers, 2nd officers and 3rd officers)
Type of own ship	Container (Speed 16kt, Length 280m)
Type of target ship	Container (Speed 16kt, Length 280m)
Navigational waters	Ocean, Coast and Harbor
Situation of collision	Crossing situation when an own ship is a stand-on vessel
	Crossing situation when an own ship is a give-way vessel
	Head-on situation
	Overtaking situation

Fairway condition	Fine visibility, no aids to navigation, no other vessels
Items of question	Distance to recognize or report target vessel
	Distance to start an avoiding action
	Passing distance

The four kinds of situations of collision are shown with the photos of radar screen in the questionnaire form. On the photos, an own ship is started 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’.

1) The collision situation in ocean

Fig. 2.1 shows the four kinds of encountering situations between two vessels in ocean.



(a) Head-on situation

(b) Crossing situation

(An own ship is a stand-on vessel)

(c) Overtaking situation

(d) Crossing situation

(An own ship is a give-way vessel)

Fig. 2.1 Collision avoidance situation in ocean

2) The collision situation in coastal waters

Fig. 2.2 shows the four kinds of encountering situations between two vessels in coastal waters.

(a) Head-on situation

(b) Crossing situation
(An own ship is a stand-on vessel)

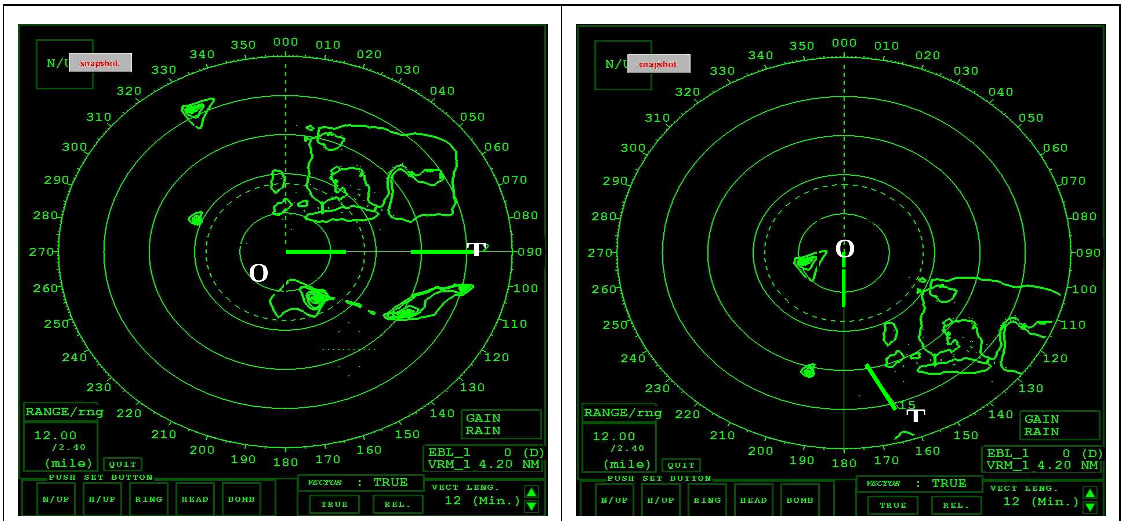
(c) Overtaking situation

(d) Crossing situation
(An own ship is a give-way vessel)

Fig. 2.2 Collision avoidance situation in coastal waters

3) The collision situation in harbor

Fig. 2.3 shows the four kinds of encountering situations between two vessels in harbor.



RANGE/rng 12.00 /2.40 (mile)
EBL_1 0 (D)
VRM_1 4.20 NM
VECTOR : TRUE
VECT LENG. 12 (Min.)

(a) Head-on situation

(b) Crossing situation
(An own ship is a stand-on vessel)

RANGE/rng 12.00 /2.40 (mile)
EBL_1 0 (D)
VRM_1 4.20 NM
VECTOR : TRUE
VECT LENG. 12 (Min.)

(c) Overtaking situation

(d) Crossing situation
(An own ship is a give-way vessel)

Fig. 2.3 Collision avoidance situation in harbor

2.2 Variation of ship-handling characteristics caused by navigational environment

The followings show the distributions of ***Tr*** (Time from recognizing target ship to estimated collision), ***Ta*** (Time from starting an avoiding action to estimated collision) and ***Pd*** (Passing distance between two vessels) for each navigational waters based on the obtained contents from the questionnaire.

The distances to recognize the target vessel under the given navigational waters were divided by the present speed (16 kts) and the values are shown with time unit. Thus ***Tr*** can be calculated by the speed.

And the distances to start an avoiding action under the given the navigational waters were divided by the present speed (16 kts) and the values are shown with time unit. Thus ***Ta*** can be also calculated by the speed.

That is, ***Tr*** and ***Ta*** were calculated by the method mentioned above. They are displayed in horizontal axis every two minutes with ***Pd*** in the following figures. The values of ***Tr***, ***Ta*** and ***Pd*** for 91 persons are converted into percentage unit and the percentage values (%) for them are indicated in vertical axis.

2.2.1 Crossing situation when an own ship is a stand-on vessel

The distributions of ***Tr***, ***Ta*** and ***Pd*** for each navigational waters are shown in this section. The own ship is a stand-on vessel and the target ship is a give-way vessel in this case.

1) The distribution of ***Tr*** values for each navigational waters

Fig. 2.4 shows the distributions of ***Tr*** values according to each navigational waters.

The average values of ***Tr*** for each navigational waters are 36, 28.3 and 22.7 as shown in Fig. 2.4 (a)-(c) respectively. The peak points of these distributions, that is, the values that most mariners take, are different from ocean to harbor.

This indicates that the widest ocean has the largest value and then coast, harbor in that order.

2) The distribution of ***Ta*** values for each navigational waters

Fig. 2.5 shows the distributions of ***Ta*** values according to each navigational waters.

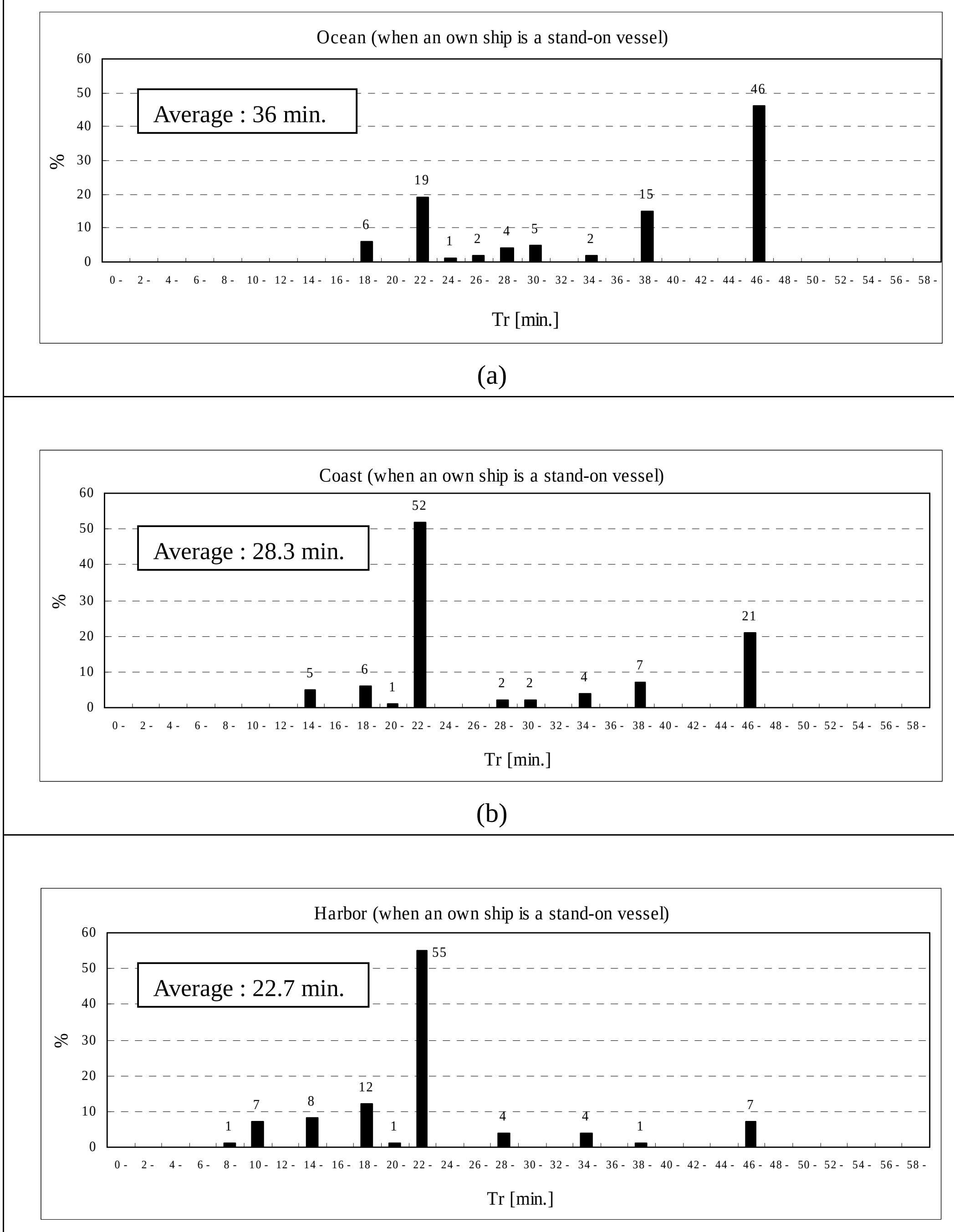
The average values of ***Ta*** for each navigational waters are 14.8, 14.4 and 13.1 as shown in Fig. 2.5 (a)-(c) respectively. The peak points of these distributions, that is, the values that most mariners take, are different from ocean to harbor.

This indicates that the widest ocean has the largest value and then coast, harbor in that order.

3) The distribution of ***Pd*** values for each navigational waters

Fig. 2.6 shows the distributions of ***Pd*** values according to each navigational waters. The average values of ***Pd*** for each navigational waters are 1.5, 1.3 and 0.7 as shown in Fig. 2.6 (a)-(c) respectively. The peak points of these distributions, that is, the values that most mariners take, are different from ocean to harbor.

This indicates that the widest ocean has the largest value and then coast, harbor in that order.

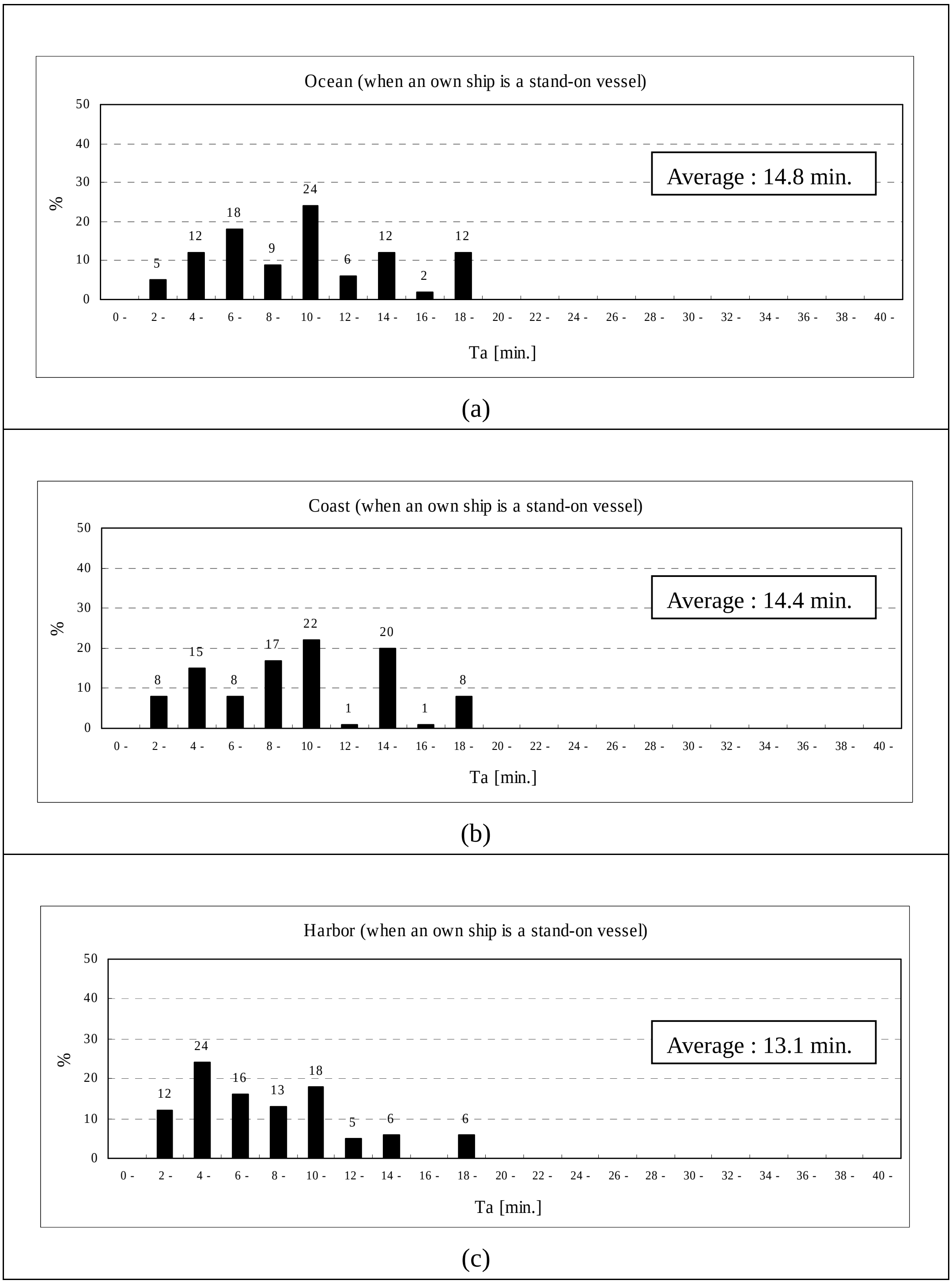


(a)

(b)

(c)

Fig. 2.4 Distribution of ***Tr*** values for each navigational waters when an own ship is a stand-on vessel in crossing situation

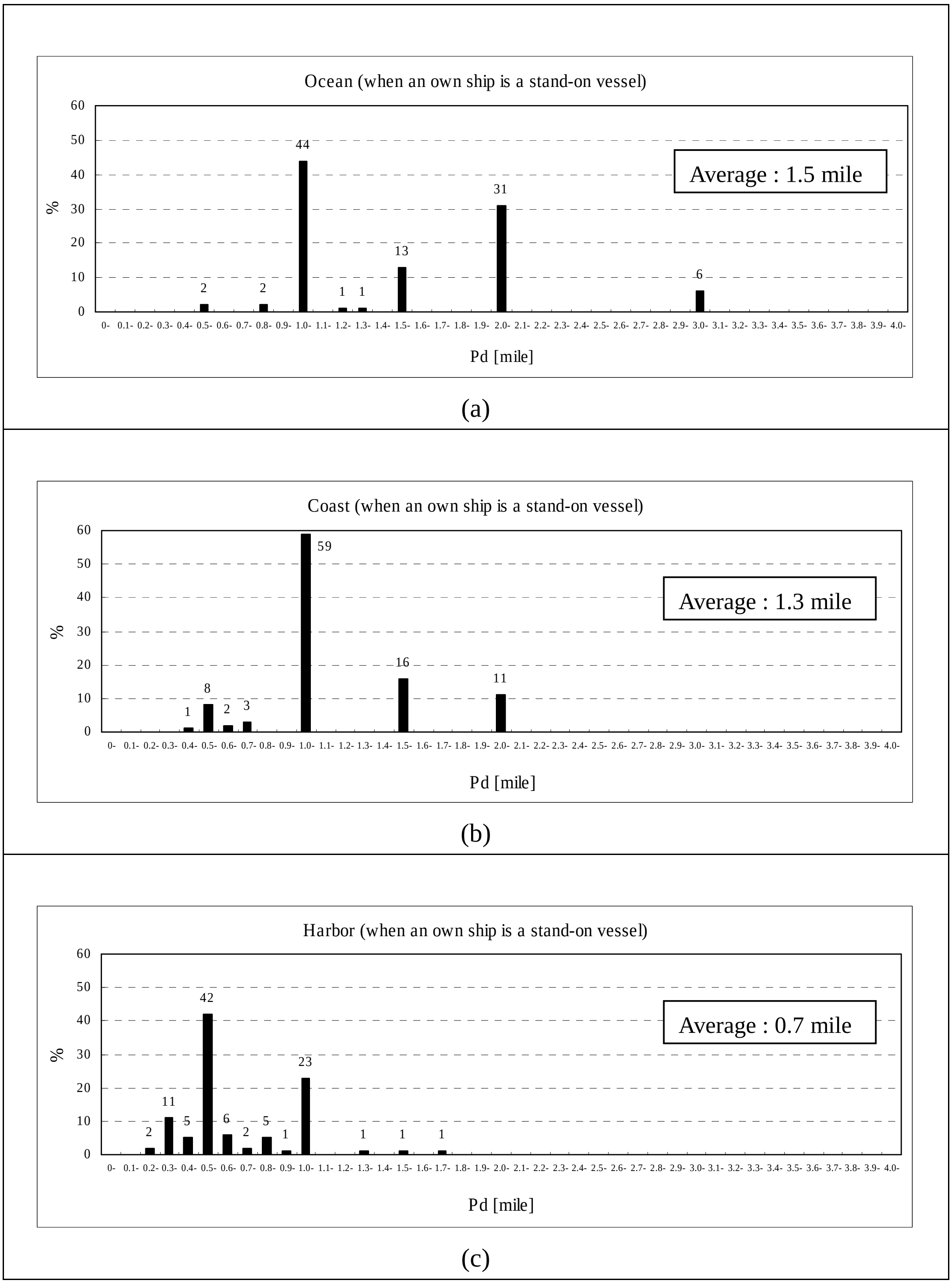


(a)

(b)

(c)

Fig. 2.5 Distribution of ***Ta*** values for each navigational waters when an own ship is a stand-on vessel in crossing situation



(a)

(b)

(c)

Fig. 2.6 Distribution of ***Pd*** values for each navigational waters when an own ship is a stand-on vessel in cossing situation

2.2.2 Crossing situation when an own ship is a give-way vessel

The distributions of ***Tr***, ***Ta*** and ***Pd*** for each navigational waters are shown in this section. The own ship is a give-way vessel and the target ship is a stand-on vessel in this case.

