Input paper: [[1]](#footnote-2) ARM21-9.1.1

Input paper for the following Committee(s): check as appropriate Purpose of paper:

**X** ARM **□** ENG **□** PAP **X** Input

**□** ENAV **□** VTS **□** Information

Agenda item [[2]](#footnote-3) 9.1

Technical Domain / Task Number 2 Task 1.4.7

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Proposal for the Introduction of a Maritime Hydro-Meteo Fusion Index (MHFI) into Risk Management Framework

# Summary

Effective maritime risk assessment requires not only the analysis of vessel traffic but also the consideration of environmental conditions that directly affect navigational safety. IALA Guideline G1018 provides various risk assessment tools such as PAWSA, IWRAP, and SIRA, which are effective for analyzing collisions, groundings, and contacts in congested waterways. However, the current toolbox lacks a framework for quantitatively assessing environmental risk factors such as wave height, swell, current, wind, and visibility. In fact, many maritime accidents occur through the combination of traffic conditions and environmental factors, emphasizing the need for an environment-based assessment tool.

To address this gap, this study proposes the Maritime Hydro-Meteo Fusion Index (MHFI) as an environment-based risk assessment tool. The MHFI quantifies five key elements—wave height, swell, current, wind, and visibility—each classified into five levels of risk based on international standards and domestic indices. The final composite index is derived by applying weight to the three most influential factors to effectively reflect significant environmental risks to navigation.

The MHFI offers several key advantages:

* It reflects the combined impact of multiple environmental factors rather than a single element
* Results can be visualized on S-100 based electronic charts, using color-coded levels (LV0–LV4: green–yellow–orange–red–deep red) for intuitive understanding and visualization
* It is developed based on numerical weather and ocean forecast data, making it inherently suitable for real-time application

Including the MHFI in the IALA Risk Management Toolbox would extend the current traffic-oriented framework into a more comprehensive system that also incorporates environmental factors. This will support safe navigation in coastal and port areas, provide objective criteria applicable to both small and large vessels, and strengthen IALA’s overall risk management strategy.

# Background

Quantitative risk assessment that integrates hydrographic and meteorological conditions is insufficiently addressed in the current IALA risk assessment framework, which highlights the need for a new complementary tool. Currently, the IALA G1018 Risk Management Toolbox is mainly composed of traffic-based methods such as IWRAP, PAWSA, and SIRA, which rely on AIS traffic data for both quantitative and qualitative evaluation. These methods are effective for assessing traffic-related risks such as collisions, contacts, and groundings. However, in practice, many maritime accidents occur not only due to traffic conditions but also through the combined effects of wave height, swell, current, wind, and visibility. A structured method to quantify such environmental risks is absent from the current Toolbox. Therefore, it is necessary to establish a risk assessment framework that comprehensively incorporates hydro-meteo conditions.

Various indices have been developed domestically and internationally to address this gap. In Korea, the Ship Operation Index developed by KHOA provides four levels of risk based on forecast data such as wind, current, and wave height, but it does not capture the interaction among these factors. The Harbor and Marine Safety Index translates waves, currents, and winds into external forces to calculate risk at the port scale, but it does not sufficiently reflect the operational characteristics of small coastal vessels. The index developed by the National Federation of Fisheries Cooperatives relies on the single most dangerous factor, making it difficult to represent complex risk situations. Internationally, major ports such as New York and New Jersey have introduced Operational Forecast Systems that combine real-time observations with numerical models to provide nowcasts and forecasts. However, these systems are primarily focused on prediction at the port scale and differ from a framework designed to quantify integrated risks for coastal navigation and small vessels.

These limitations clearly demonstrate the need for a new quantitative approach that comprehensively incorporates hydro-meteo risk factors. MHFI individually quantifies five major environmental elements—wave height, swell, current, wind, and visibility then incorporates the three most critical factors to calculate the final composite. This approach enables the representation of complex risks that occur in actual operational environments. Unlike existing indices that depend on a single factor, the MHFI provides objective warning criteria rather than relying on the subjective judgment of operators or authorities.

As such, MHFI should be recognized as a practical and innovative tool that complements the traffic-oriented assessments of the current Toolbox. It can enhance safety for coastal and small vessels, and should be considered in the revision of the Risk Assessment Toolbox under Guideline 1018.

