Application of potential assessment of risk (PARK) model in Korea waterways

Youngsoo Park\(^a\), Jinsoo Park\(^b\), Daewoon Shin\(^c\), Myoungki Lee\(^c\) and Sangwon Park\(^d\)

\(^a\)Division of Maritime Transportation Science, Korea Maritime and Ocean University, Busan, R.O.K.; \(^b\)Division of Global Maritime Studies, Korea Maritime and Ocean University, Busan, R.O.K.; \(^c\)Korea Maritime and Ocean University, Busan, R.O.K.; \(^d\)Korea Maritime Institute, Busan, R.O.K.

**ABSTRACT**

Korean coastal waterways are potentially the most dangerous zones for marine accidents owing to a high volume of traffic, irregular traffic patterns of fishing vessels, frequent ship encounters, and narrowness of navigable area because of offshore construction and port enlargement construction. However, there are only few marine traffic assessment models that can be referenced from other countries, and none of them contain a risk assessment model suitable for the situation regarding Korean waterways. Therefore, it is necessary to develop a quantitative assessment of marine traffic environments based on ship navigator's consciousness. To develop a new, suitable assessment model for marine traffic, the internal and external elements of vessels, based on a questionnaire survey and simulation experiment, are considered. The ship's internal static parameters, vessel type, length, and width, as well as mariner's experience, license, and rank on board are determined for the risk value. Furthermore, the external dynamic elements are calculated by the results of the questionnaire, which addresses the ship's encounter situations and distances. Through this potential assessment of risk model, we used function as navigation equipment onboard to prevent a collision accident, applied it as a solution of a Vessel Traffic System (VTS) decision-making support system, and used the vessel evacuation route to recover the vessel's normal situation from an emergency.

**Introduction**

Korea coastal waterways undergo a high volume of traffic compared to other countries and more than 3000 islands exist along the Korean coast. At least 11 main marine traffic flows have been observed in the Korean coastal waters. Moreover, 60,000 fishing vessels have been registered to date (Park et al. 2015, 318–325). These vessels have irregular traffic patterns in coastal waters. Some areas undergoing offshore construction and port enlargement construction at sea have restricted the vessels' ability to navigate safety. As a result, it can be said that Korean coastal waters have a high risk of marine accidents because the navigable space for ships has become smaller. However, it has been difficult to easily determine the danger level for certain ships and areas in the coastal waterways until now.

Therefore, there is a present need to develop a marine traffic assessment model to represent the degrees of navigation danger based on the ship navigator's consciousness to prevent or reduce ship accidents in advance in the congested waters. Korea has had the maritime traffic safety audit scheme, which was instituted by the maritime safety law since 2009. This revised Korea maritime safety law requires a quantitative assessment of the marine traffic environment. Unfortunately, it has no risk assessment model that is suitable for the situation in the Korean waterways.

This paper aims to introduce a quantifiable display of the degree of traffic danger among a designated (own) ship and other ships in the Korean waterways to develop the traffic assessment. Furthermore, this research introduces the technological development and application of the mariner/VTSO decision-making system based on the ship operator's danger level.

**Necessity for development of marine traffic assessment model in adaptive Korean waterways**

**Change in features of Korean waterways**

The northern part of R.O.K. is blocked by division and three sides of the country are surrounded by the sea. More than 99% of export and import cargo volumes are transported by ships. R.O.K. (henceforth, Korea) needs to keep maritime transportation continuously active for national economic development. Thus, it is expected that marine transportation volumes will continuously increase in Korean waterways. Figure 1 shows the changing trend of vessels' calling numbers in Korea. In this figure, the line represented by square shapes shows the...
water, etc. in order to navigate the vessel safely. The distance depends on the speed of the vessel, visibility, kinds of dangerous goods. This zone in which the navigator is trying to maintain a certain distance is called the bumper zone as shown in Figure 3. 8L(FA) × 3.2L(SP) is a typical famous ship’s domain bumper zone for safe navigation in overseas waterways from the 1970s (Fujii, Makishima, and Hara 1983). But the mariner’s consciousness of bumper zone has changed in Korea and oversea waterways for decades. As seen in Table 2, there are differences in bumper zones among waterways in other countries, and the ship domain for safe navigation is becoming smaller with time (Park, Jeong, and Kim 2010, 406–410; Um et al. 2012, 416–422; Park and Jeong 2014, 535–542).

