Development of a new tool for objective risk assessment and comparative analysis at coastal waters

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ABSTRACT
The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) introduced maritime traffic risk assessment models such as Waterway Risk Assessment Program and Ports and Waterway Safety Assessment for being used in ports and approaches. Having said that, its effectiveness was not fully verified at coastal waters yet. According to statistics, most accidents occurred at coast by human factor. It needs to develop a new tool for coast considering human factor. For that reason, this study aimed at developing a new coastal model. Common risk factors of the risk assessment models from three maritime states were identified by data availability at coastal waters, and risk incidences drawn by quantitative data and risk weight by qualitative survey were calculated for the indexed factors. The newly developed model, Numerical Risk Assessment Model for Coast (NURI-C), successfully indicated conspicuous risks in an area and the risk level of each target water for comparative analysis. Therefore, it could be utilized for identifying which area is more dangerous along the coast and which risk factor in an area needs first care. NURI-C might be useful not only for safe navigation but also for efficient distribution of limited available resources to coastal safety.

Introduction
Risk assessment tools are divided into qualitative and quantitative models in general. Representative risk assessment models in the field of maritime traffic are Waterway Risk Assessment Program of International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) (IWRAP) and Ports and Waterway Safety Assessment (PAWSA) of the United States Coast Guard (USCG). The IWARP is a quantitative model and PAWSA is a qualitative model.

In 2010, the two tools were recommended to International Maritime Organization (IMO) by IALA for ports and restricted waterways for the use by national members (IALA 2017). Its utilities were verified in a number of waterways, so IALA believed that the models were fit for Chapter 5 of the 1994 SOLAS Convention, as amended, regulation 13 which requested the contracting governments to provide such aids to navigation (AtoN), as the volume of traffic justifies and the degree of risk requires. Similarly, regulation 12 of SOLAS Chapter 5 also demands contracting governments to arrange for the establishment of vessel traffic services (VTS) where, in their opinion, the volume of traffic or the degree of risk justifies such services. The 88th session of IMO Maritime Safety Committee approved its circulation of the IALA Recommendation O-134 (IMO 2010).

The two circulated models were for the use at the confined area like ports and approaches regardless of wording of Recommendation O-134. Therefore, its effectiveness and utility at coastal waters have been in question.

On the other hand, most of the marine accidents occurred at the coastal waters by human factors. In accordance with the marine accident statistics of the Korea Maritime Safety Tribunal as shown in Table 1, 17% of accidents occurred at ports and approaches and 22% occurred in open seas beyond 12 nautical miles from shore. Last but not least, 61% of the total accidents took place in coastal waters within 12 nautical miles from shore (KMST 2017).

The main cause of the accidents was due to the human error which consisted in 80% of the total causes. Thirty-six percent of the human error was failure to comply with general principle. Twelve percent was inadequate machinery servicing and 9% was violation of rules and regulations. Five percent was improper measures for disaster prevention. Three percent was inappropriate preparation for sailing and unsuitable handover of watch (KMST 2017).

Considering the case of collision, the causal factor of collision accidents in Korean waters during 2007–2016 increased up to 97.7% (Park et al. 2017). Table 2 indicates ratio of human error classified by ship’s type. The highest ratio is 87%, and the lowest is 76%. The arithmetic mean of the all ships is 81.8%. When fishing vessel is exempted from the statistics,
the mean is 83.3%. It is known that the reason why fishing vessels show the lower ratio is not because fishermen were well educated but fishing vessels suffered frequent engine trouble caused by moderate fishing operation. The statistics shows that 30.1% of accident types of fishing vessels is engine failure, while the engine failure of non-fishing vessel is 11.4%. Therefore, human factors should be considered when maritime risk assessment models are developed.

Conclusively, there were reliable tools for maritime risk management in ports and approaches. However, more concerns should be given to the coastal area because most accidents occurred at coastal area by human factor. With a view to improving the safety of navigation, adequate tools for coastal zone should be developed. For this purpose, this study intended to propose a coastal risk model based on risk factors available for objective data collection at coastal waters with the subjective survey result that how seafarers rate the factors.

