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A Study on the Relationship between Marine accidents and Near-miss using PARK model

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Abstract : *Marine accidents often stem from near-miss incidents, which are critical indicators of potential collisions. Understanding the causal factors associated with these incidents is essential for enhancing maritime safety. This study employs the PARK model to identify causal factors related to maritime accidents, with a focus on near-miss incidents in Busan Port. By analyzing AIS data from 2017 to 2021, the research identifies 36 collision incidents. The PARK model assesses risk levels, setting a threshold of 5.0 for near-miss scenarios and examines the relationship between these incidents and actual collisions. The analysis indicates an average of 0.8 collisions per year, with the PARK model estimating a probability of approximately 2.34 collisions annually per million vessel encounters at a risk score of 5.0. This research highlights the effectiveness of the PARK model in identifying causal factors related to marine accidents. By correlating near-miss incidents with actual collision probabilities, the study offers insights that can improve reporting practices and proactive safety measures among vessel operators, ultimately contributing to enhanced maritime safety in South Korea.*

Key words : *marine accident, near-miss, causal factor, risk assessment, collision probability, PARK model*

1. Introduction

The number of marine accidents has been on the rise, with a total of 3,092 accidents reported in 2023, reflecting an 8.0% increase compared to the previous year. However, fatalities and missing persons totaled 94, a decrease of 5 individuals (5.1%) from the prior year (KMST, 2024a). The Korea Maritime Safety Tribunal has been actively promoting the Near-Miss Reporting System to prevent marine accidents and is making every effort to enhance maritime safety (KMST, 2024b).

According to Heinrich's Law, minor incidents often precede major accidents, highlighting the need for managing minor incidents as a preventive measure before they escalate into serious accidents (Heinrich, 1941). In response to recommendations from the International Maritime Organization (IMO), South Korea implemented the Near-Miss Reporting System in 2011 to manage near-miss incidents (IMO, 2008). This system, though non-mandatory, operates on voluntary participation by stakeholders involved in near-miss incidents. Under the relevant regulations, near-miss incidents are defined as situations where collisions, contacts, groundings, sinkings, fires, marine pollution, or other accidents were narrowly avoided. Among these, collisions, groundings, sinkings, fires, and safety incidents pose significant risks to human life and are classified as major accidents by the government (KMST, 2024b).

According to a report by the Korea Maritime Institute (KMI), approximately 70% of the near-miss incidents reported to the government involve safety incidents or equipment failures, which are common occurrences in daily operations (Park et al., 2023). This high reporting rate is likely due to the ease with which ship operators, who frequently encounter such events, can report these incidents. However, despite collisions being the most common type of major accident, near-miss reports related to collisions are relatively few, comprising only 6.6% of the total. Based on Heinrich's Law, which suggests that minor incidents occur at a ratio of 1:300 relative to major accidents, it is possible that many near-miss incidents related to collisions are under reported and remain unnoticed.

This study aims to quantify minor events that occur before a collision and derive the correlation between marine traffic risk assessment models and marine accidents. To

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achieve this, we focus on the waters near Busan Port, a high-traffic area in South Korea, and seek to estimate the number of marine accidents and the rate at which dangerous moments lead to actual accidents.

2. Literature review

Bixler (2009) emphasized the importance of the near-miss reporting system in the maritime industry through an analysis of marine accident case studies. Hasanspahic et al. (2022) investigated the barriers to reporting near-miss incidents among seafarers, revealing that under reporting and issues with the reporting process hinder the activation of the near-miss reporting system. The authors suggested simplifying and standardizing the reporting forms to encourage more active reporting. They also pointed out that in some cases, reports are fabricated to meet mandatory quotas, underscoring the need to foster a culture of voluntary reporting rather than enforcing mandatory submissions.

ABS (2014) developed and distributed methods for investigating near-miss incidents since 2005 and provided causal maps to analyze root causes. In the maritime sector, the near-miss reporting system operates primarily through shipowners reporting near-miss incidents from ships in accordance with the ISM Code, with much research focusing on the system from the perspectives of shipowners or operators. There is consensus on the importance of running a near-miss system as part of creating a safety culture to prevent major accidents. Kang et al. (2017) developed an accident analysis model to activate the current near-miss reporting system and proposed various policies to improve the system overall, including suggestions to revitalize the Near-Miss Incident Reporting Development Council. They also examined the relationship between marine accidents and near-miss big data analysis results by developing techniques to analyze near-miss information.

