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Analyzing the Factors Affecting the Safe Maritime Navigation for Training Apprentice Officers

M.K. Lee
Ocean Science and Technology School of Korea Maritime and Ocean University, Busan, South Korea

S.W. Park
Korea Maritime Institute, Busan, South Korea

Y.S. Park & M.J. Park
Korea Maritime and Ocean University, Busan, S.Korea

E.K. Lee
SafeTechResearch, Inc., Daejeon, S.Korea

ABSTRACT: One of the primary factors that affect the safe maritime navigation is the insufficient experience and skill of an apprentice officer, which may be improved using simulation-based training by ensuring operational efficiency. This study aims to determine appropriate factors for achieving effective and intensive simulation-based training of apprentice officers and present the guidelines for such a training scheme. Initially, a marine traffic risk model, which interprets and accurately measures the risk of collision with other vessels, is analyzed to derive the most influential factors in safe navigation. Subsequently, simulation experiments are conducted by applying machine learning to verify the required safe navigation factors for effectively training the apprentice officers. As a result of the above analysis, it was confirmed that the factor affecting safe maritime navigation was the distance from other vessels. Finally, the differences between these distances in the simulations are analyzed for both the apprentice officers and the experienced officers, and the guidelines corresponding to both these cases are presented. This study has the limitation because of the difference between the ship maneuver simulation and the actual ship navigation. This can be resolved based on the results of this study, in combination with the actual navigation data.

1 INTRODUCTION

The primary tasks of a navigation officer include the collection and interpretation of information as well as the forecast of future occurrences through conscientious watch. Based on this perspective, apprentice officers are observed to lack the experience required to conduct a timely and realistic awareness of a situation, which often results in some inaccurate interpretations or erratic predictions. Sometimes, despite the accurate interpretation of the situation, the action to avoid collision is conducted late, endangering the safety of the ship or situation. An effective resolution to ensure safe navigation is simulation-based training that has been essentially designed to equip apprentice officers with the required set of skills and experience. Lee (2018) confirmed that simulation of the navigation scenarios will help the apprentice officers to improve their awareness and abilities.

Karlsson (2011) denoted the importance of briefing and debriefing for ensuring effective training and presented the evaluation items to students during simulation and debriefing. Park (2016) provided standardized evaluation items with respect to the simulation operators. These studies identified the factors of focus during the training as evaluation items; however, they did not provide the importance and quantitative guidelines for such items.

A previously conducted study suggested a guideline for ensuring safe navigation by attempting to define the optimal possible speed for sea voyage legs (Rutkowski, 2016). This study further suggested a method of preparing a table for ensuring safe minimum distances during a navigational watch (Rymarz, 2007), similar to the one that was suggested based on the safety consciousness of the Korean ship operators (Park et al., 2010), and proposed a basic VTS guideline with the ship's closest point of approach/time to the closest point of approach (CPA/TCPA), collision risk, control frequency, and minimum safety distance through VHF communication analysis (Park et al., 2017). Regardless, these studies were conducted with respect to the general navigation officers and did not reflect the characteristic behaviors of the apprentice officers.

Further, this study intends to derive the items intended for ensuring the extensive and effective training of apprentice officers through an analysis of the maritime traffic risk assessment model and the simulation experiment. Additionally, the guidelines are presented quantitatively after respective analysis of the simulation results.

2 EXTRACTION OF THE EXTENSIVE TRAINING FACTORS

2.1 *Analysis based on marine traffic risk model*

2.1.1 *PARK model*

The potential assessment of risk factors (PARK) model was used to evaluate the risk involved in the vessel operators navigating the coastal waters of Korea (Nguyen, 2014). Here, the risk factors of the ship operator were classified as internal factors, such as the ship length, tonnage, ship type, and rank of the officer, and external factors, such as the crossing direction, ship speed, and separation distance between ships. In this model, the risk value can be calculated as follows:

$$\begin{aligned} Risk\,value &= 5.081905 + T_p + T_f + L_f + \\ & W_f + C_{1f} + L_f + P_f + 0.002517L + C_{2f} + \\ & S_f + H_{i/o} + S_p - 0.004930 \cdot S_d - 0.430710 \cdot D \end{aligned} \quad (1)$$

where,
T_p = Own ship type factor;
T_f = Own ship ton factor (Ton);
W_f = Own ship width factor (m);
C_{1f} = ship operator's career factor;
L_f = license factor;
P_f = position factor;
L = LOA of the own ship (m);
C_{2f} = crossing situation factor;
S_f = side approaching factor;
$H_{i/o}$ = inner / outer harbor factor;
S_{po} = own ship speed factor (kt);
S_d = speed difference between ships (kt); and
D = distance (NM).