### Risk analysis

Modern vessels are equipped with ARPA (Automatic Radar Plotting Aid) and ECDIS (Electronic Chart Display and Information System) which displays CPA (Closest Point of Approach) and TCPAs (Time to CPA) of target ships by the help of dynamic risk assessment method relying on real-time data. Although the dynamic method of electronic navigation equipment offers assistance to seafarers during underway, seafarer need, in terms of safe navigation, to be informed more of static data like the degree of common risk factors for route planning prior to sailing. In reality, however, bulky raw data would be improper for seafarers navigating in busy and congested waters. They need simple and conspicuous contrast of risk level of the route. Safety policy planners also need practical static tools in order to efficiently and effectively distribute limited social, economic, and administrative resources to the safe navigation.

Accordingly, officially recommended risk assessment models were reviewed from the view point of usability in coastal waters. The risk analysis tools of maritime traffic could be divided into two groups:

1. Quantitative analysis
2. Qualitative analysis

### Quantitative analysis

In the risk assessment of maritime traffic, IWRAP is well known as a modeling tool that is useful for calculating the possibility of collision and ground of ship. Its precision and functionality have been enhanced through international cooperation prepared by IALA. The test result was found to be close to the historical evidence data at hand. The latest version is IWRAP MK II. IWRAP modeling principles are basically for prediction of collision and grounding frequencies which is based on conceptual principles formulated by Fujii and MacDuff (Friis-Hansen 2008).

First, the calculation of the geometric number of collision or grounding candidates (NG) is involved in the procedure. Subsequently, NG is multiplied by the causation factor (PC). Hence, the risk value is shown by formula (1).

\[
\lambda_{\text{Col}} (\text{or} \lambda_{\text{Gnd}}) = NG \times PC
\]

where \(\lambda_{\text{Col}}\) is the frequency of collisions (or groundings, \(\lambda_{\text{Gnd}}\), NG is the geometric number of collision or grounding candidates, and PC is the causation factor.

The model can be used in any area as a quantitative tool if risk factors of the formula are available. This model, however, is weak at accepting human factors because the IWRAP is a kind of numerical analysis model used for predicting collision and grounding frequencies. As we studied, most accidents have been occurred by human factors so we need to anticipate human factors together when we try to measure risk level.

IALA also noticed the limitation of the quantitative model so it recommended to use a qualitative model together. The IALA risk management tool encompassing both IWRAP Mk I and PAWSA was approved by the IALA Council in April 2006. IALA also informed IMO that both PAWSA and IWRAP were available for the use by its membership (IALA 2018).

### Qualitative analysis

Qualitative analysis performs a study into the reasoning behind human activity. It uses subjective judgment based on unquantifiable factors, such as navigators’ expertise, handling ability against dangerous situation, and human relations aboard.
PAWSA is one of the best examples of the qualitative analysis tool judging how high risks are present or how much human feels or rates the risks. This model was developed by the USCG in the late 1990s to assess the requirement for the use of VTS and other AtoN under the direction of the US Assembly (USCG 2012).

The result of PAWSA comes from team work. Total 15 teams consist of 2 experts or stakeholders classified by their expertise. The research course is a systematically prepared 2-day workshop of 30 participants who have knowledge on the local area. Each team performs a subjective assessment of the probable risk factor under the supervision of a competent facilitator. Expertise and experience of the participants are highly inevitable requirements for securing objectivity of the qualitative model.

PAWSA regards risk level as the total harm that includes activities for risk prevention and risk mitigation, so PAWSA equation is shown as formula (2).

$$
\sum_{1}^{n} H = \sum_{1}^{n} T_{CR} + \sum_{1}^{n} I_{C} + \sum_{1}^{n} S_{P,R,P} \tag{2}
$$

where \(H\) is the harm; \(T_{CR}\) is the tangible consequences of risks realized; \(I_{C}\) is the intangible consequences of all risks, real, and perceived; and \(S_{P,R,P}\) is the costs of prevention, protection, response preparedness.

PAWSA was basically tailored to local circumstances and developed for finding out weak links of a certain port and waterway for deciding proper VTS position. The PAWSA participants are selected among the local experts and stakeholders of confined waters, and consequently it is not confirmed for them to be eligible for the research of the other local areas. Thus, the risk level comparison of an area with the other areas would not be theoretically possible because of the unauthentic subjectivity of the participants.

