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Systematic Review of Risks in Ship Acquisition: Identification of Risks and Methodologies for their Analysis and Evaluation

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ABSTRACT

Ship procurement is a strategic process that requires careful decision-making under conditions of uncertainty, in which design alternatives must be assessed across multiple factors, with risk being one of the most critical at this early stage. **Objective.** To systematically analyze associated risks before selecting the most appropriate alternative from a risk management

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perspective. **Methodology.** A systematic literature review was conducted to identify, categorize, and analyze the major risk factors and the methodologies employed to assess them. The review was conducted in accordance with the PRISMA guidelines and includes peer-reviewed academic works published from 2014 to 2024, which were screened for relevance and quality. **Results.** The findings reveal a fragmented approach to risk assessment, with fuzzy logic and multi-criteria decision-making methods (such as AHP, TOPSIS, and Fuzzy-AHP) being the most widely employed techniques. Nevertheless, few studies present a comprehensive framework that integrates the various risk categories during the ship selection phase. **Conclusion.** This article advances the field by proposing a conceptual framework for integrated, risk-based decision-making in ship procurement, thereby enhancing the rigor, transparency, and sustainability of procurement strategies.

KEY WORDS: Risks, Selection of alternatives, Assessment methodologies, Risk analysis, Multi-criteria methods.

Revisión sistemática de los riesgos en la adquisición de buques: identificación de riesgos y metodologías para su análisis y evaluación

RESUMEN

La adquisición de buques es un proceso estratégico que comprende la toma de decisiones complejas, bajo condiciones de incertidumbre, en las que deben evaluarse alternativas de diseño al considerar múltiples dimensiones. Una de las dimensiones más relevantes a considerar en esta etapa temprana es el riesgo. **Objetivo.** Analizar de manera sistemática los riesgos asociados antes de seleccionar la alternativa más adecuada desde una perspectiva de

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gestión de riesgos. **Metodología.** Se llevó a cabo una revisión sistemática de la literatura orientada a identificar, clasificar y analizar los principales factores de riesgo y las metodologías utilizadas para su evaluación. La revisión se desarrolló bajo la metodología PRISMA. Se abarcaron fuentes académicas arbitradas publicadas entre 2014-2024, filtradas por criterios de relevancia y calidad. **Resultados.** Los resultados evidencian una evaluación fragmentada de los riesgos, siendo la lógica difusa y los métodos de decisión multicriterio (como, por ejemplo, AHP, TOPSIS y Fuzzy-AHP) los más empleados. Sin embargo, pocos estudios contemplan un marco integral que consolide las distintas categorías de riesgo durante la fase de selección de buques. **Conclusión.** Este artículo aporta a la ciencia al proponer un marco conceptual para la toma de decisiones integradas basada en riesgos en la adquisición de buques; esto fortalece el rigor, la transparencia y la sostenibilidad de estrategias de contratación.

PALABRAS CLAVE: riesgos, selección de alternativas, metodologías de evaluación, análisis de riesgos, métodos multicriterio.

Revisão sistemática dos riscos na aquisição de navios: identificação dos riscos e metodologias para sua análise e avaliação

RESUMO

A aquisição de navios é um processo estratégico que envolve tomada de decisão complexa em condições de incerteza, exigindo a avaliação de alternativas de projeto considerando múltiplas dimensões. Uma das dimensões mais relevantes a serem consideradas nesta fase inicial é o risco. **Objetivo.** Analisar sistematicamente os riscos associados antes da seleção da alternativa mais adequada, sob a perspectiva da gestão de riscos. **Metodologia.** Foi

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realizada uma revisão sistemática da literatura para identificar, classificar e analisar os principais fatores de risco e as metodologias utilizadas para sua avaliação. A revisão foi desenvolvida utilizando a metodologia PRISMA. Foram incluídas fontes acadêmicas revisadas por pares, publicadas entre 2014 e 2024, filtradas por critérios de relevância e qualidade. **Resultados.** Os resultados mostram uma abordagem fragmentada para a avaliação de riscos, sendo a lógica Fuzzy e os métodos de decisão multicritério (como AHP, TOPSIS e Fuzzy-AHP) os mais frequentemente utilizados. No entanto, poucos estudos consideram uma estrutura abrangente que consolide as diferentes categorias de risco durante a fase de seleção de navios. **Conclusão.** Este artigo contribui para a ciência ao propor uma estrutura conceitual para a tomada de decisão integrada baseada em riscos na aquisição de navios. Isso fortalece o rigor, a transparência e a sustentabilidade das estratégias de aquisição.

PALAVRAS-CHAVE: riscos, seleção de alternativas, metodologias de avaliação, análise de risco, métodos multicritério.

