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A Study on Incidence of Risk Factor for Assessing Maritime Traffic Risk

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Abstract : *In order to assess risk as a basic step for securing safety, it requires to select risk factors and determine the frequency and the severity of the consequence of each risk factor. This research adopted common risk factors among well-known maritime risk assessment models, and proposed objective criteria to gauge the risk level of each risk factor. The starting points of risk evolution were chosen for criteria according to related studies and seafarers' experience. The rate of risk appearance over the criteria is named as the incidence of risk factor. Therefore, the total risk level is expressed as the combination of incidence of each risk factor and severity. This quantitative method would be applied to measuring and comparing the risk level of target maritime zones, and it would also be useful to survey which risk factor be focused for reducing the total risk of a certain maritime zone.*

Key Words : *Risk, Risk factor, Risk frequency and severity, Risk assessment model, Incidence of risk factor*

1. Introduction

There are well-known maritime risk assessment models in high repute such as 'Port and Waterway Safety Assessment tool' (PAWSA), 'IALA Waterway Risk Assessment Program' (IWRAP). These models are officially approved and recommended as 'Risk Management Tool' by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) in July 2006 (IALA, 2009a). On the other hand, there are noteworthy local models.

Firstly, Environmental Stress model (ES model) was developed by Japanese researchers in order to express mariners' stress degree caused by ship-handling difficulties in restricted waters like harbours and narrow channels (Inoue, 2000). In 2009, the government of the Republic of Korea adopted a new safety system named marine traffic safety examination which is a mandatory maritime audit scheme for securing safe navigation in navigable waters, and the ES model has been widely used in the audit process for quantifying the risks involved in vessel traffic in specific waters. Japan also adopted a similar maritime audit scheme that was known to use ES model but it was not mandatory.

Secondly, Potential Assessment of Risk Model (PARK model) and Numerical Risk Assessment model (NURI model) were recently devised by Korean researchers (Park, 2007; Lee, 2013).

The above mentioned models are classified into two large groups. IWRAP, ES model and PARK model are quantitative risk assessment tools. PAWSA and NURI model are qualitative risk assessment tools. The two groups have the complementary nature (IALA, 2009b).

The tools are all proved its practical use at port zones and restricted channels, but marine casualty and incident occur along coastal waters in most cases as shown in Table 1 (MOF, 2017). Therefore, this paper intends to contribute to introducing a new risk tool that can be used at coastal waters.

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Table 1. Marine Casualty and Incidence (2012-2016)

Area \ Year		2012	2013	2014	2015	2016	Total
Territorial Waters	South	508	293	425	783	807	2,816
	West	454	366	405	546	579	2,350
	East	172	110	112	206	250	850
	Ports & Approaches	171	126	145	308	335	1,085
International Waters	South	79	61	93	75	96	404
	West	32	30	25	42	36	165
	East	79	60	66	101	132	438
	Others	22	11	10	4	4	51
Foreign Waters	Southeast Asia	35	27	31	29	38	160
	Japan	21	9	18	7	30	85
Total		1,573	1,093	1,330	2,101	2,307	8,404

2. Risk Assessment Tools

In accordance with the study of comparison assessment applying ES model with PARK model in the *Busan* adjacent waterways, the result showed similarity in the waterways within the harbor and approaches. Moreover, the PARK model gave more consistent results than the ES model in 2～10 nautical miles' coastal area near ports (Nguyen, 2013). Kim et al. (2011) and Kim and Lee (2012) found that ES model of Japan showed a difference of result in Korean coast by comparison with PARK model. The difference of result was minor and believed to come from subjective evaluation part of the model making process.

The quantitative tool is a form of ready made formula which just needs application, but the qualitative tool requires human's intervention during application. So, human's intervention should be carefully reviewed not to weaken objectivity of the result. In this context, NURI model is quite useful because it determines the risk level of each risk factor on a logarithmic scale which is based on statistics of risk factors.

NURI model's structure is quite similar to that of PAWSA because NURI model takes 20 risk factors whose origin is basically 24 factors of PAWSA, though the risk factors were chosen after analysis and comparison with other tools' risk factors. The utilization of NURI model was evaluated in ports of *Mokpo*, *Wando* and approaching channels. The results showed high consistency with marine casualty statistics in the considered area and proceeding studies on the risk of the areas (Lee, 2013).