Chae et al. (2018) proposed expanding the system to allow for voluntary reporting, transferring management to private organizations, and introducing an incentive program. Roh and Kang (2021) quantitatively analyzed text-based near-miss data, demonstrating the potential of near-miss data analysis using big data techniques. Kang (2020) highlighted the problems with the current near-miss reporting forms and proposed the need for standardization.

The near-miss reporting system in the maritime industry has largely been influenced by the ISM Code and is primarily managed by shipowners. While the system focuses on shipowners as the main reporting entities, management direction may vary depending on the values of individual companies. In South Korea, various measures have been proposed through research to enhance the effectiveness of the near-miss reporting system, such as improving reporting procedures, standardizing reporting forms, and suggesting efficient implementation strategies.

Regarding collision accidents, Ha et al. (2020) proposed the following criteria for near-miss collisions: a Closest Point of Approach (CPA) of less than 0.22 miles, a Time to Closest Point of Approach (TCPA) of less than 3 minutes, and a separation distance of less than 0.2 nautical miles (NM). Kim et al. (2014) proposed near-miss collision criteria based on ship position clustering and bumper zones. Yoo (2018) suggested near-miss collision criteria with a CPA of less than 0.1 miles, TCPA of less than 3 minutes, and a rate of distance change of less than 0.3 NM. Vestre et al. (2021) used CPA and TCPA to assess near-miss incidents, while Montewka et al. (2012) utilized ship domains to evaluate near-miss collisions. CPA, TCPA, and ship domain theory are commonly used criteria for determining near-miss collisions with other vessels. However, Montewka et al. (2010) noted that failing to properly consider regional and causal factors can lead to discrepancies in collision risk assessments. Therefore, when establishing near-miss collision criteria, it is necessary to account for regional environmental factors as well.

This study aims to quantitatively assess near-miss collisions in South Korea and present the rate at which these events escalate into accidents. As suggested by Montewka et al. (2010), this study will not only consider CPA, TCPA, and ship domain factors but will also incorporate a model that reflects the maritime environment of South Korea to derive collision-related causal factors.

3. Methodology

3.1 PARK model

The Potential Assessment of Risk (PARK) model is a marine traffic risk assessment model that reflects the safety awareness of South Korean ship operators. It is designed to assess the navigational risks of vessels operating in coastal waters of South Korea.

This model was developed through a survey targeting South Korean ship operators, which focused on their perceptions of subjective risk regarding various ship encounters and vessel-related factors. The model was then constructed based on the results of analysis of variance (ANOVA), multiple comparison analysis, and regression analysis (Kim et al., 2011; Heo et al., 2012). Studies by KMOU (2011), Nguyen (2014), and Nguyen et al. (2015) applied the PARK model to Korean waterways for comparison with the Environmental Stress (ES) model, which is used in marine traffic safety diagnostics in Korea. Their findings validated that the PARK model is more suitable for assessing collision risk in Korean waterways.

The formula for calculating the risk level in the PARK model, as well as the values of its calculation elements, are based on both internal and external factors that influence ship collision risk.

$$Risk = 5.081905 + (T_p + T_f + L_f + W_f + C_f + L_{of} + P_f) + (0.002517L + C_f + S_f + Hi/o + S_p - 0.004930S_d - 0.430710D) \quad (1)$$

where,

T_p : own ship type factor;

T_f : own ship ton(GT) factor;

L_{of} : own ship length factor;

W_f : own ship width factor;

C_f : own ship operator's license factor;

P_f : own ship operator's position factor;

L : target ship's LOA (m);

C_f : approaching crossing factor of target ship;

S_f : approaching side factor of target ship;

$H_i/_o$: in/out harbor factor of own ship;

S_p : speed (kt) factor between ships;

S_d : speed (kt) difference between ships;

D : distance between ships (NM)

The risk level calculated using the PARK model is compared with the adjusted risk level based on the ship's Length Overall (LOA), the distance to the Closest Point of Approach (CPA), and the Time to CPA (TCPA). The lower of the two risk levels is used forthe final assessment (Lee, 2018). The PARK model evaluates risk on a scale of 1 to 7, where a score between 1 and 3 indicates a safe situation, 3 to 5 represents a neutral situation (neither safe nor dangerous), and a score above 5 signifies a dangerous situation.