Introduction

The acquisition of a vessel can be undertaken through various means, such as the construction of a new unit, the purchase of a second-hand ship, or the modification of existing vessels. Regardless of the chosen modality, this process requires the evaluation and comparison of multiple design alternatives, as each presents its own technical, economic, and operational characteristics, which may not be equally advantageous in all respects. One option may offer superior technical features, whereas another might present more favourable economic conditions. Given the scale of investment involved, it is essential to employ structured and rigorous analytical methods to guide the selection of the most suitable alternative, in line with the project's technical requirements and financial constraints, in a comprehensive manner

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(Lamb, Thomas, ed 2003).

In this regard, the risk assessment of each alternative also plays a crucial role in the selection process, as it enables the anticipation of potential negative impacts and supports more informed decision-making (Golany and Kress 2000). However, while consolidated procedures exist within the military sector, there is still no standardised methodology in the civil domain to holistically guide ship acquisition, particularly concerning the identification and analysis of risks. This gap increases the likelihood of suboptimal decisions, with adverse implications for cost, operations, and the sustainability of naval projects (Park et al. 2018). This is particularly true in a highly competitive, regulated environment characterized by rapid technological advances and growing environmental demands (Roy and Chakraborty 2025).

In the military domain, for instance, the United States Department of Defense (DoD) utilises the Analysis of Alternatives (AoA). This systematic methodology compares different design options based on effectiveness, cost, and risk criteria before proceeding to stages such as prototype construction (Office of the Under Secretary of Defense for Acquisition and Sustainment 2023). Nevertheless, many of these processes are classified and not openly available for academic scrutiny.

By contrast, in the civil and maritime sectors, academic literature reveals a significant gap in the comprehensive treatment of the risks involved in this process. Although some studies address operational risks (Ozturk and Cicek 2019), system-specific risks (Erbas, Khalil, and Tsiopoulos 2024), or risks associated with emerging technologies such as autonomous systems (Chaal et al. 2023), , there is no systematic review that organises and classifies the risks linked to the various modalities of ship acquisition, nor the methodologies applied for their analysis.

Therefore, this article conducts a systematic literature review to compile, classify, and analyze

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the risks associated with ship acquisition. Risk is understood, by the definition established by the Project Management Institute (PMI), as an uncertain event or condition that, if it occurs, may affect at least one of the project objectives, namely, scope, schedule, cost, or quality (PMI, 2021). The review also aims to identify and compare the methodologies used for identifying, evaluating, and managing these risks, to support decision-making processes related to the selection of acquisition alternatives.

The following research questions guide the review:

1. What types of risks have been identified in the scientific literature concerning ship acquisition, and how might they influence the selection of vessel alternatives?
2. What methodologies or approaches have been employed to analyse and evaluate the risks associated with ship acquisition?

The findings of this study may be of use to naval engineers, maritime project managers, industry consultants, and academic researchers, as they facilitate the identification of conceptual gaps, risks, and evaluation methodologies related to ship acquisition and selection. This enables the development of a critical and methodological foundation to enhance decision-making in this field.

Considering the above, the structure of this paper is as follows: Section 2 details the methodology used for the review; Section 3 presents the results obtained; Section 4 discusses the key findings; and finally, Section 5 outlines the conclusions, highlighting limitations, practical implications, and future research directions.

Methodology

This systematic literature review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, a methodological framework designed to support the development of rigorous scientific reviews by facilitating the

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identification, selection, appraisal, and synthesis of relevant studies, thereby ensuring traceability, transparency, and robustness of findings (Page et al. 2021). This section outlines the key aspects of the search and document selection process employed in this review.

Initially, selection criteria were established to objectively filter the most relevant records, thereby ensuring the organisation, integrity, and quality of the information aligned with the research objective (Van Wee and Banister 2024). Thematic relevance was among the primary criteria, ensuring that selected documents specifically addressed risks related to ship acquisition, while excluding studies that were tangential.

The inclusion of academic articles was based on the need to work with methodologically sound and verifiable sources. Regarding the timeframe of analysis, the period from 2014 to 2024 was chosen to capture recent developments in naval technology, regulatory frameworks, and sustainability approaches, thereby avoiding reliance on outdated references. Furthermore, the language was limited to English and Spanish, as these are predominant in scientific output and more accessible in terms of technical comprehension and linguistic proficiency. As a result, studies published in languages other than English were excluded to prevent interpretative errors or bias. Full-text availability was also required, allowing for thorough analysis and leading to the exclusion of restricted-access materials. Table 1 presents the criteria applied for document selection.

Criteria	Description
Thematic Relevance	The following characteristics were considered: Thematic connection with engineering, operations research, and naval project management. The research topic must relate to ship acquisition,

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	selection, and/or risk assessment in ships. Studies must present methodological approaches for risk assessment in naval projects.
Document Type	Only research articles and systematic literature reviews were included.
Time Coverage	Documents published between 2014 and 2024 were considered.
Language	Only documents in English and Spanish were included.
Accessibility	Only open-access documents were reviewed, allowing for detailed

Table 1. Criteria Inclusion

Given the focus on scientific literature, the searches were conducted using Scopus and Web of Science (WoS) databases, both recognised for providing access to high-quality, peer-reviewed academic journal articles with thematic relevance (Animah 2024). These databases were also selected due to their regular updates, user-friendly data retrieval functionalities, and efficient information management capabilities, which are essential for conducting a systematic and reproducible review (Pranckutė 2021).

