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Original Paper

Legal institutionalization of risk management in aids to navigation placement: An analytical study on the implementation of IALA risk management tools

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Abstract: This study examines the necessity of introducing the risk management tools adopted by the International Organization for Marine Aids to Navigation to enhance the adequacy of Aids to Navigation placement in the Republic of Korea. It proposes institutional directions to incorporate international standards into the domestic legal framework. The International Organization for Marine Aids to Navigation recommends conducting risk assessments using quantitative and qualitative methods. Major coastal states such as the United Kingdom, the United States, and Denmark have already integrated these approaches into their legal and policy systems to implement evidence-based aid to navigation. This study analyzes these international examples and argues for the need to codify the definition, procedures, and applications of risk assessment within domestic regulations. Furthermore, it contends that the legalization of risk management tools can be justified as not only a technical measure but also a constitutional duty of the state to prevent disasters and protect the public. This study examines risk management challenges and potential strategies to address them, as well. Finally, this study proposes measures to ensure coherence among legal and administrative domains and, thereby, establish an institutional foundation for evidence-based and prevention-oriented maritime policy.

Keywords: International organization for marine aids to navigation, Aids to navigation, Risk management, Risk assessment, Maritime safety

1. Introduction

1.1 Research Background and Purpose

Aids to Navigation (AtoN) are essential maritime infrastructure and operational systems designed to assist the safe navigation of vessels. Similar to providing road signs or traffic signals on land, every country provides and manages AtoN as a public good as part of their governmental responsibility. To be effective, an AtoN must be designed and operated in accordance with international standards to enhance navigational safety and operational efficiency. Accordingly, the nongovernmental organization International Association of Marine Aids to Navigation and Lighthouse Authorities, which had been spearheading the standardization and development of such systems, was transformed into the International Organization for Marine Aids to Navigation (IALA) with the enforcement of the “Convention on the International Organization for Marine Aids to Navigation” in August 2024 **[1]**.

In addition to clarifying AtoN’s technical standards, IALA recommends scientific risk-based methodologies to evaluate the adequacy of AtoN placement and deployment. To date, the Republic of Korea has incorporated many IALA technical standards into its domestic regulations.

However, gaps remain between such international recommendations and the country’s legal implementation. In particular, scientific risk assessment methodologies are yet to be completely institutionalized in the AtoN installation and deployment process, raising concerns about the adequacy of such deployments in certain coastal areas. For instance, although international standards recommend the application of quantitative and qualitative risk management tools in AtoN deployment or relocation, decision-making in Korea continues to rely on experience-based and administrative practices, rather than formalized risk assessment systems. This disparity highlights the need to enhance mar-

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itime safety by narrowing the gap between international recommendations and domestic regulations.

This study examines why Korea should incorporate IALA's risk management tools into its national AtoN management system and how such integration can be achieved. It aims to enhance the rationality and adequacy of AtoN deployment, thereby improving maritime safety. To date, IALA has developed several representative tools, such as the IALA Waterway Risk Assessment Program (IWRAP) Mk2, Port and Waterway Safety Assessment (PAWSA), and Simplified IALA Risk Assessment (SIRA), which are widely applied in international maritime planning and design. Despite their proved utility, these tools are rarely used within Korea's current regulatory arrangements. Accordingly, this study highlights the practical necessity of adopting such tools and suggests legal and institutional measures to support their incorporation.

The study's significance twofold: First, by adopting an internationally compatible risk-based approach, it supports the modernization of South Korea's AtoN management system. Second, this study proposes feasible policy options by integrating legal, administrative, and technical perspectives and offers practical, rather than conceptual, solutions. Accordingly, the study helps improve the legal and institutional bases for AtoN deployment, prevent maritime accidents, and strengthen overall maritime traffic safety.

1.2 Examining the Distinctiveness of the Current Study

AtoN is aids for navigation prescribed by the ordinance of the Ministry of Oceans and Fisheries. They are visual, shape, audible, radio, or special signal aids that inform navigating vessels of their position and direction, the position of obstacles, and so on, through lights, shapes, colors, sounds, and radio signals **[2]**. Traditionally, AtoN placement was based on environmental conditions, accident history, and expert judgment. However, to overcome the increasing complexity of maritime traffic, international organizations have started implementing scientific risk-based management concepts in AtoN placement. Since the early 2000s, IALA has been emphasizing risk-based approaches and developing several tools, including IWRAP Mk2, PAWSA, and SIRA. Today, many countries use these tools to assess collision or grounding risks in important waterways and validate the appropriateness of their AtoN deployment.

In South Korea, several studies have attempted to address the growing recognition of the need to adopt a risk-based approach to AtoN installation and operation. For example, Lee *et al.* **[3]** applied IWRAP Mk2 and the Potential Assessment of Risk Model to assess the collision risk of light buoys in the Fifth Channel of Busan Port. Although their findings revealed discrepancies between the two models, IWRAP Mk2 effectively identified high-risk buoys. Further, Park et al. developed an evaluation model incorporating indicators such as appropriateness, effectiveness, efficiency, sustainability, and influence to assess AtoN by supporting management prioritization **[4]**.

Additionally, several studies report quantitative collision risk assessments that apply IWRAP Mk2 to high-traffic areas such as the Mokpo Port approach channel and Wando coastal waters **[5]**. These analyses enable researchers to identify locations with potentially high accident probabilities and propose appropriate countermeasures. For example, Kim *et al.* calculated collision probabilities using IWRAP in the vicinity of the Mokpo New Port and predicted changes in risk associated with the increase in traffic volume **[6]**. Similarly, Lee *et al.* investigated the relationship between navigational congestion and collision risk at Busan Port entrance, indicating that sections with high congestion indices did not necessarily exhibit high collision probabilities and emphasizing the importance of considering the navigational channel's structural characteristics **[7]**.

Recently, quantitative evaluation methods incorporating big data and machine learning were proposed for AtoN placement assessment: In a 2023 study, Baek *et al.* **[8]** developed an algorithm to verify the suitability of AtoN placement by implementing an evaluation system that utilized vessel trajectory data and the distance ratio concept. The study not only highlights many countries' periodic safety assessments of navigational aid layouts but also emphasizes the necessity of introducing objective quantitative evaluation tools in South Korea, as well.

Despite these efforts, systematic risk assessment methods are not yet widely institutionalized in Korea's AtoN deployment process. Although the Ministry of Oceans and Fisheries acknowledges the potential for risk evaluation in its notice, IALA's quantitative and qualitative tools are yet to be formally embedded in regulations. Therefore, the scientific legitimacy of AtoN deployment decisions must be enhanced through regulatory reform.

Despite being based on existing academic efforts, this study's specific focus is on concrete implementation pathways. Whereas earlier studies depict theoretical models or case-specific analyses, this study proposes a realistic legal and institutional integration strategy aligning domestic regulations with international standards.

1.3 Research Scope

This study comprehensively explores the incorporation of IALA's risk management tools in South Korea's AtoN framework. Initially, IALA's risk-based standards are examined and international case studies reviewed to identify each tool's function and contribution to advanced maritime safety governance. Subsequently, Korea's domestic AtoN legislation and operational practices were investigated to reveal the gaps between international recommendations and local implementation. In particular, the study identifies the failures of current laws and ministerial regulations to reflect formal risk assessments. Finally, based on the study's findings, legal and administrative reforms to support the institutionalization of scientific risk management practices in the Korean AtoN system are proposed.