If the participants who supply their subjective decisions should only make pairwise comparison between A and B factors in order to draw the weight of risk, the subjective localism of PAWSA could be overcome. Conclusively, this study would apply AHP (Analytic Hierarchy Process) as a proven systematic decision-making of converting the opinions of survey participants into quantified results.

### Risk factor classification and incidence

Every risk assessment tool has its own risk factors for evaluation. All risk factors of quantitative models would be countable or calculable so as to be applied in its formula.

In a coastal model, risk factor should be compared with the data available in the coast. First of all, this paper chose representative risk assessment models in three maritime states. Two local models were chosen from the Republic of Korea (henceforth, Korea) and Japan, and an international model was from USCG.

Table 3 listed the risk factors. The Korean model is numerical risk assessment model (NURI), and Japanese model ES stands for environment stress.

There are five common risk factors such as wind, tidal current, visibility, traffic volume, and flow. There are three common factors between Korean and Japanese models and two factors between Korean and US models. Except for physically unmeasurable objects, this study identified some of the common factors and reorganized into 16 objects of importance such as wind, visibility, tidal current, wave, width and depth of navigable waters, complexity and obstruction of route, traffic of deep draft vessel, shallow draft vessel, fishing vessel and leisure boat, AtoN, VTS, traffic separation scheme (TSS), and designated route. The chosen factors could be paired for AHP analysis (Kim and An 2016). Figure 1 shows the paired structure.

Formal safety assessment of IMO defines that risk is the combination of the frequency and the severity of the consequence (IMO 1997). A logarithmic scale using indices is generally recommended to facilitate the validation of ranking. Those are expressed by formulas (3) and (4) (IMO 2002):

$$
Risk = Probability \times Severity \tag{3}
$$

$$
\log(Risk) = \log(Probability) + \log(Consequence) \tag{4}
$$

PAWSA followed formula (3). This study also adopted the same formula and presented as shown in formula (5) upon consideration of 16 recognized factors such as the one shown in Figure 1.

### Table 3: Comparison on risk factor.

| No | NURI, Korea | ES, Japan | PAWSA, USA |
|----|-------------|----------|------------|
| 1  | Wind        | Wind     | Winds      |
| 2  | Tidal current | Tidal current | Water movement |
| 3  | Rain, snow  | Visibility | Visibility restrictions |
| 4  | Fog         | Traffic volume | Volume of commercial traffic |
| 5  | Traffic flow | Traffic flow | Volume of small craft traffic |
| 6  | Tide        | Tide     | Traffic mix |
| 7  | Wave        | Wave     |            |
| 8  | AtoN        | AtoN     |            |
| 9  | Depth       | Obstruction* | Dimensions |
| 10 | Obstruction* | Congestion | Congestion |
| 11 | Tug boat    |          |            |
| 12 | Pilotage    |          |            |
| 13 | VTS         |          |            |
| 14 |             | Obstructions* |            |
| 15 |             | Visibility impediments |            |
| 16 |             | Bottom type |            |
| 17 |             | Configuration |            |
| 18 |             | Deep draft vessel quality |            |
| 19 |             | Shallow draft vessel quality |            |
| 20 |             | Commercial fishing vessel quality |            |
| 21 |             | Small craft quality |            |
| 22 | Accident(9) | Accident(2) | Accident impact(8) |

*Definition of obstructions are different.
The calculation formula is “days over daily maximum wind of 8 m/s” divided by 365 days. Data can be obtained from the Annual Weather Report.

**Visibility**

Domestic passenger ships of Korea cannot set sail by maritime traffic regulations when visibility is under 1 km. In Korea, visibility less than 1 km is considered as foggy weather so data acquisition is possible. If there is no foggy day in a year, the incidence calculation is 0/365. It is “0” and consequently means “safe.” The formula is “days less than visibility of 1 km divided by 365 days.” Data can be obtained from the Annual Weather Report.

**Tidal current**

PAWSA regards over 2 knots of tidal current as risk. Two knots are frequent in coastal channels but it is not common in open sea. A set of tugboat and barge maintains 4–5 knots for course keeping. So, tidal current criterion could be 2 knots. The formula is “days over 2 knots divided by 365 days.” Data can be obtained from the Korea Hydrographic and Oceanographic Administration (KHOA).