Only the factors related to the other ship were identified because the information about the own ship remained constant. Figure 1 denotes the degree of these factors with respect to the final risk.

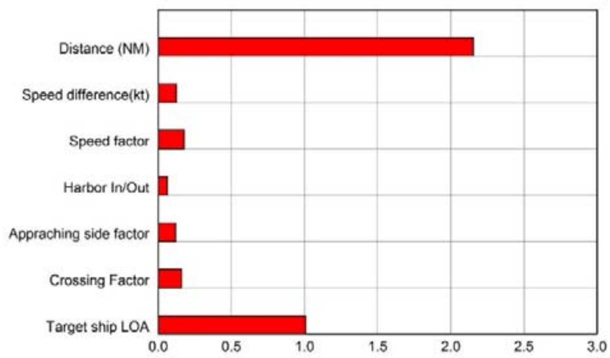

Figure 1. Risk factor by PARK model

The PARK model estimated that the range of risk is 1–7, the sensitivity of the distance factor is 2.15355, the factor of the speed difference between ships is 0.12325, the speed factor is 0.1777098, the inner and outer harbor factor is 0.062305, the side approaching factor is 0.118905, crossing situation factor is 0.158458, and the length overall (LOA) of the other ship is 1.0068. Among these, the distance was 2.15355, confirming that the distance factor affect on approximately 30.7% of the total risk.

2.1.2 *ES model (ESS)*

The environmental stress (ES) model is based on the difficulty associated with the operation of the ship accompanied by the load imposed on the operator and attempts to quantify the natural, terrain, facility, and traffic conditions surrounding the operator (Inoue et al., 1998). This model is subjected to two types of stress, including stress with respect to the environment of operation and stress with respect to the traffic environment. However, this study was limited only by the analysis of the traffic environment stress relevant to the ship traffic. The determinants of the traffic environment stress included the distance to oppnent ship and the average length of the own ship and the opponent ship. In this model, the risk value can be determined as follows:

$$\begin{aligned} \text{Risk value} &= \alpha \times (R / V \cdot V / Lm) + \beta \\ &= \alpha \times (R / Lm) + \beta = \alpha \times (R') + \beta \\ \alpha &= 0.00192 \times \text{Lm} \end{aligned} \quad (2)$$

Crossing factor with other ship

$$\text{starboard crossing } \beta = -0.65 \times \ln(\text{Lm}) - 2.07$$

$$\text{port crossing } \beta = -0.65 \times \ln(\text{Lm}) - 2.35$$

$$\text{Head on } \beta = -0.65 \times \ln(\text{Lm}) - 2.07$$

$$\text{Overtaken } \beta = -0.65 \times \ln(\text{Lm}) - 0.85$$

The ES model is based on the difficulty of ship operation accompanied by the restriction of the load imposed on the operator when the surrounding conditions surrounding the operator, such as natural conditions, terrain conditions, facility conditions, and traffic conditions, it was a model that tried to quantify (Inoue et al., 1998). The ES model has stress on the environment of operation, and stress on the traffic environment. However, this study limitedly analyzed the traffic environment stress related to the traffic of the ship. The determinants of the traffic environment stress are the distance to the opponent ship and the average length of the own ship and other ship.

Figure 2 illustrates the degree of the factors with respect to the final risk based on the ES model.

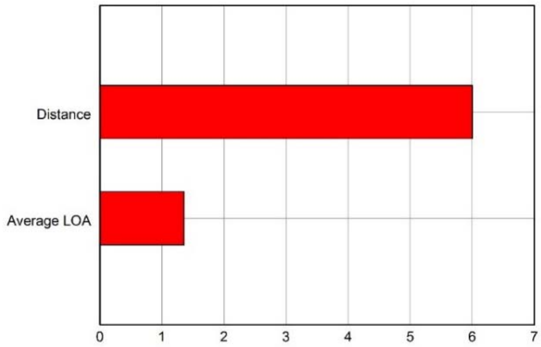

Figure 2. Risk factor by ES model (ESS)

The range of risk was 0–6, the sensitivity of distance was 6, and the average length of the own and opponent ships was 1.354532. Among these, the distance factor was 6, confirming that the distance factor affect on 100% of the total risk.