Although this study does not involve any new numerical simulations, it explicitly clarifies how quantitative and qualitative IALA risk management tools can be operationally applied in the AtoN decision-making process. By defining data inputs, assessment stages, and measurable outputs, this study provides a technical foundation for engineering-based risk quantification.

2. Risk Management Tools

2.1 Concept and Structure

The risk management tools developed by IALA include procedural techniques that quantitatively and qualitatively assess the risk of maritime accidents and, accordingly, establish appropriate response strategies. IALA has consistently encouraged the standardization of risk assessment procedures among its member states. In particular, its Recommendation O-134, introduced in 2005, was replaced by Recommendation R1002, presenting a more advanced system for waterway risk management, in 2017 **[9]-[10]**. R1002 integrates risk management into the core process of AtoN deployment and encourages member states to use various tools to ensure both navigational safety and environmental protection **[11]**. Accordingly, IALA provides a comprehensive suite of tools, including IWRAP, PAWSA, SIRA, and simulation, and recommends that each country apply them according to the specific characteristics of its waterways.

2.1.1 IWRAP Mk2

IWRAP Mk2 is a representative quantitative model for assessing maritime traffic risks. It calculates the probabilities of ship collisions and groundings in designated areas using Automatic Identification System (AIS) data to track vessel movements **[12]**. IWRAP was developed by the Canadian Coast Guard and Technical University of Denmark as part of a joint project from 1998 to 2001, and Mk2 is its current version. It is designed to conform to the Formal Safety Assessment procedures established by the International Maritime Organization (IMO) **[13]**.

IWRAP evaluates accident risk using vessel data (e.g., type, size, speed, and trajectory), environmental factors (e.g., channel width, depth, and obstacles), and dynamic data (e.g., traffic volume). The tool calculates accident probability as the product of "geometric collision probability" and "causal probability" (i.e., the failure to avoid collision) and, thereby, provides a quantitative estimate of accident frequency based on traffic density and channel geometry **[14]**. IWRAP can be used to assess the validity of route designs and AtoN placement strategies in high-risk zones, as well. Finally, many countries have adopted it to obtain scientific and statistically reliable data, including comparisons with annual accident statistics for validation, to support policy decisions.

2.1.2 PAWSA

PAWSA, an IALA qualitative risk management tool, is an assessment system developed by the U.S. Coast Guard in the early 1990s. Rather than relying on quantitative metrics, PAWSA focuses on expert and stakeholder experiences. At the core of PAWSA is a one- to two-day workshop involving parties related to the waterway under assessment. During the workshop, participants systematically identify risk factors, estimate the risk level, and evaluate the adequacy of existing risk mitigation measures **[15]**. Subsequently, they discuss additional measures, such as waterway design improvements, regulatory enhancements, and route modifications, and establish practical improvement plans by predicting the measures' expected effects on risk reduction.

The workshop brings together a wide range of waterway users and local stakeholders, including mariners, traffic controllers, fishers, environmental groups, and passenger–transport operators. Because it incorporates practical insights, the process ensures both policy acceptance and field relevance. In particular, PAWSA enables the qualitative reflection of waterway risks and user needs in AtoN installation decisions. Hence, PAWSA has the advantage that it can encompass the social and economic factors that cannot be fully captured through technical judgment alone.

However, because the workshop participants' composition and perceptions may affect the results' objectivity, PAWSA is limited by potential subjectivity **[14]**. Consequently, clear criteria must be established to select sufficiently qualified experts and ensure neutrality.

2.1.3 SIRA

SIRA is a lightweight qualitative tool designed for rapid deployment and ease of use. SIRA assigns numerical scores to the likelihood and severity of potential accidents in a simple matrix-based form. Likelihood is ranked from "very rare" (1 point) to "very frequent" (5 points), whereas severity is scored based on operational disruption, human casualties, environmental damage, reputation loss, and economic impact. Multiplying accident likelihood and severity yields a composite risk index that determines the necessity of further action. For example, a likelihood score of 2 and severity score of 3 produce a risk index of 6, which indicates a moderate level of risk that potentially warrants mitigation.

SIRA is particularly useful in regional offices and frontline institutions because it facilitates internal risk evaluations without requiring full-scale workshops. Further, it includes nine categories of potential mitigation strategies (e.g., route planning, training, regulations, and route modifications), which help translate assessments into actionable plans **[16]**.

2.1.4 Simulation

The simulator is an important IALA risk management tool that reproduces vessel traffic and AtoN's functions and placement within a specific waterway or port in a virtual environment, thereby facilitating the advance verification of the validity of installation locations and configurations. In waters with high-density marine traffic, the simulator can be used prior to AtoN installation, relocation, or modification to assess how proposed placement arrangements may influence maritime traffic flow. By providing information such as AtoN location, type, and characteristics and examining various navigational scenarios based on vessel operating data, users are able to evaluate the AtoN's effectiveness in terms of visibility, collision probability, avoidance distance, and congestion **[17]**.

In South Korea, the AtoN simulation system installed at the Korea Institute of Aids to Navigation Testing and Inspection Facility in Yeosu, Jeollanam-do, is currently used to assess visibility based on AtoN placements. This system secured a leading technological position when it was filed for an international patent with the European Union in 2015 and subsequently registered in 2017. The simulator is used in hands-on training at the institute's training center and in training programs for government officials from developing countries, thereby contributing to the international dissemination of domestic technology.

Moreover, simulation-based analysis can complement other risk management tools, such as IWRAP, PAWSA, and SIRA. In particular, by visualizing the risk levels perceived by practitioners, the simulator enhances the transparency and persuasiveness of the AtoN layout design. IALA emphasizes the combined use of both quantitative and qualitative tools: Whereas quantitative analyses rely on objective indicators such as AIS data, qualitative analyses capture unstructured information from elements not reflected in AIS, such as small-vessel movements and fishing activity. Finally, international trends suggest that both approaches must be integrated to obtain a comprehensive understanding of maritime risk.

2.2 Legality Risk Management Tools

In general, IALA recommendations and guidelines are nonbinding international standards. Despite not creating direct obligations under international law, IALA guidelines, unlike treaties or conventions, are widely accepted as de facto international norms in the maritime safety domain **[18]**.

Accordingly, the use of IALA's risk management tools is considered a means of fulfilling obligations under relevant international conventions: Article 13 of Chapter V of the International Convention for the Safety of Life at Sea (SOLAS) requires contracting parties to consider navigational risks in the provision of AtoN **[19]**. Specifically, it mandates the deployment of AtoN in accordance with traffic density and risk levels, thereby endorsing a risk-based approach. The same provision calls for conformity with international standards and explicitly requires the consideration of IALA's recommendations and guidelines. In this context, AtoN installation and operation based on risk assessment is not merely advisable but part of the legal obligations of contracting states under the SOLAS framework, with IALA's tools serving as practical mechanisms to fulfill these obligations **[20].**

Furthermore, the technical standards and risk management tools developed by IALA are closely linked to the technical activities of the IMO, which officially acknowledges IALA's significance in several of its circulars. For example, in Circular SN.1/Circ.296/Rev.1, which was issued in 2024, the IMO officially adopted and disseminated IALA's Risk Management Toolbox for Aids to Navigation and Vessel Traffic Services to Its Member States **[21]**. Such formal recognition by the IMO effectively elevated IALA's tools to the status of practical international standards, even though they remain formally nonbinding.