1) The distribution of ***Tr*** values for each navigational waters

Fig. 2.7 shows the distributions of ***Tr*** values according to each navigational waters.

The average values of ***Tr*** for each navigational waters are 36, 24.9 and 23.1 as shown in Fig. 2.7 (a)-(c) respectively. The peak points of these distributions, that is, the values that most mariners take, are different from ocean to harbor.

This indicates that the widest ocean has the largest value and then coast, harbor in that order.

2) The distribution of ***Ta*** values for each navigational waters

Fig. 2.8 shows the distributions of ***Ta*** values according to each navigational waters.

The average values of ***Tr*** for each navigational waters are 17.3, 16.3 and 13.5 as shown in Fig. 2.8 (a)-(c) respectively. The peak points of these distributions, that is, the values that most mariners take, are different from ocean to harbor. This indicates that the widest ocean has the largest value and then coast, harbor in that order.

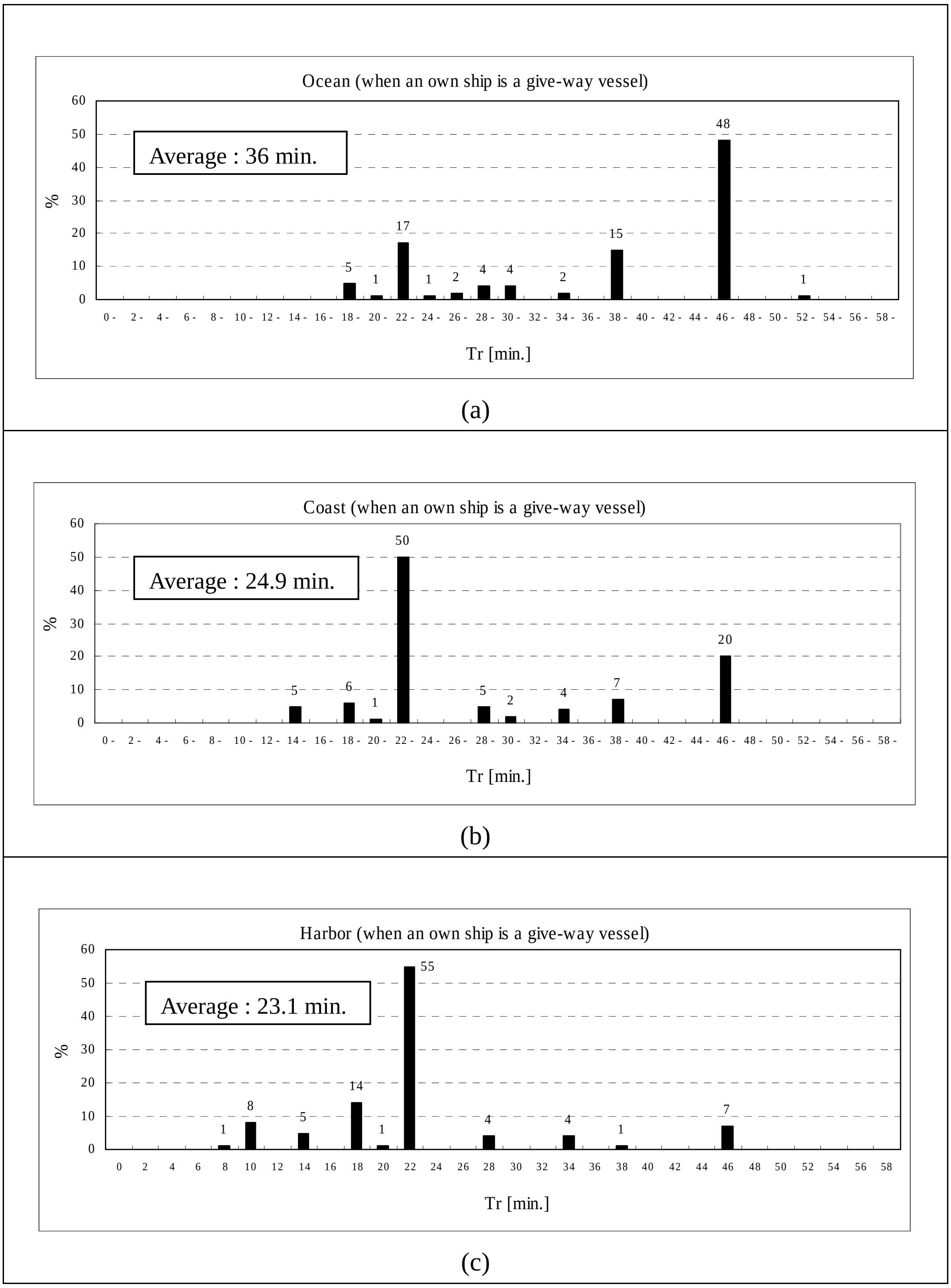
However the average values of ***Ta*** in Fig. 2.8 (a)-(c) are larger than those in Fig. 2.5 (a)-(c). It means that most mariners have a tendency to start an avoiding action earlier when an own ship is a give-way vessel than a stand-on vessel while the average values of the ***Tr*** shown in Fig. 2.4 and Fig. 2.7 are similar to each other.

3) The distribution of ***Pd*** values for each navigational waters

Fig. 2.9 shows the distributions of ***Pd*** values according to each navigational waters.

The average values of the ***Pd*** for each navigational waters are 1.5, 1.3 and 0.7 as shown in Fig. 2.9 (a)-(c) respectively. The peak points of these distributions, that is, the values that most mariners take, are different from ocean to harbor.

This indicates that the widest ocean has the largest value and then coast, harbor in that order.

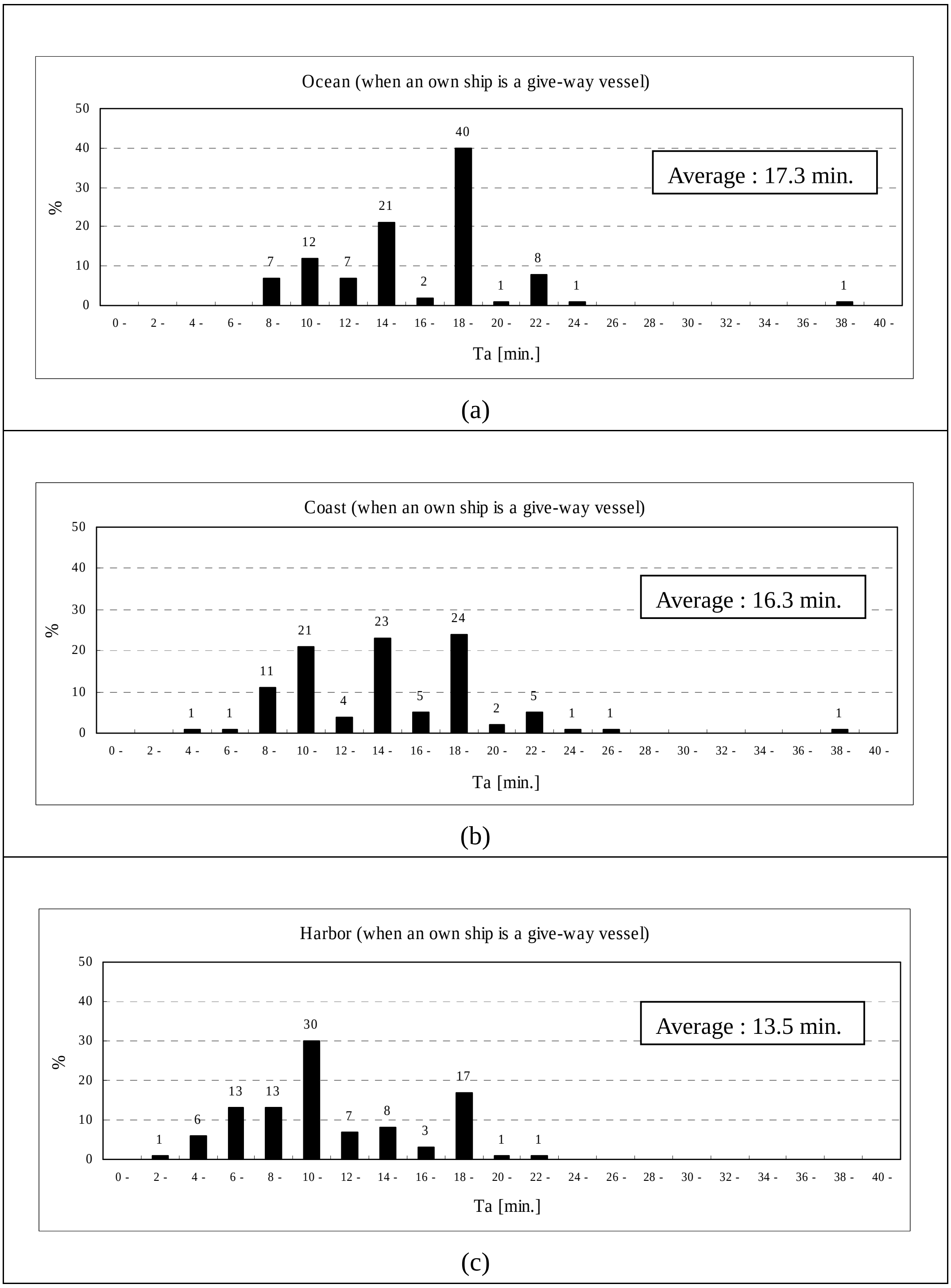


(a)

(b)

(c)

Fig. 2.7 Distribution of ***Tr*** values for each navigational waters when an own ship is a give-way vessel in crossing situation



(a)

(b)

(c)

Fig. 2.8 Distribution of ***Ta*** values for each navigational waters when an own ship is a give-way vessel in crossing situation

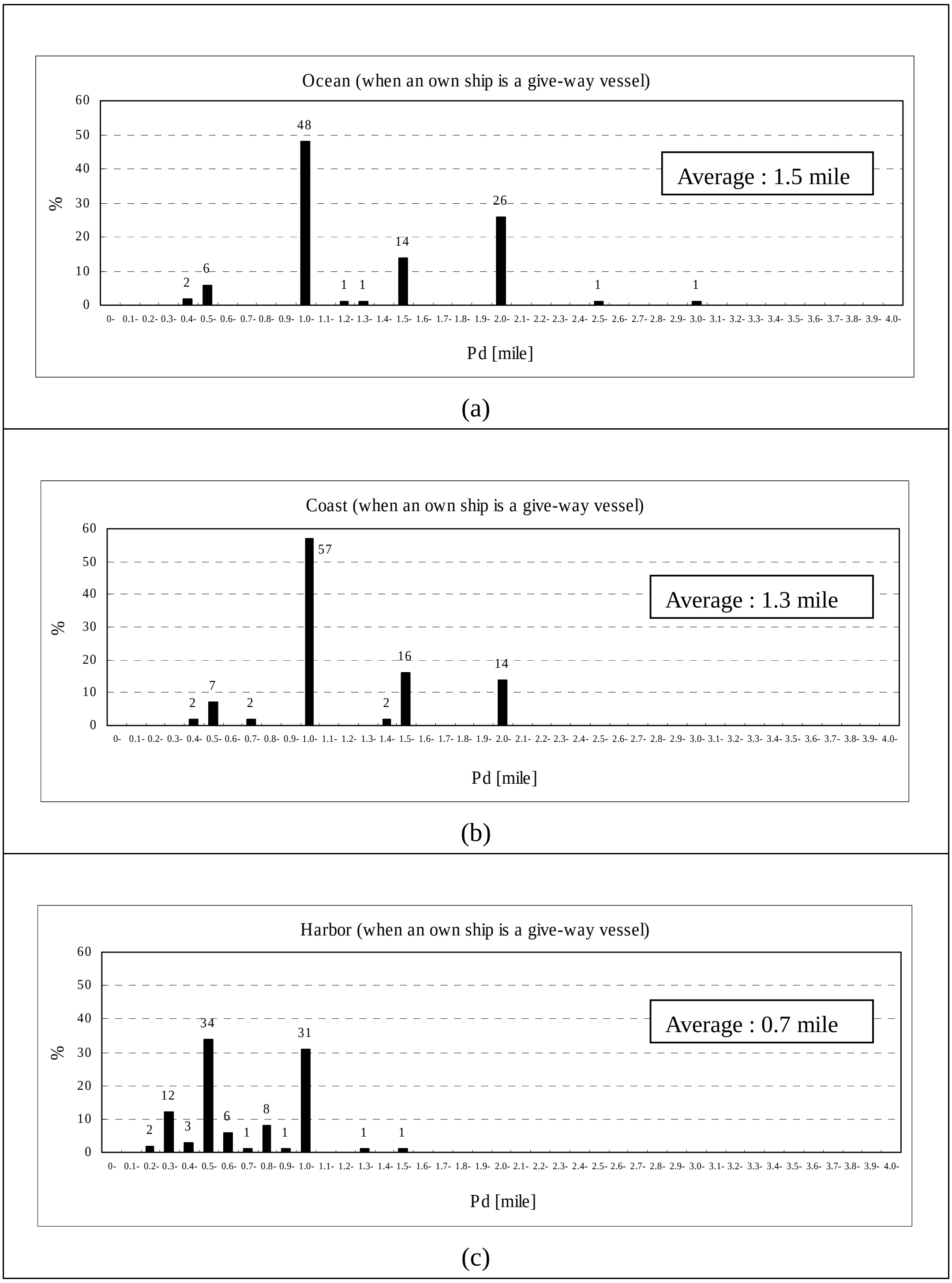


Fig. 2.9 Distribution of ***Pd*** values for each navigational waters when an own ship is a give-way vessel in crossing situation

2.2.3 Head-on situation

The distributions of ***Tr***, ***Ta*** and ***Pd*** for head-on situation between two vessels in each navigational waters are shown in this section.