3.2 Estimation of correlation for accident candidates

Montewka et al. (2012) estimated the correlation between actual accidents and potential accident candidates. The correlation coefficient for a given encounter situation is estimated as follows:

$$P_{C,e} = \frac{N_{accidents}}{N_{cnadidate}} \quad (2)$$

In this context, $N_{accident}$ represents marine accidents that occurred in a given encounter situation, while $N_{candidate}$ refers to the accident candidates for that encounter situation. In other words, if actual accidents and potential accident candidates exist within a specific area, the correlation between them can be estimated. In the case of collision accidents, an additional step, called "ship maneuvering factors" is introduced. The ship maneuvering factor refers to the proportion of near-ship situations among collision candidates and is expressed by the following formula:

$$SHF_e = \frac{N_{near-collision}}{N_{collision-candidate}} \quad (3)$$

The final correlation is derived by multiplying the "ship maneuvering factor" with the collision candidates for each encounter relationship, and is represented by the following formula:

$$P_{C,e} = SHF_e \frac{N_{accidents}}{\sum_e N_{candidate}} \quad (4)$$

Montewka et al. (2012) used the MDTC model to derive collision accident candidates, while near-ship situations were determined using the ship domain concept proposed by Wang et al. (2009). In this study, collision candidates are derived using the PARK model, and for collisions, the correlation coefficient is estimated by applying the ship domain to near-ship situations.

4. Results analysis

4.1 Data

The analysis focused on the area around Busan Port, where marine accidents have occurred most frequently over the past five years. AIS data was collected for a total of seven days from August 5, 2021, at 00:00 to August 12, 2021, at 24:00. Inoue & Hara (1974) stated that at least three days of marine traffic data are required to assess the marine traffic characteristics of a given area over the course of a year. Yoo et al. (2015) also indicated that marine traffic surveys need to be conducted for at least one week, considering the day-of-week variability index. Furthermore, the "Guidelines for Marine Traffic Safety Diagnostics" specify in Appendix 3 that a minimum of three days of AIS data is required. Therefore, this study also utilized seven days of marine traffic data.

4.2 Result Analysis

4.2.1 Marine Accident Occurrence

Excluding port areas, a total of 36 collision accidents occurred in the coastal waters from 2017 to 2021, averaging about seven incidents per year. Table 1 shows the number of collision accidents in the study area. Among these incidents, four collisions occurred between cargo ships, 15 between fishing vessels and cargo ships, and 17 between fishing vessels.

In this study, marine accidents involving cargo ships were analyzed, considering the notification targets for near-miss incidents. On average, there were 0.8 collisions per year between cargo ships.

Table 1 Number of marine accident in target area

Year	Non fishing vessel - Non fishing vessel	Non fishing vessel - Fishing vessel	Fishing vessel - Fishing vessel	Total
2017	-	2	4	6
2018	2	1	3	6
2019	1	3	4	8
2020	1	4	4	9
2021	-	5	2	7
Total	4	15	17	36

4.2.2 High risk value of ship collision

In the PARK model, dangerous encounter relationships are defined as having a risk value of 5.0 or higher (Nguyen, 2014). In this study, the threshold for near-miss incidents is assumed to be a risk value of 5.0 or above, further subdivided into intervals of 0.5. This subdivision aims to provide a more detailed assessment of near-miss incidents. Fig. 1 illustrates the distribution of PARK model risk values in the study area. It is notable that vessels with a risk value of 5.0 or higher are predominantly concentrated closer to the port area.