In summary, although IALA risk management tools are not legally binding in themselves, they derive an indirect normative force through their integration into the SOLAS framework and formal endorsement by the IMO. States are increasingly conducting risk assessments based on IALA standards as part of their duty to ensure maritime safety, making these tools de facto instruments to implement convention obligations. Accordingly, IALA's risk management tools, although nonbinding, hold significant legal relevance as practical standards facilitating the implementation of obligations under international maritime conventions.

3. Status of AtoN Deployment and Review of the Domestic Legal Framework

3.1 Current AtoN Legal Framework and the Absence of Risk Assessment Procedures

South Korea's AtoN system is governed by the Aids to Navigation Act, which ensures maritime traffic safety and enhances vessel navigation efficiency through the rational establishment and management of AtoN **[2]**. In particular, a presidential decree and a ministerial rule **[22]-[23]** enacted under the Act specify appropriate procedures and standards in detail. Moreover, the technical standards issued by Ministry of Oceans and Fisheries (MOF), such as Standards on the Functions and Specifications of Aids to Navigation and Standards on the Functions and Specifications of AtoN Equipment and Supplies, supplement the statutory framework. Ministerial guidelines, such as the Guideline on the Management of AtoN Facilities, and ministerial directives, including the Guideline on the Installation and Management of Private AtoN **[24]-[27]**, govern highly detailed operational aspects. Local governments rarely issue their own AtoN ordinances, and the central government retains primary authority over such guidelines.

Under Article 51 of the Aids to Navigation Act, MOF may delegate authority to the heads of affiliated organizations or to the Commissioner General of the Korea Coast Guard as prescribed by Presidential Decree **[2][22]**. In practice, despite retaining primary control, the Minister delegates significant authority to regional offices (e.g., Busan, Incheon, and Yeosu) and regional Coast Guard commands. Accordingly, AtoN management is centralized, with local governments having only limited jurisdictional autonomy, except in specific cases involving port authorities or municipal ports.

Despite having a legal framework, AtoN deployment does not require any formalized risk assessment procedure by law. Although the technical standards indicate that simulations and risk assessments "may be conducted" while installing buoys on key routes **[24]**, these references are nonbinding. In practice, AtoN deployment is primarily based on expert consultation, existing nautical charts, and traffic statistics, rather than institutionalized quantitative or qualitative risk assessments.

3.2 Limitations of the Absence of Risk Assessment Procedures

AtoN deployment is a critical administrative act directly linked to maritime safety. Internationally, IALA recommends risk-based AtoN planning through standardized qualitative and quantitative assessments. Simultaneously, the prevailing domestic approach is mainly empirical, leading to the structural considerations discussed in Sections 3.2.1 through 3.2.4:

3.2.1 Limitations in Preventive Measures

In the absence of systematic risk management, institutional vulnerabilities occur in maritime accident prevention. Although South Korea has steadily been implementing various risk management measures, such as AtoN installation, Vessel Traffic Service (VTS) operation, and traffic separation schemes, accident statistics continue to indicate an upward trend. In 2023, the number of marine accidents was 3,092, an 8% increase from previous year's data, and the number of deaths or missing people was 94.

Collisions, groundings, and allisions comprised the majority of accident types, with fishing vessels accounting for approximately 66% of the total number of incidents **[28]**. This suggests that ensuring the safety of small vessels operating primarily in coastal waters remains a challenge. Further, this indicates the need to conduct highly systematic prenavigational risk analyses in coastal areas with persisting risk factors, as well as strengthening the standards for AtoN installation.

For instance, in 2024, near Daejin Port in Goseong, Gangwon Province, an emergency report mistaking a drying rock for a submarine and a collision involving a fishing vessel occurred in close succession. Only after the occurrence of these incidents did the relevant authorities install temporary AtoN and start considering the placement of permanent ones **[29]**. Although the area had long contained submerged rocks, the associated risks had not been incorporated in advance through any installation standards or assessment procedures; therefore, there was room for institutional improvement.

3.2.2 Over- and Under-Installation Issues

In the absence of risk-based planning, AtoN may be unevenly placed. Whereas multiple AtoN may overlap or provide more coverage than necessary in some areas, the aids' coverage level may be insufficient, despite the presence of navigational hazards, in others. These patterns suggest that existing deployment practices can benefit from more standardized and evidence-based criteria to ensure appropriate AtoN distribution.

According to IALA, although an appropriate density of AtoN can enhance the ease and accuracy of navigation in route design, excessive concentration may reach a saturation point at which additional AtoN provide little practical benefit in terms of positional awareness. Therefore, simulations or risk assessments are essential to determine the optimal density of AtoN along a given route **[30]**. However, a comprehensive framework incorporating these international guidelines is yet to be fully established domestically. According to one study, although national technical standards for AtoN deployment exist and IALA recommendations are widely available, practical decisions regarding installation continue to be influenced by individual judgments in the field **[8]**.

In cases of over-installation, AtoN spacing may become overly dense, which can confuse mariners and result in unnecessary maintenance expenditures. Moreover, in some instances, existing AtoN remain in place even after the occurrence of traffic pattern changes or route modifications, leading to situations in which installations continue to be maintained despite their limited operational relevance. Contrastingly, under-installation presents a more direct source of navigational risk than over-installation. For example, in the previously mentioned area near the drying rock off Goseong, the absence of AtoN resulted in incidents in which vessels failed to detect underwater hazards.

Further, in a study conducted in the waters near Mokpo Maritime University, AtoN spacing was reported to exceed IALA recommendations in certain segments, indicating the necessity of conducting a review evaluating visibility and identification **[8]**. Finally, according to international guidelines, excessive distances between AtoN may create gaps in navigational awareness, suggesting potential implications for the area's overall safety.

3.2.3 Resource Allocation Inefficiencies

AtoN, which are national infrastructures, comprise systems operating under budget and personnel limitations. Accordingly, the efficient allocation of resources is a significant policy concern. Although the importance of risk-based decision-making is widely recognized, a fully developed resource distribution framework based on systematic risk analysis is yet to be established. Consequently, structural inefficiencies can occur. In some waters, AtoN may be deployed in more numbers than necessary; contrastingly, in many other areas, the deployed number may be insufficient with respect to the level of navigational risk. Such imbalances can lead to both the under- and over-allocation of resources and, finally, a reduction in overall operational efficiency.

When resources continue to be allocated to maintaining an AtoN that is redundant or no longer operationally essential, fewer funds may be available to install or upgrade the AtoN in areas with higher risk levels. Conversely, areas not previously identified as high risk may experience incidents requiring emergency funding, suggesting that a preventive and risk-based allocation system has not yet been fully institutionalized.