1) The distribution of ***Tr*** values for each navigational waters

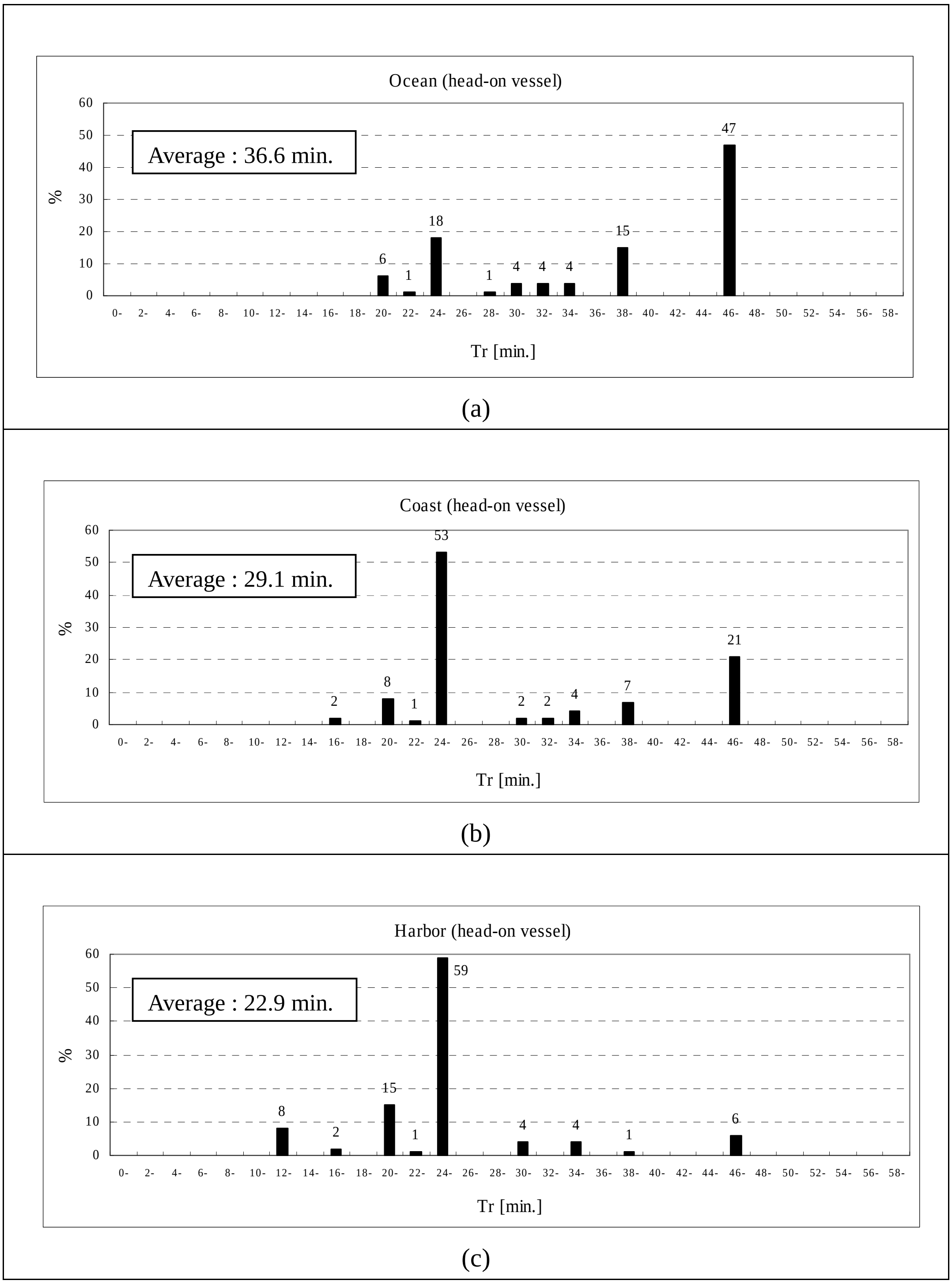
Fig. 2.10 shows the distributions of ***Tr*** values according to each navigational waters. The average values of ***Tr*** for each navigational waters are 36.6, 29.1 and 22.9 respectively. The peak points of these distributions, that is, the values that most mariners take, are different from ocean to harbor. This indicates that the widest ocean has the largest value and then coast, harbor in that order.

2) The distribution of ***Ta*** values for each navigational waters

Fig. 2.11 shows the distributions of ***Ta*** values according to each navigational waters. The average values of ***Ta*** for each navigational waters are 18.4, 16.3 and 13.9 respectively. The peak points of these distributions, that is, the values that most mariners take, are different from ocean to harbor. This indicates that the widest ocean has the largest value and then coast, harbor in that order.

3) The distribution of ***Pd*** values for each navigational waters

Fig. 2.12 shows the distributions of ***Pd*** values according to each navigational waters. The average values of ***Pd*** for each navigational waters are 1.4, 1.1 and 0.9 respectively. The peak points of these distributions, that is, the values that most mariners take, are different from ocean to harbor. This indicates that the widest ocean has the largest value and then coast, harbor in that order.

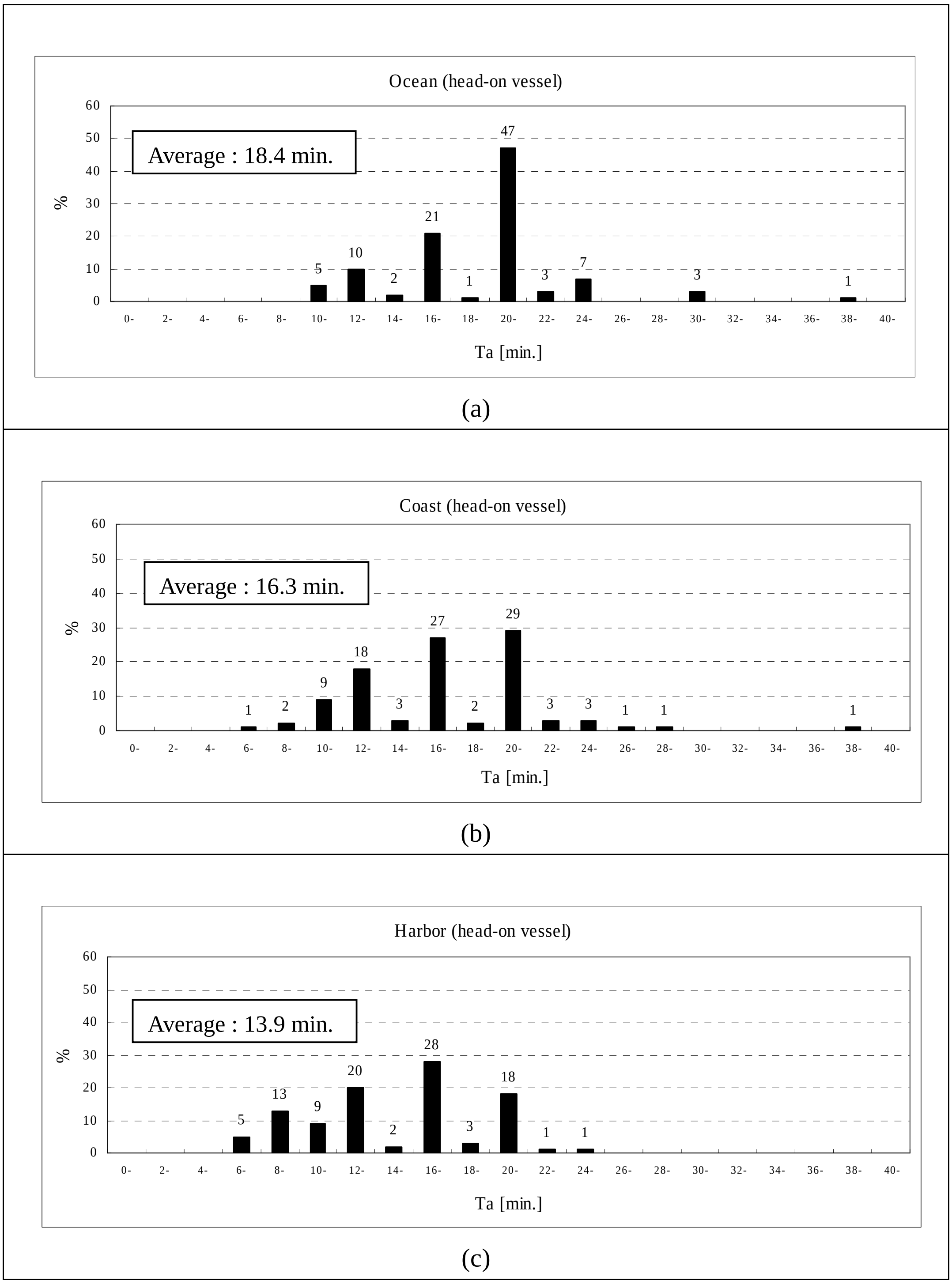


(a)

(b)

(c)

Fig. 2.10 Distribution of ***Tr*** values for each navigational waters when two vessels meet on reciprocal courses

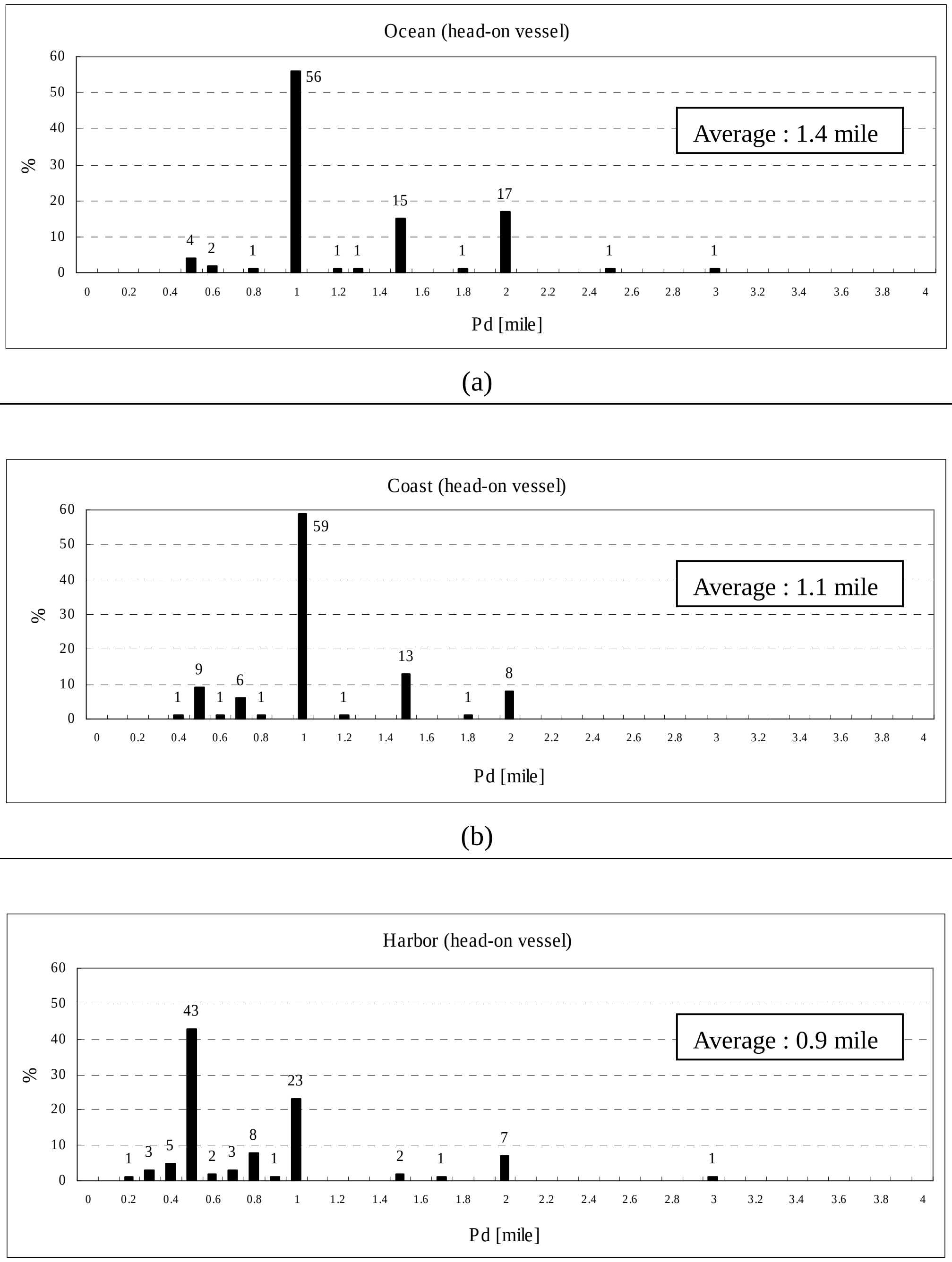


(a)

(b)

(c)

Fig. 2.11 Distribution of ***Ta*** values for each navigational waters when two vessels meet on reciprocal courses



(a)

(b)

(c)

Fig. 2.12 Distribution of ***Pd*** values for each navigational waters when two vessels meet on reciprocal courses

2.2.3 Overtaking situation

The distributions of ***Tr***, ***Ta*** and ***Pd*** for each navigational waters when the own ship overtakes the target vessel are shown in this section.

1) The distribution of ***Tr*** values for each navigational waters

Fig. 2.13 shows the distributions of ***Tr*** values according to each navigational waters.

The average values of ***Tr*** for each navigational waters are 35.6, 27.6 and 21.6 as shown in Fig. 2.13 (a)-(c) respectively. The peak points of these distributions, that is, the values that most mariners take, are different from ocean to harbor.

This indicates that the widest ocean has the largest value and then coast, harbor in that order.

2) The distribution of ***Ta*** values for each navigational waters

Fig. 2.14 shows the distributions of ***Ta*** values according to each navigational waters.

The average values of ***Ta*** for each navigational waters are 13.5, 8.1 and 7.9 as shown in Fig. 2.14 (a)-(c) respectively. The peak points of these distributions, that is, the values that most mariners take, are different from ocean to harbor. This indicates that the widest ocean has the largest value and then coast, harbor in that order.

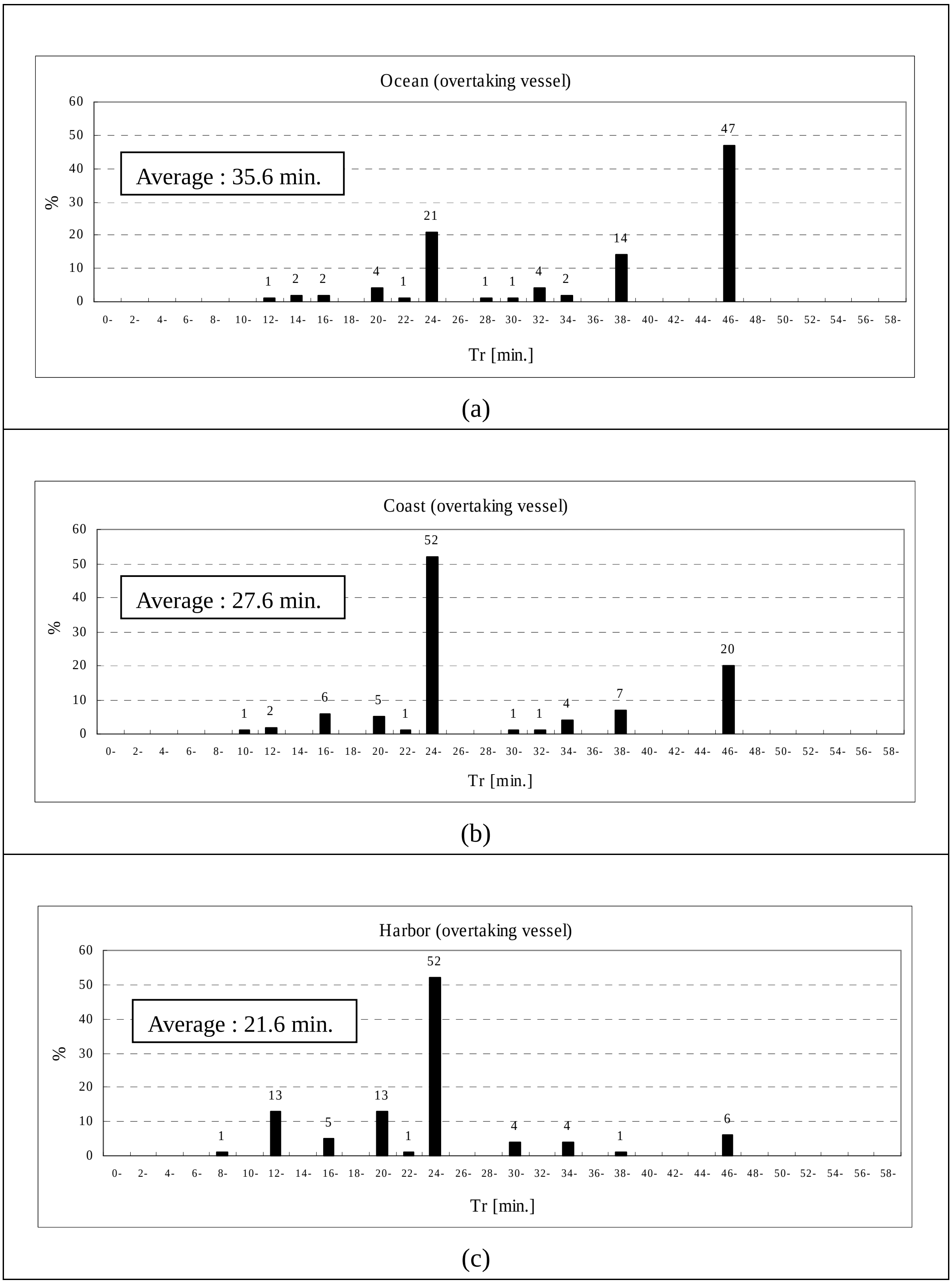
However these ***Ta*** values are smaller than those in the other situations. it means that mariners usually tend to take an avoiding action more slowly than other situations because there is more time allowance due to small relative speed between two vessels.

3) The distribution of ***Pd*** values for each navigational waters

Fig. 2.15 shows the distributions of ***Pd*** values according to each navigational waters.

The average values of the ***Pd*** for each navigational waters are 1.35, 1.2 and 0.7 as shown in Fig. 2.15 (a)-(c) respectively. The peak points of these distributions, that is, the values that most mariners take, are different from ocean to harbor.

This indicates that the widest ocean has the largest value and then coast, harbor in that order.