**Wave**

Wind of 8 m/s is accompanied by 2 m of waves in accordance with Beaufort scale. So, wave criterion could be 2 m. Incidence criterion is significant wave height of 2 m. The formula is “days over 2 m divided by 365 days.” Data source is KHOA.

**Incidence of route conditions**

Route conditions consist of width and depth factors, complexity, and obstruction factors.
**Width**

A ship’s occupation area is 8.0 times of ship’s length ($L$) × 3.2$L$ in open waters, 6$L$ × 1.6$L$ in restricted waters as shown in Figure 2 (Park, Park, and Na 2013). When three ships are crossing, occupation areas of each ship depend on the relationship among the ships and obstacles (MMU 2015).

Width incidence could be 6.4$L$ of the biggest ship at the target area. The biggest ship might be 12,000 TEU container ship in Korean coast (henceforth, model ship). Model ship’s length, beam, and draft are, generally, 398, 55, and 15 m. The formula is “area less than 6.4$L$” divided by target area. Size of target areas is 400 nm (IMO 2010) that is 20 nautical miles multiplied by 20 nautical miles in this paper. Data can be obtained from nautical charts. The target area is a kind of cell that is scheduled to be compared with each other.

**Depth**

Shallow effect occurs when water depth ($h$) is less than 2 times of ship’s draft ($d$). Equation is $h/d < 2$. Incidence criterion is 30 m which is 2 times of the model ship’s draft. The formula is “area less than depth of 30 m” divided by target area. Data can be obtained from nautical charts.

**Complexity**

Port Design Guideline of Korea regulates that curvature of fairway should be within 30°. If curvature exceeds 30°, the radius of curvature shall be more than 4 times of the biggest vessel’s length as shown in Figure 3.

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 (Automatic Identification System) records.

**Obstruction**

Ships are reluctant to enter into 1 mi range of obstruction to avoid contact or grounding, so incidence could be calculated from the sum of 1 mi occupations of the obstructions in a target area.

**Incidence of traffic conditions**

Traffic conditions are composed of deep draft vessel and shallow draft vessel, fishing vessel, and leisure boat.

**Deep draft vessel**

Maritime Safety Act of Korea defines a deep draft vessel as length of 200 m. Quantity of traffic saturation could be calculated from the sum of 8.0$L$ × 6.4$L$ area of each target vessel. Peak time traffic congestion would be applied to consider the big deviation value of night and day navigation because many harbors prohibit night work. Occupation area could be checked at VTS centers or at sites.

**Shallow draft vessel**

A standard ship could be 1000 G/T and 70 m long. It is average size in Korean coast (MMU 2015). Incidence could be made by comparing total coverage of the maximum number of standard ships with real sailing ships. Peak time congestion would be applied.

**Fishing vessel and leisure boat**

Fishing vessels engage in fishing with nets or tackles so other ships do not approach 1 mi diameter of a fishing vessel considering nets and tackles. So, the diameter of 1 nm could be occupation area of a fishing vessel. Peak time congestion should be used

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Figure 2. Occupation areas at crossings situation.

Figure 3. Radius of curvature on fairway bend.
because fishing vessels are generally engaged in fishing at daytime.

The number of leisure boats is increasing according to economic development, but there are no reliable data in Korea. Moreover, it is not checkable at sites because boats sail at irregular intervals by seasons, weathers, and so on. Anyhow, incidence of leisure boat would be the same as fishing vessels.

**Incidence of assistance conditions**

Assistance conditions consist of AtoN and VTS, TSS and designated route. Nautical maps show the data. Incidence could be the ratio of non-covered area over target area because the coverage can be regarded as safe areas. Therefore, calculation formula is \(1 – \text{the sum of safe area.} \)

Visible distance of light would be used to determine the coverage of AtoN. Incidence equation of AtoN would be the same as the others.

When it comes to a designated route, it is a series of lines indicating routes. Therefore, \(3.2L \) of the model ship would be applied to the lines.