2.2 *Analysis based on machine learning*

2.2.1 *Classification model construction based on RFC algorithm*

Random forest (RFC) algorithm is a type of ensemble learning method used in classification and regression analysis in machine learning. It operates by outputting class (classification) or average predicted value (regression analysis) from a plurality of decision trees constructed in the training process (Park, 2017). In this study, classification model was constructed by using RFC model through analysis of navigation pattern and the importance of the features was assessed. Simulation experiments were conducted to collect the data to construct the model.

1 Simulation overview

The Kanmon Strait was selected as the test water body because of its high level of difficulty (Shin et al., 2017). Additionally, because of the highest traffic volume from 8:00 am to 9:00 am, this time zone was selected, where the corresponding AIS data was received and the corresponding scenario was created (Hiroaki et al., 2010; Lee, 2018).

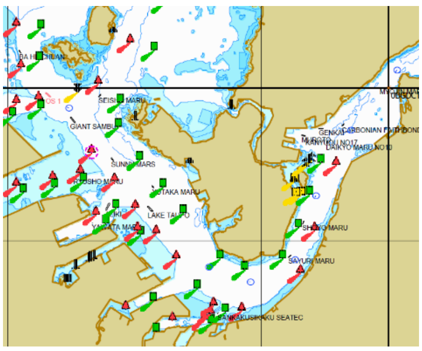

Figure 3. Test waters (Kanmon Strait)

The subjects are consisted of two groups, one is the apprentice officer group who is the 4th grade student at the Korea Maritime and Ocean University with one year of onboard training, and the other is experienced officer group. Figure 4 illustrates the career of experienced officer group.

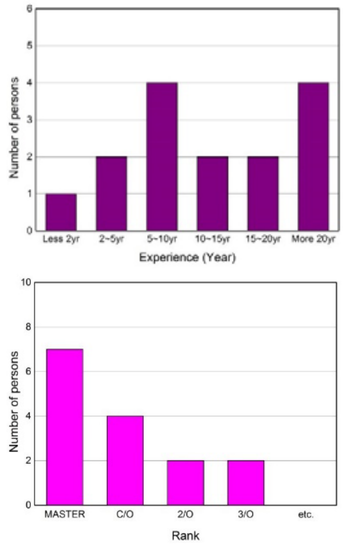

Figure 4. Rank and experience of the test officers

7 teams were formed and each team including a captain who are experienced in Kanmon Strait. The familiarization were conducted in different parts of the test waters and repeated more than twice to minimize the influence of ship maneuver simulation familiarity. The tests were subsequently conducted.

2 Construction of Classification model

For analyzing the navigation patterns, the following data were collected: ship speed at each time zone, vessel size considered to be the most dangerous, distance between the vessels, DCPA, TCPA, PARK model risk value, and encounter situation. The random forest algorithm was employed for constructing a classification model by learning using 80% of the data and performing model testing using the remaining 20% of the data. Currently, the average score obtained using the test data was 0.87.

3 Evaluation of the classification model and feature importance

Table 1 presents the evaluation results for the constructed model.

Table 1. Evaluation index of the constructed model

	Precision	Recall	F1-score
Apprentice officer	0.88	0.94	0.91
Experienced officer	0.83	0.67	0.74
Average	0.86	0.86	0.86

In Table 1, precision indicates the ratio of actual True that the machine learning model evaluated as True, whereas recall indicates the ratio of the correct answer value of the model to the correct answer value.

F1-score denotes the harmonic mean value obtained using precision and recall as appropriate (Park, 2017). Note that the constructed model denoted reliability with average values of 0.86 for precision, recall, and F1-score.

Subsequently, a receiver operator characteristic (ROC) graph was created for the model as other evaluation methods. The ROC graph was obtained by visualizing the horizontal axis to denote a false positive rate and the vertical axis to denote a true positive rate. This model uses values of the area under curve (AUC) to represent the accuracy as a single number, and the ROC–AUC value is the area of the ROC graph. Figure 5 displays the ROC graph for the created model.