Kim (2016) compared and analyzed representative tools of Korea, Japan and the United States in order to sort out common risk factors that can be used in coastal waters while minimizing subjective evaluation of participants. The selected tools were maritime audit schemes of Korea and Japan, and PAWSA of US. Then, several factors of PAWSA like vessels' quality are excluded owing to the difficulties of obtaining correct value of the factors at coastal waters. Maritime casualty records were also excluded because casualty is a kind of phenomenon that is caused by unsafe environment.

Kim and An (2016) reorganized the common risk categories into 16 factors. In order to use AHP tool for producing weights of risk factors, Related 2 risk factors were grouped into 1 category. For example, tidal current factor and wave factor compose sea category. Sea and weather also compose natural conditions. Natural environment consists of natural conditions and route conditions. So, the 3-step structure is composed as shown in Fig. 1.

The grouping structure is the same as NURI model and PAWSA, but risk measurement of each factor is different. The PAWSA risk assessment process is handled by participants because the process requires the participation of professional waterway users of the designated water, port operators or stakeholders if needed. Participants identify major hazards, estimate risk levels and consequences, evaluate potential mitigation measures, and set the stage for implementation of selected measures to reduce risk (IALA, 2009b).

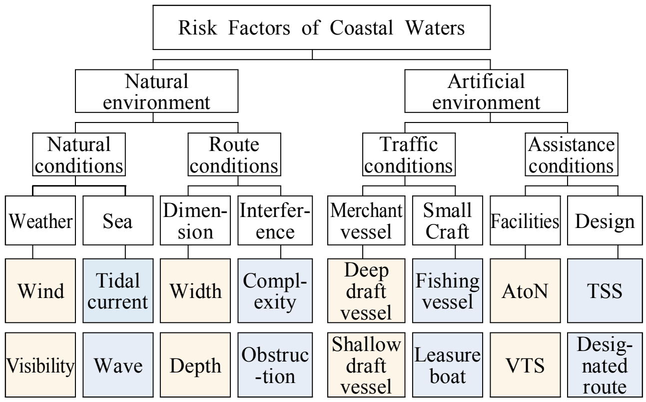

Fig. 1. Marine Traffic Risk Factors of Coastal Waters.

Conclusively, risk level of PAWSA factor is checked by participants based on their expertise. The concept of risk evaluation in PAWSA is shown in Eq. (1).

$$\Sigma_1^n H = \Sigma_1^n TC_{RR} + \Sigma_1^n IC_{All} + \Sigma_1^n \$_{P,P,RP} \quad (1)$$

where
H: Harm
TC_{RR}: Tangible Consequences of Risks Realized
IC_{All}: Intangible Consequences of All Risks, Real and Perceived
$\$_{P,P,RP}$: Costs of Prevention, Protection, Response Preparedness

PAWSA participants vary case by case but NURI model does not require human participation in each case. NURI model takes pre-determined 1 to 5 scale index system shown as Table 2 instead of participants' expertise.

Table 2. Frequency & Consequence Index

Index	Frequency	Consequence
1	Extremely Remote	Extremely Minor
2	Remote	Minor
3	Normal	Normal
4	Frequent	Major
5	Extremely Frequent	Extremely Major

Thus, NURI model is believed to be more objective than PAWSA because it minimizes human intervention in the risk assessment process.

The risk concept of NURI model is shown in Eq. (2). Applied form is Eq. (3).

$$R = C_f \times C_c \tag{2}$$

where
R: Risk
C_f: Frequency of Casualty
C_c: Consequence of Casualty

$$RI = FI + CI \tag{3}$$

where
RI: Risk Index
FI: Frequency Index
CI: Consequence Index

However, the index system of NURI model involves fundamental errors. Wind factor would be an example. If wind speed is under 13.9 m/s, the consequence index (CI) is 3 according to Table 3. When wind speed is 13.9 m/s, the CI is allocated to 4. The one step of CI means 20 % difference because there are only 5 steps. It would not be understandable to give 20 % difference for the gap of ‘under 13.9 m/s’ and ‘13.9 m/s.’ Moreover, frequency index (FI) also shows the same difference of 20 %. When wind blows 90 days, FI is 3, and it is called as ‘normal.’ 91 days’ wind is FI 4 and it is ‘frequent.’