Three sets of search equations were defined in line with the article's objectives and research questions, aiming to comprehensively and systematically cover the study's thematic pillars. The combination of these three approaches enabled the capture of a broad and coherent spectrum of relevant literature, aligned with the purpose of the review. The structure and formulation of the search equations are detailed in Table 2.

The first set focused on identifying general risks associated with ship acquisition, serving as a

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starting point for compiling and categorising risk scenarios and methodologies. The second set specifically addressed risks linked to the acquisition of environmentally friendly vessels, considering the industry's growing interest in sustainability and clean technologies, which may introduce novel sources of uncertainty. The third set targeted studies examining acquisition alternatives, in recognition of the study's broader aim to identify methodologies and criteria employed in evaluating comparative risks across different vessel options.

Set	Topic	Search Expressions
A	Risks in Ship Acquisition	"ship*" OR "vessel*" OR "naval*"
		"risk identif*" OR "risk evaluat*" OR "risk categor*" OR "hazard* identif*" OR "risk* list*" OR "risk analy*" OR "risk* hierarch*"
		"design* select*" OR "design* decision*" OR "decision* support*" OR "concept* design*" OR "purchas*" OR "acqui*"
B	Risks in the Acquisition of Environmentally Friendly Vessels	"ship*" OR "vessel*" OR "naval"
		"risk" OR "risk identification" OR "risk evaluation" OR "risk categorization" OR "hazard identification" OR "list of risk" OR "risk analysis" OR "risk hierarchy"
		"design* select*" OR "design* decision*" OR "decision* support*" OR "concept* design*" OR "purchas*" OR "acqui*" OR "alternative selection" OR "design" OR "alternative selection"
		"green*" OR "sustain*" OR "eco-friend*" OR

		"environment*"
C	Risks in the Analysis of Alternatives	"ship*" OR "vessel*" OR "naval*"
		"analysis of alternatives" OR "AOA" OR "alternative* decision*" OR "alternative* assessment*" OR "alternative* evaluation*" OR "option* analysis" OR "comparative analysis" OR "trade-off analysis" OR "feasibility study"
		"risk*" OR "hazard*"

Table 2. Search Equations

To construct the search expressions, the wildcard symbol "*" was used at the end of specific terms, allowing for the recognition of word variants with different suffixes; for instance, "ship" encompasses terms such as "ship", "ships", and "shipping". Terms within each thematic group were linked using the Boolean operator OR, and the resulting expressions were combined using the AND operator. In Scopus, searches were restricted to titles, abstracts, and keywords to avoid irrelevant results stemming from secondary sections of the documents. In contrast, Web of Science (WoS) allowed searches across all available fields, taking advantage of its structured indexing system (Pranckutė 2021).

After conducting the searches, the data from the retrieved articles were compiled, and duplicates were removed using R Studio software. The remaining results were organised into a Microsoft Excel spreadsheet, where key information such as title, abstract, year of publication, and DOI code were recorded. The review was carried out independently by two evaluators to ensure the objectivity and reliability of the process. This review followed a three-stage procedure: first, the titles were assessed to exclude those unrelated to the thematic focus; then, abstracts were reviewed to discard records not meeting the predefined criteria; finally, a full-text reading was undertaken for the remaining documents to determine their final inclusion (see Figure 1).