(a)

(b)

(c)

Fig. 2.13 The distribution of ***Tr*** values for each navigational waters when an own ship overtakes the target vessel

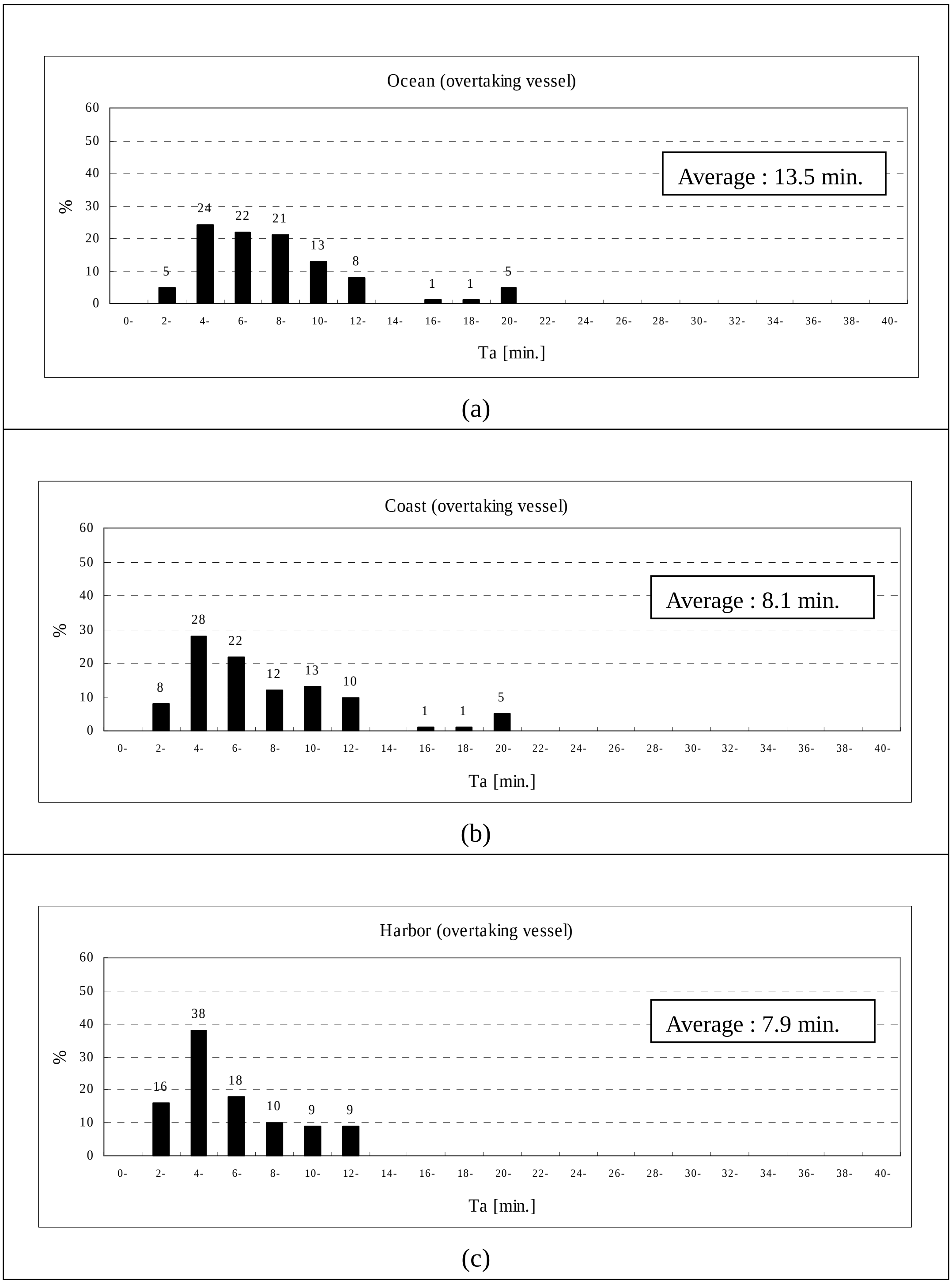
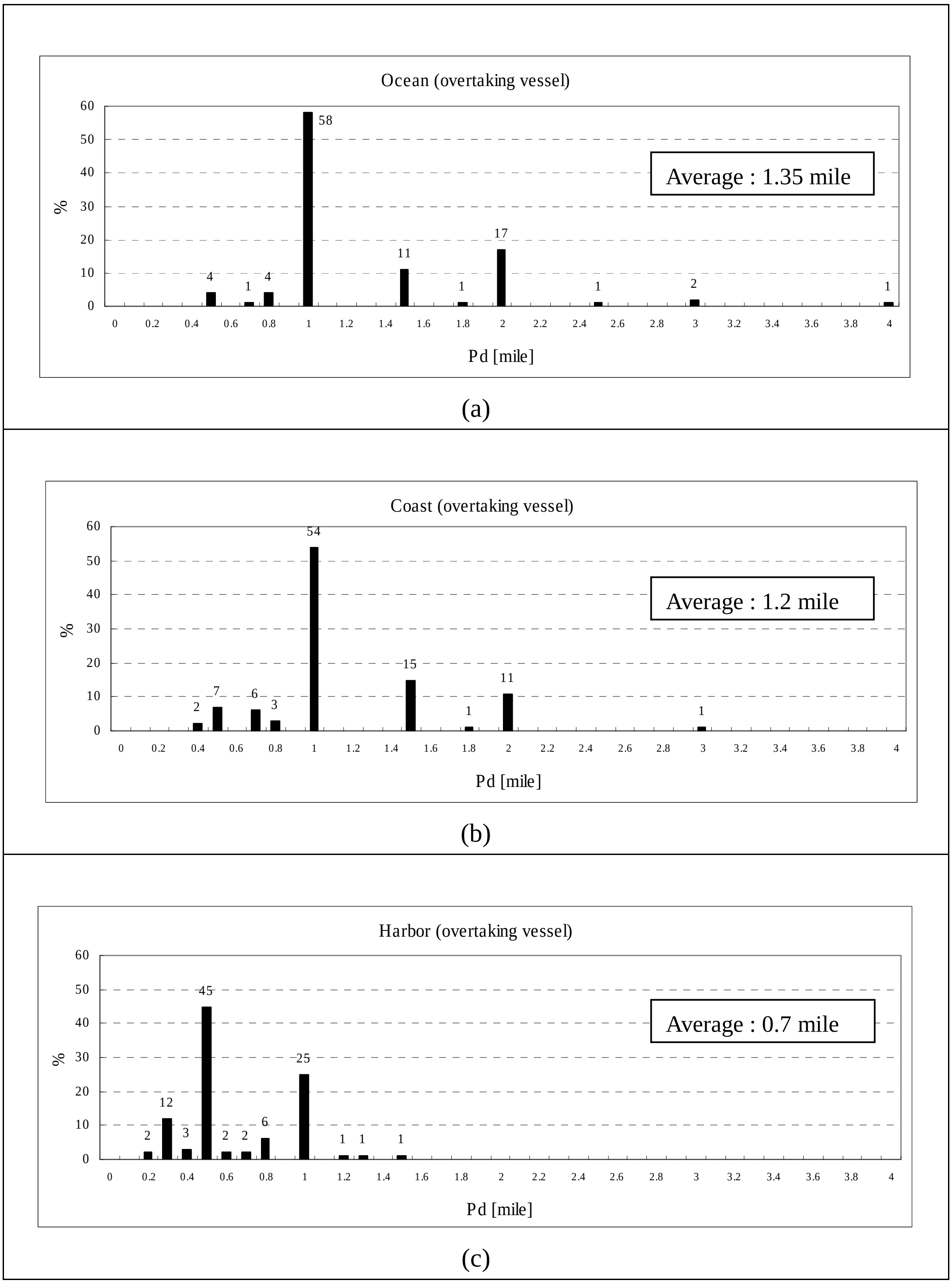


Fig. 2.14 Distribution of ***Ta*** values for each navigational waters when an own ship overtakes the target vessel



(a)

(b)

(c)

Fig. 2.15 Distribution of ***Pd*** values for each navigational waters when an own ship overtakes the target vessel

2.3 Summary and discussion

The obtained results from the questionnaire are summarized as follows;

In case of the distributions of ***Tr*** for the four situations of collision in each navigational waters, the obtained results are appeared variously.

Considering the shape of the distributions, the peak points of the envelopes are indicated differently according to the area of navigational waters under the same condition. Most data of distributions in ocean are generally concentrated on high position in the horizontal axis, which denotes that ***Tr*** or ***Ta*** or ***Pd*** have larger values comparatively than other navigational waters. But those in harbor are extended to smaller scope in the horizontal axis.

The peak points of the distributions for ***Ta*** are also shown variously depending on navigable waters. That is, as the area of navigational waters enlarges, the peak points are getting moved to the position where the value is larger on the horizontal axis.

Moreover, the average values of ***Ta*** are shown variously under the given situations. In the crossing situation, there is a tendency for mariners to take an avoiding action earlier than a stand-on vessel when an own ship is a give-way vessel because all mariners would follow COLREG (Collision Regulations). In the overtaking situation, the majority of mariners tend to take an avoiding action more slowly than other situations because there is more time allowance due to small relative speed between two vessels.

In case of the distributions for ***Pd***, the envelopes show that the breadth and the peak points move to larger extent as the area of the navigational waters increases.

It is natural that it should be shown that the mean values of ***Tr***, ***Ta*** and ***Pd*** in the ocean are generally largest and then coastal waters, harbor in that order because they depend on the area of navigational waters where they are operating.

Thus we can consider that as navigable waters enlarges, the average value of horizontal axis, which denotes ***Tr*** or ***Ta*** or ***Pd*** as mentioned above, becomes larger and the breadth of envelope becomes wider. And the ***Tr***, the ***Ta*** and the ***Pd*** also could be changed by own ship's status. It means that such mariners' behavior as ship-handling characteristics is related with the area of navigational waters where they are operating the vessel and own ship's status in the collision avoidance situation.

Chapter 3

Relations between Ship-Handling Ability and Risk of Collision

3.1 Introduction

To clarify the relation between mariners' behavior and safety in crossing situation, the results of BTM training was investigated in this chapter.

A team in the BTM training was organized with the captain or chief officer who is commanding ship-handling in bridge, 2nd and 3rd officers who take charge of the lookout, operation of VHF and radar and position fix, and a quartermaster. And a scenario of the training contains various cases which may happen in ship operation. Among various cases of the scenario, we selected and discussed two cases shown in Fig. 3.1 (a) and (b).

The first case is that an own ship encounters a small high-speed vessel on 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. Then the risk of collision occurs between two vessels.

In the Fig. 3.1 (a) and (b), the symbols marked with black and those filled with a lattice denote an own ships and a target ship respectively. The results for the two cases were analyzed by Pearson's Correlation Coefficient (r).

3.1.1 Definition of the correlation coefficient (r)

The Pearson Product-Moment Correlation Coefficient (r), or correlation coefficient for short is a measure of the degree of linear relationship between two variables, usually labeled X and Y. The emphasis in correlation is on the degree to which a linear model may describe the relationship between two variables. And the interest is non-directional, the relationship is the critical aspect. The correlation coefficient may take on any value between plus and minus one ($-1.00 \le r \le +1.00$). The sign of the correlation coefficient (+, -) defines the direction of the relationship, either positive or negative. A positive correlation coefficient means that as the value of one variables increases, the value of the other variable increases, as one decreases the other decreases. A negative correlation coefficient indicates that as one variable increases, the other decreases, and vice-versa. The formula for the correlation is;

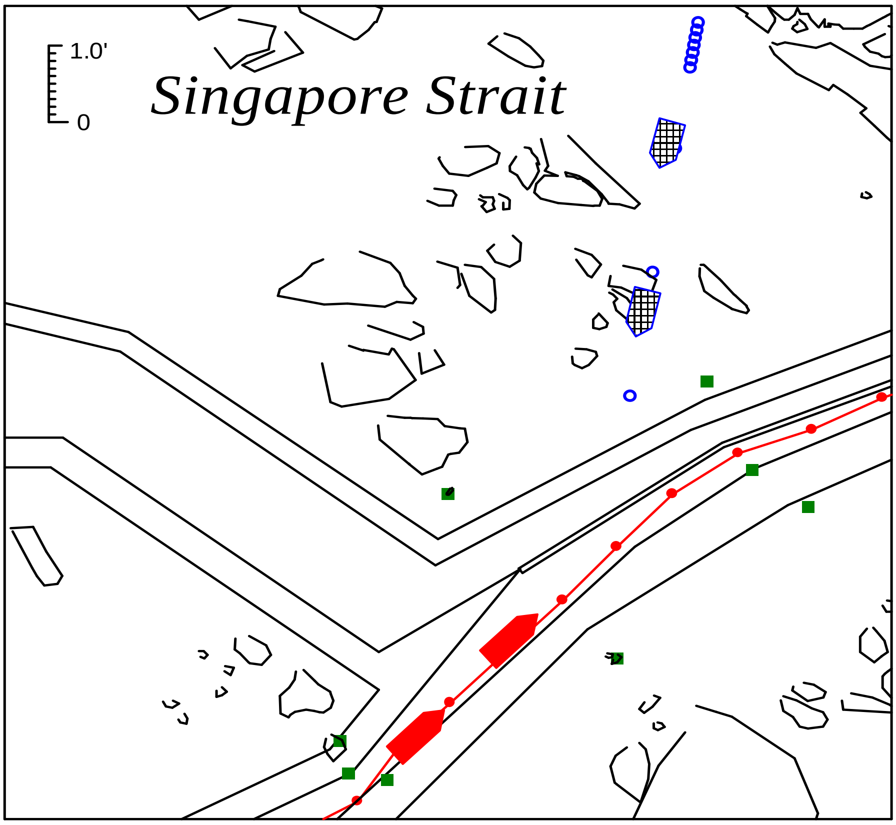
$$r = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2 \sum_{i=1}^{n}(y_i - \overline{y})^2}} \qquad (1)$$

where, x is variable of x axis, y is variable of y axis, $\bar{x}$ is mean value of the x variables and $\bar{y}$ is mean value of the y variables.

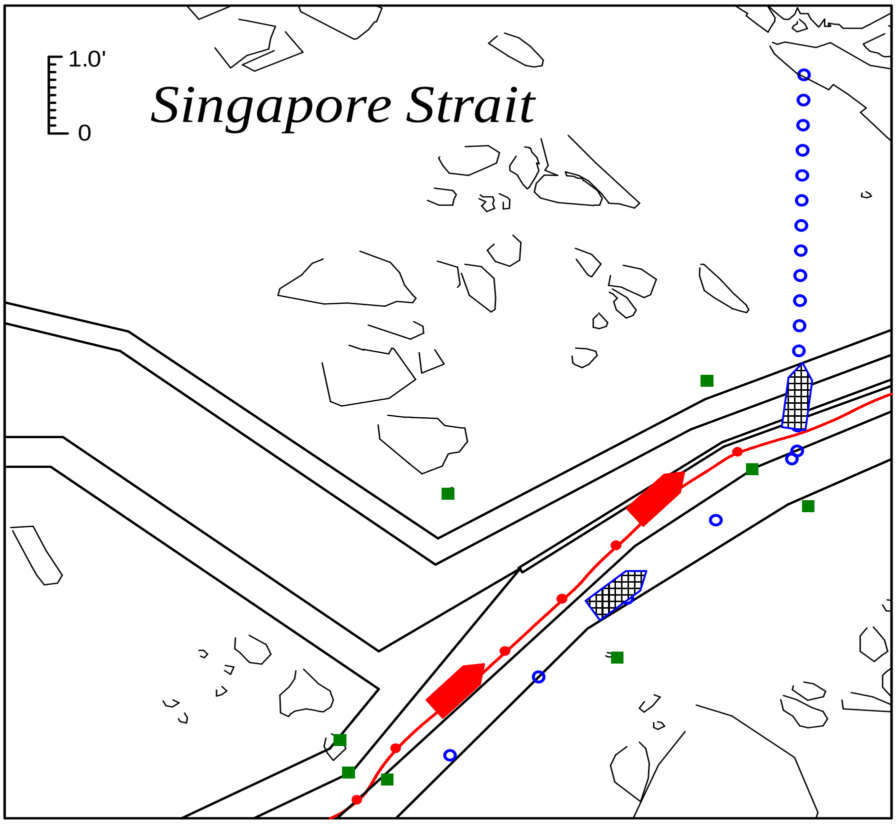
3.2 Variation of collision probability caused by ship-handling ability

To discuss contents of avoiding behavior, the main factors representing the features of them are used as follows;

Tr	: The time from the report to estimated collision when dangerous relation to target vessel is reported or recognized
Ta	: The time from the action to estimated collision when the action to avoid target vessel is started
CPA	: Closest Point of Approach (CPA)
R	: Correlation coefficient (r)



(a) Crossing with a small high-speed vessel



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

Fig. 3.1 Two cases in scenario of Bridge Team Management (BTM)