Table 3. Wind Indexes of NURI model

CI	Consequence	Application	FI	Frequency	Application
1	Extremely Minor	under 3.4m/s	1	Very Remote	7 days or less per 1 year
2	Minor	under 8.0m/s	2	Remote	30 days or less per 1 year
3	Normal	under **13.9m/s**	3	Normal	**90 days** or less per 1 year
4	Major	**13.9m/s** or more	4	Frequent	180 days or less per 1 year
5	Extremely Major	Typhoon	5	Very Frequent	181 days or more per 1 year

It is caused by the 5 integer of CI and FI that cannot express decimal fraction between whole number. So, there exists digital cliff between index numbers. In addition, the titles of indexes include pre-judged value although it is not fixed yet. For instance, index 3 is ‘normal’, index 4 is ‘major’ or ‘frequent.’

In order to reduce the malfunction of index system and increase reliability, this study suggests incidence. In case that incidence criterion of wind is 13.9 m/s, and wind over 13.9 m/s blows 100 days in a year, the incidence calculation of wind is 100/365. Accordingly, incidence of wind is 0.274, and incidence rate is 27.4 %. If wind over 13.9 m/s did not blow, incidence is ‘0.’ It means no risk in terms of wind. So, it is better to express risk level by analog incidence rate instead of digital index number in this case.

Therefore, this study aims at proposing incidence criteria of the 16 risk factors as substitute for the index system, and proposes a new risk equation.

3. Risk Assessment Formula

Safety and risk by definition of IMO were applied to most risk assessment models with necessary modification. Typical quantitative tools are IWRAP, ES model and PARK model, and qualitative tools are PAWSA and NURI model. The two types of tools have the complementary nature.

In order to secure objectivity of the qualitative tools up to quantitative tools, human’s intervention should be carefully reviewed. In this regard, NURI model adopts a logarithmic scale that consists of 1～5 scales of CI and FI. However, the index system of NURI model would lack accuracy and contain errors caused by the 5 integer of CI and FI that cannot express decimal fraction between whole number.

3.1 General Formula of Risk Assessment Models

Safety is the absence of unacceptable levels of risk to life, limb and health from unwilful acts, and Risk is the combination of the frequency and the severity of the consequence (IMO, 2015). So most of maritime risk assessment models are based on the Eq. (4), and there are several modified equations according to evaluation methods.

$$R = P \times C \tag{4}$$

where
R = Risk
P = Probability that undesired incident occurs
C = Consequences of undesired incident

IWRAP as a qualitative tool adopts the Eq. (5). It is a modified form of Eq. (4).

$$\lambda_{Col}\ (or\ \lambda_{Gnd}) = NG\ x\ PC \quad (5)$$

where
λ = *Annual casualty frequency* (λ_{Col}: *annual collision frequency*, λ_{Gnd}: *annual grounding frequency)*
NG = *Geometric Number of Collision or Grounding Candidates*
PC = *Causation Factor*

Formal Safety Assessment (FSA) of the International Maritime Organization (IMO) recommended to define probability index and consequence index on a logarithmic scale for facilitating the ranking of hazards and validation of ranking. The equation is Eq. (6) (IMO, 2002). NURI model adopted the Eq (6) in order to use risk matrix.

$$Log\ (Risk) = log\ (Probability) + log\ (Consequence) \quad (6)$$

3.2 New Formula for Risk Assessment

As we studied, the index system could sometimes include avoidable errors. NURI model showed the example of index error. The concept of risk needs to be reviewed to avoid errors by the use of indices. ‘Probability that undesired incident occurs’ can be expressed as ‘Incidence of risk factor’, and ‘Consequences of undesired incident’ can be as ‘Weight of risk factor.’ Therefore, a new formula is shown in Eq. (7).

$$R = R_{f1} \times \omega_1 + R_{f2} \times \omega_2 + \cdot\ \cdot\ \cdot\ R_{fn} \times \omega_n \quad (7)$$

where
R: Risk
R_f: *Risk Factor Incidence*
ω: *Risk Factor Weight* ($0 \leqq \omega \leqq 1$)

4. Incidence

Incidence could be calculated by criteria of each risk factor. So criteria should be reasonable for general acceptance and tangible for data collection. This study suggests that the followings be criteria of risk factors, but the weight as a component of the formula remains for further study.