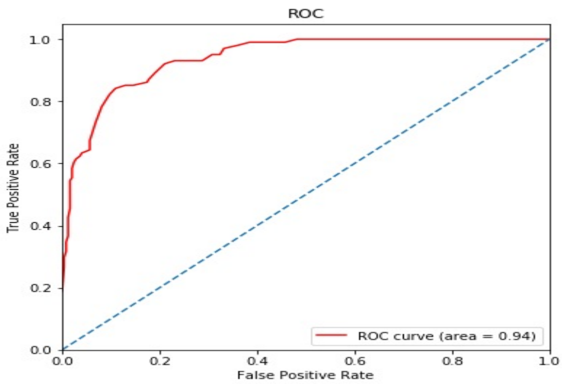

Figure 5. ROC graph for constructed model

From Fig. 5, AUC exhibits a value of 0.94, which is a high score. Thus, the evaluation methods confirmed the reliability of the model. The importance of each feature was analyzed using this model to distinguish between the apprentice officers and the experienced ones.

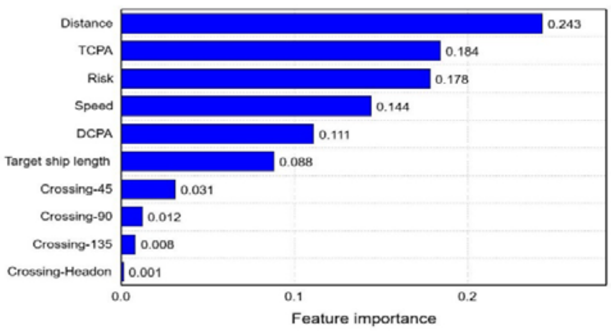

Figure 6. Feature importance

Figure 6 displays the importance of the analyzed features by distinguishing the apprentice or experienced officers in order of distance with other vessel > TCPA > PARK model risk > speed > DCPA > secondary ship length > crossing factor. The distance denoted the highest importance of 0.243.

2.3 *Sub-conclusion*

In order to acquire the factors that can enhance the safe navigation skill by intensively training the apprentice officers, marine traffic risk model was analyzed and the navigation pattern was analyzed using machine learning.

First, The PARK and ES models were analyzed to evaluate the marine traffic risk and derive the factors that should be included in the extensive training of apprentice officers to acquire the necessary navigation skills. There was a significant variation between the risk factors for both the models, except in term of the separation distance, which were observed to be the factors that contributed most to safety risks. Particularly, the distance reflected a 100% maximum risk possibility in the ES model, and the PARK model determined that the risk contributed by the distance could constitute up to 30.7% of the total risk.

Secondly, the navigation patterns were analyzed to identify the most important features that can be used to distinguish the experience between the apprentice and experienced officers. As a result, the distance from other vessels was identified as the most important factor with the importance of 0.243.

Therefore it was confirmed that that it is important for the apprentice officers to sailor to acquire the skill to maintain a constant distance from other ships for safe maritime navigation.

3 COMPARATIVE ANALYSIS RESULT OF EXTENSIVE TRAINING FACTORS

3.1 *T-test for distance*

To verify whether there was a statistical difference in the mean of the distance between the apprentice and the experienced officers, a T-test was conducted based on the encounter relation presented in Fig. 7.

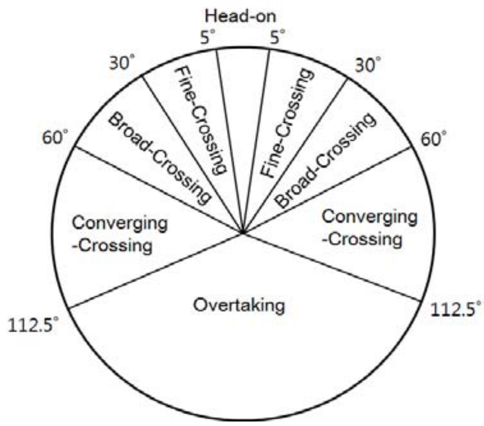

Figure 7. Encounter degrees

The null hypothesis is that the average distance between the apprentice and experienced officers was the same; the alternative hypothesis is that the average distance between the apprentice and experienced officers was different. Table 2 reflects the results of the T-test.

Table 2. Results of the T-test

		N	M	SD	T(p)
Head-on	Apprentice	235	764.22	171.58	−3.949
	Experience	228	820.77	135.03	(.00)***
Fine Crossing (St'bd)	Apprentice	558	744.81	180.80	2.408
	Experience	222	707.24	202.53	(.017)**
Broad Cross. (St'bd)	Apprentice	504	651.09	201.28	4.474
	Experience	155	566.21	222.94	(.00)***
Converging Cross. (St'bd)	Apprentice	518	609.27	228.54	3.050
	Experience	154	544.15	245.91	(.002)**
Overtaking	Apprentice	1622	670.41	224.85	5.283
	Experience	953	621.79	226.52	(.00)***
Fine Cross.(port)	Apprentice	634	733.77	178.69	−1.566
	Experience	493	750.71	182.22	(.118)
Broad Cross.(port)	Apprentice	731	681.41	214.43	2.440
	Experience	271	640.90	240.11	(.015)**
onverging Cross.(port)	Apprentice	590	536.96	202.04	1.625
	Experience	270	510.57	229.17	(.105)