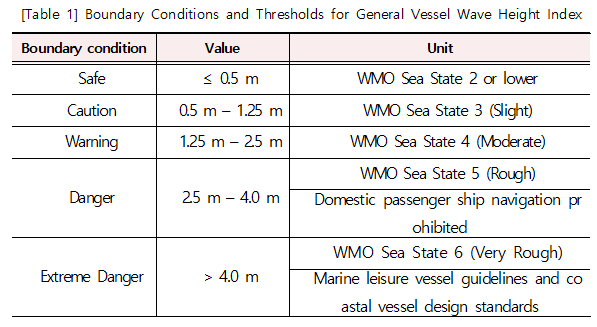
# MHFI Development

The MHFI is designed to quantitatively evaluate hydrographic and meteorological conditions that affect vessel operations as, well as to present corresponding levels of risk. The index is structured around five key elements—wave height, swell, current, wind, and visibility—which are each quantified individually. Based on these individual assessments, a final composite risk index is derived.

Each element is classified into five levels (Safe, Caution, Warning, Danger, Extreme Danger) using criteria drawn from international standards, domestic and international research results, accident statistics, and operational restrictions. When calculating the final index, the three most critical elements with the highest risk levels are integrated, rather than applying a simple sum. The composite risk result is then represented on S-100 based electronic charts, enabling clear spatial visualization of maritime risks.

## Wave Height Risk Index

The wave height risk index is established based on the widely used WMO Sea State classification. A wave height of 0.5 m or less corresponds to the *Safe* level, as it generally does not interfere with normal navigation. The range of 0.5–1.25 m is classified as *Caution*, where small vessels may experience reduced manoeuvrability. The range of 1.25–2.5 m corresponds to the *Warning* level, equivalent to Sea State 4, where vessel motions increase substantially and the likelihood of accidents involving small coastal vessels rises. The range of 2.5–4.0 m is classified as *Danger*, corresponding to Sea State 5, and is directly linked to domestic and international operational restrictions. When wave height exceeds 4.0 m, it is categorized as *Extreme Danger*, consistent with marine leisure vessel guidelines and certain design criteria that define such conditions as unsuitable for safe navigation.

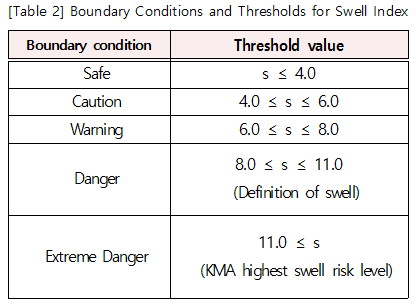


This classification is not limited to a simple adoption of international standards but was also compared and adjusted against the wave height criteria used in existing domestic indices, such as the Ship Operation Index and the Harbor and Marine Safety Index. As a result, the wave height risk index of the MHFI has been designed to ensure both international validity and practical applicability to real navigation.

## Swell Risk Index

Swell is generally defined as conditions with a significant wave height exceeding 2 m and a wave period longer than 8 seconds. The swell risk index is classified according to wave period in order to quantitatively represent the risks posed by long-period waves to vessels and coastal activities. Analysis of accident data shows that even when the significant wave height is below 2 m, frequent casualties and property damage occur within the 4–8 second period range. In other words, low wave heights can still be hazardous when the period is long, indicating that wave period must be considered separately from wave height.

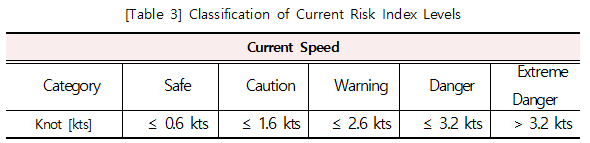
Based on this analysis, the swell risk index is divided into five levels according to wave period (s). The *Safe* level is defined as s < 4.0, when the likelihood of swell occurrence is low and conditions are relatively safe. The *Caution* level is 4.0 ≤ s < 6.0, requiring attention as swell conditions may develop. The *Warning* level is 6.0 ≤ s < 8.0, where swell characteristics become more pronounced, necessitating caution for coastal operations and small vessel navigation. The *Danger* level is 8.0 ≤ s ≤ 11.0, which also corresponds to the conventional definition of swell, where navigational risk becomes significant. Finally, the *Extreme Danger* level is s ≥ 11.0, which aligns with the highest risk classification used by public agencies in Korea, such as the Korea Meteorological Administration (KMA). This classification system was established by combining past accident analysis with official public standards.