One underlying factor is the absence of a formalized method to quantitatively assess investment priorities and allocate resources according to risk levels. The current evaluation of AtoN deployment adequacy largely relies on visibility checks and expert consultations **[8]**. Analytical methods based on maritime traffic data, such as AIS, have only limited use. Consequently, qualitative judgments based on light buoy visibility or inputs from small numbers of mariners remain the primary bases for decision-making, which limits the objectivity and predictive capacity of resource allocation assessments.

When resource distribution is conducted without the support of risk management tools, budgets and personnel may be allocated in ways that do not correspond to the relative hazards or traffic characteristics of each area. This can reduce the cost-effectiveness of AtoN management and prevent the full realization of navigational safety improvements that can otherwise be achieved through more strategic resource use. Ultimately, insufficient risk assessments undermine optimal resource allocation and may, in the long run, constrain the safety outcomes that are attainable with respect to investment levels in the maritime domain.

3.2.4 Regional Disparities in Navigational Safety

South Korea's AtoN installation and management system operates in a decentralized manner, primarily through the Regional Offices of Oceans and Fisheries, in accordance with the characteristics of each maritime area and administrative jurisdiction. This structure is advantageous in that it reflects regional maritime conditions and offers a degree of administrative autonomy. However, it can simultaneously contribute to regional variations in AtoN deployment quality and navigational safety levels, as well.

Investments have been relatively concentrated in major hub ports, such as Busan and Incheon, as well as large port areas, and the modernization of AtoN facilities, which has been progressing over time, has helped develop a comparatively stable navigational safety environment. Contrastingly, areas such as the island waters of the southwest, the northern East Sea coast, fishing routes, and local passenger vessel routes tend to have lower AtoN densities and technological capacities than large ports. Many of these waters are located outside the real-time monitoring coverage of VTS, as well. Despite involving hazards such as rocks, drying rocks, and strong tidal currents, AtoN installations have not always accounted for local risk conditions, which may increase the likelihood of maritime accidents.

Additionally, regional accident patterns reflect these disparities. According to Korea Safety Tribunal of the Ministry of Oceans and Fisheries data **[31]**, the period 2019–2023 witnessed 14,802 marine accidents, among which fishing vessels accounted for 9,602 cases (64.9%). Further, 41.9 and 20.8 percent of all fishing vessel accidents occurred in the waters of Jeollanam-do and Gyeongsangnam-do, respectively, indicating that more than half of such accidents nationwide occurred in these two regions.

Although the concentration of accidents in particular regions cannot be attributed to the presence or absence of AtoN alone, differences in the distribution of navigational infrastructure may indirectly contribute to risk level variations. In general, fishing vessels have only limited navigational equipment and weather response capabilities than larger vessels. Accordingly, fishing vessels have a higher reliance on AtoN as the primary source of navigational information than their larger counterparts. When the adequacy of AtoN deployment is insufficient, fishers' ability to respond effectively to local hazards may likewise become constrained.

4. Comparative International Practices and Legal Implications

International practices depict a wide range of approaches for the use of IALA risk management tools. Many countries incorporate IALA recommendations and guidelines into their national policies, making risk assessment a required step in the establishment of new AtoN or design of new routes. A common trend for these practices is the shift toward evidence-based decision-making. Whereas earlier approaches tend to focus on postincident responses, current practices emphasize preventive management through data analysis to ensure risk anticipation and mitigation. The widespread adoption of AIS and advances in digital technologies support this transition.

IALA emphasizes the adoption of an integrated approach combining quantitative data, such as AIS information, with qualitative insights from experts and encourages the use of tools designed to merge these two input types **[15]**. It considers quantitative analysis alone to be insufficient for completely assessing AtoN-related risks and emphasizes that data-driven modeling must be supported by expert knowledge and professional judgment as essential aspects of the overall evaluation process. For example, because IWRAP analyzes historical vessel traffic patterns, it requires expert input to adjust traffic assumptions or reflect the potential effects of future risk mitigation measures.

Accordingly, IALA emphasizes that its quantitative tools are intended to provide information supporting expert discussion and interpretation, rather than producing final or definitive assessments on their own **[32]**. The numerical outputs generated by these tools must be qualitatively evaluated to obtain a well-grounded determination of risk. Under this approach, an integrated method that combines quantitative modeling and expert workshops is increasingly becoming a standard procedure in international risk management practices.

4.1 United States: PAWSA-Based Risk Management

The United States uses PAWSA, IALA's recommended qualitative risk assessment tool, as a core method to manage maritime risk. Since 1999, the U.S. Coast Guard has been conducting PAWSA workshops in major ports and waterways nationwide and has hosted more than 47 workshops to date. In the workshops, which follow a structured two-day format, experts and stakeholders jointly identify key risks, assess their significance, and discuss mitigation strategies for each waterway. The process strengthens the collaboration between the government and private sector and enhances the communication among local maritime organizations, such as Harbor Safety Committees **[33]**.

In particular, a PAWSA workshop conducted in Boston Harbor examined the navigational challenges associated with strong tidal currents and recommended temporary AtoN installations until the completion of dredging. The workshop addressed the traffic congestion caused by increased recreational boating and discussed the following redressal measures: enhanced boater education, the mandatory carriage of AIS by small vessels, and the use of daytime marks on recreational crafts **[34]**. Subsequently, these mitigation measures, which contributed to navigational safety, were reviewed and implemented by the Coast Guard and local authorities. Accordingly, PAWSA became an established component of the United States' broader maritime and waterway safety management system.

In parallel, the United States uses IWRAP for quantitative modeling, as well. A 2021 study on approaches to Chesapeake Bay applied IWRAP to compare collision probabilities among alternative routing options. United States Coast Guard Navigation Center (NAVCEN) used the results to evaluate the potential reduction in collisions and groundings for a two-way routing system and referred to the findings while considering route adjustments **[35]**.

Therefore, despite employing PAWSA as its primary risk assessment tool, the United States uses IWRAP in cases requiring detailed quantitative analysis for large-scale waterway planning. Although these tools are not directly mandated by federal statute, they are de facto standards based on internal Coast Guard guidance and administrative documents, such as navigation and vessel inspection circulars **[36]**.

4.2 Denmark: IWRAP-Based Quantitative Accident Analysis

Denmark is one of the Countries leading the development and application of IALA's risk management tools, particularly the use of IWRAP in quantitative accident analysis. For example, Denmark has used IWRAP to assess whether the replacement of traditional manned lighthouses with floating AtoN would reduce visual detectability and create additional navigational risk **[37]**. Further, the tool has been applied to evaluate proposed route closures or modifications, enabling authorities to compare accident probabilities across alternative scenarios and estimate the safety implications of route changes. In the Great Belt, one of Denmark's busiest waterways, collision risk studies using IWRAP revealed that the model's predicted accident probabilities were closely aligned with historical accident records, apparently confirming the reliability of using this tool in high-traffic areas **[38]**.

From an institutional perspective, Denmark does not legally mandate the use of PAWSA or IWRAP through any act or regulation. Instead, the Danish Maritime Authority (DMA) issued administrative guidance requiring major maritime projects or route adjustments to undergo advance risk assessment, which considers the use of IALA's risk management tools a de facto standard. For instance, once the installation of a new offshore wind farm along the Danish coast is proposed, developers must submit a navigational risk assessment report that quantifies collision and grounding probabilities and identifies risk reduction measures **[39]**. The DMA reviews these quantitative assessments and proposes mitigation measures during project approvals. Despite the absence of any fixed legally prescribed thresholds, the Authority evaluates on a case-by-case basis whether the residual risk is within an acceptable range **[37]**.