**Weight of risk factor**

Questionnaire survey was performed in order to measure weights of the selected 16 factors. Total 244 responses were drawn. The questionnaire required to add respondent’s age, boarding career, occupation, title, mariner’s license, academic background, representative ship of the respondent, etc.

Answer comparison was carried out in order to eradicate contradictory answer. In case that A item was more dangerous than B item, and B item is more dangerous than C item, A should be more dangerous than C. If A was less dangerous than C, those answers were excluded. Total 209 answer sheets are used for analysis by AHP software “MakeIt.”

Prior to analyzing the whole data, this paper carried out simple analysis to check whether there is a meaningful difference if expertise of respondents is divided.

For instance, PAWSA classifies participants’ expertise by their own decision because expertise or experience of the participants could not be the same. Those classifications are believed to enhance the accuracy of the result especially in the process of qualitative survey.

We chose two sample groups like navigators and marine engineers as shown in Table 4. Navigators replied to the questionnaire that traffic conditions were more important than route conditions, but marine engineers’ answer was not the same. So, it was found that classification of expertise would add accuracy to questionnaire result (Lee et al. 2016).

First, we could categorize respondents’ job into seven groups except marine engineer and gave code to the occupation as shown in Table 5.

Second, their expertise on each risk factor was classified into three groups after brainstorming with participating researchers of this paper, and two occupations are allocated to top level, three to middle, and the other two to low as shown in Table 6.

Therefore, weighted value should be calculated by the following formula (6).

\[
\omega_i = \frac{\omega_1 \times \frac{1}{3} + \omega_m \times \frac{2}{3} + \omega_l \times \frac{3}{3}}{2}
\]

(6)

where \(\omega_i\) is the weight of a risk factor, \(\omega_h\) is the high expertize, \(\omega_m\) is the middle expertize, and \(\omega_l\) is the low expertize.

Arithmetic mean was shown in Table 7 and total weighted value is in Table 8.

Conclusively, total risk value of the target area is calculated by the final formula (7):

\[
R = R_{f1} \times \omega_1 + R_{f2} \times \omega_2 + \ldots + R_{fn-1} \times \omega_{n-1} + R_{fn} \times \omega_n
\]

(7)

**Table 4. Survey result on risk factor according to job.**

| Risk category | License | Navigator (79) | Engineer (19) | Arithmetic mean |
|---------------|---------|----------------|---------------|----------------|
| Natural conditions | 17.8    | 14.4           | 17.1          |                |
| Route conditions | 26.5    | 36.4           | 28.2          |                |
| Traffic conditions | 39.3    | 33.9           | 38.0          |                |
| Assistance conditions | 16.5    | 15.3           | 16.7          |                |
| Total          | 100.0   | 100.0          | 100.0         |                |

**Table 5. Classification of occupations.**

| No. | Occupation                  | Code |
|-----|-----------------------------|------|
| 1   | Captain and deck officer    | A    |
| 2   | PSC officer                 | B    |
| 3   | VTS operator                | C    |
| 4   | Ship surveyor               | D    |
| 5   | Staff of ship management company | E    |
| 6   | Government officers of maritime and fisheries part | F |
| 7   | Professor and researcher    | G    |

**Table 6. Classification of occupation on risk factors.**

| No. | Risk factors | High | Middle | Low |
|-----|--------------|------|--------|-----|
| 1   | Weather      | A    | C      | B   |
| 2   | Visibility   | A    | C      | E   |
| 3   | Sea          | A    | G      | B   |
| 4   | Wave         | A    | D      | C   |
| 5   | Dimension of route | A | B | C | E |
| 6   | Depth of route | A | G | B | C |
| 7   | Interference of route | A | C | F | G |
| 8   | Obstruction  | A    | G      | B   |
| 9   | Merchant vessel | A | G | B | C |
| 10  | Shallow draft | A | G | B | C |
| 11  | Small craft   | A    | F      | B   |
| 12  | Leisure boat  | A    | F      | B   |
| 13  | Facility      | A    | G      | C   |
| 14  | AtoN          | A    | G      | C   |
| 15  | VTS           | A    | C      | B   |
| 16  | Design        | A    | C      | B   |
| 17  | Designated route | A | C | B | E |
| 18  | TSS           | A    | C      | B   |
Where $R$ is the risk, $R_{f1}$ is the risk factor incidence, and $\omega_i$ is the weight.