3.2.1 Operators' behavior for a small high-speed vessel

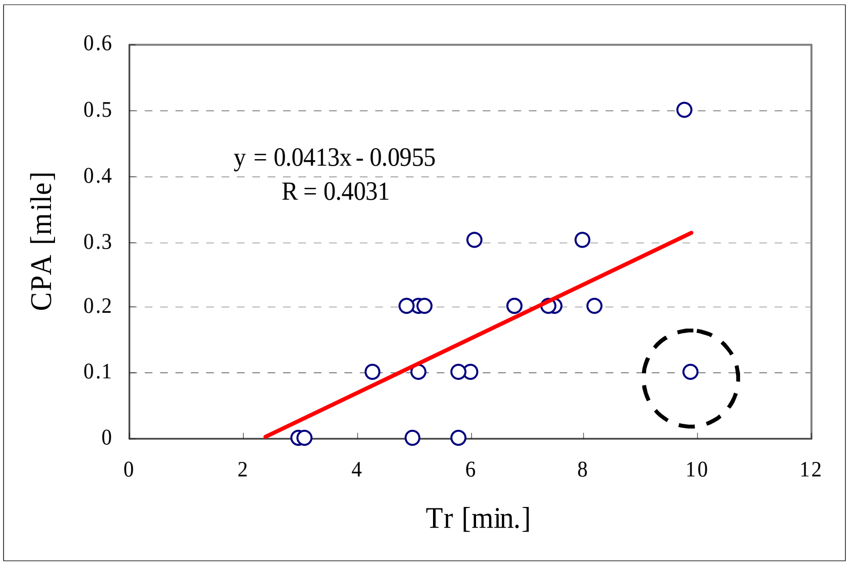
1) The background and analysis items

In this section, a crossing situation as shown in Fig. 3.1 (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 waypoint. According to COLREG, the own ship is a stand-on vessel and the target is a give-way vessel. However, the target ship does not take any action to avoid the collision and steadily approaches to the own ship. At this moment, mariners' behavior in the course of coping with these dangerous situations was examined. The contents of avoidance behavior were analyzed with following items;

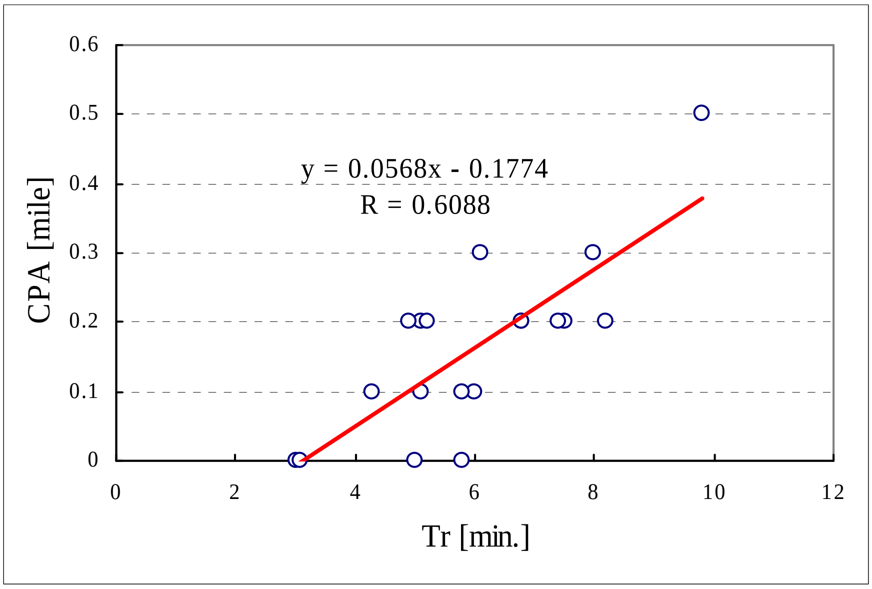
① The time when mariner reports or recognizes the target vessel
② The time when mariner starts an avoiding action
③ Closest Point of Approach (***CPA***)

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

Fig. 3.2 (a) and (b) show the relation between ***Tr*** and ***CPA***.



(a)



(b)

Fig. 3.2 Relation between ***Tr*** and ***CPA***

Fig. 3.2 (a) shows the relation between ***Tr*** and ***CPA*** for all cases of 20 teams regardless of normal or abnormal case. The circle in dotted line denotes abnormal case that forced to get to very small ***CPA*** by taking improper actions to avoid the risk of collision even if the target vessel was early recognized or reported. This case is exceptional one which has no meaning for clarifying the relation between the two factors, ***Tr*** and ***CPA***.

Thus the correlation is recalculated without the abnormal case and is showed in Fig. 3.2 (b). The recalculated correlation coefficient (***R***) shows 0.6088. It turns out that there are some relations between ***Tr*** and ***CPA***. In other words, it means that ***CPA*** could be changed by the recognition time for target vessels. Conversely, the time of recognizing to secure the safety with target vessels also can be estimated. 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. 3.2 (b).

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

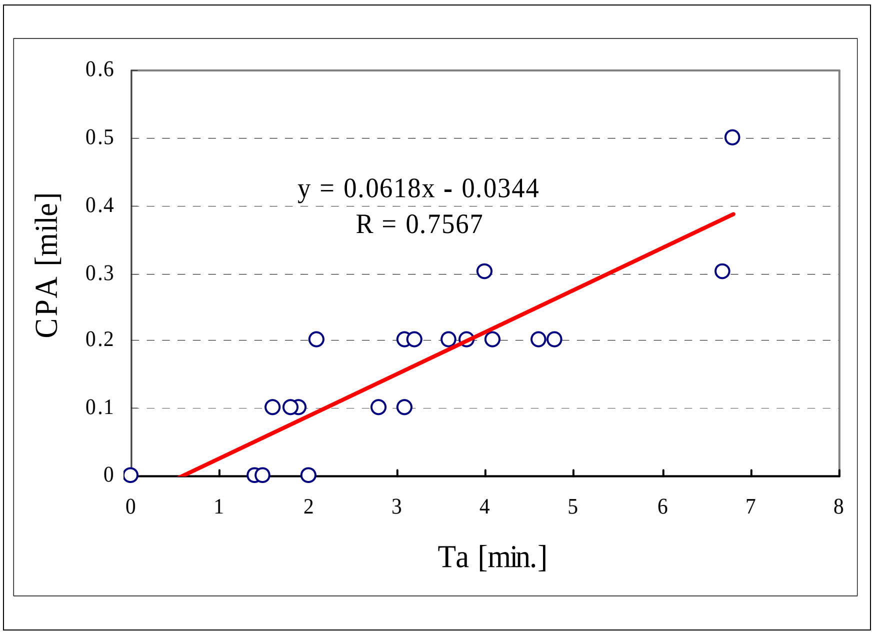


Fig. 3.3 Relation between ***Ta*** and ***CPA***

Fig. 3.3 shows the relation between ***Ta*** and ***CPA***. The correlation coefficient (***R***) between ***Ta*** and ***CPA*** is 0.7567, which shows higher correlation than the one between ***Tr*** and ***CPA***. That is, it could be easy for ***CPA*** to change by the action time rather than the recognition time to target vessel and is more closely related to it.

And the avoiding time can be estimated for keeping the safety, too. For example, it can be considered that mariners have to take an avoiding action, at least, at the time of 5 minutes or more before collision in order to secure ***CPA*** of 3 cables as shown in Fig. 3.3.

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

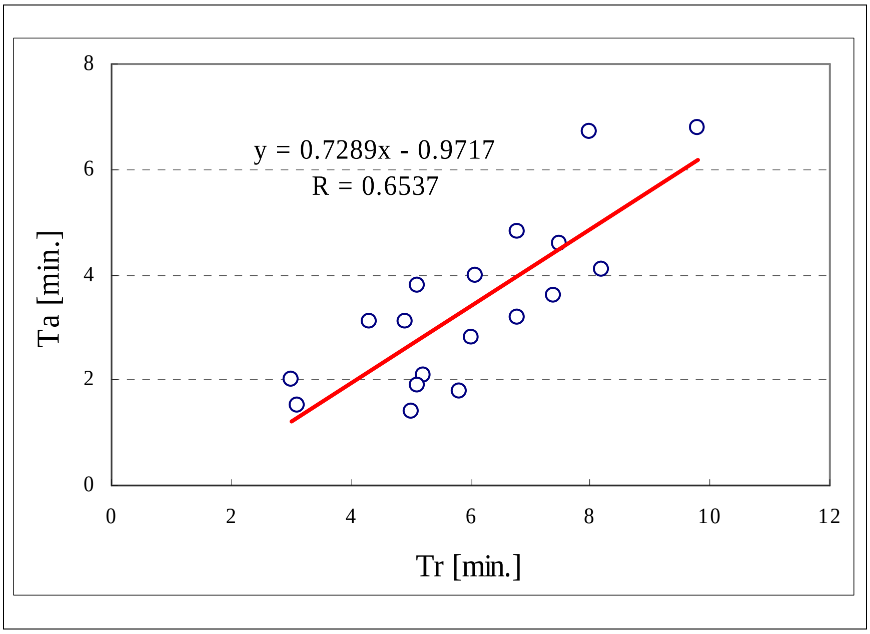


Fig. 3.4 Relation between ***Tr*** and ***Ta***

Fig. 3.4 displays the relation between ***Tr*** and ***Ta***. The correlation coefficient (***R***) is 0.6537, which shows some relations between ***Tr*** and ***Ta***. It means that the two factors are correlated to each other. That is, the avoiding action could be taken lately as it recognizes more lately for target ships. On the contrary, the avoiding action could be also taken quickly, the more it recognizes target ships early.

5) The relation between ***Tr*** and ***Ta*** or ***CPA*** for each avoiding method

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

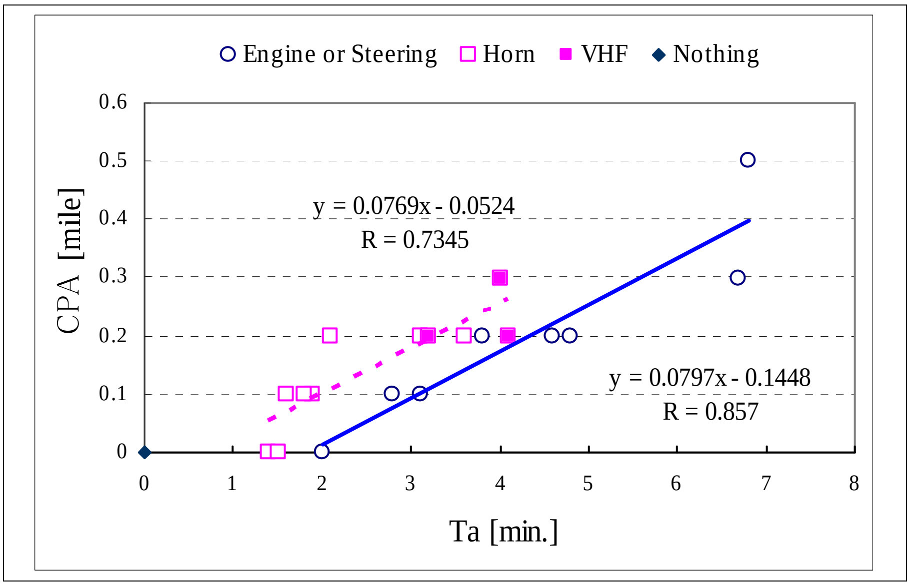


Fig. 3.5 Relation between ***Ta*** and ***CPA*** for each avoiding method

Fig. 3.5 shows the correlation between ***Ta*** and ***CPA*** 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.

There is a tendency of avoiding by own ship when ***Ta*** is ample time while there is a tendency of making the target ship take an avoiding action when ***Ta*** is small.

Considered ***CPA***, the values of ***CPA*** in case of ② are larger than those of ① when the ***Ta*** is 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, it is necessary that we have to consider quick avoiding actions for the safety and ask target vessel's cooperation, as the time to collision is short.

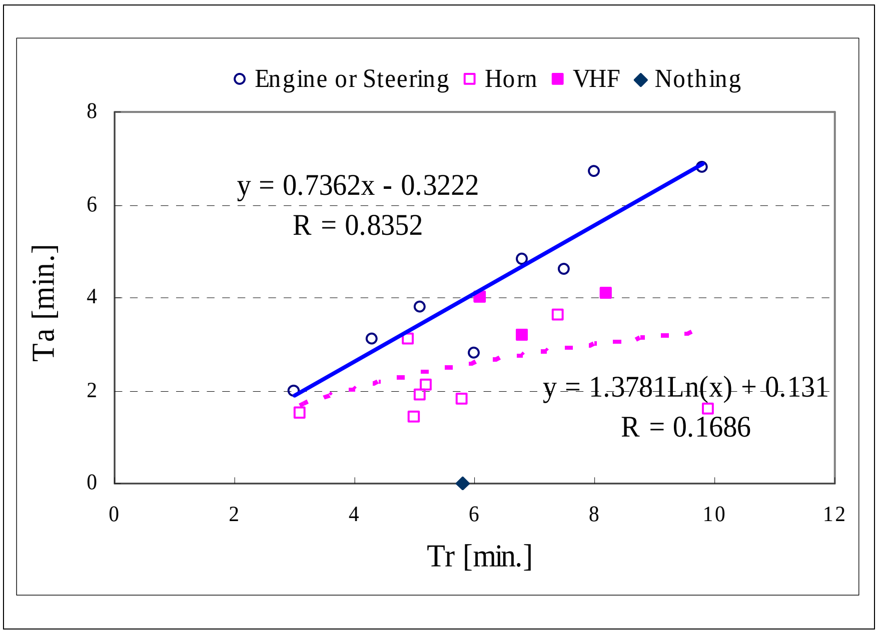


Fig. 3.6 Relation between ***Tr*** and ***Ta*** for each avoiding method

Fig. 3.6 shows the correlation between ***Tr*** and ***Ta*** for each method of avoiding action. The correlation coefficient is quite high when the avoiding action is taken by only own 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. That is, while engine or steering was mainly used when there is ample time to avoid, air horn was used abundantly when the time to collision is short and VHF was used when there is a little time clearance.

It seems that there is a tendency of making the target vessel take avoiding actions when time to collision is short.

6) The variation of ship-handling ability

The variation of ship-handling characteristics was analyzed.

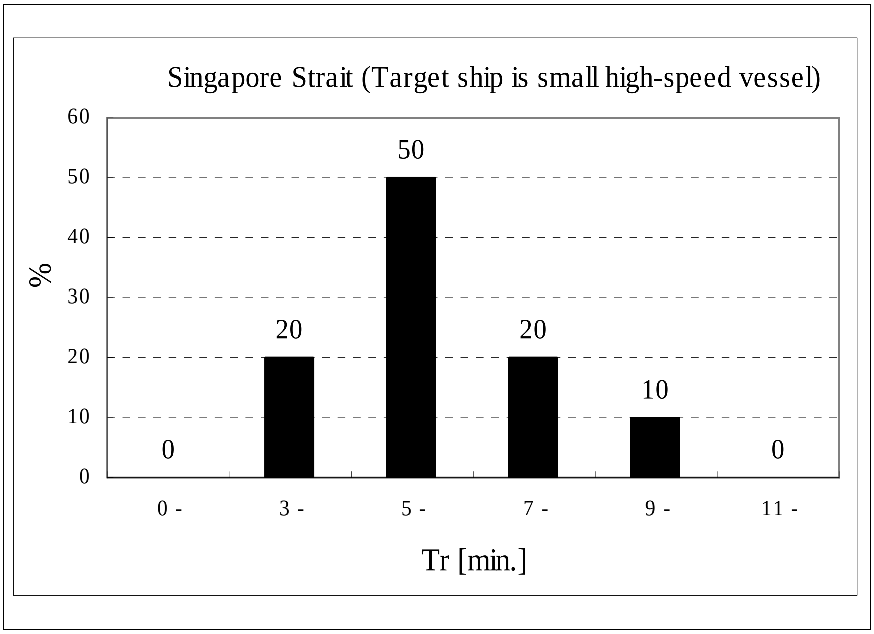


Fig. 3.7 Distribution of ***Tr*** values

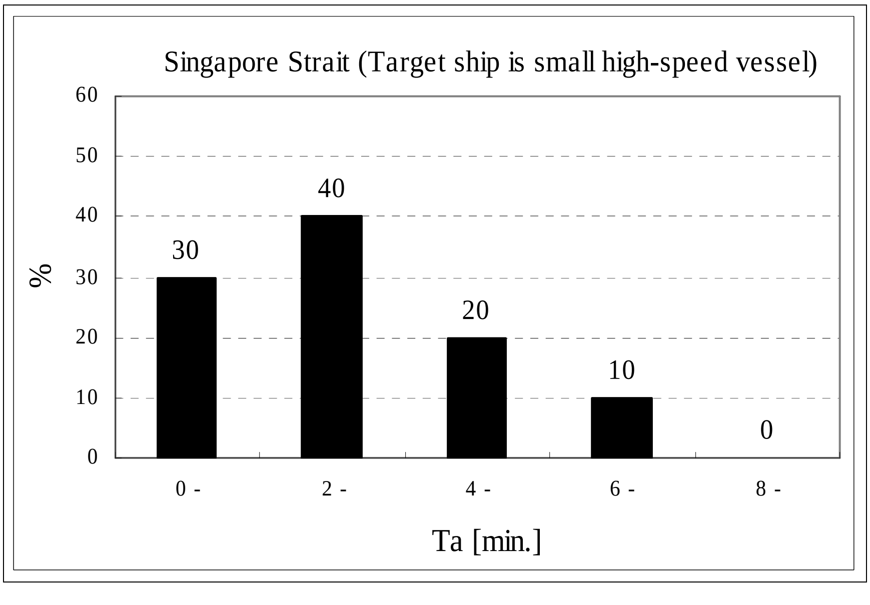


Fig. 3.8 Distribution of ***Ta*** values

Fig. 3.7 shows the distribution of ***Tr*** for every 2 minutes. The data are concentrated between 5 minutes and 7 minutes, and the average value is 6.2

minutes. The majority of mariners, that is, 14 teams of 20 teams recognize target vessel at 3-7 minutes before collision.