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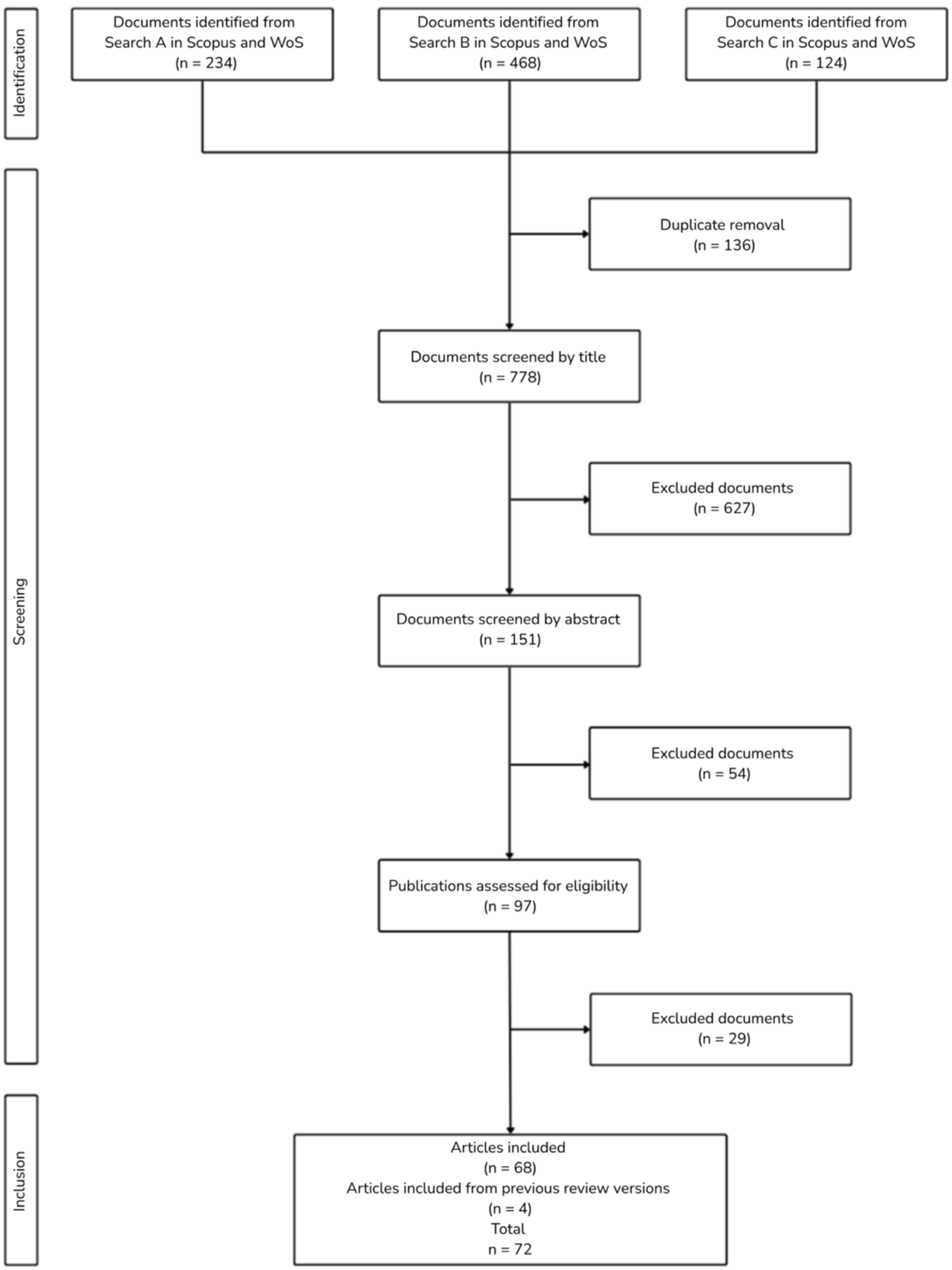

Figure 1. Document Exclusion and Selection Process

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Once the records were selected, additional fields were added to the Excel spreadsheet to capture each study's aim, key findings, and methodological focus. These included: the ship lifecycle phase addressed, the level of analysis within the Expanded Ship Work Breakdown Structure (ESWBS), the type of acquisition considered (new build, second- hand purchase, or retrofit), the method employed for risk identification, assessment and/or management, and whether the article made explicit reference to the selection of alternatives. This systematisation enabled comparative pattern analysis across studies, the identification of thematic gaps, and an understanding of how knowledge is distributed about the context of naval acquisition.

Furthermore, the specific risks identified in each article were recorded and classified into four categories, distinguishing between technical, economic, schedule-related risks and *Environmental risk,* offering a robust and transferable structure suitable for complex projects such as the acquisition of military vessels.

Complementarily, subcategories were defined for each risk group, based on the findings extracted during the systematic review. This structure aligns with Project Management Institute (PMI) guidelines, which recommend the use of a hierarchical risk breakdown structure to represent the potential sources of uncertainty within projects. The PMI also highlights that such structures can be tailored to fit the type of initiative or organisational context (Project Management Institute 2021).

Results

From the analysis of the selected articles, patterns were identified that help to understand how the study of risk in ship acquisition has been approached, highlighting the most frequently

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examined phases of the vessel's life cycle, the technical levels considered, the classification of risks, and the diversity of methodological approaches. These findings provide a foundation for recognising trends, knowledge gaps, and opportunities for improvement in the naval domain.

Distribution of Studies by Life Cycle Phase and Technical Level of Analysis

The first aspect explored was the life cycle phase in which risk treatment is focused within the selected studies. Of the 72 documents identified, the majority concentrate their analysis on the utilisation and support stages, i.e., the operational phase of the vessel. By contrast, there is a notably lower presence of studies addressing the design and production phases.

Figure 2 illustrates this distribution, revealing a predominant focus on risks that arise during the vessel's operational lifespan, particularly those related to technical performance and operational safety. This trend reflects a practical orientation in the literature, aimed at mitigating risks during the most extended and operationally critical phase of the ship's life. However, the underrepresentation of studies during the early stages, such as acquisition or conceptual design, indicates a significant gap, especially considering that many strategic decisions, including the selection of alternatives, are made in these initial phases.

