WMU Journal of Maritime Affairs
https://doi.org/10.1007/s13437-023-00328-z

ARTICLE

Risk maturity model for the maritime authorities: a Delphi study to design the R-Mare matrix model

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Received: 23 August 2023 / Accepted: 3 December 2023

Abstract

Maritime authorities have the administrative responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution caused by ships. This responsibility involves various tasks that can be supported through effective risk management, but currently, there are no models available to evaluate its level of maturity in maritime administrations. To fill this gap and respond to the needs identified by maritime authorities, this article introduces a new risk maturity model called the R-Mare matrix. This model is built on recent scientific knowledge in the field of risk management, and it has been designed in close cooperation with end-users and maritime risk management experts using the Delphi methodology. As a result of this process, the article provides a qualitative risk maturity matrix specifically tailored to support the self-evaluation of maritime authorities. The matrix consists of 17 state-of-the-art risk management attributes, a five-step risk maturity scale, and associated risk maturity grid descriptions. These elements can be used to evaluate the current risk management performance of maritime authorities, identify areas for improvement, and develop a plan to achieve a higher level of maturity. Overall, the R-Mare matrix model represents an important step forward in this field while laying the foundation for further development.

Keywords Maritime safety · Maritime sustainability · Maritime administration · Risk management · Risk maturity · Risk maturity model matrix

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1 Introduction

The shipping industry serves as the backbone of international trade and the global economy, but it also poses risks to human life, the marine environment, and the global atmosphere (Schröder-Hinrichs et al. 2020). Therefore, there is a need to procure the benefits and manage the risks of this transportation mode, where authorities hold specific responsibilities focused on preventing maritime accidents, minimizing their potential consequences, and ensuring the sustainability of this industry (IMO 2023). Although many of these associated tasks are already well established, several factors can introduce uncertainties and jeopardize their successful execution. Some of these factors can be attributed to the internal context of maritime administrations, such as a lack of leadership, resources, or commitment, while others are linked to its external context, including the increasing number of sub-standard vessels, illegal dumping, and cyberattacks, among others. To effectively address this complex array of responsibilities, maritime authorities need to be aware of and understand the risks stemming from both their internal and external contexts (Laine et al. 2021).

A substantial number of studies have indicated that systematic risk management strongly supports the work of maritime authorities (Goerlandt and Montewka 2015; Parviainen et al. 2021; Montewka et al. 2014). To this end, various risk management frameworks, processes, and tools have been introduced in academic literature and professional contexts (Kulkarni et al. 2020; Lim et al. 2018; Li et al. 2012). However, the current selection of available risk assessment tools does not include risk maturity models, despite calls for such applications (Laine et al. 2022; IALA 2023). These models have proven useful in evaluating and developing the risk management performance of organizations across different industrial sectors (Maier et al. 2011), transport modes (ERA 2018; EASA 2017), and governmental bodies (Cienfuegos Spikin 2013). In the maritime sector, such models could also support compliance with international regulations on aids to navigation, goal-based standards, and national contingency planning (Laine et al. 2022). Consequently, there is a need to address the risk maturity models from a maritime perspective and close this identified gap in risk assessment tools for competent authorities and the academic fields of risk research.

To take the first step for providing a risk maturity model for the maritime authorities, an extensive background literature review was conducted to explore recent developments in this field (Laine et al. 2022). The results of this review laid basis for the new model development, which was made in close collaboration with the competent authorities and risk management experts through a process based on the Delphi methodology. Following its results, this article introduces a new risk maturity model called the R-Mare that is founded on the matrix technique. This matrix incorporates 17 risk management attributes, a five-step risk maturity scale, and associated risk maturity grid descriptions. By using this matrix, maritime authorities can evaluate their current risk management performance, identify areas for improvement, and develop a plan for achieving a higher level in risk management maturity. Even though the R-Mare matrix has been primarily developed for the maritime authorities of Finland, its approach could also be considered in other coastal and flag states. The here presented risk maturity model thus provides an important step forward in this field, while setting the basis for further development.

The remainder of this paper is organized as follows. Section 2 presents the theoretical background of the proposed risk management maturity model. Section 3 outlines the Delphi-based process used to develop the model. Section 4 presents the resulting R-Mare matrix model, while Section 5 discusses its strengths and anticipated challenges and points to opportunities for future research. Finally, Section 6 provides overall conclusions of this work.

2 Background

2.1 Risk maturity models

Risk maturity models are conceptual models that an organization can use to evaluate and improve its ability to manage risks (Hoseini et al. 2021; Perrenoud, 2018; Becker et al. 2009). These models have proven to be useful to evaluate organization's current level of maturity, identify realistic targets for improvement, and produce action plans for developing or enhancing its risk capacity (Hilsson 1997). The specific criteria and levels of risk maturity can vary depending on the model and the type of organization (Cienfuegos Spikin 2013). In addition, the techniques that these models are built upon can range from simple to complex.

While many of the risk maturity models introduced in the academic literature are based on different types of approaches and specific end-user requirements, some best practices can be identified from the recent works to support the model development. Firstly, according to Cienfuegos Spikin (2013), a risk maturity model should be built on a sound scientific basis. This statement may seem self-evident, but in many of the recent models, the scientific criteria have not been fully considered (ibid). Second, Hoseini et al. (2021) have highlighted that the risk maturity model should be founded on an appropriate technique that aligns with its purpose, objectives, and end-user requirements. In other words, there are no one-size-fits-all solutions in this field. Third, Maier et al. (2011) have stated that the model's risk management attributes, risk maturity levels, and risk maturity grid descriptions should be meaningful and tailored for its end-users. This requirement applies especially to models based on qualitative techniques, such as attributes-maturity level matrices. For a comprehensive review on the risk maturity models, the reader is referred to Laine et al. (2022).

2.2 Delphi methodology

The Delphi methodology is a research approach based on developing consensus among a group of experts through a series of questionnaires and controlled feedback (Whiting et al. 2003). This methodology is established on the principle of anonymity and the assumption that group judgments are more valid than individual ones (Dalkey 1972). The Delphi-based process typically involves several steps, including planning and question generation, panelist nomination, administration of interview and questionnaire rounds, and establishment of consensus criteria.

The Delphi methodology is commonly applied in fields such as healthcare and futurology to gather expert and stakeholder input for decision-making, policy development, and strategic planning (Keeney et al. 2011). The field of its application includes also risk maturity models (Monda and Giorgino 2013) and maritime risk research (Lahtinen et al. 2020; Duru et al. 2012; Szwed 2011). Based on the authors' literature review, the Delphi methodology is also strongly applicable to the development process of a risk maturity model for maritime authorities (Laine et al. 2022).

2.3 ISO 31000 standard on risk management

The ISO 31000 is the international standard for organizational risk management. This standard has been developed by the International Organization for Standardization to provide *principles*, *framework*, and *process* to manage risks within the internal and external context of organizations (ISO 2018). These three key components of the ISO standard are based on best practices and have been developed through extensive consultations and expert input. Moreover, the standard offers flexibility to take into account specific organizational needs.

Even though several authors have critically examined the ISO 31000 standard as a whole (Aven et al. 2019; Leitch 2010; Purdy 2010), it has been widely utilized in various research and industrial sectors. The application area of the standard also includes risk maturity models (Proença et al. 2017), maritime risk research (Parviainen et al. 2021; Nevess et al. 2015), and risk management guidelines of maritime administrations (Helcom 2018; IALA 2022). Therefore, it can be argued that the ISO standard is appropriate for benchmarking when developing a risk maturity model for maritime authorities.