Additionally, many collisions and ground accident positions are located in the coastal areas, especially the Korean VTS area. The number of marine accidents in Korean waterways was about 566 in 2007, as opposed to 2549 in 2016. Figure 4 shows that marine accidents have increased continuously year by year. Additionally, Table 3 shows the causal factor of collision accidents in Korean waterways over the last 10 years. The biggest cause of accidents is negligence, including improper look-out, lack of regulation observation, etc., occurring due to human factors. Thus, human factors must be considered in order to reduce the number of marine accidents.

Consciousness change in Korea waterways

The mariner who navigates the vessel tries to maintain a certain distance from other vessel, fixed object, shallow water, etc. in order to navigate the vessel safely. The distance depends on the speed of the vessel, visibility, kinds of dangerous goods. This zone in which the navigator is trying to maintain a certain distance is called the bumper zone as shown in Figure 3. 8L(FA) × 3.2L(SP) is a typical famous ship’s domain bumper zone for safe navigation in overseas waterways from the 1970s (Fujii, Makishima, and Hara 1983). But the mariner’s consciousness of bumper zone has changed in Korea and oversea waterways for decades. As seen in Table 2, there are differences in bumper zones among waterways in other countries, and the ship domain for safe navigation is becoming smaller with time (Park, Jeong, and Kim 2010, 406–410; Um et al. 2012, 416–422; Park and Jeong 2014, 535–542).

Consciousness change in Korea waterways

Revised Korea maritime traffic law 2009

On 28 November 2009, the maritime traffic safety audit scheme and quantitative assessment of marine
Figure 2. Track results by the marine traffic survey in each main waterway of Korea (Source: Kim 2014).

Figure 3. Bumper zone of vessel.

Table 2. Bumper zones among other countries.

| Year | Japan | Korea | Shanghai | Denmark |
|------|-------|-------|----------|----------|
| 1980 | 7.7L  | 3.5L  | 8L       | 7.5L     |
| 2000 | 3.3L  | 1.5L  | 2.6L     | 3.2L     |
| 2010 | 4L    | 4L    | 4L       | 4L       |
| 2006 | 5.9L  | 5.9L  | 5.9L     | 5.9L     |
| 2012 | 4L    | 4L    | 4L       | 4L       |

Figure 4. Number of marine accidents (2007–2016).
traffic environments were fully implemented through the revision of the Korea Maritime Traffic law. The maritime traffic safety audit stipulates that the navigational

Table 3. Causal factors of collision accidents in Korean waterways (2007–2016).

| Year | Negligence | Fault | Etc | Total |
|------|------------|-------|-----|-------|
| 2007 | 88(97.8%)  | 1(1.1%) | 1(1.1%) | 90 |
| 2008 | 84(96.6%)  | 0     | 3(3.4%) | 87 |
| 2009 | 84(96.6%)  | 0     | 3(3.4%) | 87 |
| 2010 | 89(96.7%)  | 0     | 3(3.3%) | 82 |
| 2011 | 85(97.7%)  | 0     | 2(2.3%) | 87 |
| 2012 | 82(98.8%)  | 0     | 1(1.2%) | 83 |
| 2013 | 71(95.9%)  | 0     | 3(4.1%) | 74 |
| 2014 | 89(98.9%)  | 1(1.1%) | 0     | 90 |
| 2015 | 77(100%)   | 0     | 0     | 77 |
| 2016 | 88(97.8%)  | 0     | 2(2.2%) | 90 |
| Total| 837(97.7%) | 2(0.2%) | 18(2.1%) | 857 |

safety hazards that may occur in the project, subject to diagnosis, are professionally investigated, measured, and evaluated. This is a tool for improving marine traffic safety in Korean waterways and the formal safety assessment for existing or future maritime transportation by an independent audit team. Figure 5 shows the flow of the maritime traffic safety audit scheme (Cho, Kim, and Lee 2010, 699–704).

The maritime traffic safety audit scheme significantly enhances marine traffic safety in the waterways and provides clear guidelines to the designers of port construction and civil engineering. However, there is no adequate quantitative risk assessment model to reflect the situation in Korea. A need still exists to develop an assessment model suitable for Korean waterways.