In addition, studies were grouped according to levels defined by the Expanded Ship Work Breakdown Structure (ESWBS). The classification used in this review recognises system, component, and consumable levels, along with two additional categories: the operating environment and the system of interest, in this case, the vessel itself. The distribution of documents across these levels is shown in Figure 2.

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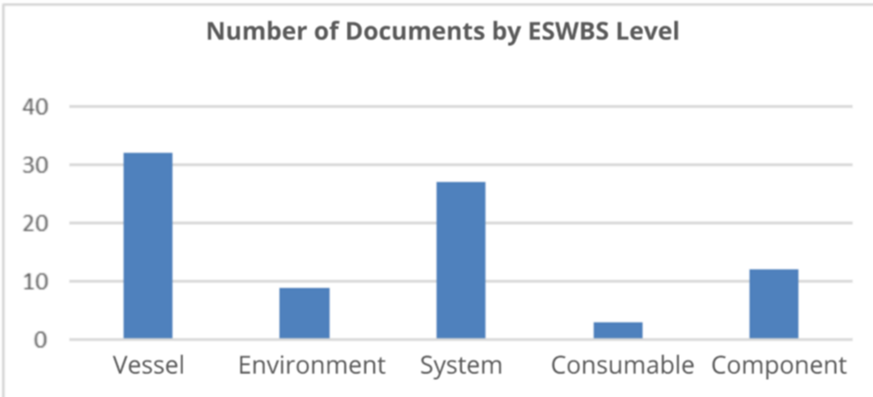

Figure 2. Number of Documents by ESWBS Level

Risks in Ship Acquisition

Based on the previously defined typology, the risks identified in the 69 articles were grouped into four categories: technical, economic, schedule-related, and environmental. Each category was further divided into multiple subcategories, which group the most frequently reported risk factors in the literature. This classification structure is detailed in Table 3. The most relevant findings by category are presented below.

Technical Risks	Economic Risks	Schedule Risks	Environmental Risks
• Human Factors • Operational • Design • Equipment and Systems • Technological • Maintainability • Operational Environment	• Financial • Market Conditions • Governmental • Regulatory • Civil Society • Residual Value and Return on Investment • Operational	• Planning and Time Estimation • Schedule Execution and Control • External Dependencies and Uncontrollable Events	• Atmospheric Pollution • Marine Pollution • Hazardous or Non-Hazardous Waste and Material Management • Energy Efficiency and Resource Use • Impact on Biodiversity

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Table 3. Classification of Risks Associated with Ship Acquisition and Subcategories

Technical Risks

Technical risks refer to uncertainty in achieving or maintaining the technical capability required for a vessel to meet its projected operational, safety, and performance requirements throughout its life cycle. These risks are central to decision-making in ship acquisition, as technical capacity directly affects the ship's performance and operational viability in real-world conditions. The subcategories derived from the findings include:

- *Human Factors Risks:* These have been consistently cited as key contributors to incidents and operational failures. Risks range from errors during manoeuvring or navigation (Zeng, Yang, and Zhang 2014), to lapses caused by fatigue, lack of training, or poor communication among crew members (Han et al. 2024). Notably, some studies warn of deficient interaction with automated systems (Z. Li et al. 2023). This aspect should be incorporated into risk assessments, as improved training strategies and human-machine interface design can significantly reduce these risks.
- *Operational Risks:* These refer to failures or unsafe conditions that may arise during vessel operation and affect its performance, safety, or integrity. Examples include LNG leaks (Iannaccone et al. 2019), failures in propulsion, control systems, or other machinery (Rokseth, Utne, and Vinnem 2017).
- *Design Risks:* These include structural failures linked to suboptimal designs and the inappropriate selection of materials or technologies (Zou et al. 2020; Kondratenko, Kujala, and Hirdaris 2023). Hybrid propulsion systems and the integration of complex components also emerge as critical points (Batra et al. 2023), as do miscalculations in energy sizing that can compromise vessel efficiency and sustainability (Dolatabadi and Mohammadi-Ivatloo 2018).