4.1 Incidence of natural conditions

Referring to Fig. 1, natural conditions are composed of weather and sea. Weather consists of wind factor and visibility factor, and sea has tidal current factor and wave factor.

4.1.1 Wind

Beaufort Scale is the most widely used wind scale indicator at sea. Beaufort Scale 4 means that wind speed is 5.5~8.0 m/s, sea shows numerous white caps as shown in Table 4. Wind speed of Beaufort Scale 5 is 8.0~10.8 m/s. It is believed that normal navigation could be possible in Beaufort Scale 4 condition. So, incidence criterion of wind could be 8.0 m/s which is between Beaufort Scale 4 and 5.

If wind over 8.0 m/s blows 365 days, the incidence equation is 365/365. It is ‘1’ and 100 % risky. It mean unsafe condition. The wind data can be collected by consulting a climate year book published by the meterological administrations. Therefore, the criterion 8.0 m/s is practicable in terms of data aquisition and utility. The denominator of natural conditions is 365 days.

Table 4. Beaufort Scale (MET, 2016)

Wind Force	WMO Classification	Speed (m/s)	Appearance of Wind Effects
0	Calm	<0.3	Sea surface smooth and mirror-like
1	Light Air	0.3~1.5	Scaly ripples, no foam crests
2	Light Breeze	1.5~3.3	Small wavelets, crests glassy, no breaking
3	Gentle Breeze	3.3~5.5	Large wavelets, crests begin to break, scattered white caps
4	Moderate Breeze	5.5~8.0	Small waves 1-4 ft. becoming longer, numerous white caps
5	Fresh Breeze	8.0~10.8	Moderate waves 4-8 ft taking longer form, many white caps, some spray
6	Strong Breeze	10.8~13.9	Larger waves 8-13 ft, white caps common, more spray
7	Near Gale	13.9~17.2	Sea heaps up, waves 13-19 ft, white foam streaks off breakers
8	Gale	17.2~20.7	Moderately high (18-25 ft) waves of greater length, edges of crests begin to break into spindrift, foam blown in streaks
9	Strong Gale	20.7~24.5	High waves (23-32 ft), sea begins to roll, dense streaks of foam, spray may reduce visibility
10	Storm	24.5~28.4	Very high waves (29-41 ft) with over-hanging crests, sea white with densely blown foam, heavy rolling, lowered visibility
11	Violent Storm	28.4~32.6	Exceptionally high (37-52 ft) waves, foam patches cover sea, visibility more reduced
12	Hurricane	≥32.6	Air filled with foam, waves over 45 ft, sea completely white with driving spray, visibility greatly reduced

Wind speed is daily maximum speed because daily mean wind speed is low and daily maximum instantaneous wind speed does not represent daily continuous wind. Wind consists of speed and direction but wind direction is disregarded in this study because wind direction is a relative element to sailing ships.

4.1.2 Visibility

Korea Meteorological Administration regards visibility 1 km as foggy weather and publishes the data in the year book. Hence, visibility data can be obtained without difficulty. On the other hand, domestic passenger ships cannot set sail when visibility is under 1 km by domestic regulation of Korea. If there is no foggy day in a year, the incidence equation is 0/365. It is '0', in other words, it is safe.

4.1.3 Tidal current

PAWSA noticed 2 knots of tidal current as a risky factor. Tidal current over 2 knots is frequent in narrow channels of Korea, but it is not frequent in open sea. Average speed of a set of tugboat and barge is 4~5 knots. The speed is known as the minimum for course keeping. So, it is reasonable to assure that tidal current criterion would be 2 knots. Data can be obtained by the hydrographic and oceanographic administration.