Fig. 3.8 shows the distribution of ***Ta*** for every 2 minutes. The data is mostly distributed in the interval between 2 minutes and 4 minutes, and the average value is 3.2 minutes. It means that mariners usually start an avoiding action at average 3.2 minutes before collision.

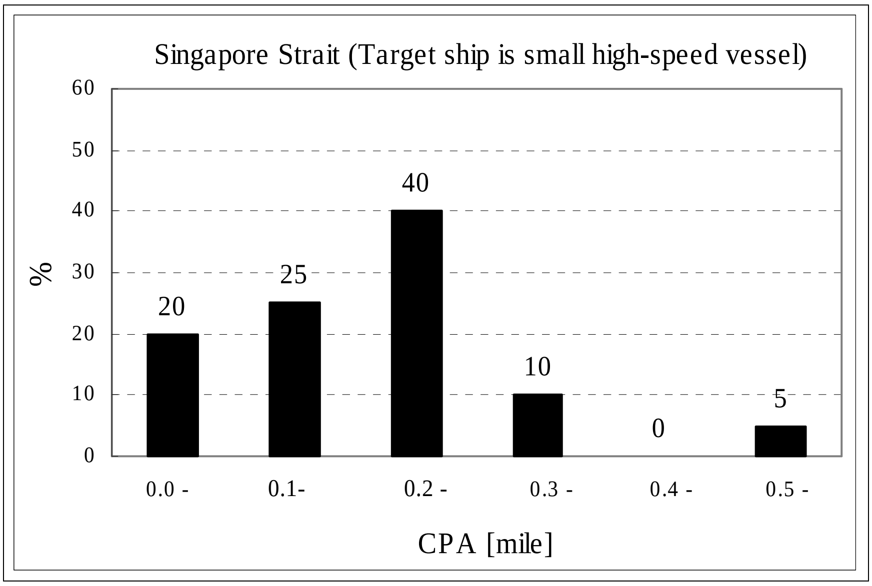


Fig. 3.9 Distribution of ***CPA*** values

Fig. 3.9 shows the distribution of ***CPA***. The 40 percent of total 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, 17 teams among 20 teams of BTM training had been took small ***CPA***s of 0.2 mile or less.

Thus we can understand that small values of ***CPA*** are generally taken in confined waters as Singapore Strait and the difficult navigational environment may force to get close to risk of collision.

3.2.2 Operators' behavior for a container 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. 3.1 (b). And then the crossing situation was occurred suddenly and according to COLREG, an own ship is a give-way vessel and the target ship is a stand-on vessel.

The behavior of mariners to cope with the situation at this moment was analyzed with following items;

① The time when mariner reports or recognizes the target vessel
② The time when mariner starts an avoiding action
③ Closest Point of Approach (***CPA***)

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

The correlation between the ***Tr*** and the ***Ta*** and the correlation between the ***Tr*** and the ***Ta*** for each avoiding action (engine or steering, horn, VHF) are shown in Figs. 3.10 and 3.11 respectively.

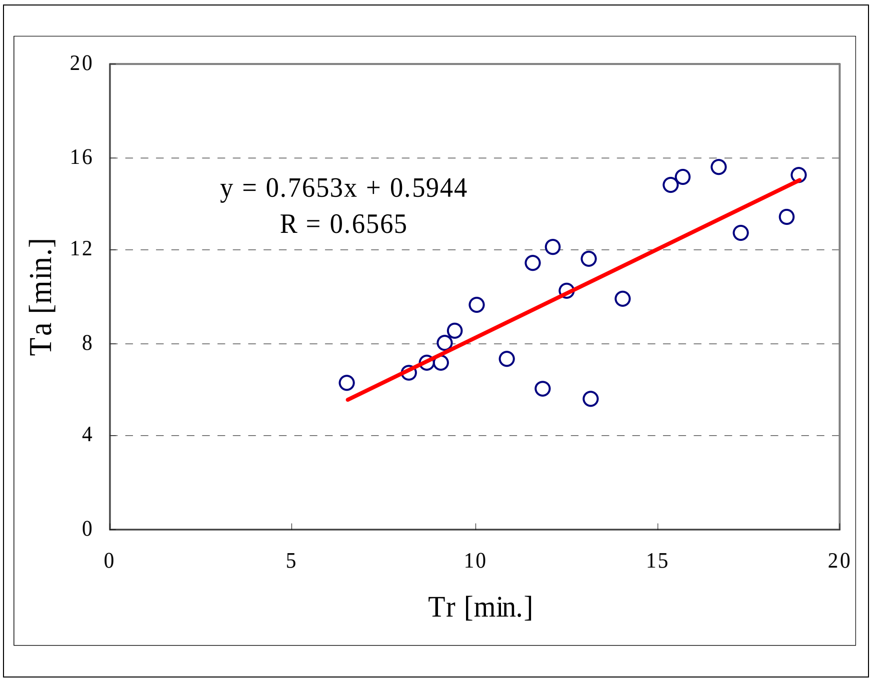


Fig. 3.10 Relation between ***Tr*** and ***Ta***

Fig. 3.10 displays the relation between ***Tr*** and ***Ta***. The correlation coefficient (***R***) between ***Tr*** and ***Ta*** is 0.6565. It means that the two factors are also correlated to each other.

And the coefficient is almost same as the one in case of a small high-speed vessel as shown in Fig. 3.4.

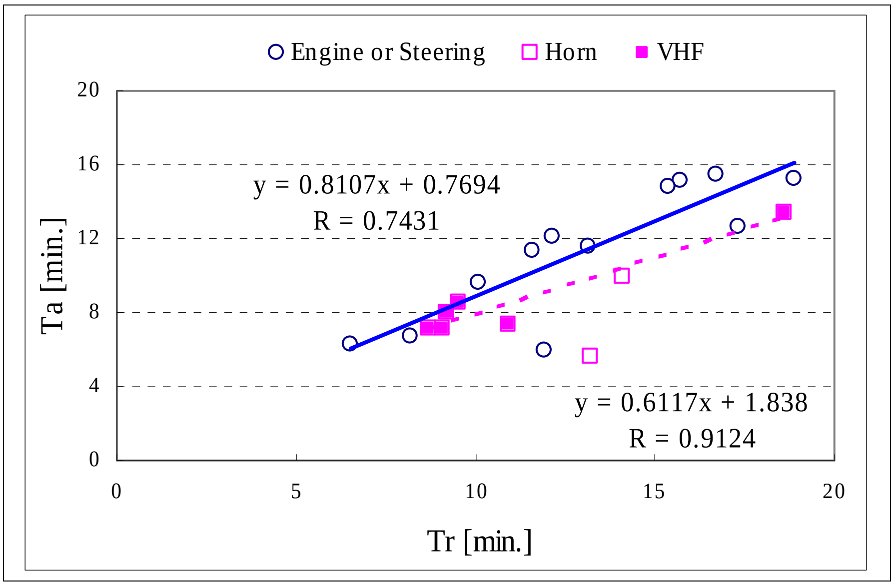


Fig. 3.11 Relation between ***Tr*** and ***Ta*** for each avoiding method

Fig. 3.11 shows the relation between ***Tr*** and ***Ta*** for each method of avoiding action, which is divided into 3 categories, as explained in previous section.

The correlation for engine or steering is high but also the correlation between ***Tr*** and ***Ta*** for only VHF excluding horn is very high. VHF is mainly used rather than horn for making the target ship avoid.

3) The variation of ship-handling ability

The distribution of ***Tr***, the distribution of ***Ta*** and the distribution of ***CPA*** are shown in Figs. 3.12 – 3.14 respectively.

Fig. 3.12 and Fig. 3.13 show the distribution of ***Tr*** and ***Ta*** respectively. It is shown that the average value of ***Tr*** is 12.6 minutes, while the average value of ***Ta*** is 10 minutes.

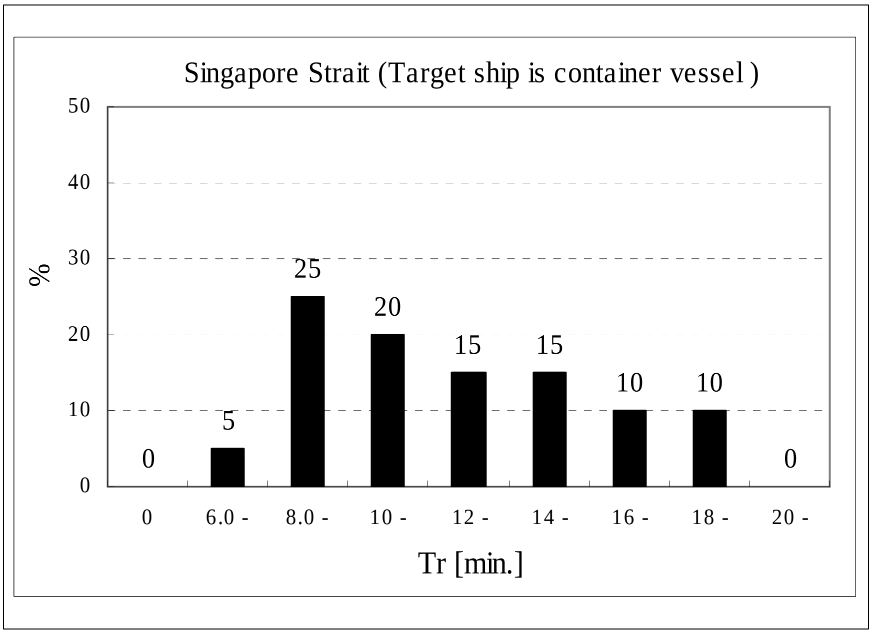


Fig. 3.12 Distribution of ***Tr*** values

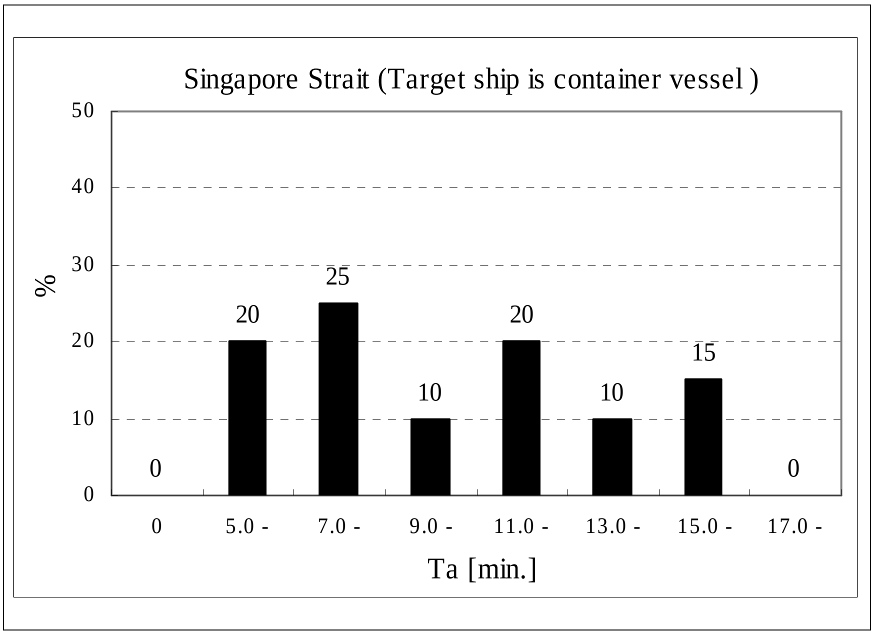


Fig. 3.13 Distribution of ***Ta*** values

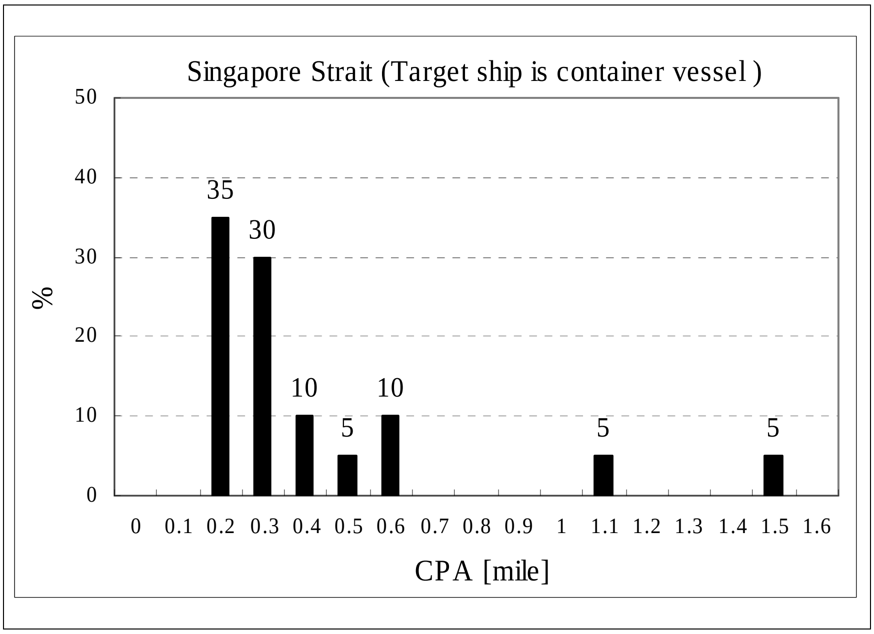


Fig. 3.14 Distribution of ***CPA*** values

And it is found from the distribution of ***CPA*** in Fig. 3.14 that 65 percent of operators take avoiding actions in the range of small values between 0.2 mile and 0.4 mile.

It indicates that 13 teams of 20 teams in the BTM training had been took small ***CPA*** values of 0.3 mile or less. That is, the majority of mariners forced to get to small ***CPA*** values for container vessel explained in previous section.

3.3 Summary and discussion

The obtained results from the BTM training are summarized as follows;

① The correlation between ***CPA*** and ***Tr***, and between ***CPA*** and ***Ta*** indicated high value for the small high-speed vessel.

② The correlation between ***Tr*** and ***Ta*** indicated high value for both a small high-speed vessel and a container vessel.

③ In the two cases of BTM training, the values of ***CPA*** were mostly distributed in small values.

④ In case of small high-speed vessel, average ***Tr*** and ***Ta*** were 6.2 minutes and 3.2 minutes respectively. And the majority of operators took in the range of average 0.17 mile for ***CPA***.

⑤ In case of container vessel, average ***Tr*** and ***Ta*** were 12.55 minutes and 10.2 minutes respectively. And the majority of operators took in the range of average 0.42 mile for ***CPA***.

Chapter 4

Variation of Ship-Handling Characteristics

4.1 Introduction

To understand the variation of ship-handling characteristics, the questionnaire was compared and analyzed with the BTM training based on the obtained results (***Tr***, ***Ta***, ***Pd***, ***CPA***) from previous chapters.

And we investigated the relation between the variation of ship-handling characteristics and traffic volume because the traffic volume was considered as one of the most important reason for the variation.

4.2 Comparison between the questionnaire and the BTM training

We selected two situations from the questionnaire. The one situation is that an own ship is a stand-on vessel and the other one is that an own ship is a give-way vessel.

We compared the former with the case of small high-speed vessel and the latter with the case of container vessel in the BTM training respectively.

4.2.1 Comparison between the questionnaire and the BTM training in case of small high-speed vessel

The respective average values of ***Tr*, *Ta*** and ***Pd*** for ocean, coast and harbor in the questionnaire and for Singapore Strait in the BTM training are shown in Figs. 4.1 - 4.3.

There are no buoys, no waypoints and no other vessels around in the questionnaire, 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, waypoints and other vessels, and traffic separation zone is applied.

The conditions for the BTM training and the questionnaire when an own ship is a stand-on vessel are shown in Table 4.1. As the results of this comparison, various differences from ocean to Singapore Strait have been appeared.