$p^* < 0.1$, $p^{**} < 0.05$, $p^{***} < 0.01$

Except for fine and converging crossing at the port, the null hypothesis was rejected; hence, the alternative hypothesis was adopted. In short, the average distance navigated by majority of the apprentice and experienced officers was different. Particularly, as confirmed by the average values, the experienced officers navigate longer distances than that navigated by the apprentice officers.

3.2 *Density*

The separation distance between the ships was confirmed by plotting every 10 s using the direction and relative distance. Figures 8 and 9 display the scatter plots of the relative distances.

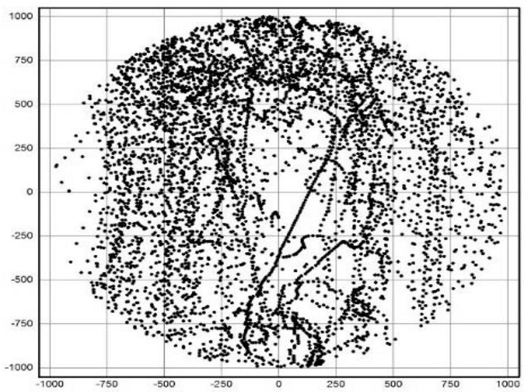

Figure 11. Ship plotting in case of the apprentice officer

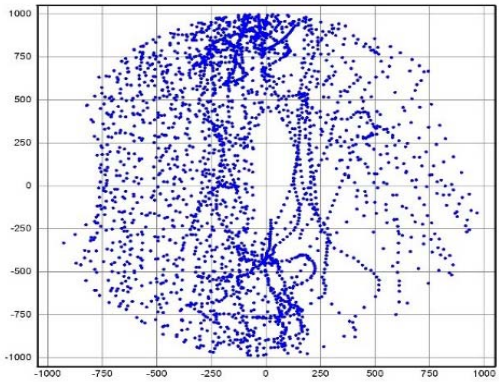

Figure 10. Relative distance scatter plot in case of the experienced officer

Based on these figures, the junior officer seemed to maintain a space of approximately 150 m without a ship, nearly 200 m in front and approximately 750 m on both the sides. The density of the ship was provided by a mesh of 50 m to verify the ship distribution, as depicted in Figures 10 and 11.

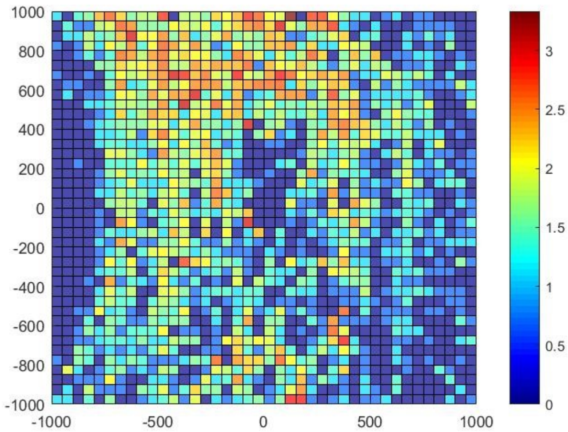

Figure 9. Mesh of ships in case of the apprentice officer

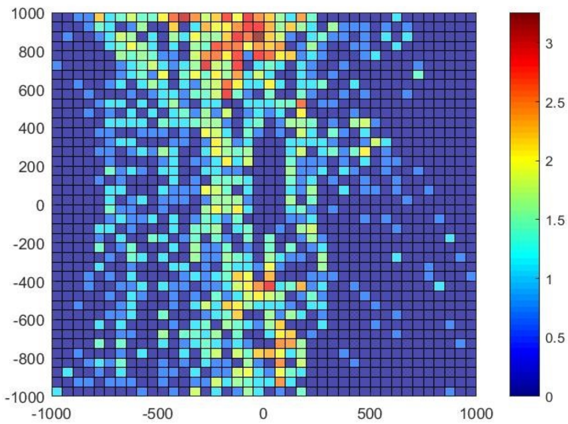

Figure 8. Mesh of ships in case of the experienced officer

Note that the ship distribution in case of the apprentice officer safe separation distances between the front and rear of the ship were uncertain. On the contrary, the safe separation distances are observed when the experienced officers navigate, where a 400m separation in the forward direction and a 200m separation in the backward direction were maintained.