## Current Risk Index

The current risk index is designed to quantify the impact of tidal and coastal currents on vessel navigation in ports and coastal areas. Currents are a major hazard arising from water flow and are one of the primary causes of grounding, route deviation, and collision. The index is divided into five levels based on current velocity. These thresholds were established with reference to HF-Radar ocean current data and operational regulations from straits such as Kurushima Strait and Kanmon Strait in Japan.

The *Safe* level is defined as a current velocity of 0.6 kn or less, under which vessels can generally maintain their course during port entry and departure without major difficulty. The *Caution* level is 0.6–1.6 kn, where the influence of the current increases and navigational caution is required. The *Warning* level is 1.6–2.6 kn, at which vessels may struggle to maintain course and the likelihood of drift increases. The *Danger* level is 2.6–3.2 kn, where the risk of collision with breakwaters, rocks, or other vessels increases rapidly. Finally, the *Extreme Danger* level is defined as currents above 3.2 kn combined with a difference between vessel speed and current speed of 4 kn or less. Under these conditions, the vessel’s propulsion is insufficient to overcome the current, making navigation virtually impossible and categorizing the situation as the highest level of risk.

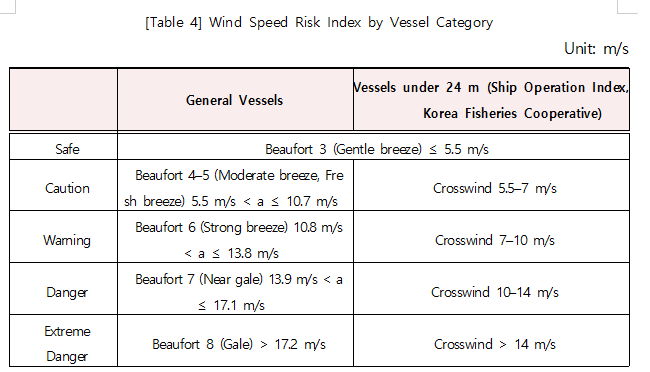


## Wind Speed Risk Index

The wind speed risk index is designed to quantitatively represent the effect of wind on vessel operations at sea. Wind directly affects vessel maneuverability, course keeping, and port entry or departure, and under crosswind conditions, it can cause severe rolling or make steering difficult. As wind strength increases, the lateral force on the vessel’s hull also increases, leading to greater drift and consequently raising the risk of route deviation and collision.

The index is divided into five levels based on the Beaufort scale and domestic navigation standards. The *Safe* level is 5.5 m/s or less (Beaufort 3), under which normal maritime operations face minimal restrictions. The *Caution* level is 5.5–10.7 m/s (Beaufort 4–5), where small vessels require attention due to reduced stability. The *Warning* level is 10.8–13.8 m/s (Beaufort 6), where strong winds may cause significant vessel motion and reduce navigational safety. The *Danger* level is 13.9–17.1 m/s (Beaufort 7), which also corresponds to the criteria for issuing a domestic strong wind advisory and makes port entry and departure difficult. The *Extreme Danger* level is 17.2 m/s or more (Beaufort 8 or higher), equivalent to typhoon or near-typhoon conditions, under which virtually all vessel operations are suspended.

In addition to the general vessel criteria, stricter thresholds are applied for small vessels. For example, small vessels are considered at risk starting around 7 m/s, and when wind speed exceeds 14 m/s, navigation becomes impossible. These stricter levels reflect the limited stability and propulsion power of small vessels. The wind speed risk index is therefore established by combining the international Beaufort scale with the Korean Ship Operation Index, ensuring both global applicability and close alignment with domestic navigation safety regulations.

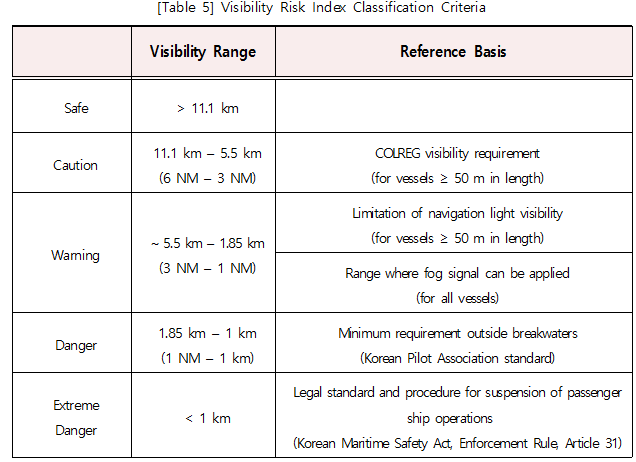


## Visibility Risk Index

The visibility risk index is established to quantitatively assess the risks of collisions and groundings that occur when visibility deteriorates at sea. Reduced visibility prevents vessels from avoiding collisions, makes it difficult to maintain course, and severely impacts safety during port entry and departure. Visibility restriction is considered a critical factor that can lead to accidents, even more directly than traffic congestion or adverse weather conditions.