$$\omega_i = \frac{\omega_{t} \times \frac{2}{3} + \omega_{m} \times \frac{2}{3} + \omega_{l} \times \frac{1}{3}}{2}$$

### Case study and verification

#### Site selection

There exists over 3000 islands along the Korean peninsula, minimum 11 main maritime traffic flows lies along the coast, more than 60,000 registered fishing vessels, and offshore construction and port renewal operations are undergoing (Park et al. 2017). The length of Korean coastline is 14,963 km which is 37% of the length around the earth. Fifty-two percent of the Korean coastline is land part and the other 48% is island part (KHOA 2014).

It could be said that there are a lot of risk factors for coastal sailing. In addition, most islands are in southern and western part of South Korea, counterwise to simple east coast. So, this study selected five target areas which are located in busy traffic lanes such as ① Ongdo, ② Buk-Maemulsudo, ③ Nam-Maemulsudo at west coast, and ④ Bogildo and ⑤ Geomundo at south coast. The areas are blocked 20 nm by 20 nm including a TSS as shown in Figures 4–8 considering most traffic is concentrated to the TSS.

#### Risk analysis and comparison

Table 9 shows the final data of Ongdo area and the calculation result. Risk level of Ongdo area can be compared with the other areas referring to Table 10. Total risk of Ongdo area is 31.19, Buk-Maemulsudo is 17.21, Nam-Maemulsudo is 18.56, Bogildo is 22.17, and Geomundo is 18.01. It was found that Ongdo area is the most dangerous navigable water among five areas so that it needs first treatment in reducing risks.

In addition, we have an indicator that reveals which risk factor or category should be focused in terms of minimizing total risk by comparison of risk values of the same factors. For instance, natural conditions of Ongdo area are not conspicuous but route conditions, especially depth of route should draw attention because the risk value of depth, 2.06, is more than 2 times than the mean value, 0.99. Also, fishing vessel density should be interested because the risk value of fishing vessel

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**Table 7. Weight of risk factor.**

| No | A   | B   | C   | D   | E   | F   | G   | Mean |
|----|-----|-----|-----|-----|-----|-----|-----|------|
| 1  | 0.0282 | 0.0311 | 0.0444 | 0.0316 | 0.0287 | 0.0401 | 0.0150 | 0.0313 |
| 2  | 0.0782 | 0.0886 | 0.0493 | 0.0894 | 0.0385 | 0.0782 | 0.0656 | 0.0697 |
| 3  | 0.0352 | 0.0224 | 0.0422 | 0.0593 | 0.0317 | 0.0206 | 0.0343 | 0.0351 |
| 4  | 0.0130 | 0.0216 | 0.0330 | 0.0591 | 0.0213 | 0.0263 | 0.0196 | 0.0277 |
| 5  | 0.0428 | 0.0474 | 0.0420 | 0.0357 | 0.0274 | 0.0350 | 0.0708 | 0.0459 |
| 6  | 0.0950 | 0.0292 | 0.0572 | 0.0702 | 0.0449 | 0.0574 | 0.0791 | 0.0619 |
| 7  | 0.0387 | 0.0524 | 0.0571 | 0.0502 | 0.0358 | 0.0458 | 0.0650 | 0.0453 |
| 8  | 0.0753 | 0.1419 | 0.0738 | 0.0873 | 0.1670 | 0.1076 | 0.0995 | 0.1075 |
| 9  | 0.0836 | 0.0988 | 0.0941 | 0.0415 | 0.0349 | 0.0922 | 0.0436 | 0.0698 |
| 10 | 0.0842 | 0.0724 | 0.0874 | 0.0397 | 0.0821 | 0.0677 | 0.0443 | 0.0711 |
| 11 | 0.2427 | 0.1371 | 0.2193 | 0.1665 | 0.2983 | 0.1472 | 0.2309 | 0.2060 |
| 12 | 0.0604 | 0.0761 | 0.0546 | 0.0938 | 0.0703 | 0.0943 | 0.0741 |
| 13 | 0.0385 | 0.0392 | 0.0594 | 0.0375 | 0.0190 | 0.0531 | 0.0475 | 0.0420 |
| 14 | 0.0395 | 0.0650 | 0.0708 | 0.0436 | 0.0674 | 0.0572 | 0.0438 | 0.0553 |
| 15 | 0.0213 | 0.0531 | 0.0316 | 0.0523 | 0.0240 | 0.0505 | 0.0344 | 0.0382 |
| 16 | 0.0234 | 0.0237 | 0.0118 | 0.0223 | 0.0097 | 0.0308 | 0.0123 | 0.0191 |
| Sum| 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