2.4 Formal Safety Assessment

Formal Safety Assessment (FSA) is a risk assessment methodology developed by the IMO. This methodology has been described as "[…] a rational and systematic process for assessing the risks associated with shipping activity and for evaluating the costs and benefits of IMO's options for reducing these risks (IMO 2018)." The key element of FSA is a five-step risk assessment process that includes (i) hazard identification, (ii) risk assessment, (iii) risk control options, (iv) cost-benefit assessment, and (v) decision-making recommendations. To support the implementation of this process, the FSA also provides risk terminology, risk assessment tools, decision-making principles, and other useful elements.

The FSA methodology has faced a criticism especially in academic contexts concerning its narrow risk perspective, lack of transparency, and use of expert judgements, to name a few (Montewka et al. 2014; Kontovas and Psaraftis 2009). Nevertheless, it has been used in various maritime research applications and activities of maritime administrations, port authorities, and their stakeholders (Vidmar and Perkovič 2018; Zhang et al. 2013; Vantikos and Psaraftis 2004). In addition, the methodology shares many similar elements and process descriptions with current risk maturity models and the ISO 31000 standard, such as hazard identification and risk assessment. Therefore, it can be argued that the FSA methodology is also appropriate for benchmarking purposes in the development of risk maturity models.

3 Methods and material

3.1 Overview of the study process

The basic design of the development process for the risk maturity model for maritime authorities is derived from recent studies in this field and risk management guidelines. First, the study by Maier et al. (2011) was applied to support the specification of the purpose, objectives, end-users, and success criteria of the model, as it provides thorough guidance in this regard. Second, the review of Laine et al. (2022) was used to specify the methodology for the development process of the risk maturity model and the technique to be employed in the model itself. Third, the results of this same review were also utilized to determine the initial number of risk maturity levels and risk management attributes for the model and to identify best practices for describing the model's risk maturity grids. Finally, both the ISO 31000 standard and the IMO FSA guidelines were used as benchmarks to support the definition of the risk management attributes for the model. Table 1 provides a summary of the design specifications, end-user needs, and development basis for creating this so-called R-Mare matrix model.

The standard Delphi methodology process used for creating the R-Mare matrix model is illustrated in Fig. 1. This process involved four steps: (1) Delphi study

Table 1 The summary on the design specifications for the R-Mare matrix model

Subject	Specification
1. Purpose	Support the development of maritime authorities' risk management performance
2. Objectives	Assist maritime authorities to evaluate their current risk management performance, identify areas for improvement, and develop a plan for achieving a higher risk maturity level
3. End-users	Maritime safety and response authorities of Finland
4. Methodology	Delphi methodology for the R-Mare model development
5. Technique	Attributes-maturity level matrix as the R-Mare model technique
6. Maturity levels	Five risk maturity levels for the *X*-axis of R-Mare model
7. Attributes	Approximately 20 risk management attributes for the *Y*-axis of R-Mare model
8. Grid descriptions	Best practices to support maturity grid descriptions
9. Benchmarking	ISO 31000 standard and IMO FSA guidelines focusing on risk management attributes
10. Success criteria	Useful to assist the R-Mare matrix model end-users to evaluate and develop their risk management performance

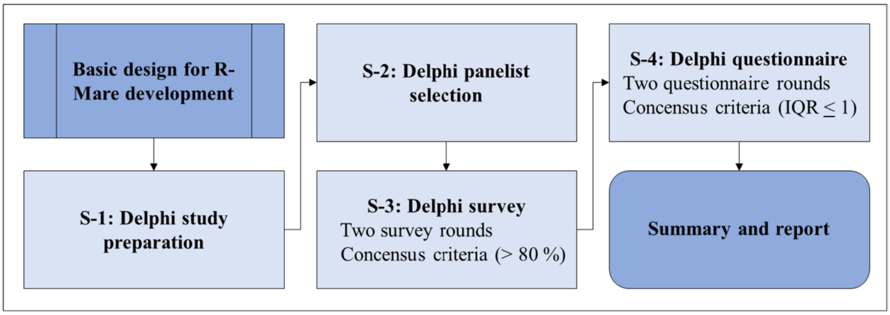

Fig. 1 Overview of the Delphi process for R-Mare matrix model development

preparations, (2) Delphi panelist selection, (3) Delphi survey, and (4) Delphi questionnaire. The aim of the Delphi survey step was to support the construction of the R-Mare matrix, while the questionnaire step focused on evaluating the importance of its risk management attributes. Both steps also considered consensus criteria in line with the principles of Delphi methodology. The content of this four-step process is described in Sections 3.2 to 3.4, and the summary of its results in Section 4.

3.2 Preparations for Delphi study

The first step of the Delphi process of Fig. 1 (S-1) focused on the study preparations for the R-Mare matrix model development. To begin with, both the semi-structured interviews of Delphi survey rounds (S-3) and the multiple-choice questionnaires of Delphi questionnaire rounds (S-4) were prepared and tested. To support these preparations, the review results (Laine et al. 2022), as well as the ISO 31000 standard and the IMO FSA guidelines, were used for cross-checking and benchmarking.

Next, the preparations focused on defining the consensus criteria for the Delphi survey (S-3) and questionnaire rounds (S-4). For this purpose, the work of Keeney et al. (2011) was adopted, as it provides suitable criteria for the associated semi-structured interviews and multiple-choice questionnaires. These criteria are as follows:

1. *Semi-structured interviews:* greater than 80 percent agreement among the Delphi panelists;
2. *Multiple-choice questionnaires:* interquartile range is equal or less than one (IQR $\leq$ 1) among the Delphi panelist, when rated on a 5-point sematic differential scale.

The output of this first step thus provided a methodologically solid plan for executing the interview and questionnaire rounds of this Delphi-based study for the R-Mare matrix model development, including the associated consensus criteria.

3.3 Selection of Delphi panelists

The second step of the Delphi process of Fig. 1 (S-2) considered the selection of panelists to ensure sufficient resources for the R-Mare matrix model development. By utilizing the professional networks of the authors, 11 experts were chosen to the Delphi panel in line with the academic state of the art (Keeney et al. 2011).

Table 2 presents a list of the chosen Delhi panelists, along with a summary of their relevant expertise and distribution between organizations. To describe their roles briefly, both maritime safety and response authorities represented potential end-users of the model, providing essential insights for its development, particularly from a practical perspective. On the other hand, the contribution of academics was also considered necessary to ensure that the model meets scientific criteria related to maritime risk management. Further, the input of an aviation safety authority expert was extremely valuable, as it offered best practices and new ideas from this industrial sector to complete the model development.

The output of this second step therefore established a Delphi panel comprising professional experts, which was a key element in successfully implementing the R-Mare matrix model development process.

3.4 Delphi survey

The aim of the third step of this Delphi process of Fig. 1 (S-3) was twofold: (i) to create the R-Mare matrix model and (ii) to achieve a target level of consensus

Table 2 Summary of Delphi panelists

Organization	Expertise	Panelist
Maritime safety authority	Hydrography and fairways Port and Flag State Control Vessel traffic services Maritime pilotage services Maritime safety management	5
Maritime response authority	Pollution preparedness and response Search and rescue operations Contingency planning	1
Aviation safety authority	Aviation safety and risk management Just Culture Aviation cybersecurity	1
University of Applied Sciences	Navigation safety and bridge design Bridge resource management Maritime autonomous surface ships Pollution preparedness and response	2
University	Maritime safety and risk management Offshore operations Maritime autonomous surface ships Pollution preparedness and response	2
Total		**11**

(> 80%) on its elements among the 11 Delphi panelists. This step took place from December 2022 to February 2023 and involved two rounds of Delphi surveys conducted through online semi-structured interviews.