In this sense, Denmark does not directly codify specific tools such as IWRAP into legislation. However, IWRAP and other IALA risk management tools have become deeply embedded in administrative practice over the years and are extensively used in maritime planning and regulatory decision-making.

4.3. United Kingdom: Integrated Framework for Navigational Risk Management

The United Kingdom incorporates IALA's risk management tools into its national Port and Marine Facilities Safety Code (PMSC), which requires all ports and lighthouse authorities to conduct systematic risk assessments. The PMSC mandates that risks must be reduced to the As Low As Reasonably Practicable level, and its accompanying Guide to Good Practice encourages the use of assessment methods consistent with international recommendations **[39]-[40]**.

The general lighthouse authorities (GLAs) of the United Kingdom and Ireland, comprising the Trinity House, Northern Lighthouse Board, and Commissioner of Irish Lights, have formally adopted PAWSA and IWRAP. A 2012 policy document explicitly states that these authorities use IALA-approved risk management tools. While planning AtoN or route arrangements, GLAs apply PAWSA, IWRAP, or their combination depending on the context, thereby integrating qualitative and quantitative inputs in accordance with IALA guidelines and aligning their practices with international standards for navigational safety **[11]**.

Some practical applications of these tools include the ACCSEAS project, which was conducted with DMA's cooperation. The project used IWRAP to generate heat-map visualizations of collisional risk distribution in the North Sea to support emergency response planning **[41]**. Furthermore, IALA's risk management tools are routinely used in maritime infrastructure projects, such as offshore wind farm development and new port construction. For example, the navigational risk assessment for the Morecambe Bay offshore wind project highlights maritime authorities' use of the IALA IWRAP Mk II model in the United Kingdom, Denmark, and Sweden for the evaluation of new routing schemes; the project applied IWRAP to estimate collision probabilities, as well.

From an institutional standpoint, neither the Ports Act 1991 nor Merchant Shipping Act 1995 imposes a statutory obligation to conduct PAWSA or IWRAP analyses. Instead, port authorities implement these tools in adherence to the PMSC, a self-regulatory framework overseen by the Maritime and Coastguard Agency. Accordingly, the use of IALA's risk management tools is a de facto standard within the United Kingdom's maritime safety system.

In summary, in the United Kingdom, PAWSA and IWRAP are established as standard instruments for maritime risk management through national policy and a self-regulatory safety code, rather than direct legislative mandates. Accordingly, ports and lighthouse authorities employ IALA risk assessment methods as part of a structured, evidence-based approach to navigational safety management.

4.4 Comparative Legal Assessment

International AtoN standards have largely been shaped by the recommendations issued by IALA and IMO. For example, the IALA Maritime Buoyage System divides the world into Regions A and B and prescribes buoy colors, shapes, and light characteristics. South Korea, which is part of Region B, adheres to these standards. For technical specifications, ministerial notice, such as Standards on the Functions and Specifications of Aids to Navigation **[24]**, incorporates IALA criteria to a considerable extent.

However, a discrepancy exists between international recommendations and the domestic legal framework in the risk management domain. IALA actively encourages the use of its risk management tools and requires competent maritime authorities to introduce formalized risk assessments as part of the decision-making process. Although IALA recommendations are not legally binding, many member states voluntarily follow them as de facto norms. As clarified by the GLA example in Section 4.3, some jurisdictions incorporate formal risk assessments into their internal policies and consider them mandatory procedural steps **[11]**.

Contrastingly, neither the Aids to Navigation Act nor its subordinate regulations in Korea explicitly prescribes the formal risk assessment procedures recommended by IALA. In the absence of such provisions, no legal mechanism mandates the inclusion of risk assessments in AtoN-related administrative decision-making. Article 18-2 of the Standards on the Functions and Specifications of Aids to Navigation **[24]** clarifies that simulation tests and risk assessments may be conducted when installing buoys in critical routes. However, since this provision is mentioned in a non-statutory ministerial notice in permissive terms, it does not impose any binding obligation. Although international practices increasingly emphasize the inclusion of formalized and structured risk management procedures, the current domestic framework is still in the process of developing comparable mechanisms for risk-based AtoN management. In practice, regional offices often make decisions based on established procedures and supplement them with expert input when necessary.

Under a legal and institutional structure that does not completely align with international standards, efficient resource allocation and preventive safety measure implementation become difficult. In Korean coastal waters, collisions, groundings, and other navigational accidents occur annually. However, the nation's systematic causal analysis and proactive preventive strategies remain underdeveloped. For instance, collisions accounted for 242 cases (i.e., 34 percent) of all major maritime accidents in 2024 **[42]**. According to international recommendations, areas with recurrent collision patterns should undergo detailed risk assessments to determine whether they require additional or improved AtoN. However, such practices are yet to be incorporated into the domestic system. Hence, the gap between international recommendations and the domestic legal framework directly affects the adequacy of AtoN deployment, and many commentators opine that this discrepancy must be addressed urgently.

Whereas international standards promote continuous and proactive risk management, the current South Korean legal system for AtoN operates on a largely reactive and case-specific basis. Accordingly, the installation and adjustment of AtoN is often carried out without a structured, risk-based preliminary assessment. When AtoN allocation primarily depends on customary practice or empirical judgment, latent hazards may be overlooked or unnecessary over- or underinvestment may occur. Such institutional limitations create a qualitative gap between domestic practice and the risk-based approach promoted by international standards, as well as constraining efforts to scientifically optimize AtoN deployment.

Therefore, a systematic comparative review should be performed to assess the structure and application of IALA's risk management tools and examine ways to integrate them into domestic law and policy. Further, the core elements of international standards that can be feasibly adopted within the Korean legal framework must be identified, and appropriate legislative and policy strategies must be considered for their effective incorporation. Section 5 examines the rationale for adopting IALA's risk management tools and proposes appropriate approaches for doing so.

5. Necessity of and Justification for the Legal Adoption of Risk Management Tools

5.1 Legal Basis of Tool Adoption

The introduction of new systems such as IALA's risk management tools requires additional financial resources and specialized personnel. However, the implementation of risk assessment procedures and its associated expenditures are justified as not only aspects pertaining to administrative convenience but also measures fulfilling the constitutional duty to actively protect people's lives and ensure their safety. Article 23(2) of the Constitution **[43]** states that "the exercise of property rights shall conform to the public welfare," indicating that preventive investment and administrative action for public safety are aligned with constitutional principles even when they entail additional budgetary burdens. Since maritime accidents can involve significant human casualties, environmental damage, operational rescue costs, and insurance losses, all of which may arise from a single incident, preventive institutional investments represent the essence of constitutional responsibility. Accordingly, the adoption of risk management tools is understood as not a discretionary expenditure but a constitutionally mandated measure that is necessary for the protection of fundamental rights and realization of public welfare.