Table 4.1:Comparison of conditions between the BTM training and the questionnaire when an own ship is a stand-on vessel

	BTM training	Questionnaire
Type of target ship	Small high-speed vessel	Container vessel
Navigational waters	Singapore Strait	Ocean, Coast, Harbor
Navigational environment	With buoys, waypoints and other vessels. Confined waters	No aids to navigation, no other vessels. Open sea
Own ship	Stand-on vessel	Stand-on vessel

1) The comparison of ***Tr*** values

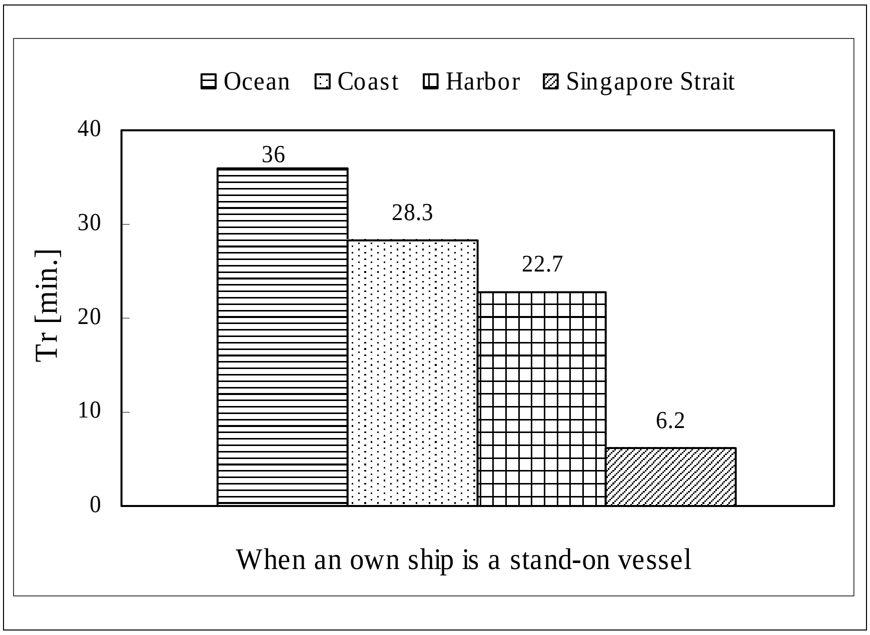


Fig. 4.1 Comparison of ***Tr*** values

Fig. 4.1 shows mean values of ***Tr*** in different navigational waters. ***Tr*** value of ocean displays the most large one and then coast, harbor, and Singapore Strait in that order.

There is a large gap between the BTM training and the questionnaire, while value of ***Tr*** between ocean and coast and that of coast and harbor show small gap respectively.

That is, it is considered that different values shown in Fig. 4.1 are caused by not only navigable waters but also complex factors as buoys, waypoints, high traffic volume and traffic separation scheme.

2) The comparison of ***Ta*** values

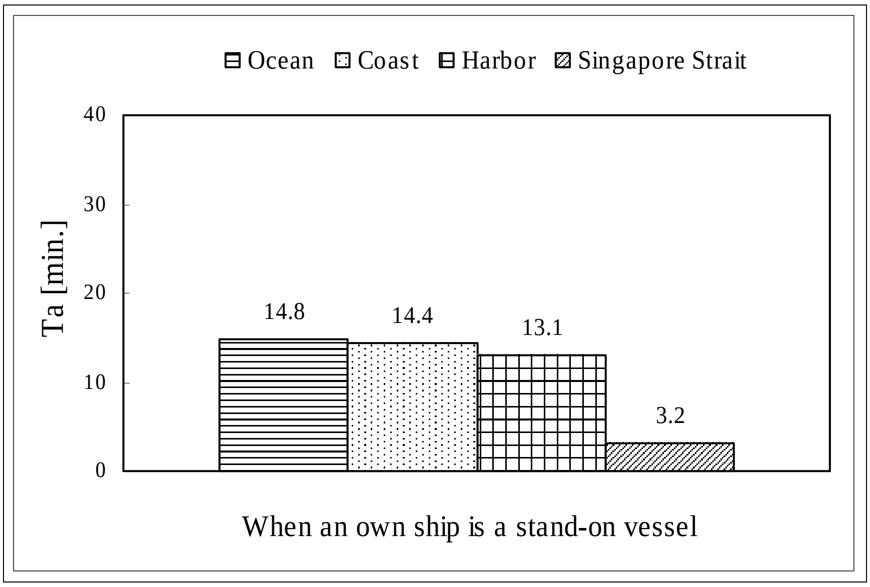


Fig. 4.2 Comparison of ***Ta*** values

Fig. 4.2 shows mean values of ***Ta*** in different navigational waters. There is a large gap between the BTM training and the questionnaire, while values of ***Ta*** for ocean, coast and harbor in the questionnaire are similar to each other.

It means that the ***Ta*** is affected strongly by not only navigable waters but also factors as high traffic volume, traffic separation scheme, etc. It turns out that the time to start an avoiding action can be changed by various conditions depending on navigational environment.

It is considered that ***Tr*** and ***Ta*** become smaller as condition of navigational environment becomes difficult.

3) The comparison of ***Pd*** values

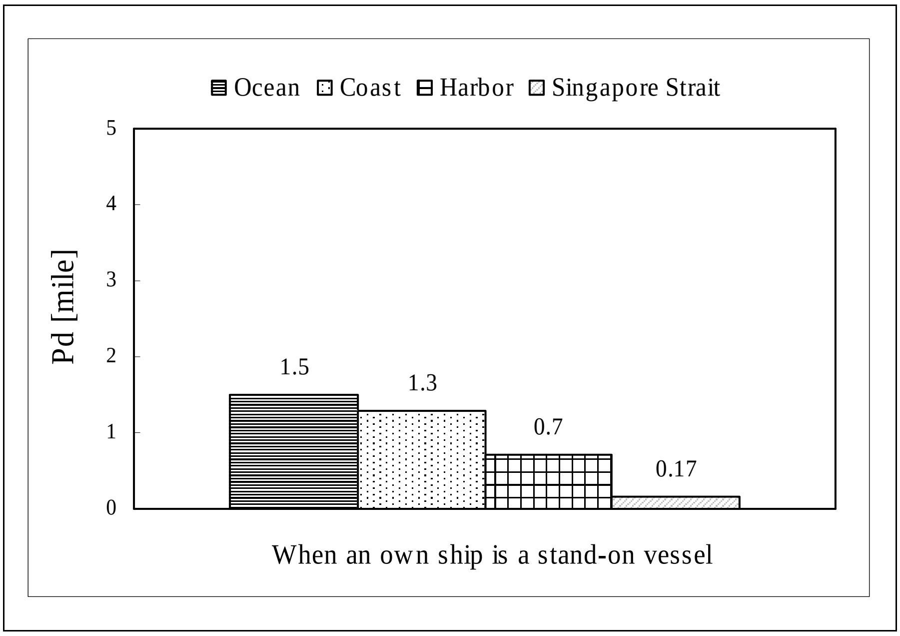


Fig. 4.3 Comparison of ***Pd*** values

Fig. 4.3 shows the mean values of ***Pd*** in ocean, coast and harbor from the questionnaire, and the ***CPA*** obtained from Singapore Strait in the BTM training. The ***Pd*** and the ***CPA*** can be displayed on the same graph because they have the same meaning, that is, the closest point of approach between the two vessels. As a result, different values are appeared according to the navigational waters as shown in Fig. 4.3.

4.2.2 Comparison between the questionnaire and the BTM training in case of container vessel

The values of ***Tr***, ***Ta*** and ***Pd*** for container vessel in the BTM training and for ocean, coast, harbor in the questionnaire are compared and shown in Figs. 4.4 - 4.6.

The target ship is same kind of container vessel, and there are no buoys, no waypoints and no other vessels around in the questionnaire. In the BTM training, the target ship is a container vessel, too. However, there are many buoys, waypoints and other vessels around and traffic separation scheme is applied.

The conditions for the BTM training and the questionnaire when an own ship is a give-way vessel are shown in Table 4.2. With these conditions, we analyzed mean values of ***Tr***, ***Ta*** and ***Pd*** for ocean, coast, harbor and Singapore Strait.

Table 4.2 : Comparison of conditions between the BTM training and the questionnaire when an own ship is a give-way vessel

	BTM training	Questionnaire
Type of target ship	Container vessel	Container vessel
Navigational waters	Singapore Strait	Ocean, Coast, Harbor
Navigational environment	With buoys, waypoints and other vessels. Confined waters	No aids to navigation, no other vessels. Open sea
Own ship	Give-way vessel	Give-way vessel

1) The comparison of ***Tr*** values

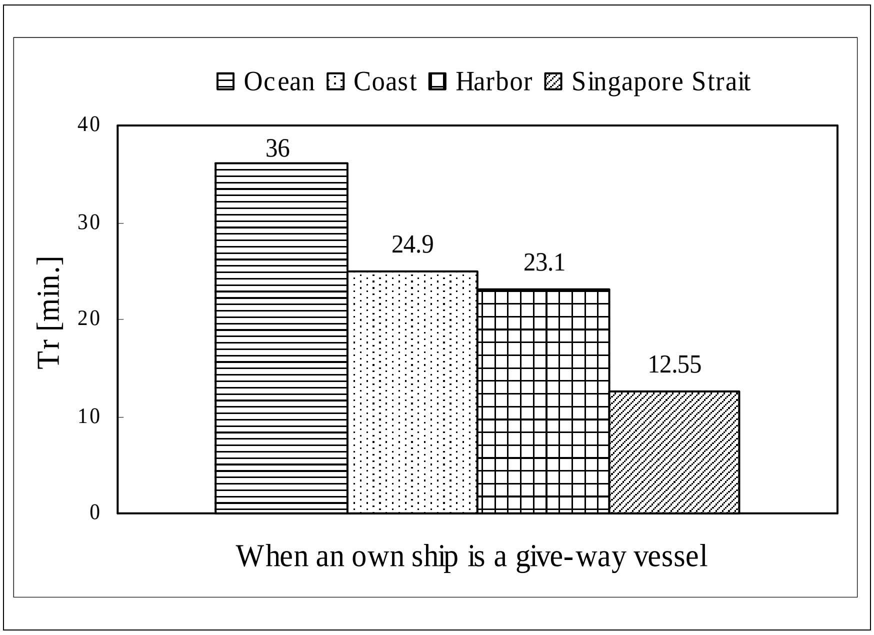


Fig. 4.4 Comparison of ***Tr*** values

Fig. 4.4 shows mean values of ***Tr***. The value of ***Tr*** for a container vessel in BTM training becomes larger than that for a small high-speed vessel, so that the gap between the BTM training and the questionnaire is smaller than that in Fig. 4.1.

That is, it is considered that the majority of operators give more care for lookout when the target ship is a large one than a small high-speed vessel.

2) The comparison of ***Ta*** values

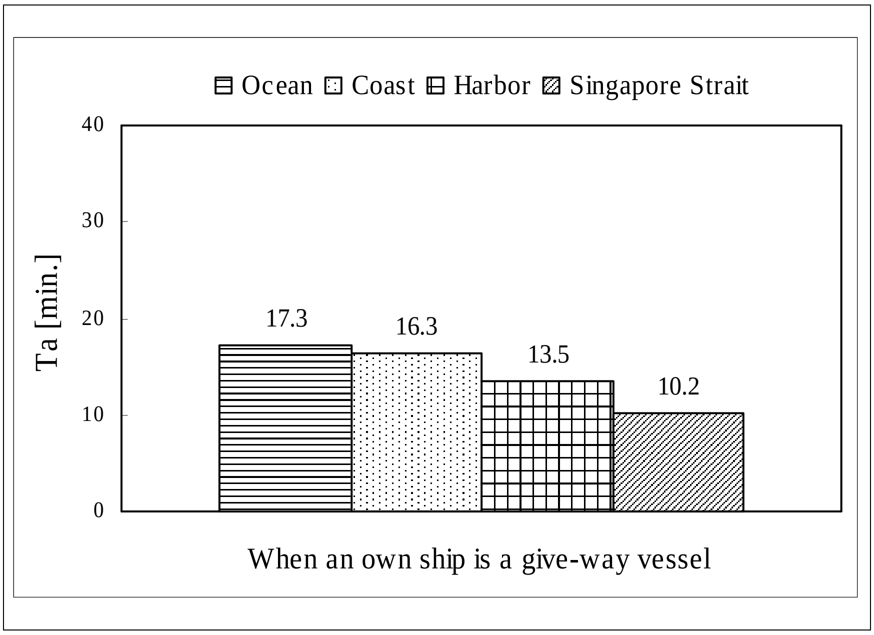


Fig. 4.5 Comparison of ***Ta*** values

Fig. 4.5 shows the mean values of ***Ta*** which from the BTM training in case of container vessel are much larger than those in Fig. 4.2.

Thus we can understand that there is a tendency to start an 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, the characteristics of ship-handling could be changed by factors such as navigational environment, own ship's status in crossing situation, and the type of target ship.

3) The comparison of ***Pd*** values

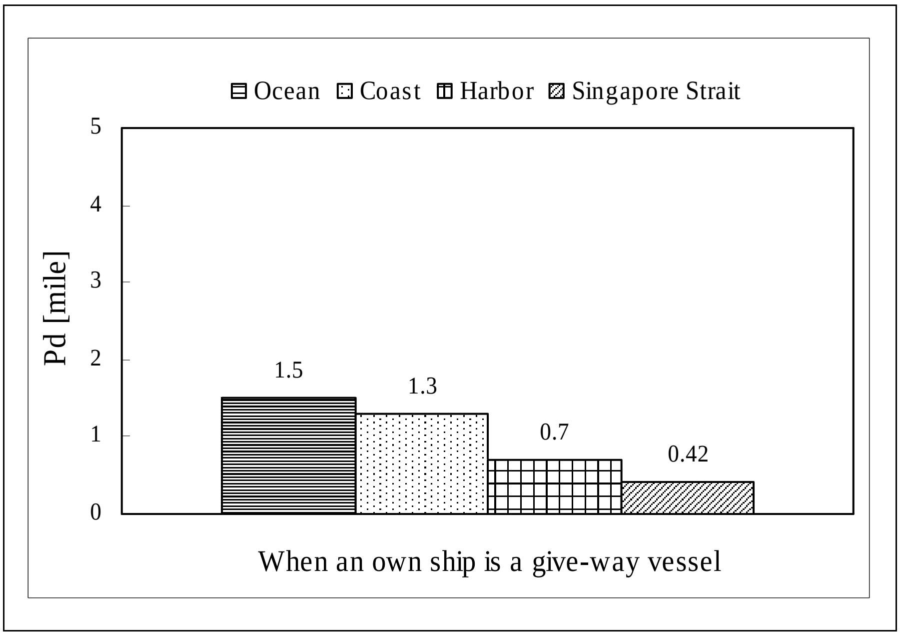


Fig. 4.6 Comparison of ***Pd*** values

Fig. 4.6 shows the mean values of ***Pd*** for ocean, coast and harbor obtained from the questionnaire and ***CPA*** for Singapore Strait from the BTM training. The ***Pd*** and the ***CPA*** are shown on the same graph because they have the same meaning, that is, the closet point of approach between two vessels. As a result, different values are appeared according to the navigational waters as shown in Fig. 4.6.

4.3 Reasons for the variation of ship-handling characteristics

As shown above, it found from the comparison that different values were appeared according to various navigational waters in each case.

The more there are a lot of target vessels around, the smaller mean values of ***Tr*** and ***Ta*** are because operators generally start an avoiding action earlier or give more care for ships which are considered as the most dangerous or closest. However, if there are not so many vessels around, it is possible for mariners to recognize the target vessel, which has the probability of collision, earlier and take an avoiding action in ample time.

Therefore we considered that traffic volume or navigable waters had large influence on operator's ship-handling characteristics. Thus we investigated the average traffic volume per 1 day for each waters and analyzed the relation between the ship-handling characteristics and the traffic volume.

4.3.1 Traffic volume

1) The statistics for the traffic volume of main waters[1]

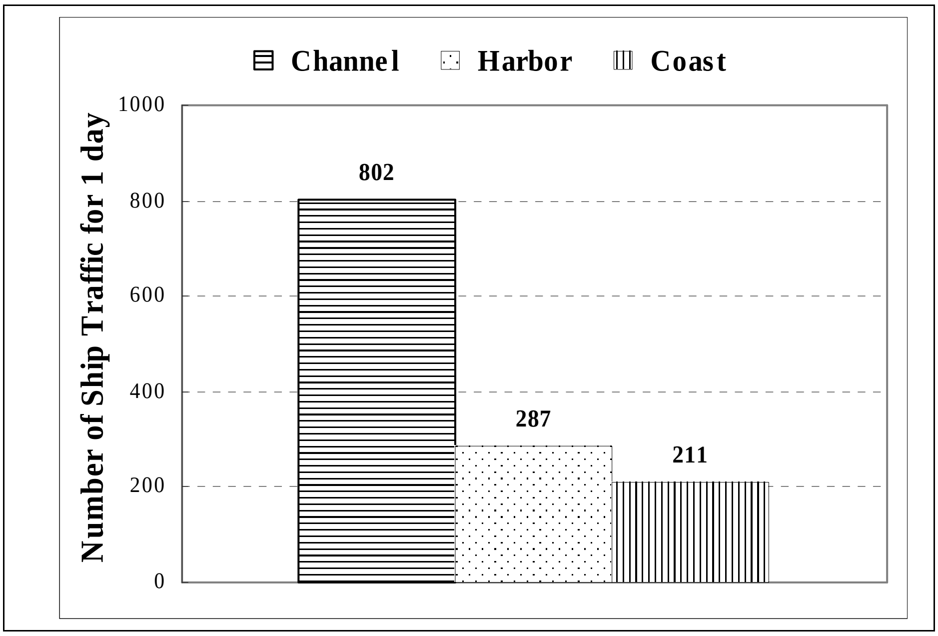


Fig. 4.7 The Traffic Volume per 1 day for main waters

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[1] Refer details to appendix.