The index is divided into five levels based on visibility range. The *Safe* level is greater than 11.1 km (≥ 6 NM), where most vessels can clearly identify other ships and navigation aids. The *Caution* level is 11.1–5.5 km (6–3 NM), when mast lights of vessels 50 m or longer become difficult to distinguish. The *Warning* level is 5.5–1.85 km (3–1 NM), where vessels must rely on fog signals and other aids, and collision risk increases. The *Danger* level is 1.85–1 km, which corresponds to the minimum requirements for pilotage and may restrict port entry or departure. The *Extreme Danger* level is less than 1 km, which is also defined as a condition prohibiting passenger vessel operations under the Korean Maritime Safety Act and operational regulations signifying a state where safe navigation is virtually impossible.

This classification system was established by combining the International Regulations for Preventing Collisions at Sea (COLREGs), the Korean Maritime Safety Act, and actual port operation regulations. As such, the visibility risk index is directly connected not only to meteorological conditions but also to legal and regulatory navigation limits.



## MHFI Calculation

MHFI is derived by first calculating individual indices for each element and then integrating them. The individual indices are calculated from the five defined elements—wave height, swell, current, wind, and visibility—based on their observed values relative to established thresholds. Each element is quantified either by comparing observed values with stage thresholds or by applying ratios to determine which risk level is reached. For example, wave height and wind speed are calculated by comparing observations with stage thresholds; in the case of currents, the risk level dramatically increases if the difference between vessel speed and current speed falls below a critical threshold (approximately 4 knots). For visibility, the observed range is compared against maximum visibility benchmarks, with lower values assigned to higher risk stages. Each element is classified on a scale from Level 0 (Safe) to Level 4 (Extreme Danger).

The final MHFI is calculated by integrating the three highest-risk factors among the five elements, rather than using a simple sum. A weighted approach is applied to the most dominant factors while also considering the influence of the other major factors. This reflects findings from accident analysis, which show that maritime accidents are rarely caused by a single factor, but rather by a combination of two or more hazardous conditions. For example, even if wave height is moderate, strong currents combined with rapidly deteriorating visibility can seriously influence safe navigation. Therefore, focusing on the most critical elements in the final index calculation is a rational approach.

The MHFI is classified into five levels: Level 0 (Safe), Level 1 (Caution), Level 2 (Warning), Level 3 (Danger), and Level 4 (Extreme Danger). Level 0 indicates conditions for normal navigation. Level 1 requires caution for vulnerable vessels such as small boats. Level 2 indicates conditions where general coastal navigation and offshore operations must be carried out with warning measures. Level 3 requires intervention and safety management by port authorities. Level 4 represents conditions under which all vessel operations should be suspended. This multi-level structure is designed to be intuitively understood by mariners, authorities, and policymakers, and unlike single-factor indices, it scientifically reflects complex maritime risk conditions.