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- *Equipment and System Risks:* The reviewed literature highlights a high incidence of failures associated with the integrity and performance of energy, electrical, and mechanical systems. Prominent issues include deficiencies in fuel and energy storage system ventilation (e.g., LNG and hydrogen) (Shao et al. 2022), along with electrical faults and mechanical degradation of components (Dionysiou, Bolbot, and Theotokatos 2022). Additional risks involve poor-quality third-party components (Para-González, Mascaraque-Ramírez, and García 2018), lack of redundancy in critical systems (Pham and Hoang 2024), and challenges in integrating complex technologies such as alternative propulsion (Taghavifar and Perera 2023). A stricter quality approach in supplier selection and the implementation of redundant systems are recommended to ensure operational safety.
- *Technological Risks:* These encompass failures, limitations, or vulnerabilities related to automated, digital, or advanced energy systems integrated into the vessel. The reviewed studies highlight failures in control software and hardware (Thieme et al. 2020), incompatibilities between emerging technologies and legacy systems (Pagonis et al. 2016), and specific risks in autonomous ships such as algorithmic or AI-related errors (Durlik et al. 2024). Also noted are cybersecurity vulnerabilities (Tao et al. 2024) and the lack of maturity in critical technologies (Fan et al. 2020).
- *Maintainability Risks:* Several studies emphasise limitations in maintaining, repairing, or upgrading ship systems. Common issues include limited availability of spare parts and technical support for emerging technologies (Aspen, Haskins, and Fet 2018). Structural ageing also poses a critical risk, requiring frequent maintenance due to thermal, mechanical, or fatigue-related degradation (Liu, Frangopol, and Cheng 2019; Bahrebar et al. 2018).
- Operational Environment Risks: These primarily involve events such as collisions, groundings, flooding, and extreme weather conditions (Landquist et al. 2016). Intentional threats are also reported, including piracy, sabotage, cyberattacks, or signal interference (Nguyen, Chen, and Du 2023). The integration of real-time monitoring technologies and early warning systems can help mitigate these risks by improving emergency response capabilities.

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Economical Risks

Economical risks refer to the uncertainty associated with the estimation, variability, and control of the costs involved in the acquisition and operation of a vessel, affecting both the financial viability of the project and its long-term profitability. The analysis identified seven key subcategories that encompass the main economic risk factors discussed in the reviewed literature:

- *Monetary Risks:* Several studies warn that the actual costs associated with acquisition may exceed initial estimates. Critical factors include unplanned redesigns (Para- González, Mascaraque-Ramírez, and García 2018), the implementation of sustainable technologies with high upfront costs (Sun et al. 2023) and the increasing costs of manufacturing or retrofitting processes (Baihaqi, Lazakis, and Supomo 2024).
- *Market Condition Risks:* These include fuel price volatility (Huang et al. 2021), (Huang et al. 2021), uncertainty in demand trends, and changes in broader economic contexts (Zhu, Wang, and Xu 2021). In addition, constant market fluctuations and the introduction of green technologies are identified as project risks (Metzger 2022).
- *Governmental Risks:* These encompass reliance on state subsidies for the implementation of sustainable technologies (Kolios 2024), and variations in taxation or port regulations depending on the country or region (Gaspar, Hagen, and Erikstad 2016). Risks also arise from weak or insufficient legal frameworks governing autonomous ships (Fan et al. 2020).
- *Regulatory Risks:* These are mainly related to the cost of complying with international regulations, including the imposition of financial penalties and uncertainty surrounding regulatory changes, particularly environmental standards and newly established Emission Control Areas (ECAs) (Aspen, Haskins, and Fet 2018). Additional risks include discrepancies in carbon standards (Metzger 2022; Kolios, 2024), certification and documentation requirements (Dinis, Figueira, and Teixeira 2023), and legal challenges

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specific to autonomous vessels (Torben et al. 2023).

- *Civil Society Risks:* These include negative public perceptions regarding potential technological failures, especially in the case of autonomous vessels, as well as media scrutiny and social pressure related to safety and operational responsibility (Fan et al. 2020). Other reported risks involve public acceptance (Kondratenko, Kujala, and Hirdaris 2023), social impact, and sociocultural shifts (Zhu, Wang, and Xu 2021).
- *Residual Value and Return on Investment (ROI) Risks:* This category includes uncertainty regarding expected profitability and variability in payback periods for invested capital (Taghavifar and Perera 2023). Risks also arise from depreciation in vessel resale value (Kolios 2024) and fluctuating profitability of alternative technologies (Sun et al. 2023).
- *Operative cost Risks:* These cover cost-related risks due to technological failures (Fan et al. 2020), unplanned maintenance (Nwaoha and Adumene 2019) and downtime (Kolios 2024). The most critical among these is the risk of financial losses caused by material damage, cargo loss, fuel loss, or even total vessel loss (De Vos, Hekkenberg, and Koelman 2020). Although these risks materialise during the operational phase, several studies consider them key economic evaluation factors, as they influence the total life cycle cost.

Schedule Risks

These refer to the uncertainty associated with meeting the scheduled timeline for the completion and delivery of the vessel. Based on the analysis, three main subcategories were identified:

- *Planning and Time Estimation Risks:* These primarily involve delays in delivery deadlines and contractual commitments. Key issues identified include problems within shipyards such as lack of automation in contractual management and unqualified personnel for scheduling and cost control (Azizi et al. 2019).
- *Execution and Schedule Control Risks:* The literature highlights risks related to the

operational and organisational performance of shipyards during the construction or conversion phases. Notable examples include poor internal management (Jeong, Cha, and Kim 2020), inadequate contractor monitoring (Azizi et al. 2019), and safety- related risks (Baihaqi, Lazakis, and Supomo 2024).