The first Delphi survey round focused on defining the risk maturity levels and risk management attributes of the R-Mare matrix, whereas the second considered its risk maturity grid descriptions and consensus criteria. The results of these survey rounds yielded five risk maturity levels, 17 risk management attributes, and 85 risk maturity grid descriptions, specifically tailored for the self-evaluation of the maritime authorities. The results also indicated that 9 out of 11 panelists (82%) were satisfied with these model elements or had only minor additional suggestions. The feedback from the two panelists with more critical views was also carefully considered to enhance the level of consensus.

The output of this third step thus provided the final version of the R-Mare matrix model with an acceptable level of consensus on its elements among the Delphi panelists. These results are described in detail in Section 4.

3.5 Delphi questionnaire

The aim of the fourth step of this Delphi process of Fig. 1 (S-4) was also twofold: (i) to evaluate the importance of 17 risk management attributes within the R-Mare matrix model and (ii) to achieve a target consensus level (IQR $\leq$ 1) on these evaluations among the 11 Delphi panelists. This step took place from March 2023 to April 2023 and involved two rounds of Delphi questionnaires conducted with the panelists. These rounds were performed using online multiple-choice questionnaires that comprised a 5-point ranking scale for each of the attributes (1 = *Not important*, 2 = *Slightly important*, 3 = *Moderately important*, 4 = *Important*, and 5 = *Extremely important*).

The results of these questionnaire rounds indicated that all 17 attributes of the R-Mare matrix were considered either *Important* (4) or *Extremely important* (5) by the panelists. The consensus criteria were achieved for 14 of the attributes, while three attributes had an IQR value exceeding the established limit. Nevertheless, after these two questionnaire rounds, it was determined to conclude the study in accordance with the general practices of the Delphi methodology (Keeney et al. 2011).

The output of this fourth step confirmed the usefulness of the R-Mare matrix model and provided an evaluation of importance to its risk management attributes and an analysis of the associated level of consensus. These results are described in Section 4.5 and Table 5.

3.6 Reliability and validity of Delphi study

This section briefly addresses the critical aspects of reliability and validity in utilizing the Delphi process for designing the R-Mare matrix model. In general, reliability focuses on the consistency and stability of the "measuring instrument," while validity concerns the accuracy of measuring what was intended to be measured in the analysis (Aven and Heide 2009). Both of these aspects are of paramount importance in ensuring the overall quality of the model.

The reliability in the context of Delphi methodology refers to the consistency and stability of the results obtained through multiple rounds of expert input and feedback (Landeta 2006). To address the consistency aspect, the presented Delphi process for the R-Mare matrix model incorporates detailed design specifications (Section 3.1), comprehensive study preparations (Section 3.2), and the selection of an appropriate number of expert panelists (Section 3.3). As for the stability criteria, the process integrates state-of-the-art consensus criteria for both the survey (Section 3.4) and questionnaire (Section 3.5) rounds.

The validity in the context of the Delphi methodology refers to the accuracy and truthfulness of the results in reflecting the knowledge and judgments of the expert panel (Landeta 2006). One well-recognized concept in the field of risk validation is *face validity* and its associated tests (Sadeghi and Goerlandt 2023). These tests involve a peer review process where experts assess whether the model appears reasonable to them (Collier and Lambert 2019; Sargent 2013). When considering the presented Delphi process for the design of the R-Mare matrix model from the perspective of face validity, several key observations can be made.

First, the Delphi methodology employed in this work provides a systematic and well-documented approach, which is advantageous from a validity perspective as it serves as a form of quality assurance (Goerlandt et al. 2017). Several authors have also demonstrated the Delphi method's capability to provide evidence of validity (Alarabiat and Ramos 2019; Landeta, 2006) and its effectiveness in conducting both qualitative and quantitative studies (Hsu and Sandford 2007; Skulmoski et al. 2007).

Second, the Delphi panel assembled in this work comprises 11 members, involving both model end-users and risk management experts (Section 3.3). The number of panelists aligns with current best practices. Moreover, specific attention has been paid to ensure that these panelists possess comprehensive knowledge and the necessary competence to provide input for the model design, cross-check its elements, and guarantee the meaningfulness of the output.

Third, the Delphi process implemented in this work encompasses four distinct rounds with associated consensus criteria (Sections 3.4 and 3.5). These rounds are used to increase intersubjective agreement among the panelists and ensure the attainment of an acceptable level of consensus. In other words, their objective is to establish this model as a shared mental framework among the panelists.

Consequently, the presented Delphi process for the R-Mare matrix model design can be considered reliable and valid from the methodological perspective. The subsequent section elaborates on the outcomes of this process.

4 Results

4.1 Overview of the R-Mare matrix model

The results of the Delphi process provided the R-Mare matrix risk maturity model for maritime authorities. Figure 2 shows the basic idea of this model.

Attributes	Maturity levels 1. Inadequate	2. Reactive	3. Compliant	4. Proactive	5. Optimal
1 Ethics and integrity	L1/A1	L2/A1	L3/A1	L4/A1	L5/A1
2. Leadership and commitment	L1/A2	L2/A2	L3/A2	L4/A2	L5/A2
3. Design	L1/A3	L2/A3	L3/A3	L4/A3	L5/A3
4. Integration	L1/A4	L2/A4	L3/A4	L4/A4	L5/A4
5. Resources	L1/A5	L2/A5	L3/A5	L4/A5	L5/A5
6. Communication and consultation	L1/A6	L2/A6	L3/A6	L4/A6	L5/A6
7. Continuous improvement	L1/A7	L2/A7	L3/A7	L4/A7	L5/A7
8. Risk terminology	L1/A8	L2/A8	L3/A8	L4/A8	L5/A8
9. Definition of context	L1/A9	L2/A9	L3/A9	L4/A9	L5/A9
10. Data and information	L1/A10	L2/A10	L3/A10	L4/A10	L5/A10
11. Tools and techniques	L1/A11	L2/A11	L3/A11	L4/A11	L5/A11
12. Hazard identification	L1/A12	L2/A12	L3/A12	L4/A12	L5/A12
13. Risk analysis and evaluation	L1/A13	L2/A13	L3/A13	L4/A13	L5/A13
14. Risk control measures	L1/A14	L2/A14	L3/A14	L4/A14	L5/A14
15. Cost-benefit assessment	L1/A15	L2/A15	L3/A15	L4/A15	L5/A15
16. Recommendations	L1/A16	L2/A16	L3/A16	L4/A16	L5/A16
17. Decision-making	L1/A17	L2/A17	L3/A17	L4/A17	L5/A17
Score	1	2	3	4	5

Fig. 2 Overview of the R-Mare matrix risk maturity model

The *Y*-axis of the R-Mare matrix addresses the scope dimension of the model, elaborated through 17 risk management attributes. These attributes consider ethics and integrity (1), leadership and commitment (2), basic risk management requirements (3–5), parallel activities (6–7), risk assessment (8–16), and decision-making (17). To support the self-evaluation of the maritime authorities, Section 4.2 and Table 3 provide a detailed list of these attributes and the aspects to be considered in their evaluation.

The *X*-axis of the R-Mare matrix focuses on the progress dimension of the model. This involves five risk maturity levels namely *Inadequate* (1), *Reactive* (2), *Compliant* (3), *Proactive* (4), and *Optimal* (5). Section 4.3 and Table 4 provide a detailed description for each level. Their overall aim is to support the self-evaluation of the maritime authorities concerning the maturity of the organizational practices with respect to the 17 risk management attributes.