[Table 6] MHFI Criteria

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Meaning | | Safe | Caution | Warning | Danger | Extreme Danger | |
| Level | | **LV 0** | **LV 1** | **LV 2** | **LV 3** | **LV 4** | |
| Description | | Safe condition | Attention required, especially for small vessels with limited stability | Vessel motions become significant, requiring precautionary measures | Pre-danger stage, navigation requires strong caution | Critically dangerous, navigation should be suspended | |
| Wave Height (Hs) | General Vessel | ≤ 0.5 m (WMO Sea State 2) | ≤ 1.25 m (WMO Sea State 3) | ≤ 2.5 m (WMO Sea State 4) | 2.5–4.0 m (Passenger ship sailing prohibited, Korea) | > 4.0 m (Marine leisure vessel guideline, coastal vessel design criteria) | |
| Small Vessel | ≤ HS\_K IMO | ≤ HS IMO (minimum stability, capsizing threshold for small vessels) | ≤ HS IMO × 1.2 (capsizing threshold) | ≤ HS IMO × 1.5 (capsizing threshold) | > HS IMO × 1.5 | |
| Swell (Period, s) | | ≤ 4 sec | ≤ 6 sec | ≤ 8 sec | 8–11 sec (dictionary definition of swell) | > 11 sec (highest risk level by KMA) | |
| Current (Velocity, m/s) | | ≤ 0.6 m/s (Ocean Info Service, HF-Radar classification – Blue) | ≤ 1.6 m/s (HF-Radar classification – Green) | ≤ 2.6 m/s (HF-Radar classification – Yellow/Orange) | ≤ 3.2 m/s (HF-Radar classification – Red) | <4 lv>  > 3.2 m/s; if vessel speed–current diff ≥ 2.06 m/s (4 kts) → Stage 4 | <4.5 lv>  if < 2.06 m/s → |
| Wind Speed | General Vessel | ≤ 5.4 m/s (Beaufort 3) | ≤ 10.7 m/s (Beaufort 4–5) | ≤ 13.8 m/s (Beaufort 6) | ≤ 17.1 m/s (Beaufort 7; domestic strong wind advisory) | ≥ 17.2 m/s (Beaufort 8; small typhoon threshold) | |
| Small Vessel | ≤ 5.4 m/s | ≤ 7 m/s (Navigation Index Stage 1) | ≤ 10 m/s (Navigation Index Stage 2) | ≤ 14 m/s (Navigation Index Stage 3) | > 14 m/s (Navigation Index Stage 4) | |
| Visibility (km) | | > 11.1 km (≥ 6 NM) | 11.1–5.5 km (6–3 NM, mast light visibility of ships ≥ 50 m restricted) | ~5.5–1.85 km (3–1 NM, all lights restricted, fog signal zone) | 1.85–1 km (Pilotage minimum requirement) | < 1 km (Maritime Safety Act; passenger vessel navigation prohibited) | |
| Individual Index | | 0–1 | 1–2 | 2–3 | 3–4 | 4+ | |

## APPLICATION AND UTILIZATION OF THE MODEL

The MHFI is calculated based on numerical weather and ocean forecast data, and once fully developed, it is structured to immediately incorporate real-time forecast inputs. This enables the early detection and dynamic evaluation of hazardous conditions, thus providing an effective decision-making support for navigators.

The MHFI also offers the advantage of visualization on S-100 based electronic charts (ECDIS). Risk levels are displayed using a color scheme from LV0 to LV4 (green–yellow–orange–red–crimson), allowing mariners and authorities to easily identify risk conditions directly from the chart. By presenting risks as spatial and visual information rather than abstract numbers, MHFI enables immediate decision-making support in real-world navigation environments.

As an environment-based index, the MHFI provides a new capability to quantitatively assess maritime risks, distinguishing it from the traffic-centered tools that are currently available. Future research will aim to combine the MHFI with additional environmental factors, further advancing it into a more sophisticated maritime risk assessment model.

# References

1. IALA, Guideline G1018, Risk Management, Edition 4.0, June 2022.
2. Korea Hydrographic and Oceanographic Agency (KHOA), Official Website, <https://www.khoa.go.kr>.
3. NOAA, New York / New Jersey Operational Forecast System (NYOFS), [https://tidesandcurrents.noaa.gov/ofs/nyofs/nyofs.html](https://tidesandcurrents.noaa.gov/ofs/nyofs/nyofs.html?utm_source=chatgpt.com).
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# PROPOSAL

This study proposes a revision of the IALA Risk Management Toolbox described in Guideline G1018 to incorporate an environment-based MHFI as a complementary risk assessment tool. The MHFI provides a structured method to quantify maritime risks arising from wave height, swell, current, wind speed, and visibility, which are not fully addressed by the current traffic-oriented tools.  
If considered appropriate, a follow-up review may be conducted to develop a dedicated guideline or annex within G1018 to detail the methodology, classification criteria, and potential applications of the MHFI. Furthermore, future studies should examine the integration of MHFI with traffic-based models, supporting the evolution of the IALA Risk Management Toolbox into a more comprehensive framework that combines both traffic and environmental risk factors.

# Action requested of the Committee

The Committee is invited to consider the proposed inclusion of Maritime Hydro-Meteo Fusion Index (MHFI) in Guideline G1018 and take appropriate action as necessary.

1. Input document number, to be assigned by the Committee Secretary [↑](#footnote-ref-2)
2. Leave open if uncertain [↑](#footnote-ref-3)