- *External Dependencies and Uncontrollable Events:* Risks were identified concerning external suppliers, such as missed deadlines, insolvency, or insufficient production, as well as unforeseen events including natural disasters, epidemics, and strikes (Jeong, Cha, and Kim 2020).

Environmental Risks

These relate to the uncertainty associated with the vessel's potential environmental impact during its construction, modification or retrofitting, and operational phases. The following subcategories were identified:

- *Air Pollution:* Risks related to pollutant gas emissions were identified, particularly carbon dioxide (CO_2) and nitrogen oxides (NO_x), both during construction and operation (Wirkowski 2019). Additional concerns include methane leaks from LNG systems (Taghavifar and Perera 2023) and recirculated emissions affecting air quality (Batra et al. 2023). These risks demand detailed evaluation to pinpoint specific emission sources and to develop mitigation strategies such as adopting cleaner technologies and improving combustion processes.
- *Marine Pollution:* The most frequently cited risk was marine pollution caused by accidents, failures, or collisions (Das, Goerlandt, and Tabri 2022). Risks arising from the use of inappropriate materials, such as polluting coatings (Nwaoha and Adumene 2019), were also noted (Kolios 2024). Mitigation can be achieved by selecting more sustainable and less toxic materials, as well as implementing monitoring and spill prevention systems to

minimise accidental discharges of harmful substances into the sea.

- *Waste and Hazardous Material Management:* Risks were recurrently identified regarding the accidental release of hazardous substances during both construction (Landquist et al. 2016) and operation, including oil or fuel spills (Pereira and Garbatov 2022). Poor waste management practices in shipbuilding environments (Baihaqi, Lazakis, and Supomo 2024), and risks associated with the disposal of obsolete components (Kolios 2024) were also reported. To mitigate these risks, stricter and more effective waste management practices are recommended, along with the adoption of recycling and treatment technologies to prevent hazardous material releases.
- *Energy Efficiency and Resource Use:* The most prominent risk was reduced energy performance and high fuel consumption following the adoption of emission-reduction technologies (Pagonis et al. 2016; Batra et al. 2023; Kolios 2024). Studies also cited difficulties in implementing green energy systems within shipyards (Baihaqi, Lazakis, and Supomo 2024).
- *Biodiversity Impact:* Environmental risks were identified related to the disturbance of marine habitats due to oil spills (Kujala et al. 2019). Additional adverse effects included underwater noise pollution, emission recirculation, and unintentional release of ecologically disruptive substances. Further concerns included the depletion of natural resources and long-term environmental degradation (Kolios 2024). Measures to protect marine biodiversity are recommended, such as adopting quieter propulsion technologies and monitoring water quality and marine fauna, to ensure vessel operations are as environmentally respectful as possible.

Risk Assessment Methodologies in Ship Acquisition Processes

Decision-Making Models (AoA, SPADE)

In Analysis of Alternatives (AoA), risk assessment is considered the final stage in the decision-

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making process, enabling the quantification of uncertainty associated with evaluation criteria and metrics. This approach employs the calculation of a dimensionless risk metric, known as Overall Measure of Risk (OMOR), which is compared against the cost and effectiveness of each alternative (Campbell 2005; Stepanchick and Brown 2007). According to the SPADE model proposed by Aspen et al. *(2018),* risk evaluation in ship acquisition is a critical step in the formulation of actions and decision modelling. This process comprises three main methodological components: identification of the stochastic behaviour of indicators using probability distributions; scenario simulation to recognise joint uncertainties in complex activities; and variability in interpretation and data incompleteness, managed through fuzzy logic.

Risk Identification and Assessment Methods

Risk evaluation in vessels has increasingly focused on Maritime Autonomous Surface Ships (MASS), particularly due to the integration of advanced technologies stemming from Industry 4.0. The studies identified by Tao et al (2024) and Li et al (2023) classify risk assessment methodologies according to their qualitative, quantitative, or hybrid properties. These include approaches to identification, evaluation, and management of risks related to software failures, navigation support systems, human factors (both in crew and remote operations), and mechanical reliability and maintenance. In addition, the contribution by Fan et al (2020), introduces the 4P4F method, which structures operational analysis around four factors, Human, Technology, Environment, and Vessel and four operations (Voyage planning, berthing and unberthing, port approach and departure, and open-sea navigation). The framework identifies multiple methods tailored to each operational scenario.

Approaches Applied in MASS

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In the context of MASS, risk analysis must incorporate historical accident data, the operational environment, and its interaction with the vessel. Kujala et al (2019) emphasise the importance of integrating human factors into the analysis, particularly in the context of accidents, and stress that such elements must be evaluated in relation to both vessel operations and onboard systems. Additionally, the analysis must consider the vessel's structural response to adverse events and the resulting environmental impacts.