Each cell of the R-Mare matrix model is further populated with a specific textual grid description to characterize traits of performance at each level and attribute (L1/A1–L5/A17). To complete the support for self-evaluation of maritime authorities, Section 4.4 and Table 6 (Appendix) provide general criteria and two practice-oriented examples for all 85 risk maturity grids of the model. By using the associated 5-point score system, the authorities can also quantify, visualize, and further analyze the results of their self-evaluation as needed.

Table 3 Risk management attributes of the R-Mare matrix model

Risk management attribute	Aspects to be considered
1. Ethics and integrity	The maritime administration should determine ethical values for its work embracing safety, security, and environmental sustainability of shipping, in accordance with the IMO objectives The administration should ensure that its values consider the national emergency supply, as the role of shipping is critical in the crisis management of coastal states The administration should ensure that these values account for the economic aspects of shipping, as it is essential for the world economy and provides livelihood for millions of people The administration should make the ethical values visible and embed them to its daily risk management activities
2. Leadership and commitment	The top management should ensure that risk management is integrated into all activities of the maritime administration, while considering also the ethical, national, and economic aspects of shipping They should allocate adequate resources for this purpose and establish robust communication channels with internal stakeholders (e.g., ministry and sister organizations) and external stakeholders (e.g., private sector and intergovernmental bodies) They should focus on creating safe working conditions and an environment of trust for the administration and its stakeholders They should demonstrate willingness and commitment to continuously improve the risk management performance of the administration in both the short and long term
3. Design	The maritime administration should have a systematic and documented process in place to design the risk management framework that considers both its internal and external context The design should address all rules, conventions, procedures, and ethical aspects based on which decisions concerning risks are taken and implemented The design should indicate clearly and transparently the accountabilities and responsibilities of the administration and its stakeholders The design should recognize resources, factors to create resilience, appropriate communication channels, and the principle of continuous improvement
4. Integration	The maritime administration should have a systematic and documented process in place for integrating the risk management framework into its organizational activities The process should consider the structure, internal and external context, and QSE-management system of the administration, as well as the redundancy of critical tasks, organizational reforms, and stakeholder responsibilities The process should ensure that the associated tasks are also implemented to the daily activities of the administration and its stakeholders, considering, e.g., decision-making and available resources The process should involve verification measures to ensure that integration and implementation of the risk management framework to the organizational settings meet its objectives

Table 3 (continued)

Risk management attribute	Aspects to be considered
5. Resources	The maritime administration should aim to allocate sufficient resources to its risk management to make it effective and keep the staff motivated The resource allocation should particularly consider the adequate number of trained personnel, technical equipment, redundancy of critical tasks, financial assets, and training opportunities in relation to the set objectives The resource allocation should address changes in the risk levels and their possible impacts to the need of, e.g., human and technical resources The resource allocation should include cost-benefit assessments to optimize resources into changing conditions and cooperation with stakeholders to create resilience
6. Communication and consultation	The maritime administration should have a systematic and documented process in place for communication and consultation The process should enable receiving risk-related information from the different departments of the administration and stakeholders and to transmit it at the right time to the right persons The process should be used to support decision-making on risk control measures and receive feedback on their actual functionality The process should support the evaluation of the risk assessment quality aspects, crisis and reputation management, and sharing of tacit knowledge The process should establish incentives and an environment of trust for both the administration and its stakeholders to make it successful
7. Continuous improvement	The maritime administration should have a systematic and documented process in place to continuously monitor and review its risk management performance by using the best achievable data and information The process should monitor the changes in risk levels, new emerging risks, hazardous phenomena, and drift into failure The process should review whether the effectiveness of the current risk control measures is sufficient to maintain the risks at an acceptable level in varying conditions The process should consider the resilience factors of the administration to recover or adapt in case of, e.g., Black Swan types of events The process should involve actions based on the results of monitoring and review to either adjust the current performance or to plan for a new cycle of improvements
8. Risk terminology	The maritime administration should provide a common risk terminology to support effective and transparent communication and consultation within the risk management process The risk terminology should be based on, e.g., the IMO ISM Code, IMO FSA guidelines, or ISO 31000 standard, as these are familiar to the actors of shipping sector The risk terminology should be updated regularly and consider new conceptualizations and perspectives from the academic risk field The risk terminology should be included in the training programs of the administration and its stakeholders to harmonize approaches and support capacity building

Table 3 (continued)

Risk management attribute	Aspects to be considered
9. Definition of context	The maritime administration should have a systematic and documented process in place to define a scope, context, and criteria for a risk assessment, while considering its purpose and objectives The process should include means to consider the data and information sources, as well as risk assessment tools and techniques to be used in this work The process should promote cooperation so that decision-makers, risk experts, and stakeholders of the administration have a common understanding of the risk assessment purpose and objectives
10. Data and information	The maritime administration should have a systematic and documented process to collect the best achievable data and information for its risk assessment, including both quantitative and qualitative sources The process should include incentives for stakeholders to share their sources and means to follow relevant scientific research and global megatrends The process should provide criteria to ensure the usefulness of data and information, while considering the scope of risk assessment and available resources for data analytics The process should address the sensitivity of the data and information due to privacy concerns and account the limitations and uncertainties
11. Tools and techniques	The maritime administration should have a systematic and documented process in place to select and apply appropriate tools for risk assessment, as there is no one-size-fits-all solution for this purpose The tool selection should consider the risk assessment purpose and objectives, tool's applicability for the different steps of this process, available resources, and type of output The tool selection should utilize, e.g., the IMO, IALA, HELCOM, or ISO risk management guidelines, or scientific research to identify tools fit-for-purpose The tools selection and their practical application should be supported by systematic education and training to ensure capacity building in both administration and stakeholder groups
12. Hazard identification	The maritime administration should have a systematic and documented process for hazard identification focusing on a particular situation, environment, or activity within its internal and external context The hazard identification process should address interactions, phenomena, and future development paths that could create new sources of risk to the maritime domain The hazard identification process should apply multiple data and information sources, while involving active cooperation with stakeholders at the national and international levels The hazard identification process should provide a list of results that is documented, reviewed, and updated on a regular basis

Table 3 (continued)

Risk management attribute	Aspects to be considered
13. Risk analysis and evaluation	The maritime administration should have a systematic and documented process in place for analyzing and evaluating the risks associated with the identified hazards The process should comprise specific metrics for risk analysis, focusing on likelihood, potential consequences, and strength of evidence aspects The process should involve evaluation, where the results of the risk analysis are compared to the earlier defined criteria to determine whether the risks are at an acceptable level The process should involve stakeholders to make use of their risk expertise and understanding of the complex interdependencies in the maritime field The process should describe the results of risk analysis and evaluation of the risks acceptability in a clear and transparent manner
14. Risk control measures	The maritime administration should have a systematic and documented process to identify the appropriate measures for reducing the risks to an acceptable level The process should consider different options for this purpose, such as maintaining the *status quo*, removing the risk source, reducing the likelihood, or limiting the potential consequences of an undesirable event The process should ensure that the risk control measures are practical, suitable, and applied in a timely manner and do not create additional hazards The process should address sharing of risks with stakeholders, interdependencies, and cases where risk control measures are not available or insufficient, such as Black Swans The process should provide a documented list of potential risk control measures, timelines, and consideration of responsibilities
15. Cost-benefit assessment	The maritime administration should have a systematic and documented process in place to conduct cost-benefit assessment for different potential risk control measures The cost-benefit assessment should indicate the estimated cost of different risk control measures compared to its potential benefits that could be linked into, e.g., maritime accident prevention or minimizing its potential consequences The cost-benefit assessment should involve the use of the ALARP principle to address the boundaries of acceptable and unacceptable risks and the area where risks are as low as reasonably practicable The cost-benefit assessment should provide a documented list of the strengths and weaknesses of different risk control measures over their entire life cycle