The Administrative Procedures Act **[44]** strengthens this constitutional framework by requiring the establishment of procedural safeguards prior to the execution of any administrative action that affects individual rights and interests. Similarly, Article 22 mandates hearings in cases where administrative dispositions significantly affect the public or where such procedures are required by law. Further, Article 27 ensures individuals' right to express their opinions prior to an administrative disposition and obligates administrative authorities to document such statements. These provisions serve as institutional mechanisms ensuring that administrative decisions reflect public input and authorities fulfill their explanatory duties in advance.

Similarly, the General Act on Public Administration **[45]** codifies the principles of proportionality and protection of trust. According to Article 10, any administrative action should be effective and appropriate to realize administrative purposes, be performed to the minimum extent necessary, and not infringe citizens' interests to any degree greater than the public interest it upholds. Article 12 requires administrative agencies to protect the citizens' legitimate and reasonable trust unless doing so will significantly harm public or third-party interests. Moreover, legalizing risk assessment procedures helps operationalize these principles by embedding objective criteria, transparency, and predictability in administrative practice.

From a legal standpoint, international standards are not automatically enforceable within the limits of the domestic legal system. Under Article 6(1) of the Constitution **[43]**, the treaties duly concluded and promulgated under the Constitution and the generally recognized rules of international law have the same effect as domestic laws. Accordingly, IALA's tools should be localized and adapted to reflect Korea's maritime and institutional conditions, rather than being accepted uncritically. The appropriate approach is not the wholesale adoption of specific models but the legislative integration of a rational decision-making framework that has such tools as practical instruments.

5.2 Policy and Operational Necessity of Tool Adoption

The prevention of maritime accidents, irrespective of their severity, come under the purview of the State's legal responsibility to ensure public safety. Further, statistics indicate a continued increase in vessel collision incidents, particularly among small vessels. Such risks come under the State's preventive obligations within the Maritime Safety Act and Act on the Investigation of and Inquiry into Marine Accidents **[46]-[47]**. Moreover, Article 34(6) of the Constitution **[43]** clarifies that "the State shall endeavor to prevent disasters and to protect citizens from harm therefrom," and maritime accidents clearly constitute such disasters.

In addition, changes in the maritime environment, such as the introduction of autonomous ships and expansion of offshore wind farms, expose the limitations of the existing AtoN system. To effectively respond to such structural developments, a legally grounded framework that can identify and prevent risks in advance must be established. The perspective that "a system is unnecessary simply because it does not create any visible problems" reflects an outdated reactive and non-preventive administrative mindset that does not align with contemporary rule-of-law principles, which increasingly emphasize preventive governance.

Some argue that IALA's risk management tools were developed to conform to the characteristics of European waters or major international ports and, therefore, may not suit South Korea's coastal conditions or its fishing vessel–centered traffic patterns. However, these tools constitute technical baseline instruments, and their input variables and scenarios can be adjusted to reflect a jurisdiction's specific characteristics.

5.3 Expected Effects of Legal Adoption

Participatory risk assessment methods such as PAWSA are not only technical tools but also mechanisms ensuring administrative legitimacy and transparency. By visually presenting risk factors and engaging in step-by-step discussions, citizens and other stakeholders can easily understand the issues at hand and, consequently, become more likely to accept the resulting administrative decisions. In other words, such tools help translate complex technical judgments into administrative language, enhancing policy acceptability.

Moreover, the institutionalization of the risk assessment procedure through legislation enhances administrative tasks' standardization and predictability. For responsible officials, this alleviates the burden of discretionary liability stemming from ambiguous decision-making criteria, ensuring administrative accountability based on well-defined procedures.

To date, IWRAP has already been used for risk analysis in multiple domestic cases, and these cases highlight the tool's practical effectiveness. However, the essential consideration is not the complete adoption of a specific model but its institutional purpose, that is, the establishment of a legally grounded, rational decision-making process through risk management. The tool itself is simply the means by which this purpose is realized.

Moreover, risk management tools are introduced not merely as technical supplements but as part of a broader effort to restructure maritime legal governance into a "preventive, responsibility-centered, and internationally standardized" framework. In this process, counterarguments serve as opportunities to strengthen the legitimacy and sophistication of policy establishment. Finally, due to the compelling interest of the public in enhancing maritime safety, the adoption of such a system should be considered an obligation, rather than a choice.

6. Legislative and Administrative Measures for System Introduction

6.1 Legislative Integration Measures

Legislative reforms are necessary to support the introduction of IALA's risk management tools. To establish an integrated legal framework for maritime risk management, the following measures are proposed:

First, the Aids to Navigation Act must be amended to institutionalize the introduction of risk management tools for AtoN. Current legislation does not specify the detailed assessment procedures required to establish, modify, or remove AtoN. Therefore, it is necessary to introduce a mandatory provision requiring the Minister of Oceans and Fisheries to conduct a scientific risk assessment when making a decision regarding AtoN installation or modification. Rather than remaining merely declaratory, this provision should explicitly require compliance with IALA recommendations to ensure that domestic law substantively reflects international standards.

Following such legislative amendments, subordinate regulations such as presidential decrees, ministerial decrees, or notices issued by the Ministry of Oceans and Fisheries must be enacted to define implementation procedures. These subordinate regulations should provide detailed requirements for the execution of risk assessments, including the assessment process and relevant evaluation items, responsible entities, and reporting formats. Further, they should codify the criteria and conditions for applying quantitative and qualitative assessments in accordance with guidelines such as the IALA Guideline 1138 (The Use of the Simplified IALA Risk Assessment Method, SIRA, 2022) and IALA Guideline 1124 (The Use of Ports and Waterways Safety Assessment, PAWSA MkII, 2022). In particular, a legal mechanism must be established to ensure the execution of risk assessment procedures before the incorporation of any administrative decisions regarding AtoN installation or modification; this enables risk management to function as the foundation for policy decisions.

Furthermore, legal status must be granted to the outcomes of the consultation processes conducted through PAWSA, SIRA, and similar tools so that the results are reflected in policy decision-making, rather than remaining reference materials. For example, the results of PAWSA workshops can be considered mandatory attachments during deliberations on AtoN installation, modification, or removal. Another option is to introduce procedural safeguards stating that the decisions made without associated risk assessment processes are invalid. Such mechanisms ensure the practical effectiveness of risk assessments and institutionalize the principle that only those decisions based on appropriately conducted assessments are legally valid.

Because these legislative and institutional efforts cannot be implemented solely by the Ministry of Oceans and Fisheries, an integrated legislative roadmap must be developed in cooperation with relevant agencies such as the Korea Coast Guard and the

Ministry of Land, Infrastructure and Transport. A joint governmental taskforce should be established to coordinate amendments to the Aids to Navigation Act, establish related guidelines, and revise associated legal instruments. As an IALA council member, South Korea can enhance its policy credibility and international standing in the maritime safety domain by assuming a leading role in incorporating and institutionalizing international standards.

The aforementioned legislative integration measures help consolidate fragmented regulations into a unified risk management system, thereby reinforcing the legal foundation necessary to secure the sustainability and enforceability of the adopted tools. Legislative support enables the advancement of administrative measures and technological implementation; accordingly, legislation is prioritized for reform.