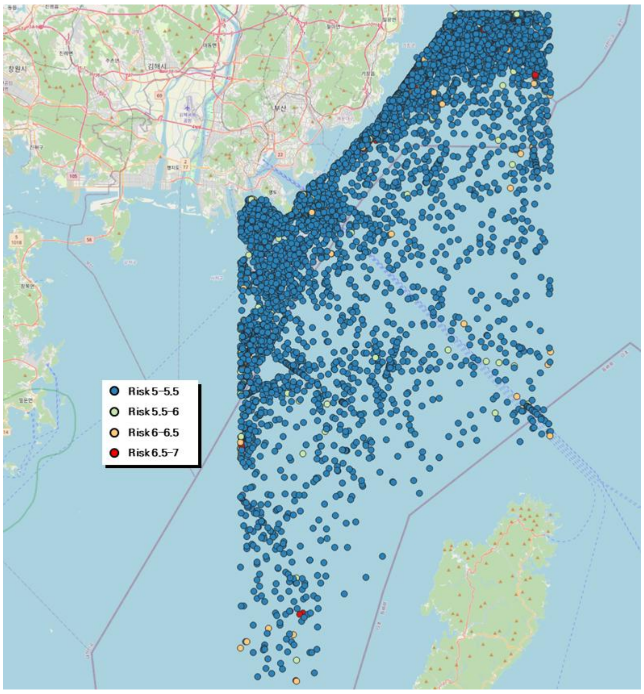

Fig. 1 PARK model risk value in target area

Table 2 presents the number of collision candidates identified using the PARK model. As vessels encounter each other and gradually come closer, their risk values may either increase or decrease as the situation is resolved. Therefore, the risk levels for the two vessels were determined based on the initial encounter time. Through a seven-day marine traffic survey, risk values were first derived and then extrapolated to represent a one-year period. Inoue and Hara (1974) noted that at least three days of marine traffic data are required to understand the traffic characteristics of a given area over one year; thus, it was concluded that the seven days of data can adequately represent one year.

Table 2 Number of collision candidates using the PARK model

days	More than Risk 5.0	More than Risk 5.5	More than Risk 6.0	More than Risk 6.5
7-day	7,363	322	135	35
1-year conversion	367,137.8	16,790	7,039.2	1,825

4.2.3 Causal Factors

To derive causal factors, it is necessary to determine the proportion of collision candidates that fall within areas where vessels cannot avoid collisions due to maneuvering constraints. The ship domain is the subject of various studies and, in some cases, may be the area that serves as the starting point for a ship operator's avoidance maneuvers(Szłapczýnski et al., 2024). This study utilized the International Maritime Organization (IMO) maneuverability performance criteria (IMO, 2002). According to these criteria, the advance of a vessel should not exceed 4.5 times its length, and the tactical diameter should not exceed 5 times its length. These measures indicate the minimum distances a vessel must travel forward and laterally when making a turn.

In this study, ellipses with long and short diameters of 4.5L and 5L, respectively, were defined as the areas where vessels cannot avoid collisions due to maneuvering constraints, which were considered near-ship situations.

Fig. 2 illustrates the heatmap of near-ship situations for vessels with a PARK model risk value of 5.0 or higher.

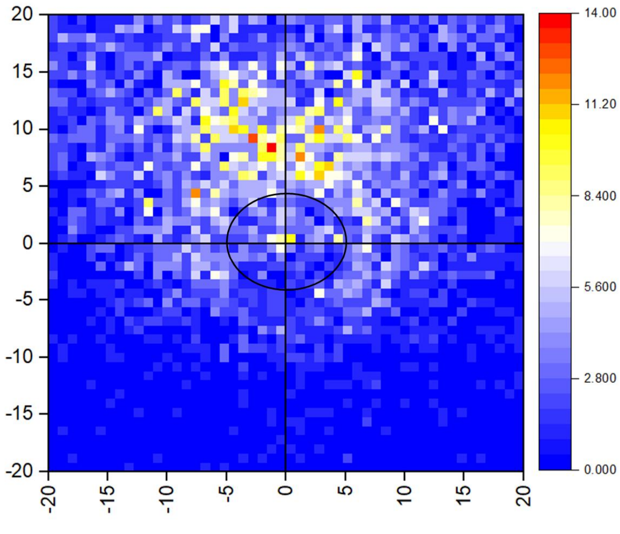

Fig. 2 Heat map of close situations (risk level 5 or higher)

The analysis focused on these vessels to assess how far they are from each other based on their lengths and to evaluate the distribution of vessels in near-ship situations among those with risk values exceeding 5.0.

Table 3 presents the proportion of near-ship situations categorized by risk value. By examining the proportion of near-ship situations, we can ascertain how many vessels within a certain risk category fall into areas where collisions cannot be avoided due to maneuvering constraints. This analysis provides insight into the proportion of vessels that are likely to lead to collision incidents.

The causal factors can be derived based on the near-ship situation ratios. As the risk value increases, the likelihood of collision occurrences also rises. This indicates that as the criteria for near-miss incidents become stricter, the probability of leading to collision accidents increases.