4.1.4 Wave

Wave and wind are closely related. Wind of 8 m/s is accompanied by 2 meters of waves according to Beaufort Scale. So, wave criterion should be 2 meters. Data can be obtained by hydrographic and oceanographic administration.

4.2 Incidence of route conditions

Route conditions consist of dimension and interference. Dimension are composed of width factor and depth factor. Complexity factor and obstruction factor constitute interference.

4.2.1 Depth

Shallow effect begins to occur when depth of water (h) is less than 2 times of ship's draft (d). Equation is $h/d < 2$. When the biggest vessel at coastal area is 12,000 TEU container whose L·B·D is, generally, 398 m, 55 m and 15 m, 30 meters would be appropriate.

4.2.2 Width

A ship's occupation area is 8.0 L (8.0 times of ship's length) × 3.2 L in open waters, 6 L × 1.6 L in restricted waters as shown in Fig. 2. (Park et al., 2013). When 3 ships are under crossing situation, the occupation area of each ship depends on the relationship among the ships and obstacles (MMU, 2015).

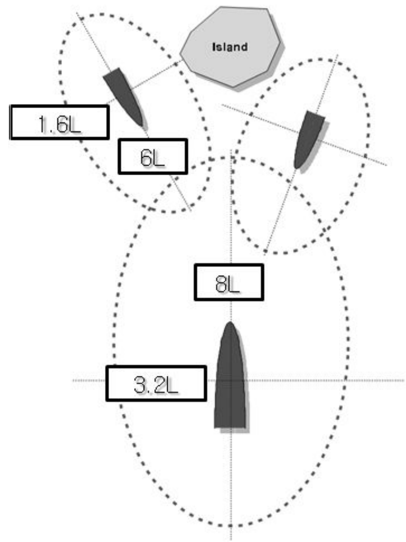

Fig. 2. Occupation areas at crossings situation.

Incidence of width could be 6.4L of the biggest ship at the target area. Data could be obtained from AIS records.

4.2.3 Complexity

Curvature of centerline on fairway should be within 30° according to 'Port Design Guideline of Korea'. When curvature exceeds 30°, the radius of curvature should be over 4 times of the biggest vessel's length as shown in Fig. 3.

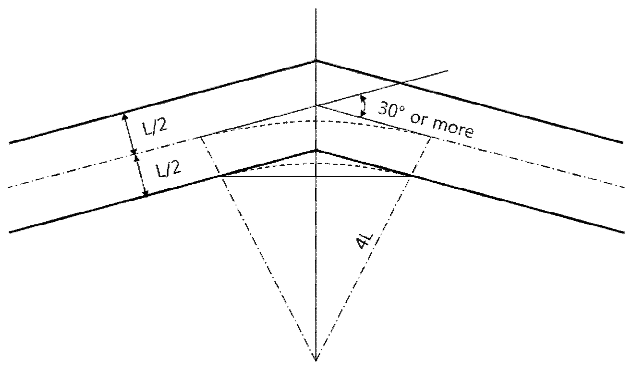

Fig. 3. The Radius of Curvature on Fairway Bend.

Incidence of complexity might be the number of curvature over 30° and its 4 L occupation area in the target area. Data could be obtained from nautical maps and AIS records.

4.2.4 Obstruction

Generally, Ships do not enter into 1 mile range of obstructions to avoid grounding. Incidence of obstruction could be calculated from the number of obstructions and the sum of its 1 mile occupations in the target area.

4.3 Incidence of traffic conditions

Referring to Fig. 1, traffic conditions consist of merchant vessels and small crafts. The merchant vessel category is composed of width and depth. Complexity and obstruction of the route constitute interference category.

4.3.1 Deep draft vessel

A deep draft vessel could be defined as a 200 m vessel quoted from ‘Maritime Safety Act of Korea (MSA, 2015)’. A degree of traffic saturation could be obtained from setting up areas of 8.0 L × 6.4 L of object vessels. Peak time congestion would be used to anticipate the big deviation value of night sailing and day sailing because many Korean ports prohibit port entering and working at night. Target area would be designated route except traffic separation area. Occupation area could be checked at VTS centers or at sites.