6.2 Administrative Measures for Implementation

In addition to facilitating legislative integration, improvements to the administrative system must be proposed and measures to ensure the effective implementation of risk management should be introduced. First, within the Ministry of Oceans and Fisheries, an organizational structure dedicated to risk management for AtoN must be established. This can be achieved by creating a new Aids to Navigation Risk Management Center or designating a specialized team within the existing Aids to Navigation Division. This unit is responsible for conducting IWRAP analyses, planning and operating PAWSA and SIRA workshops, and continuously performing effective risk assessment tasks. Furthermore, the creation of a joint team including experts dispatched by relevant organizations, such as the Korea Institute of Aids to Navigation and Korea Maritime Transportation Safety Authority, promotes institutionalized interagency cooperation and strengthens risk management capacity at the national level.

This organizational foundation necessitates the systematic enhancement of the competencies of professional personnel. In particular, domestic experts should be actively encouraged to participate in the risk management training courses offered by the IALA Worldwide Academy (Level 1.3 Risk Management Toolbox) to strengthen their operational capabilities and obtain international certification. Additionally, a domestic training curriculum should be developed to educate central and local government officials, VTS operators, and public-sector employees and, thereby, secure and continuously renew a pool of specialists. Hosting international seminars or inviting foreign experts to South Korea will benefit participants by providing them with opportunities to exchange information on the latest risk management techniques and discuss their applications, thereby expanding domestic officials' engagement with global trends.

To ensure the effective operation of risk management tools, an integrated, data-driven infrastructure must be developed. For this purpose, a maritime traffic data–sharing platform should be established among the Ministry of Oceans and Fisheries and related agencies or effort should be expended to enhance existing systems. This will enable the integration of AIS, V-Pass, radar-tracking data, and maritime accident databases into a comprehensive maritime risk information system. The system should have a user-friendly interface that enables personnel to easily calculate the accident probabilities of specific sea areas using IWRAP analyses. Further, it should provide a visualization of assessment results in different formats, such as accident probability maps or risk heat maps, to ensure that policymakers and local stakeholders intuitively understand the information.

At the time of introducing risk management tools, pilot projects can be conducted to verify the tools' practical effectiveness. For this purpose, areas with heavy traffic volumes and high accident risks, such as the straits frequented by passenger vessels or the coastal regions characterized by the close proximity of operation between fishing vessels and merchant ships. Further, PAWSA workshops and IWRAP analyses can be conducted for these areas to assess risk levels, and the results can be implemented in practice, for example, by adding or relocating buoys. For a designated period, trends in accident occurrence, user satisfaction, and navigational safety improvements should be monitored to evaluate the performance of the pilot projects and determine whether to expand the program nationwide.

Additionally, operational procedures must be established to incorporate risk management processes throughout AtoN administration. For example, once a request is submitted to establish or improve an AtoN, a preliminary assessment using IWRAP is conducted and, subsequently, stakeholder opinions are collected through PAWSA. Thereafter, the responsible department formulates the necessary measures. The results of each stage should be documented and organized into a database to serve as intellectual resources for future cases and, thereby, enhance policy continuity and administrative consistency.

Finally, institutionalizing the participation of local maritime organizations is important to improve the effectiveness of risk

Table 1: Engineering-Oriented Risk Assessment Framework for Aids to Navigation Implementation

Stage of AtoN Decision	IALA Tool Applied	Primary Data Inputs	Outputs
Preliminary screening	SIRA	Traffic volume, Hazard presence, Expert judgment	Risk index
Detailed analysis	IWRAP Mk2	AIS data, Vessel type, Vessel speed, Channel geometry	Collision/Grounding probability
Stakeholder validation	PAWSA	Expert input, Operational experience, Local constraints	Qualitative risk ranking, Mitigation options
Design verification	Simulation	AtoN layout, Vessel maneuvering models	Visibility performance, Avoidance distance
Post-implementation	IWRAP / Statistics	Updated AIS data, Accident records	Risk reduction rate, Safety performance indicators

assessments and acceptability of policies. The strengths of qualitative risk management tools such as PAWSA and SIRA can be utilized by creating Aids to Navigation Committees for major routes, comprising shipping companies, fishers, pilots, academics, and administrative authorities. These committees meet regularly to exchange opinions and share assessment results and recommendations. By establishing structured communication channels that enable local experiences to inform policy decisions, a virtuous cycle in which field knowledge enhances the quality of policies can be created.

The aforementioned administrative measures were designed to ensure that the proposed risk management system functions effectively in practice. Meaningful outcomes are achieved only when specialized organizations and personnel, data and tools, and procedural and participatory structures operate in harmony.

6.3 Step-by-Step Implementation Procedure

To successfully introduce risk management tools into the domestic AtoN system, a procedurally coherent and legally consistent process must be followed: The first stage involves the establishment of an implementation plan. Further, a taskforce should be formed under the leadership of the Ministry of Oceans and Fisheries in cooperation with relevant agencies. After assessing domestic and international practices, a concrete implementation roadmap must be developed based on legal reviews and technical feasibility studies. In particular, the legal consistency of the risk assessment procedure's institutionalization must be examined in advance. This examination includes reviewing the domestic applicability of IALA standards; determining whether international recommendations may be considered valid under Article 6(1) of the Constitution **[43]**; and evaluating the appropriateness of delegated authority with respect to acts, enforcement decrees, and ministerial notices.

The second stage involves pilot application. Before securing the formal legal effect of a new administrative regulation, pilot areas must be designated and risk assessment tools should be operated to verify both the feasibility and legitimacy of implementation. The results generated during this stage, including PAWSA workshop outcomes and IWRAP analytical data, later function as legislative materials for statutory amendments and highlight risk assessment as a legitimate prerequisite for administrative decision-making. Additionally, by appointing external experts as evaluators, transparency is ensured and stakeholder trust is strengthened.

Further, the third stage involves institutionalization based on the experience derived from pilot projects. This stage formally establishes the legal status of risk management tools within the legislative and administrative framework.

Further, the risk assessment procedures must be codified in the Aids to Navigation Act, as well as relevant administrative regulations. During the legislative process of the National Assembly, issues such as the domestic adoption of international standards, the allocation of authority among administrative bodies, fiscal implications, and potential restrictions on fundamental rights must be examined. In stages involving enforcement decrees, ministerial rules, and notices, procedural requirements must be included in accordance with the delegation standards established in high-level laws. Simultaneously, organizational restructuring, budget allocation, personnel assignment, and professional training should be conducted to ensure the institution's practical effectiveness.

The fourth stage involves nationwide expansion. On establishing legal and organizational foundations, the system should gradually be applied to coastal waters nationwide. Despite prioritizing areas with high accident rates or heavy traffic, legal standards must be introduced to ensure that assessments and follow-up measures are applied consistently across the nation. These standards should be publicly disclosed based on quantitative and qualitative evidence. Each region's risk assessment results and workshop outcomes can serve as foundational materials for administrative decision-making and satisfy the requirements for prior notice and hearing under the Administrative Procedures Act **[44]**.