Table 3 Close situation and causal factor by risk level

days	More than Risk 5.0	More than Risk 5.5	More than Risk 6.0	More than Risk 6.5
7-day	7,363	322	135	35
close situation	288	142	63	23
Rate of close situation	0.03911	0.440994	0.466667	0.657143
Causal factor	2.34×10^{-7}	2.64×10^{-6}	2.79×10^{-6}	3.93×10^{-6}
Number of cases per 1 accident	4,266,470	378,419.9	357,601.8	253,949.1

5. Discussion

This study utilized the PARK model to derive causal factors between collision candidates and marine accidents. Understanding these causal factors allows for predictions regarding the occurrence of marine accidents based on the identified collision candidates in specific areas. If the criteria for collision candidates are aligned with those for near-miss incidents, it becomes possible to estimate marine accidents through the analysis of near-miss incident data.

For instance, if it is assumed that 100,000 near-miss incidents are observed annually in a specific area, marine accidents in that region can be predicted as shown in Table 4. When using the PARK model, the estimated occurrences range from a minimum of 0.02 to a maximum of 0.39 accidents, depending on the risk criteria applied.

The prediction of collision-related marine accidents using a risk model is significant for verifying the correlation between near-miss incidents and actual collision accidents. The correlation presented between collision-related near-miss incidents and collision accidents, based on the PARK model (with a risk threshold of 6.5), indicates a correlation coefficient of 3.93×10^{-6}. This suggests that out of 1,000,000 near-miss incidents related to collisions, approximately 3.93 incidents may lead to actual collisions.

Table 4 Prediction of collision accidents by risk value

Standards	More than Risk 5.0	More than Risk 5.5	More than Risk 6.0	More than Risk 6.5
1 year near-miss	100,000			
Causal factor	2.34×10^{-7}	2.64×10^{-6}	2.79×10^{-6}	3.93×10^{-6}
Marine accident (1year)	0.0234	0.264	0.279	0.393

If clear criteria for assessing collision-related near-miss incidents are established, it would be possible to derive these incidents using vessel operational data such as AIS. This, in turn, could enable rough estimations of the number of potential collision accidents. While this analysis focused on the correlations in the waters near Busan Port, expanding the scope could facilitate the estimation of relationships between near-miss incidents and marine accidents throughout South Korea.

However, it should be noted that this study was conducted specifically on vessels navigating the waters near Busan Port and associated marine accidents, which limits its ability to represent the overall correlation of collisions across the entire country.

6. Conclusion

According to Heinrich's Law, minor accidents can lead to major accidents, as the causes of minor accidents often contribute to the causes of major accidents. Therefore, managing minor accidents is essential. In this regard, the International Maritime Organization (IMO) also recommends managing near-miss incidents, and South Korea has adopted this approach into domestic law, implementing a near-miss reporting system. This system has been in operation since 2011 and has become established over approximately 13 years through various policies. However, there are limitations to the voluntary reporting by vessel operators. This study aimed to quantitatively derive near-miss incidents related to collisions and propose correlation factors that lead to marine accidents. The findings of this research can be summarized as follows:

(1) Analysis of previous research: The risk factors associated with collision accidents should consider not only the Closest Point of Approach (CPA), Time to CPA (TCPA), and vessel domain but also the environmental factors of the area.

(2) Utilization of the PARK model: To account for the characteristics of South Korean waters, the PARK model was employed to identify risk groups for collision accidents. Following the IMO recommendations, elliptical areas where vessels cannot maneuver were defined with long diameter (4.5L) and short diameter (5L).

(3) Probability of collision: By focusing on Busan Port, it was found that when the PARK model risk level is above 5.0, the probability of leading to a collision is approximately 2.34×10^{-7}. This indicates that, considering an annual interaction of 1,000,000 vessels, around 2.34 collisions could occur. Additionally, it was confirmed that increasing the risk threshold raises the probability of collision accidents.

This study is significant in that it presents a quantitative method to derive collision accidents among near-miss incidents, beyond just relying on voluntary reporting by vessel operators. Although the research focused on the heavily trafficked Busan Port in South Korea, combining marine accidents with models in major sea areas could allow for the derivation and management of collision-related near-miss incidents across broader regions. Based on this, if voluntary participation from vessel operators is encouraged and data-driven quantitative analyses are conducted to derive and manage near-miss cases, it could significantly contribute to the prevention of marine accidents.

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