Figure 5. Audit process (Cho, Kim, and Lee 2010, 699–704).
Table 4. List of marine traffic safety assessment models.

| Assessment models | Details of contents |
|-------------------|---------------------|
| IWRAP             | • Recommended by IALA (Quantitative model)  
|                   | • Calculating collision and grounding probabilities  
|                   | • Theoretical explanation for calculation is limited |
| ES Model          | • The most-used model in MSA  
|                   | • Calculating maneuvering difficulties by surrounding environments  
|                   | • Awareness of Korean mariners is not reflected |
| PAWSA             | • Recommended by IALA (Qualitative model)  
|                   | • Assessment by expert group  
|                   | • Highly depended on the consist of group members |
| FSA               | • Evaluating the costs and benefits of solutions  
|                   | • Various application models (MARA, PMSC, etc.)  
|                   | • Could be influenced by assessor’s opinion |
| US model          | • Assessment by stopping distance  
|                   | • Ship handling simulation is the precondition  
|                   | • Could not apply in complex traffic condition |
| Others            | • Assessment by vessel encountering frequencies  
|                   | • Assessment by give way action frequencies  
|                   | • Assessment by complexity of traffic routes  
|                   | • SJ Model (Mariners' subjective awareness)  
|                   | • BC Model (Collison awareness with other vessels)  
|                   | • Assessment models used in road traffic engineering |

Table 5. Details of internal static parameters survey.

| Main contents                  | Details of contents |
|-------------------------------|---------------------|
| Recently on board ship        | ① Kind of vessel, ② Gross Tonnage, ③ Length(LOA), ④ Width |
| Personal information          | ① Age, ② On board carrier, ③ License, ④ Position |
| Risk while at sea             | ① Write in ranking of risk while entering/leaving in port  
| Vessel navigator’s risk       | ② Write in the factor of risk while at sea |
| 7 points scale depending on ship’s circumstances | |
| [7: extremely danger, 6: considerably danger, 5: a little danger, 4: neither danger nor safe, 3: a little safe, 2: considerably safe, 1: extremely safe] |

Figure 6. Example of questionnaire (Questions related to the crossing situation).

Table 6. Application of risk value.

| Factor                        | Situation      | Estimated value |
|-------------------------------|----------------|-----------------|
| Type factor                   | Tanker         | −0.082580       |
| Ton factor                    | 6000 ton       | −0.325600       |
| Length factor                 | 110 m          | −0.142000       |
| Width factor                  | 18 m           | 0.210588        |
| Career factor                 | 3–5 year       | −0.064230       |
| License factor                | 2nd Deck Cert  | 0.109177        |
| Position factor               | Chief officer  | 0.176755        |
| Crossing factor               | CNRS           | 0.468465        |
| Side factor                   | TS on Stbd     | −0.056600       |
| In/out harbor factor          | In harbor      | 0.062305        |
| Speed factor(kt)              | Os speed > TS speed | 0 |
| Speed difference(kt)          | 2 kts          | 2               |
| Distance (NM)                 | 1 NM           | 1               |

Risk value = 5.081905 − 0.082580(T_P) − 0.325600(T_t) + 0.210588(W_t) − 0.064230(C_t) + 0.109177(L_t) + 0.176755(P_t) − 0.002517·110(L_t) + 0.468465(C_t) − 0.566000(S_t) + 0.062305(H_t) + 0·(S_p) − 0.004930·2(S_d) − 0.430710·1(D)  
Risk value = 4.353345
Figure 7. Real-time AIS monitoring and analysis system (Busan port) (Source: Authors).

Figure 8. Comparison of danger degree.
Comparison analysis between the risk assessment models

Marine traffic safety assessment is aimed to understand current traffic flow, to represent and evaluate vessel’s actions by statistical or analytical method. Doing marine traffic safety assessment, it is possible to evaluate current. Table 4 shows several kinds of marine traffic safety assessment models and their features (Kim 2011, 281–287).

Development of assessment model for marine traffic in Korean waterways

Risk value calculation of internal static parameters and external dynamic elements

When vessels navigate coastal waterways, stress/risk is imposed on mariners due to other vessels and obstacles because of restricted maneuvering space. However, it is difficult to determine how much risk the mariner assumes in the coastal waterways. Therefore, the suitable assessment model for marine traffic was developed, considering all internal and external elements of vessels based on our questionnaire survey and simulation experiments.

To develop this model, first, the risk value was calculated from the ship’s internal static parameters (i.e., type, length, width, mariner’s career, license, and rank on board) to assess the risk within Korean waterways. 3.5% of mariners available in Korea were surveyed using a questionnaire for reliable statistical analysis. Table 5 shows details of contents for internal static parameters survey.