4.3.2 Shallow draft vessel

It would not be reasonable that shallow draft vessels were the exceptions of deep draft vessels. It may be small and midium sized vessel except fishing vessels and leasure boats which are other risk factors. A standard vessel would be the average coastal vessel, 1,000 G/T and 70 meters long (MMU, 2015). Incidence rate could be calculated by comparing coverages of the maximum number of standard vessels with actual sailing vessels. Peak time congestion would be used.

4.3.3 Fishing vessel and leasure boat

The number of fishing vessels should be checked at site because they are not equipped with AIS transmitters. Fishing vessels are generally smaller than shallow draft vessels that we defined as 70 meter merchant vessels. However, fishing vessels are engaging in fishing with nets or tackles. Practically, merchant vessels do not approach 1.0 mile in diameter of a fishing vessel. So, the diameter of occupation area of a fishing vessel would be 1.0 nautical mile. Data could be collected at site because fishing vessels, and peak time traffic congestion should be used because fishing vessels are generally engaged in fishing at daytime.

The number of leasure boats shows an upward tendency in registration in Korea. However, there is no available statistics. Furthermore, it is not easy to check leasure boats at site because boats’ sailing is at irregular intervals depending on time, seasons, weathers, etc. Anyhow, the peak time congestion would be used if it is checkable. The occupation area could be the same as fishing vessels.

4.4 Incidence of assistance conditions

Referring to Fig. 1, assistance conditions consist of facilities and designs. Facilities are composed of AtoN and VTS. TSS and designated routes constitute interference. Data could be gotten from nautical maps. Incidence rate should be the rate of non-coverage of factors because the coverages are safe areas. Therefore, formula will be ‘1 - the sum of safe area’

When it comes to AtoN, Visible distance of light would be used to decide the coverage of AtoN. Incidence equation of AtoN would be ‘1 - the sum of visibility of light divided by target area.’ VTS or TSS incidence will use the sum of coverage of VTS or TSS as safe area.

In terms of designated routes, a point to be considered is that designated routes are lines. Therefore, 3.2 L could be applied to the lines as we studied before. The standard vessel is the biggest vessel using the route.

5. Conclusion

This paper suggests that analog incidence rate provides more accuracy than digital index number, and proposes incidence criteria of 16 risk factors as follows:

1) The incidence equation of natural conditions is days over criteria divided by 365 days. Criteria is the boundary between normal navigation and abnormal sailing. Wind criterion is 13.9 m/s, visibility is 1 km, tidal current is 2 knots, and wave is 2 meters.

2) Route conditions consist of width, depth, complexity and obstacle. The occupation area of a ship is 8.0 L × 3.2 L in open waters, and 6 L × 1.6 L in restricted waters, so incidence criterion of width could be 6.4L of the biggest ship at a target area. Depth criterion is $h/d < 2$. Complexity criterion is the number of curvature over 30° and its 4L occupation area. Obstruction criterion is the number of obstructions and the sum of its 1 mile occupation. A common denominator is the size of a target area.

3) Traffic conditions are composed of deep draft vessel, shallow

draft vessel, fishing vessel and leasure boat. Deep draft vessel is a 200 meter merchant ship, and shallow draft vessel is a 70 meter merchant ship. The occupation area of a ship is 8.0 L × 3.2 L. The occupation area of a fishing vessel or a leasure boat is the diameter of 1.0 nautical mile. A common denominator is the size of a target area.

4) Assistance conditions are composed of AtoN, VTS, TSS and designated routes. Incidence rate is the ratio of non-coverage of the factors over target area because the coverage is safe area. However, the designated route is not area but line, 3.2 L is applied to the lines. The standard vessel is the biggest vessel using the route.

Therefore, objectivity of quantitative methods is enhanced by the use of incidence that is the rate of risk evolution over the criteria of risk factor. This new method would be applied to measuring and comparing risk levels of several target zones at a time, and it would also be useful to survey which risk factor among 16 factors should be focused for reducing the total risk at a certain maritime zone.

The total risk level could be expressed as the combination of incidence of each risk factor and severity. So, it would be worthy of further researching weights of the 16 risk factors.

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