Table 3 (continued)

Risk management attribute	Aspects to be considered
16. Recommendations	The maritime administration should have a systematic and documented process to produce recommendations for decision-makers in an auditable, traceable, and clear manner The recommendations should consider the results of risk assessment, responsibilities, stakeholder views, and follow-up mean for the selected risk control measures The recommendations should be realistic to implement and meaningful considering the nature of risk that should be managed The recommendations should account for the existing risk control measures that are proven to be useful and support their future endorsement The recommendations should be well stored, as these could be useful in the future to explain why certain decisions and actions were taken at that time
17. Decision-making	The maritime administration should have a systematic and documented process in place for decision-making on the recommended risk control measures The process should be established on the principle of risk-informed decision-making instead of risk-based decision-making, to ensure consideration of the risk assessment quality aspects and stakeholders concerns The process should carefully address the accountabilities and responsibilities of top management, staff, and stakeholders of the administration to make good decisions on the matter at hand The process should ensure that the decisions are communicated appropriately and implemented into practice at the right time and place The process should provide means for validation to ensure that decisions and actions taken are fit-for-purpose

4.2 Risk management attributes

This section focuses on the 17 risk management attributes of the R-Mare matrix model. That is the *Y*-axis of the model as shown in Fig. 2. Based on the results of Delphi survey rounds described in Section 3.4, Table 3 provides a list of the selected attributes and the key aspects to be considered in their context.

4.3 Risk management maturity levels

This section describes the five risk maturity levels of the R-Mare matrix model. That is the *X*-axis of the model as illustrated in Fig. 2. The definition of the levels is shown in Table 4, which is based on the results of the Delphi survey rounds, see Section 3.4.

Table 4 Risk maturity levels of the R-Mare matrix model

Risk maturity level	Description of the level
Level 1:	The risk management of the maritime administration is *inadequate*. There is no risk management framework in place or established processes to carry out risk assessments. The decisions on corrective actions are made on an ad hoc basis, without sufficient knowledge or consulting with stakeholders. The risk and crisis communication are poor and focus on hiding mistakes and blaming others. The Flag State is on the Black list or a corresponding rank in the international Port State Control system. The general performance of the administration is below the legal minimum
Level 2:	The risk management of the maritime administration is *reactive*. There is some effort to establish a risk management framework and implement processes for risk assessments, but both involve various shortcomings. The decisions on corrective actions are made after an undesirable event has occurred, rather than using risk assessment to prevent such an event from taking place. The risk and crisis communication are improvised and focus on the aftermath of maritime accidents or other undesirable events. The Flag State is on the Grey list or a corresponding rank in the international Port State Control system. The general performance of the administration is compliant with most of the legal requirements, but there exist also some critical deficiencies
Level 3:	The risk management of the maritime administration is *compliant*. There is a basic risk management framework in place, and risk assessments are conducted in accordance with the legislative requirements, using the IMO FSA guidelines or corresponding procedures. There is still room for improvements in the quality of risk-related information, processes for continuous improvement, and risk and crisis communication. The Flag State is on the White list or a corresponding rank in the international Port State Control system. The general performance of the administration is compliant with all legal requirements
Level 4:	The risk management of the maritime administration is *proactive* and also meets the demands of previous level. The risk management framework is designed and integrated to the organization in accordance to the best practices, while the risk assessments are used on a regular basis to support decision-making. The quality of risk-related information is high, addressing both short- and long-term risks. Furthermore, there are systematic and documented procedures for continuous improvement and risk and crisis communication. The general performance of the administration is beyond the legal compliance and ready for goal-based regulation
Level 5:	The risk management of the maritime administration is *optimal* and also meets the demands of previous level. The risk management framework is dynamic and agile to react quickly into changes in the risk levels. The administration uses risk-related information continuously to optimize resources, improve decision-making procedures, contribute to develop global maritime legislation and standards, and support its stakeholders. To bounce back from an undesirable surprise or adapt into a new reality, it has also adopted a flexible approach with stakeholders to adjust resources. The administration strives for resilience and can be used for benchmarking for other governmental bodies desiring to attain the highest achievable level in maritime administration risk management practices

4.4 Risk management maturity grids

The R-Mare model also contains textual grid description focusing on the cells of this matrix-based approach, as illustrated Fig. 2. The general criteria and examples included in these descriptions are based on the results of the Delphi survey rounds described in Section 3.4. Table 6 (Appendix) presents the results of this part.

4.5 Evaluation of the risk management attributes

The risk management attributes of the R-Mare matrix model were evaluated in the Delphi questionnaire rounds in terms of their importance for maritime administrations. This task was conducted using a 5-point ranking scale, as described in Section 3.5.

Table 5 The risk management attributes of the R-Mare matrix model; summary of their background information and results of Delphi questionnaire rounds

Attribute	Example studies	IMO FSA	ISO 31000	Rank (Med)	IQR-value
1. Ethics and integrity	Wibowo and Taufik 2017; Pangeran 2012; Sun et al. 2019	No	No	4	1
2. Leadership and commitment	Caiado et al. 2016; Zhao et al. 2013; Unger et al. 2015	No	Yes	5	1
3. Design	Pangeran 2012; Kaassis and Badri 2018; Hoseini et al. 2021	No	Yes	4	1
4. Integration	Farrell 2015; Proença et al. 2017; Wijaksono et al. 2020	No	Yes	4	1
5. Resources	de Oliveira and Di Serio 2015; Zhao et al. 2013; Unger et al. 2015	No	Yes	5	1
6. Communication and consultation	Caiado et al. 2016; Sun et al. 2019; Kaassis and Badri 2018	No	Yes	5	2
7. Continuous improvement	Tubis and Werbińska-Wojciechowska 2021; Zhao et al. 2013; Kaassis and Badri 2018	No	Yes	4	2
8. Risk terminology	Pangeran 2012; Proença et al. 2017; Zhao et al. 2013	Yes	Yes	4	1
9. Definition of context	Batenburg et al. 2014; Proença et al. 2017; Karunarathne and Kim 2021	Yes	Yes	4	2
10. Data and information	Wibowo and Taufik 2017; Hoseini et al. 2021; Unger et al. 2015	Yes	Yes	5	1
11. Tools and techniques	Shan and Lu 2020; Pangeran 2012; Karunarathne and Kim 2021	Yes	Yes	4	1
12. Hazard identification	Zhao et al. 2013; Sun et al. 2019; Kaassis and Badri 2018	Yes	Yes	4	1
13. Risk analysis	Tubis and Werbińska-Wojciechowska 2021; Zhao et al. 2013; Sun et al. 2019	Yes	Yes	5	1
14. Risk control measures	Batenburg et al. 2014; Karunarathne and Kim 2021; Sun et al. 2019	Yes	Yes	5	1
15. Cost-benefit assessment	Proença et al. 2017; Hoseini et al. 2021; Pangeran 2012	Yes	Yes	4	1
16. Recommendations	Karunarathne and Kim 2021; Hoseini et al. 2021; Proença et al. 2017	Yes	Yes	4	1
17. Decision-making	Cienfuegos Spikin 2013; Wibowo and Taufik 2017; de Oliveira and Di Serio 2015	Yes	Yes	5	1

Table 5 indicates the views of the 11 Delphi panelists from this perspective. Based on the median value of the ranking results, all 17 risk management attributes of the model were considered either 4 = *Important* (59%) or 5 = *Extremely important* (41%) in the work of maritime administrations. These questionnaire rounds also involved an analysis of these rankings regarding the consensus criteria (IQR $\leq$ 1). As shown in the table, the established target level was not achieved for only three risk management attributes (nos. 6, 7, and 9).