As the second step, the ship’s encounters, in particular situations and with various distances among ship’s position’s etc., were considered to develop the new model. Figure 6 is a sample of the questionnaire survey sheet to deduce the risk value in these encounters. Nine encounter angles were considered per distance and the risk values were divided into seven numerical values to assess the risk. The model was constructed using regression analysis to assess the encounter situations based on the navigator’s subjective risk, as seen in the following equation (Kim et al. 2011, 227–233).

Then, the model’s reliability was verified using ship handling simulation experiments by consulting related experts.

PARK model formula

The results of the quantitative survey are analyzed by using variance analysis and multiple comparison analysis, and the model is constructed by using regression analysis method. The expression of the potential assessment risk (PARK) model, is deduced to reflect the internal static parameters and external dynamic elements, which are shown in the formula (1).
When two ships encounter a crossing situation at Busan port, the risk values of the two ships are more than 4.0, which is a slightly dangerous situation under those circumstances. Therefore, the PARK model makes it possible to easily monitor and analyze these encounters in real waterways (Heo, Park, and Kim 2012, 91–100).

Based on these results, the IMO Information document was submitted to the sub-committee on Navigation Communication and search and rescue in 2015 (IMO Document 2015). In addition, an experiment was performed for the reliability of risk levels between the officer’s risk consciousness value onboard and the PARK model’s risk value at the southern waterways in Korea for two cases. Figure 8 shows the danger level felt by the ship’s operator, represented by the red line, and the risk value calculated by the PARK model, represented by the black line (Park et al. 2015, 93–98).

In both cases, the change tendency of the risk value for officers is similar to that indicated by the PARK model. After submitting the IMO Information paper, as shown in Figure 9, the presentation was made in Committee International Radio-Maritime, an annual general meeting in 2015, in concert with Italian researchers. This concept is the transmission of collision risk-level data of each ship via satellite, calculated by the PARK model, to the Fleet Management Service Centre. Through the fleet management interface, the operator can display the risk of collision for each ship, or only for those ships with risk levels beyond a specific threshold (collision alarms) (Aleandri 2015).

Application of potential assessment risk model

Use of navigation equipment on board to prevent a collision accident

The PARK model can contribute to the development of a navigation support system onboard to prevent collision accidents. Figure 7 shows the real-time AIS monitoring and analysis system based on the PARK model; it is the results display of risk analysis in the Busan approach.

Use of VTS decision-making support system

The PARK model can contribute to the basic technology of VTS Decision-Making Support System for VTSO.
Figure 10 shows the risk density percentage marked by Busan VTS officers’ experiences. Moreover, this is the risk density percentage calculated by the PARK model. The black dots in the figures are the positions of collision accidents for the last 5 years in Korean waterways. It is difficult to recognize the danger among ships quickly and accurately because of perception differences for individual danger identification of VTSO. Areas A and B are identical, but Area C is different, as seen from these figures (Nguyen et al. 2015, 246–252).

![Figure 10. Risk density percentage.](image)

![Figure 11. Decision of vessel evacuation route from emergency situation using PARK model (Source: Authors).](image)
Use of ship evacuation route in an emergency situation to recover normal condition from emergency situations

The PARK model can contribute to the vessel’s evacuation route to recover the vessel’s normal situation from emergency situations. Currently, studies have been conducted to decide the vessel evacuation route in an emergency using the PARK model. Until now, the algorithm has been developed to induce the low traffic volumes or low congestion areas to recover the ship's abnormal situations autonomously, as seen in Figure 11.

Other algorithms are under development to deduce the high volume areas, including the area the nearest coast guard ship is navigating, for easy rescue in an emergency crisis.

Conclusion

Korean coastal waterways have a high potential risk of marine accidents. However, it is difficult to identify dangerous vessels and areas; to quickly accomplish this, a new assessment model must be developed.

The findings of this study are as follows.

(1) ship’s internal static parameters (type, length, width, mariner’s career, license, and rank on board) based on surveys and the external dynamic elements, calculated by the results of the questionnaires concerning the ship’s encounter situations and distances, are utilized to develop the new suitable assessment model for marine traffic.

(2) The resulting assessment model can calculate the risk value based on Korean mariner’s consciousness in certain traffic situations and be verified by ship handling simulation.

This potential assessment of the risk model can function as navigation equipment on board to prevent a collision. Meanwhile, it can be applied as a support system for VTS decision-making. Finally, it can also use the vessel evacuation route to recover the vessel’s normal situation from an emergency.

Disclosure statement

No potential conflict of interest was reported by the authors.

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