The final stage involves the feedback process required under the constitutional principles of administrative accountability and sustainable development. Following implementation, the effectiveness of institutionalization must be evaluated and improved. This involves systematically analyzing whether the introduction of risk management tools reduced maritime accidents and assessing the degree of prevention relative to the invested resources. Any deficiencies must be corrected to stabilize the institution. Through this process, a dynamic policy structure based on risk management can be incorporated into a traditionally static legal-normative framework.

The aforementioned systematic procedure establishes a structured interface with engineering-based risk assessment, rather than merely being a policy roadmap. Each stage corresponds to the specific IALA risk management tools discussed in Sections 2 and 4 and produces identifiable technical outputs, such as risk indices, collision probabilities, and layout performance indicators. As depicted in Table 1, these elements were reorganized into an engineering-oriented implementation framework, clarifying how the proposed legal and administrative process could support quantitative and qualitative engineering evaluations without altering the fundamental policy structure.

The introduction of risk management tools through such a multistage process enables the confirmation of their substantive benefits from several legal perspectives. First, the realization of the precautionary principle aligns with modern administrative principles that emphasize procedural prevention, rather than ex-post liability. This can function as an effective means of precluding the state liability caused by maritime accidents. Second, AtoN-related decision-making shifts from empirical practice to a science-based regime; this shift reduces administrative discretion and strengthens the principles of purposiveness and proportionality. This may further decrease the likelihood of occurrence of disputes or litigation pertaining to AtoN installation or adjustment. Third, the implementation of risk management procedures consistent with IALA standards helps secure the practical effect of Article 6(1) of the Constitution **[43]**, which is concerned with the domestic effect of treaties and international laws. This has particular legal significance for South Korea, which serves as a responsible IALA council member and may, thereby, enhance its diplomatic consistency and international credibility.

Furthermore, risk management is closely connected to the environmental rights stipulated in Article 35 of the Constitution **[43]**, which affirms the right of all citizens to live in a healthy and pleasant environment and obligates the state and its citizens to work toward environmental protection. This is related to the State's obligation to protect Korean citizens abroad, as stated in Article 2, as well. If maritime accident prevention constitutes a means of ensuring public safety, risk management functions as the minimum procedural requirement to safeguard fundamental rights. Therefore, the institutionalization of risk management tools represents not merely a technical improvement but a substantive institutional advancement that shifts the paradigm of maritime law from reactive post-incident response to proactive risk prevention.

7. Conclusions

7.1 Research Summary and Contribution

This study comprehensively examined the necessity of and methods for introducing IALA risk management tools to improve the adequacy of AtoN placement in South Korea. As stated in Section 1, domestic AtoN management has some shortcomings in terms of the incorporation of international standards. Further, the absence of scientific risk assessment has emerged as the central issue in domestic AtoN management. In response, this study defined the concepts of AtoN and risk management tools and reviewed the characteristics and applications of IWRAP, PAWSA, SIRA, and simulation-based approaches, which are recommended by IALA. Based on this foundation, this study analyzed the disparities between international recommendations and the Korean legal framework and confirmed the presence of gaps in several respects, including the mandatory nature of procedures, data utilization, professional expertise, and administrative practices. The study critically examined limitations in data infrastructure, technical capacity, administrative rigidity, and implementation structures, as well.

Building on these observations, the study proposed a combination of legal and institutional reforms and clarified some administrative implementation plans. It recommended institutionalizing risk management procedures through statutory amendments, while also advancing administrative measures, such as establishing a specialized center, enhancing training programs, integrating data systems, and initiating pilot projects. By presenting a step-by-step implementation roadmap and clarifying the expected outcomes, this study indicated that the adoption of risk management tools can contribute to maritime safety, improve resource efficiency, and serve as an internationally leading model.

Finally, this study emphasizes that the introduction of risk management tools in the AtoN field is an essential, rather than optional, requirement. Maritime traffic in the 21st century is increasingly becoming complex, and public expectations regarding safety are on the rise. At the same time, technological capabilities are advancing, and the infrastructure necessary for their application is now available. If Korea proactively adopts a risk management system, it can establish a scientific and modernized maritime traffic safety framework. AtoN function as both beacons of the sea and pillars of national maritime safety; hence, it is natural to apply advanced tools and knowledge in AtoN management. If the legal, institutional, and administrative improvements proposed in this study are realized, Korea will assume a leading role in setting international standards in the field of AtoN, providing the public with a safe maritime environment.

7.2 Future Research Directions

This study must be supported by a range of follow-up studies. First, an empirical evaluation of the policy effects of introducing a risk management tool is necessary to ensure the system's continuity and credibility. After conducting the risk assessment, quantitative analyses should be performed to determine that changes in the incidence rate and overall risk level of maritime accidents in specific sea areas. For example, by comparing the changes in collision accident frequency before and after the risk assessment or examining the degree of alignment between the accident probabilities estimated from the assessment and real accident rates, it is possible to verify the system's effectiveness and identify areas for improvement.

Further research is required to clarify the potential integration of emerging smart AtoN technologies. Smart AtoN systems equipped with Internet of Things sensors and remote control capabilities can transmit real-time data and support onsite responses. These features provide a foundation for building a dynamic risk management framework that complements traditional methods based solely on historical data. In particular, the systems that automatically adjust warning signals according to real-time risk levels or transmit risk information directly to autonomous ships may fundamentally transform the future maritime traffic safety paradigms. Therefore, further research is required to examine technological models and identify the possibilities for linking them with administrative systems.

Additionally, the legal obstacles that may arise during system implementation must be analyzed and solutions should be developed to address them. Issues such as the attribution of legal responsibility for risk assessment results, data protection obligations related to assessment materials, and administrative or procedural limitations encountered during stakeholder consultations may challenge the system's practical effectiveness. Detailed discussions should clarify whether risk assessment results are sufficient bases for mitigating administrative liability when an accident occurs despite the execution of the assessment and whether legal responsibility should be strengthened in cases where assessments are conducted inadequately. Such legal analyses can enhance the system's completeness and reinforce administrative trust.

International cooperation and comparative legal analyses can help stabilize the system. For example, an in-depth comparison of how countries with similar maritime environments, such as the United Kingdom, Italy, and Portugal, adopt and operate risk management tools and a clarification of the policy outcomes and limitations experienced by them can generate useful insights for domestic system design. In addition, participating in expert training programs or joint research initiatives in collaboration with IALA can help ensure coherence between international standards and national systems.

Finally, empirical research must examine the socioeconomic impacts of an AtoN risk management framework on local communities and the economy. Changes in AtoN placement may affect various sectors, including fisheries, coastal shipping, and port management. Therefore, it is necessary to systematically analyze the resulting cost–benefit structure. Further, quantitative findings will strengthen the justification for policy implementation and serve as persuasive stakeholder evidence. Finally, the system's establishment and expansion require follow-up research addressing its legal, technological, and economic aspects.

Author Contributions

Conceptualization, N. Yoo and S.-I. Lee; Methodology, N. Yoo and S.-I. Lee; Formal Analysis, N. Yoo; Investigation, N. Yoo; Resources, N. Yoo; Data Curation, N. Yoo; Writing-Original Draft Preparation, N. Yoo; Writing-Review & Editing, S.-I. Lee; Visualization, N. Yoo; Supervision, S.-I. Lee; Project Administration, S.-I. Lee.

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