Table 5 further shows that all risk management attributes of the R-Mare matrix can be identified in previous studies, with some of them present in both the ISO 31000 standard and the IMO FSA guidelines. However, in these benchmarking references, the definitions of the corresponding attributes are either generic or specific to other domains, such as mining or healthcare. In other words, they are not applicable to maritime administrations as such.

5 Discussion

5.1 Scope and applicability of the R-Mare matrix model

To respond into identified needs of maritime authorities and contribute to the academic field of maritime risk management, this article has introduced a new risk maturity model called the R-Mare matrix. The value of this model can be described by highlighting the following topics.

Firstly, the R-Mare matrix model is established on a sound scientific basis that importance has been emphasizes by Cienfuegos Spikin (2013). The model was developed using the Delphi methodology, which has strong scientific credit and applicability for the development of risk maturity models (Monda and Giorgino 2013) and the implementation of maritime risk research (Lahtinen et al. 2020; Duru et al. 2012; Szwed 2011). Although the use of this methodology was time-consuming and taxing on the consulted experts, it proved to be an appropriate approach for this work. More specifically, the methodology enabled the identification of the requirements of maritime authorities for the model, the extraction of their relevant tacit knowledge, and the incorporation of best practices from the scientific risk field and the aviation industry into the model development process. The Delphi methodology also involves the principle of consensus, which was beneficial in making the R-Mare matrix model a shared mental model among the panelists.

Secondly, the R-Mare matrix model is based on an appropriate technique that considers the end-user requirements, as suggested by Hossein et al. (2021). The model builds on the attributes-maturity level matrix technique, which has been used in several research applications of this field and identified to be strongly applicable for self-evaluation (Laine et al. 2022). The panelists of the Delphi process also considered this technique rather easy to use and understand, while having a good potential to provide valuable risk-related information. To implement this technique in the activities of maritime authorities, the R-Mare matrix was populated with 17 risk management attributes, 5 risk maturity levels, 85 risk maturity grids, and associated definitions during the Delphi process.

Thirdly, the R-Mare matrix model is tailored to the operational context of maritime authorities in line with the proposals of Maier et al. (2011). Taking the advantages of the Delphi methodology, the contents of risk management attributes, risk maturity levels, and risk maturity grids of the matrix were contextualized to the work of maritime authorities and made useful and meaningful for them. The Delphi process survey rounds also indicated a high level of consensus concerning these elements, as over 80 percent of the panelists agreed with their content. In addition, the results of subsequent Delphi questionnaire rounds confirmed the importance of these risk management attributes with a high degree of consensus.

Given the above and the fact that the Delphi panelists considered the R-Mare matrix useful for supporting the evaluation and development of maritime authorities' risk management performance and harmonizing current practices, it can be argued that the model has met its design objective.

5.2 Limitations of the R-Mare matrix model

Every model has its limitations, and so does the R-Mare matrix. This model does not consider the causal relations between its different risk management attributes and risk maturity levels. The output of this model is also based on the subjective judgments of evaluators, and its quality is highly dependent on their level of competence and available resources. In this respect, the proposed R-Mare matrix may have similar drawbacks to many other risk maturity models, as can be noted in the work of de Oliveira and Di Serio (2015). The R-Mare matrix model also has geographical limitations. The model was developed for the maritime authorities of Finland with local experts, which may limit its applicability to other coastal and flag states.

5.3 Future research

The proposed R-Mare matrix is the first risk maturity model developed for maritime authorities. To address the limitations of this model highlighted in Section 5.2, future research could be directed to examine linear and non-linear relationships between the different model elements or to extend its scope and context beyond the confines of the Finnish maritime administration.

In addition to these avenues of investigation, future research could address the quality aspects of the R-Mare matrix model, especially in terms of its practical utility and complexity. Although the presented Delphi process for this model development can be considered reliable and valid from the methodological perspective (Section 3.6), the model has not undergone explicit testing. Such testing endeavors could center around aspects like *inter-rater reliability* and *test-retest reliability*. While the former pertains to the extent of agreement among evaluators who assess the same model elements for a given maritime administration, the latter concerns the consistency of their assessments when measuring these elements on different occasions. These tests have the potential not only to provide valuable insights for improving the quality of the R-Mare matrix model but also to shed light on the necessary training, resource allocation, and organizational practices needed to ensure its effective application.

6 Conclusions

In conclusion, this study introduces a novel risk maturity model called the R-Mare matrix to support maritime authorities in developing their risk management performance. The objective of this model is to assist the authorities in evaluating their current risk management practices, identifying areas for improvement, and developing a plan for achieving a higher risk maturity level.

The development process of the R-Mare matrix model was carried out using the Delphi methodology, as it has a strong scientific credibility in delivering reliable and valid results. This systematic and documented process engaged a total of 11 expert panelists, aligning with the recent academic recommendations. As a result, the presented model incorporates 17 risk management attributes, a five-step risk maturity scale, and 85 detailed risk maturity grid descriptions. Through this process, these model elements were also customized to suit the professional context of maritime authorities, ensuring their utility, significance, and suitability for self-evaluation.

The proposed R-Mare matrix model provides a potential solution for addressing an identified gap in the academic maritime risk field, while responding to the practical needs of maritime authorities. To meet academic criteria, the model's development was grounded in the state-of-the-art concepts and perspectives within the scientific risk field. To address the practical criteria, the model development emphasized strong end-user involvement and the attainment of a high level of consensus on its elements.

This study further discusses the strengths and weaknesses of the R-Mare matrix model and outlines potential directions for future research in this area of work. These discussions can be taken into account when testing and implementing the model within the organizational processes of Finnish maritime authorities or considering its application in other coastal and flag states. Overall, this novel model represents an important step forward in both academic and practical dimensions within this area.

Appendix

Table 6 Definitions for the risk maturity grids of R-Mare matrix model and associated 5-point scoring system