Fig. 4.7 shows the average traffic volume per 1 day for channel, harbor and coast respectively. The traffic volume was referred to the statistics of Japan Coast Guard and Ministry of Land, Infrastructure and Transport, which have been researched for the traffic volume (all vessels more than 5 ton) of main waters in Japan. The number of vessel traffic per 1 day for channel displays the largest value of 802, and those for harbor and coast display 287 and 211 vessels respectively.

2) The relation between ***Tr*** or ***Ta*** and traffic volume

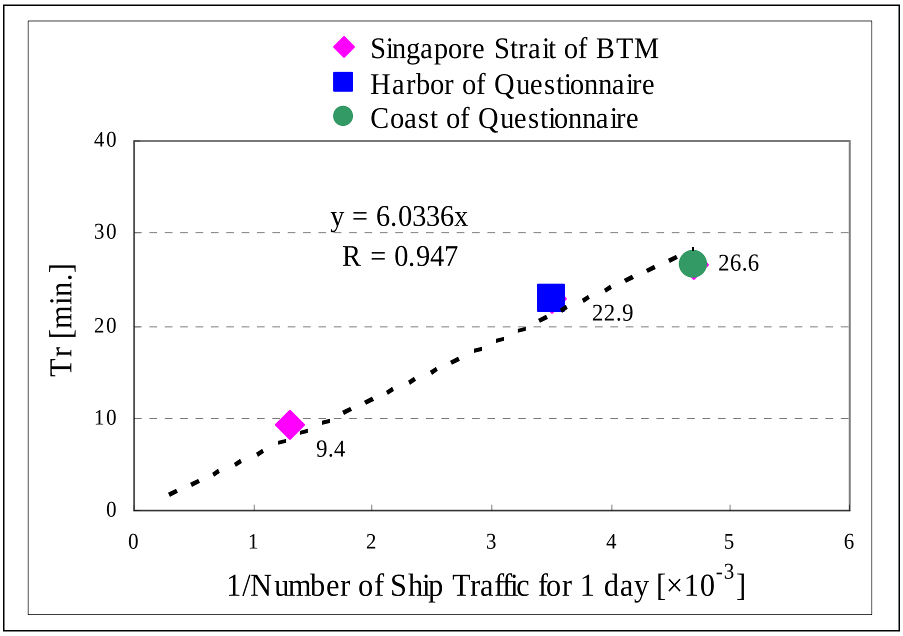

Fig. 4.8 Correlation between ***Tr*** and traffic volume

Fig. 4.8 shows the correlation between ***Tr*** and the number of ship traffic per 1 day for each navigational waters. The correlation coefficient is very high value of 0.947. It means that there is considerably close relation between the two factors.

Therefore we can understand that time to recognize target vessels which has the probability of collision is strongly affected by the traffic around.

Fig. 4.9 shows the correlation between ***Ta*** and the number of ship traffic per 1 day for each navigational waters. The correlation coefficient is also very high value of 0.8314. It means that there is close relation, too.

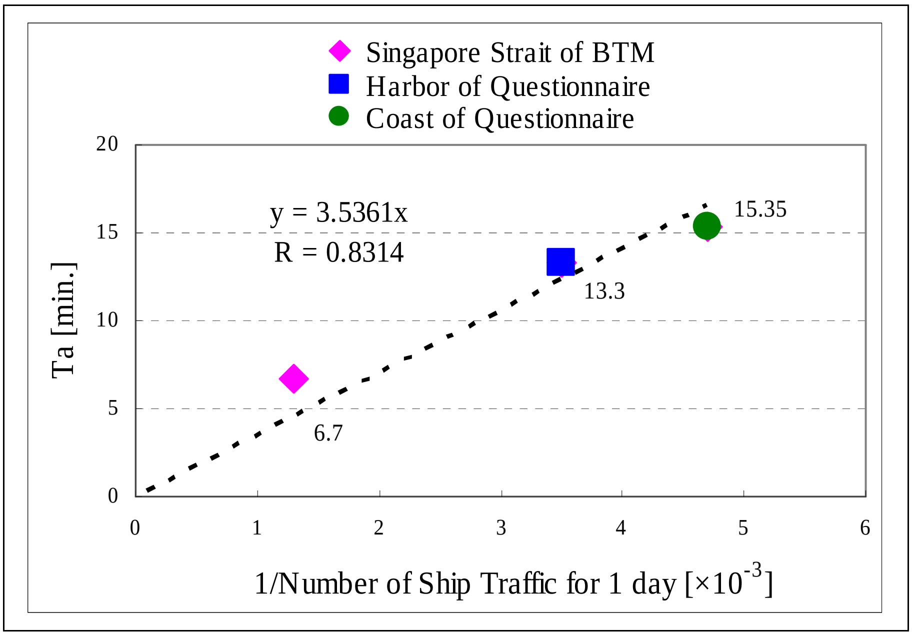

Fig. 4.9 Correlation between ***Ta*** and traffic volume

However, comparing the two values of correlation coefficient in Figs. 4.8 and 4.9, we can consider that traffic volume has stronger influence on the ***Tr*** than the ***Ta***, and the action time rather than the recognition time could be easily changed by factors such as an own ship's status in crossing situation as shown in previous section.

3) The relation between ***Tr*** or ***Ta*** and traffic volume including sea speed

Figs. 4.10 and 4.11 show the correlation between ***Tr*** and the number of ship traffic per 1 day including sea speed, and the correlation between ***Ta*** and the number of ship traffic per 1 day including sea speed respectively.

The correlation coefficient in Fig. 4.10 including sea speed has almost the same value with the coefficient excluding sea speed in Fig. 4.8. That is, in case of reporting or recognizing the target vessel, it can hardly affected by sea speed of own or target ship.

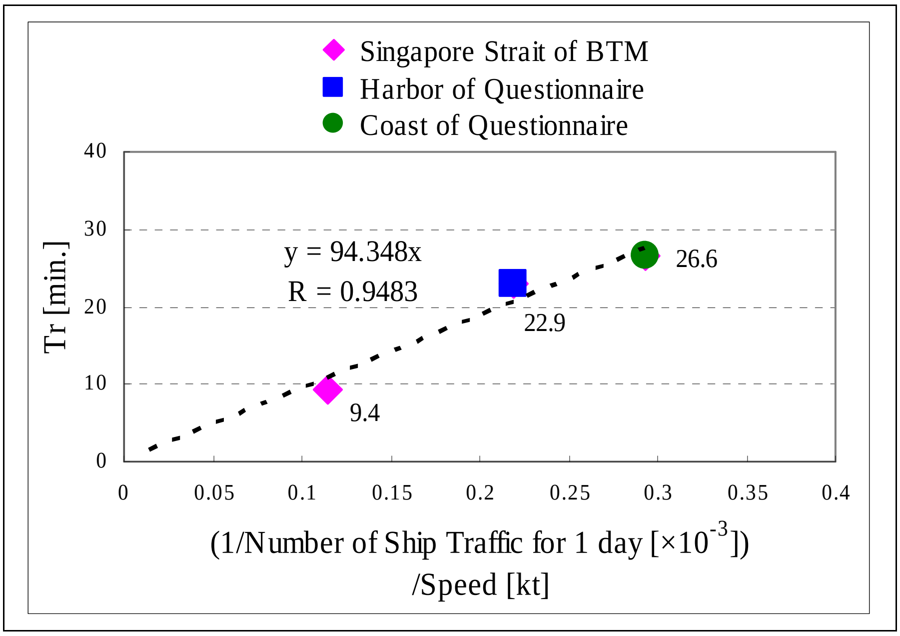

Fig. 4.10 Correlation between ***Tr*** and traffic volume including sea speed

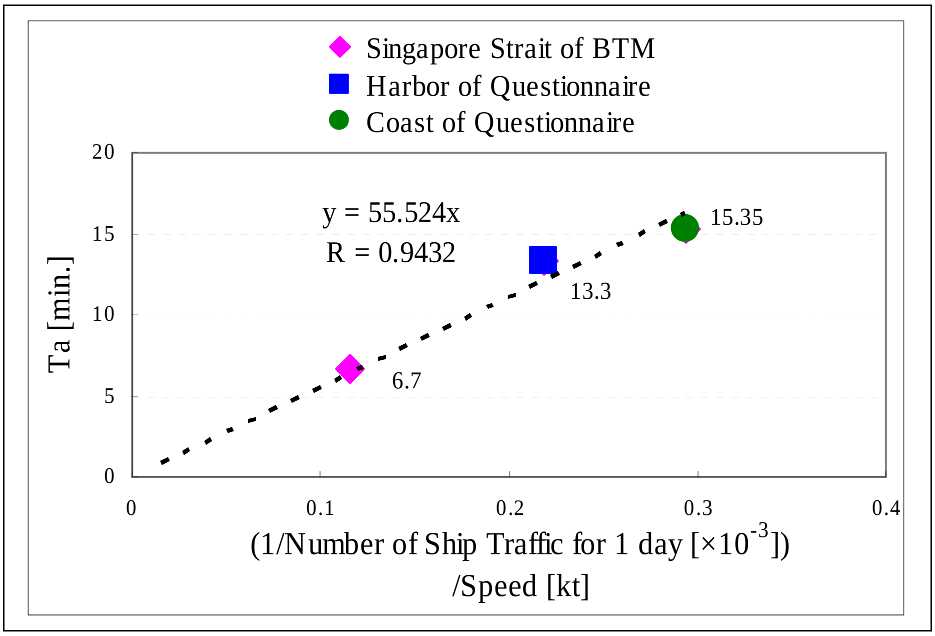

Fig. 4.11 Correlation between ***Ta*** and traffic volume including sea speed

In case of taking an avoiding action, however, the time to collide with the target vessel could be changed by sea speed of own or target ship, and the estimated collision time is very important to take an avoiding action. Thus, as shown in Fig. 4.11, the correlation coefficient for the action including sea speed became higher value of 0.9432 than that of 0.8314 excluding sea speed in Fig. 4.9.

That is, we can understand that sea speed is important to take avoiding actions.

4.3.2 Other reasons

As mentioned above, it can be considered that there are such various factors which affect ship-handling characteristics as own ship's status in crossing situation or maneuverability of ship as well as traffic volume around.

4.4 Summary and discussion

The obtained results from comparison between the questionnaire and the BTM training are summarized as follows;

① It indicated that the ***Tr***, the ***Ta*** and the ***Pd*** representing ship-handling characteristics could be changed by the conditions of navigational waters.

② The ***Tr*** and the ***Ta*** could be changed by the type or performance of target vessel. That is, there is a tendency to give much care for look out or to take an earlier avoiding action for a large vessel than a small one.

③ The ***Ta*** could be changed by own ship's status in crossing situation. In other words, mariners tend to take an earlier avoiding action when an own ship is a give-way vessel than a stand-on vessel.

④ The ***Tr*** and the ***Ta*** are strongly affected by traffic volume. And also the traffic volume is more closely related with reporting time rather than action time. Moreover, in case of taking an avoiding action, it is considered that the action time is affected by not only traffic volume but also various factors as sea speed, own ship’s status in crossing situation and the maneuverability of ship.

Chapter 5

Conclusion

In the first place, we confirmed from the questionnaire of Chapter 2 that the values of ***Tr***, ***Ta*** and ***Pd*** in the widest ocean are generally largest and then coastal waters, harbor in that order, and ***Ta***, especially, may change by ship's status in the collision avoidance situation.

As a result, it can be considered that as navigable waters enlarges, the values of ***Tr, Ta*** and ***Pd*** become larger and the envelopes become wider. And ***Ta*** also could be changed by own ship's status in crossing situation.

It means that such mariners' behavior as ship-handling characteristics is related with the area of navigable waters where they are operating the vessel and own ship's status in the collision avoidance situation.

In the second place, from two cases of the BTM training of Chapter 3, we confirmed that the recognition time (***Tr***) and the action time (***Ta***) are correlated with ***CPA***, and also each other. And the majority of mariners took small ***CPA*** of considerable danger in confined waters as Singapore Strait. That is, many teams in the BTM training occurred to dangerous situation.

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

Furthermore, we obtained from the comparison between the questionnaire and the BTM training of Chapter 4 that the recognition time (***Tr***) and the action time (***Ta***) are mainly affected by traffic volume, which is more closely related with the recognition time rather than the action time. In case of taking avoiding action, it is considerably affected by not only the traffic volume but also various factors as sea speed, own ship’s status in crossing situation and the maneuvering of ship.

It means that ship-handling characteristics could be changed by various factors as the conditions of navigational environment, the type or performance of target ship and own ship's status in the collision avoidance situation.

To sum up the results of the BTM training and the questionnaire we have studied thus far, we can conclude that the characteristics of ship-handling vary with factors as the area of navigable waters, own ship's status in the collision avoidance situation and the performance of target vessels as mentioned above, and the probability of collision may changes by characteristics of mariners’ ship-handling depending on navigational environment.

That is, as navigational conditions become difficult, mariners get to take a lookout or avoiding actions more slowly. Thus the dangerous situation could occur in congested waters and the probability of collision could be higher when the majority of operators encounter target vessel in congested navigational waters, especially.

The results obtained in this thesis suggest that mariners’ behavior to keep the safe operation at sea can be estimated. It is considered that the results also can be good guide lines for the development of onboard bridge system to support the operators and the efficient harmonization between the role of automatic navigational equipment and the role of human.

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Appendix

1. Coastal waters

入道埼沖	Nyudozaki-oki	金華山沖	Kinkasan-oki
新潟港沖	Niigatakou-oki	犬吠埼沖	Inubozaki-oki
禄港埼沖	Rokkoumisaki-oki	洲ノ埼沖	Sunosaki-oki
隠岐海峡	Okikai-kyou	下田沖	Simoda-oki
魹ヶ埼沖	Todogasaki-oki	潮の岬沖	Sionosaki-oki
塩屋埼沖	Sioyazaki-oki	日御碕沖	Hinomisaki-oki

2. Harbor

根室	Nemuro	宇野	Uno
釧路	Kusiro	水島	Mizusima
花咲	Hanasaki	福山	Hukuyama
苫小牧	Tomakomai	尾道糸崎	Onomichiitozaki
室蘭	Muroran	呉	Kure
函館	Hakodate	広島	Hirosima
小樽	Otaru	岩国	Iwakuni
留萌	Rumoi	徳山下松	Tokuyamasimomatsu

稚内	Watsukanai	宇部	Ube
青森	Aomori	荻	Ogi
八戸	Hachinohe	関門 (若松区)	Kanmon (wakamatsu-ku)
釜石	Kamaisi	関門 (若松区外)	Kanmon (wakamatsu-kugai)
気仙沼	Kesennuma	徳島小松島	Tokusimakomatsu-jima
仙台塩釜	Sendaisiogama	坂出	Sakaide
秋田船川	Akitafunakawa	高松	Takamatsu
酒田	Sakata	松山	Matsuyama
小名浜	Onahama	今治	Imabari
鹿島	Kasima	新居浜	Niihama
木更津	Kisaradu	高知	Kouchi
千葉	Chiba	博多	Hakata
京浜 (東京区）	Keihin (Tokyo-ku)	三池	Miike
京浜 (川崎区）	Keihin (Kawasaki-ku)	唐津	Karatsu
京浜 (横浜区）	Keihin (Yokohama-ku)	長崎	Nagasaki
横須賀	Yokosuka	佐世保	Sasebo
直江津	Naoetsu	厳原	Iwahara

新潟	Niigata	三角	Misumi
両津	Ryoutsu	大分	Ooita
伏見富山	Husimitoyama	細島	Hosojima
七尾	Nanao	鹿児島	Kagosima
敦賀	Tsuruga	名瀬	Nase
清水	Simizu	金武中城	Kinbunakazou
衣浦	Koromoura	那覇	Naha
名古屋	Nagoya	田子の浦	Tagonoura
四日市	Yotsukaichi	むつ小川原	Mutsuogawara
舞鶴	Maiduru	伊万里	Imari
阪南	Hannan	金沢	Kanazawa
大阪	Osaka	福井	Hukui
神戸	Koube	柳井	Yanai
尼崎西宮芦屋	Amagasakinisinomiya-asiya	三田尻中関	Mitajirinakanoseki
東播磨	Higashiharima	三島川之江	Misimakawanoe
姫路	Himeji	石巻	Isinomaki
田辺	Tanabe	日立	Hitachi
和歌山下津	Wakayamasimotu	泉州	Senshuu
境	Sakai	三河	Mikawa
浜田	Hamada	湖・河川	Mizuumi-kasen

3. Channel

津軽海峡	Tsugaru-kaikyo	来島海峡	Kurusima-kaikyou
鳴門海峡	Naruto-kaikyo	備讃瀬戸東部	Bisanseto-toubu
明石海峡	Akasi-kaikyo	備讃瀬戸西部	Bisanseto-seibu
下津井瀬戸	Simotsui-seto	速吸瀬戸	Hayasui-seto
友ヶ島水道	Tomogasima-suidou	釣島水道	Turusima-suidou
浦賀水道	Uraga-suido	クダコ水道	Kudako-suido
伊良湖水道	Irago-suido	早瀬戸	Haya-seto
宮ノ窪瀬戸	Miyanokubo-seto	音戸瀬戸	Ondono-seto