3.3 *Minimum and average of relative distance each bearing*

The separation distances were validated using relative bearing, where the average and minimum relative distances were denoted graphically by dividing the bearing around the ships into 10° units. Figures 12 and 13 shows the average and minimum distance by bearing.

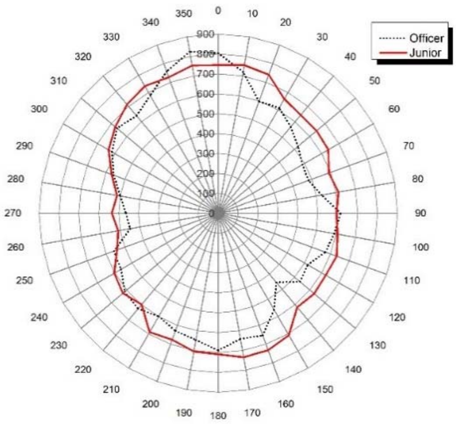

Figure 13. Average distance by bearing

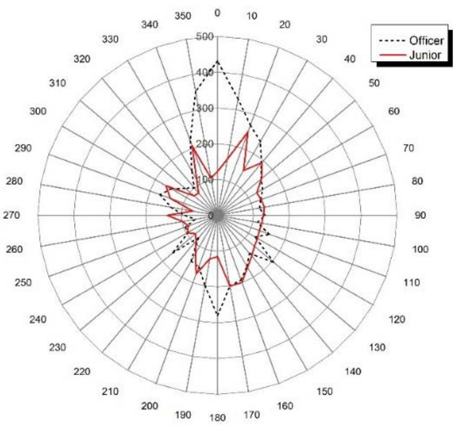

Figure 12. Minimum distance by bearing

The average distance obtained by relative bearing was 651 m for the junior officer and 598 m for the experienced officer, indicating a small distance yield for the latter. In contrast, the averages of the minimum distances were 135 m for the junior officer and 171 m for the experienced officer, indicating a large distance for the latter. Especially, the minimum distance yield for the experienced officers was large for both the front and rear of the ship. This confirms that the total distance in case of the experienced officer was shorter than that in case of the junior officers. However, the suitable clearance distance was maintained in the front and rear of the ship in case of the experienced officers.

4 CONCLUSION

This study intended to derive the factors that should be included for the extensive training of apprentice officers to ensure that they acquire the necessary set of skills and experience and, subsequently, to suggest the corresponding guidelines. The factors were selected through the analysis of the risk factors during navigation using the marine traffic risk model and the machine learning algorithm. Further, simulations were conducted for both groups of junior and experienced officers to derive the static value of the separation distance of ships, which exhibits the greatest influence among the risk factors. The conclusions can be generalized as follows:

1 The PARK and ES models were employed and analyzed for selecting the most influential factors while evaluating the navigation risk factors that should be included for the extensive training of apprentice officers. In the ES model, the separation distance between the ships exhibited a maximum influence of 100%. In the PARK model, the separation distance attributed to the maximum risk was 30.7%.
2 Based on the results of navigation simulation in Kanmon Strait by apprentice and experienced officers, a classification model was created by RFC algorithm using machine learning. Here, the factor with the greatest influence on classification was the distance factor at 0.243, which denoted the highest importance among all the features. Thus, the distance from other vessels was considered to be an extensive training item.
3 The results of the simulations conducted with respect to the junior and experienced officers that aimed to derive an appropriate separation distance yielded statistically significant values, except for the direction of 247.5° to 330°.
4 After analyzing the density of the other ships and their relative distances from the own ships according to the directions, short average distances were observed for the experienced officers even though the separation distances in the front and rear were long. Specifically, a separation distance of 400 m was maintained 350°–010° in the front and that of 200 m was maintained 170°–190° in the rear.

As a result, a safe separation distance of approximately 600 m was confirmed including the front and the rear. Thus, the minimum safe separation distance should be maintained 600m at Kanmon Strait and this should be educated inexperienced junior officers as a guideline.

In the future studies, the simulations could be extended to different test waters to achieve appropriate safe separation distance in various scenarios when the navigation is being performed by junior officers and comparative analysis with the actual navigation data should be performed to prove the appropriateness of the minimum safe separation distance.

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