	Level-1	Level-2	Level-3	Level-4	Level-5
Ethics and integrity	**Ethics and integrity - inadequate** Ethical values are not taken into account in procedures or daily activities of the maritime administration. The competent authority does not practice what it preaches, while corruption is common.	**Ethics and integrity - reactive** Ethical values are recalled after an undesirable event such as a maritime accident. The competent authority promotes the ethical values for a short period to react into stakeholders' concerns.	**Ethics and integrity - compliant** Ethical values are considered through compliance with the national legislation. The competent authority does not actively promote the ethical values beyond the legislative framework.	**Ethics and integrity - proactive** Ethical values are embedded in the daily activities and made prominently visible in the day-to-day operational work. The competent authority promotes the ethical values actively also for its stakeholders.	**Ethics and integrity - optimal** Ethical values are balanced optimally with economic interest of the shipping sector. The competent authority and its stakeholders have a common will to actively promote these values at national and international level.
Leadership and commitment	**Leadership and commitment - inadequate** Top management is not showing interest in risk management and has only a limited knowledge of this area. They are not trusted among the staff and stakeholders, and set a bad example for everyone.	**Leadership and commitment - reactive** Top management is showing interest in risk management after an undesirable event such as a maritime accident leading to e.g. acute environmental damage. They react to the identified problems rather than trying to prevent them.	**Leadership and commitment - compliant** Top management aims to ensure that the risk management considers and meets all legal requirements. They supervise that all mandatory tasks are conducted and aim to provide necessary resources for this purpose.	**Leadership and commitment – proactive** Top management aims to ensure that the risk management is integrated across the administration and considers its internal changes. They supervise that standard procedures are in place for e.g. continuous improvement and risk acceptability.	**Leadership and commitment - optimal** Top management aims to ensure that in the risk management, the ethical and financial aspects are balanced in optimal way. They motivate staff through visible endorsement, create an environment of trust and set a good example for everyone.
Design	**Design - inadequate** There is no process in place to design the risk management framework for the maritime administration. The framework has not been done, and there is no motivation to take any actions in this context.	**Design - reactive** There is an undeveloped process to design the risk management framework, which involves various shortcomings. The framework exists, but it is updated only after occurrence of undesirable event or after an external audit has identified deficiencies.	**Design - compliant** There is a basic process to design the risk management framework, which is focused on complying with the legal requirements. The framework considers all mandatory tasks, but its applicability for continuous improvement is limited.	**Design - proactive** There is tailored process to design the risk management framework based on best practices, such as the ISO 31000 standard. The framework provides clear responsibilities, as well as procedures for communication and continuous improvement.	**Design - optimal** There is a process to design the risk management framework focusing on the actual performance and optimal use of resources. The framework considers also resilience factors in order to e.g. recover from major undesirable surprises or adapt to them.
Integration	**Integration - inadequate** There is no process in place to integrate risk management framework into the maritime administration's work practices. The implementation is also missing, as the risks are managed on ad-hoc basis without consulting the stakeholders.	**Integration - reactive** There is an undeveloped process to integrate risk management framework, which is improved only due to external pressure. The implementation is incomplete, as the risks are managed through the daily actions of the staff without coordination.	**Integration - compliant** There is a process to integrate risk management framework, but it does not consider verification or continuous improvement. The implementation is focused on the mandatory tasks, but the associated responsibilities are not fully clear.	**Integration - proactive** There is a process to integrate risk management framework, which considers also verification and continuous improvement. The implementation is comprehensive and meaningful, while considering the roles and responsibilities of stakeholders.	**Integration - optimal** There is a process to integrate risk management framework aiming to optimize resources and adapt to varying conditions. The implementation emphasizes the actual performance to achieve the set objectives and factors to create resilience.
Resources	**Resources – inadequate** Resources are not sufficient to perform even the mandatory tasks of the maritime administration. There is a serious lack of trained personnel, technical equipment, training opportunities and funding instruments.	**Resources - reactive** Resources are sufficient to perform most of the mandatory tasks, but the gaps are considered only after external demands. These is a common practice to shift resource gaps from one department to another across the administration.	**Resources - compliant** Resources are sufficient to perform all mandatory tasks under normal conditions. There is a lack of processes to review resources, anticipate future needs and create redundancy for critical tasks.	**Resources - proactive** Resources are sufficient to perform all mandatory tasks under varying conditions and to keep staff motivated. There is a process to review and update resources on a regular basis, and to ensure redundancy for critical tasks.	**Resources - optimal** Resources are balanced optimally in terms of the administration's responsibilities, and are reviewed continuously. There is a flexible and adaptive approach to the use of resources, focusing on active cooperation with stakeholders.

Table 6 (continued)

Communication and consultation	**Communication and consultation - inadequate** There is no process in place in the maritime administration for risk-related information exchange. The competent authority is focused on blaming others and denying its own responsibilities when things go wrong.	**Communication and consultation - reactive** There is an undeveloped process in the administration for risk-related information exchange. The competent authority is only focused on transmitting their own information, unless there is pressure from an external stakeholder.	**Communication and consultation - compliant** There is a basic two-way process in the administration for risk-related information exchange. The competent authority is transmitting and receiving information, but there is no standard procedure for this purpose.	**Communication and consultation - proactive** There is a systematic two-way process in the administration for risk-related information exchange. The competent authority transmits and receives information regularly between different departments and stakeholders.	**Communication and consultation - optimal** There is a dynamic two-way process the administration for risk-related information exchange. The competent authority and stakeholders communicate frequently to develop and maintain a shared risk awareness in both short- and long-term risks.
Continuous improvement	**Continuous improvement - inadequate** There is no process, skills or knowledge to support continuous improvement in the maritime administration. The competent authority has a strong reluctance to change any procedures, while results of external audits are not implemented.	**Continuous improvement - reactive** The process for continuous improvement focuses on the aftermath of undesirable events or audit deficiencies. The competent authority aims to prevent similar accidents to take place, focusing on human errors and technical failures.	**Continuous improvement - compliant** The process for continuous improvement focuses on compliance with regulations and anticipating external audits. The competent authority´s process for monitoring and review include shortages, and responsibilities are not fully clear.	**Continuous improvement - proactive** The process for continuous improvement is based on the PDCA principle, including e.g. near-miss reporting and key performance indicators. The competent authority has a systematic and documented process for monitoring and review, with clear responsibilities.	**Continuous improvement - optimal** The process for continuous improvement focuses on the actual performance and considers also factors to create resilience. The competent authority provides strong incentives for stakeholders to improve common risk management performance.
Risk terminology	**Risk terminology - inadequate** There is no common risk terminology available in the maritime administration and training is missing. The competent authority does not have a professional understanding on basic terms such as hazard, risk and scenario.	**Risk terminology - reactive** There is a common risk terminology available, but the training is only organized after multiple requests from the staff. The competent authority and stakeholders have a mixed understanding on various terms of the risk field.	**Risk terminology - compliant** There is a common risk terminology available based on IMO publications, and training is organized occasionally. The competent authority and its stakeholders have a common understating on key terms of the risk field.	**Risk terminology - proactive** There is a common risk terminology and regular training available, accounting for best practices and recent academic work. The competent authority has a systematic and documented process to review and update the risk terminology.	**Risk terminology - optimal** There is a common risk terminology available that represents the state-of-the-art and can be used across the shipping sector. The competent authority provides a regular training on the use of risk terminology at national and international level.
Definition of context	**Definition of context-inappropriate** There is no process in place in the maritime administration to define the context for risk assessment. The competent authority is not interested in or has no knowledge on the importance of defining the scope and context.	**Definition of context - reactive** There is an undeveloped process to define the context for risk assessment. The competent authority and stakeholders have different and unresolved views of the purpose and objectives of a risk assessment.	**Definition of context - compliant** There is a basic process to define the context for risk assessment that is based e.g. on the IMO FSA or IALA guidelines. The competent authority and stakeholders have a common view of the work purpose and objectives.	**Definition of context - proactive** There is a systematic and documented process to define the context for risk assessment that is based on best practices. The competent authority has set the level of acceptable risk, and applies new tools and data sources as needed.	**Definition of context - optimal** There is a robust process to define the context for risk assessment that can be used for benchmarking purposes. The competent authority provides regular training to its national and international stakeholders for capacity building.
Data and information	**Data and information - inadequate** There is no processes or interest in the maritime administration to collect risk-related data and information. The data is either missing or completely useless.	**Data and information - reactive** There is an undeveloped process to collect risk-related data and information focusing on historic accidents. The data is submitted to compulsory databases, such as GISIS and EMCIP, before external audits or due to demands.	**Data and information - compliant** There is a basic process to collect risk-related data and information and receive them from the stakeholders. The focus of the process is on data collection, rather than on using it effectively in the risk assessments.	**Data and information - proactive** There is a systematic process to collect risk-related data and information, which involves a wide range of stakeholders. The data is used effectively in the risk assessments, while also considering its quality and bias aspects.	**Data and information - optimal** There is an optimized process to obtain and provide useful risk-related data and information for the risk management. The data collection is extended to also cover scientific research of the risk field, global megatrends and futurology as needed.
Tools and techniques	**Tools and techniques - inadequate** There is no process in the maritime administration to apply risk assessment tools. The tools and their applicability are unknown, and there is no interest, resources or trainings for their use.	**Tools and techniques - reactive** There is an undeveloped process to apply risk assessment tools, which is reactive and typically outsourced to consulting agencies. The tools and their applicability are known to external consultants, while the internal expertise and training are incomplete.	**Tools and techniques - compliant** There is a basic process to apply risk assessment tools focusing on compliance with the legal requirements. The tools are selected according to e.g. the IMO or IALA guidelines, and occasional training is available.	**Tools and techniques - proactive** There is a systematic process to apply risk assessment tools in order to support risk-informed decision-making. The tools are selected according to best practices or recent scientific research, and regular training is organized.	**Tools and techniques - optimal** There is a robust process to apply risk assessment tools, which considers also new emerging risks and future phenomena. The tools applied are fit-for-purpose, while training is provided also for stakeholders at national and international level.