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**Table 8. Weighted value considering respondents’ expertise.**

| No | Top | Mid | Low | Mean value | Weighted value |
|----|-----|-----|-----|------------|---------------|
| 1  | 0.0363 | 0.0287 | 0.0302 | 0.0328 | 0.0335 |
| 2  | 0.0719 | 0.0553 | 0.0890 | 0.0692 | 0.0708 |
| 3  | 0.0279 | 0.0330 | 0.0455 | 0.0325 | 0.0332 |
| 4  | 0.0230 | 0.0224 | 0.0404 | 0.0257 | 0.0263 |
| 5  | 0.0568 | 0.0389 | 0.0489 | 0.0454 | 0.0500 |
| 6  | 0.0871 | 0.0438 | 0.0638 | 0.0687 | 0.0703 |
| 7  | 0.0339 | 0.0489 | 0.0513 | 0.0418 | 0.0427 |
| 8  | 0.0746 | 0.1247 | 0.1146 | 0.0979 | 0.1001 |
| 9  | 0.0636 | 0.0781 | 0.0636 | 0.0684 | 0.0700 |
| 10 | 0.0643 | 0.0732 | 0.0749 | 0.0690 | 0.0705 |
| 11 | 0.1950 | 0.1958 | 0.2324 | 0.2015 | 0.2059 |
| 12 | 0.0654 | 0.0750 | 0.0816 | 0.0713 | 0.0728 |
| 13 | 0.0430 | 0.0438 | 0.0384 | 0.0425 | 0.0434 |
| 14 | 0.0552 | 0.0587 | 0.0504 | 0.0536 | 0.0568 |
| 15 | 0.0265 | 0.0372 | 0.0514 | 0.0342 | 0.0349 |
| 16 | 0.0176 | 0.0152 | 0.0266 | 0.0183 | 0.0187 |
| Sum| 0.9418 | 0.9727 | 1.0992 | 0.9783 | 1.0000 |

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**Figure 4. Ongdo area.**
is 11.96. It exceeds the mean value of 5.52. Every factor comprising NURI-C model can be compared for objective risk assessment on this wise.

Conclusively, these outcomes prove clearly the usage of this tool as a risk assessment model applicable to coastal waters.

**Conclusion**

SOLAS Chapter V/14 is interpreted that the contracting governments of the IMO are required to check the volume of traffic and measure the degree of risk of their navigable waters in order to arrange for the establishment and maintenance of AtoN, including radio beacons and electronic aids. Many models were developed and tested to quantify the risks involved with maritime traffic and consequently to reduce or eradicate marine accident. Especially, the competent international body for AtoN, IALA recommended IWRAP and PAWSA as risk assessment tools which proved its utilities through the tests in many water zones like ports and approaches.

NURI-C, meanwhile, was developed as one of the maritime traffic risk assessment tools for the efficient prevention of marine accidents caused by human factors at coastal waters. NURI-C cannot substitute IWRAP and PAWSA at port and approaches, but it can supplement the weak point of the models of renown at coastal waters. NURI-C was developed by following process:

1. NURI-C model adopted 16 common risk factors whose objective data were available at coastal waters among representative risk assessment tools of three maritime states.
The major contribution of NURI-C model is its utility at coastal waters for efficient mitigation of risk levels. It was proved not only to find out major risk factors in an area but also to figure out risk comparison of target areas. Navigators might use this model for the preparation of sailing, and authorities responsible for the safety of navigation could decide on quantitative analysis the commitment of social, economic, and administrative resources to the coastal safety. This study of risk analysis will be modified or refined by the target waters and application purposes for securing maritime traffic safety.

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