Table 6 (continued)

Hazard identification	**Hazard identification - inadequate** There is no process in the maritime administration for hazard identifications. The hazards are not listed or documented.	**Hazard identification - reactive** There is an undeveloped process for hazard identification focusing on maritime accident investigation. The hazards are listed and documented, but the results are out of date or "copy-pasted" from the previous years.	**Hazard identification - compliant** There is a basic process for hazard identification focusing on historic data and inspection results. The hazards are listed and documented, but the results are reviewed and updated only occasionally.	**Hazard identification - proactive** There is a systematic process for hazard identification addressing both the short- and long-term. The hazards are listed and documented, and the results are reviewed and updated regularly in cooperation with stakeholders.	**Hazard identification - optimal** There is a dynamic process for hazard identification that is based on the best achievable tools, data and information. The hazards are listed and documented and the work considers also new areas, such as hybrid and MASS operations.
Risk analysis and evaluation	**Risk analysis - inadequate** There is no process for risk analysis in the maritime administration. The risk evaluation is done on ad-hoc basis.	**Risk analysis - reactive** There is an undeveloped process for risk analysis focusing on historic accidents and expected losses. The risk evaluation is done, but involves various shortcomings.	**Risk analysis - compliant** There is basic process for risk analysis focusing on the likelihood and consequence aspects. The risk evaluation is done according to the IMO guidelines, but the level of acceptable risk is not defined.	**Risk analysis - proactive** There is a systematic process for risk analysis focusing on the likelihood, consequence and strength of evidence aspects. The risk evaluation is done according to best practices and the level of acceptable risk is defined.	**Risk analysis - optimal** There is an optimized process for risk analysis, which considers also complex interdependencies. The risk evaluation is done by using the best available tools, data and criteria with active involvement of stakeholders.
Risk control measures	**Risk control measures - inadequate** There is no process in the maritime administration to identify appropriate risk control measures. The competent authority has no documentation for this purpose.	**Risk control measures - reactive** There is an undeveloped process to identify risk control measures, which is conducted only after an undesirable event. The competent authority has documentation for this purpose, but it is out of date or includes critical shortages.	**Risk control measures - compliant** There is a basic process to identify appropriate risk control measures focusing on legal compliance. The competent authority has documentation that defines e.g. timelines and responsibilities, but not the follow-up means.	**Risk control measures - proactive** There is a systematic process to identify appropriate risk control measures, which applies also the SMART principle. The competent authority has a comprehensive documentation that also considers shared risks and follow-up means.	**Risk control measures - optimal** There is a dynamic process to identify appropriate risk control measures, which also considers interactions and resilience. The competent authority has a documentation that includes measures to recover or adapt in case of e.g. Black Swan event.
Cost-benefit assessment	**Cost-benefit assessment - inadequate** There is no process in the maritime administration for cost-benefit assessment. The ALARP principle is unknown, while the cost consideration is the only criterion for decision-making.	**Cost-benefit assessment - reactive** There is an undeveloped process for cost-benefit assessment focusing on the aftermath of e.g. maritime accidents or oil spills. The ALARP principle is not used, while short-term costs are emphasized over long-term benefits.	**Cost-benefit assessment - compliant** There is a basic process for cost-benefit assessment in accordance with the IMO FSA guidelines. The ALARP principle is applied occasionally, and a brief cost-benefit assessment is made for potential risk control measures.	**Cost-benefit assessment - proactive** There is a systematic process for cost-benefit assessment, which follows the best practices. The ALARP principle is used consistently, and the cost-benefit assessment is made for the entire life cycle and shared risks.	**Cost-benefit assessment - optimal** There is a process to optimize the balance between costs and benefits of risk control measures. The ALARP principle is also adopted by the stakeholders, and cost-benefit assessment considers also non-monetary values.
Recommendations	**Recommendations - inadequate** There is no process in the maritime administration to provide risk-based recommendations. The global recommendations to improve e.g. maritime safety, security and sustainability are generally ignored.	**Recommendations - reactive** There is an undeveloped process to provide risk-based recommendations focusing on the results of accident investigations. The recommendations are aimed to prevent similar accidents or other undesirable events to take place.	**Recommendations - compliant** There is a basic process to provide risk-based recommendations focusing on compliance with legislation. The recommendations are made in an auditable, traceable and clear manner, but follow-up procedures are missing.	**Recommendations - proactive** There is a systematic and documented process to provide risk-informed recommendations following best practices. The recommendations are realistic and meaningful, and consider ethical values, stakeholder views and follow-up procedures.	**Recommendations - optimal** There is a process to provide risk-informed recommendations, which considers also the global challenges of maritime sector. The recommendations are also distributed for stakeholders at national and international level as appropriate.
Decision-making	**Decision-making - inadequate** There is no process in place in the maritime administration for risk-based decision-making. Top management tends to avoid decision-making on risk control measures or conducts them on ad-hoc basis.	**Decision-making - reactive** There is an undeveloped process for risk-based decision-making, which takes place after an undesirable event. Top management decision-making on risk control measures is based on accident investigation results or deficiencies identified in external audits.	**Decision-making - compliant** There is a basic process for risk-based decision-making, but the means for validation and continuous improvement are missing. Top management decision-making on risk control measures focuses on compliance with legal requirements.	**Decision-making - proactive** There is a systematic process for risk-informed decision-making, including means for validation and continuous improvement. Top management decision-making on risk control measures is based on risk assessment results and stakeholders' views.	**Decision-making - optimal** There is a dynamic and agile process for risk-informed decision-making with active involvement of stakeholders. Top management decision-making on risk control measures optimizes both the cost and benefit aspects.
Score	**1**	**2**	**3**	**4**	**5**

Abbreviations *ALARP*: as low as reasonably practicable; *EMCIP*: European Maritime Casualty Information Platform; *FSA*: Formal Safety Assessment; *GISIS*: Global Integrated Shipping Information System; *HELCOM*: The Baltic Marine Environment Protection Commission; *IALA*: International Association of Marine Aids to Navigation and Lighthouse Authorities; *IMO*: International Maritime Organization; *ISM*: International Safety Management Code; *ISO*: International Organization for Standardization; *IRQ*: interquartile range; *MASS*: maritime autonomous surface ships; *PDCA*: Plan-Do-Check-Act principle; *QSE*: Quality, Safety and Environment Management System; *SMART*: Specific-Measurable-Attainable-Realistic-Timely principle

Funding The research for this article was carried out with the OpenRisk2 project co-funded by the EU Interreg Baltic Sea Region programme. The contributions by the third author were made in context of the Qanittaq Clean Arctic Shipping Initiative, funded by the Canada First Research Excellence Fund. The third author furthermore acknowledges the financial support by the Natural Sciences and Engineering Research Council (NSERC) through the Canada Research Chairs Program, under grant CRC-2018-00110.

Declarations

Conflict of interest The authors declare no competing interests.

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