There are different methods associated with risk analysis in vessels, which are related in figure 4, which provides a methodological classification is presented according to the target life cycle phase.

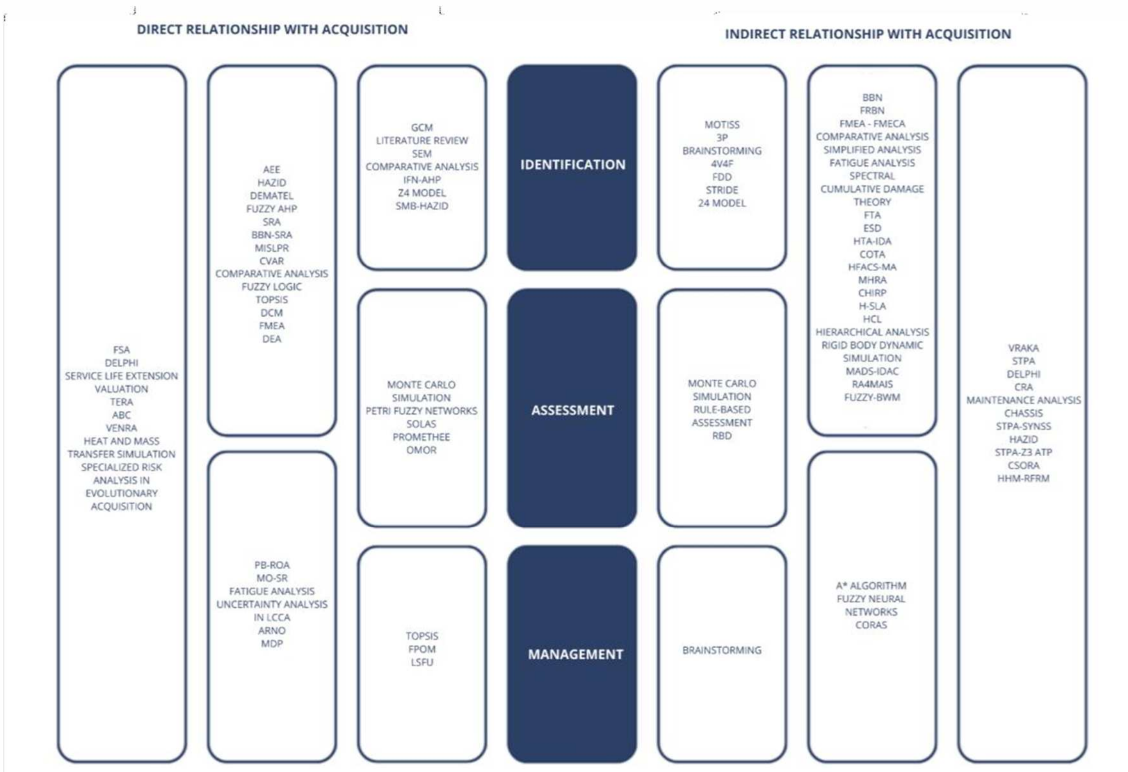

Figure 3. Risk Assessment Methodologies Associated with Vessels

According to Nikolaos & Louzis (2022), risks must be considered both during vessel design and

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during operational execution, as probability analyses are not purely static and depend on the specific context of the operation. Risks addressed during the design phase are directly related to acquisition, whereas operational risks must be assessed for proper task execution and subsequently integrated as use cases and technological applications.

Methods such as STRIDE, STPA, RA4MAIS, and CORAS are employed for the identification of operational risks, particularly in navigation assistance and the protection of onboard information systems (Lee & Lee, 2024; Goksu et al, 2024; Rokseth et al, 2017). The most widely recognised risk analysis methodologies include FMEA, FMECA, STPA, and FTA, which are broadly applied to identify event sequences and calculate risk through the likelihood of occurrence, severity, and increasingly, detectability across physical, digital, and human subsystems. These are often complemented by probabilistic analyses such as Bayesian Belief Networks (BBNs), Monte Carlo simulation, fuzzification of input data, and the application of digital models and simulations, including neural networks, rigid body dynamics simulation, and the A*algorithm, among others.

MADM/MODM Techniques for Risk-Based Selection

In terms of methods directly linked to selection, the literature includes both Multi- Objective Decision-Making (MODM) techniques (Knight et al, 2015; Gaspar et al, 2016; Bitner-Gregersen et al, 2018; Dolatabadi & Mohammadi-Ivatloo, 2018; Liu et al, 2019; Garbatov & Huang, 2020; Pereira & Garbatov, 2022,; Metzger, 2022) and Multi-Attribute Decision-Making (MADM) techniques (MADM) (Seker et al, 2017; Park ett al, 2018; Nwaoha & Adumene, 2019; Zhu et al, 2021; Pereira y Garbatov, 2022; Batra et al, 2023; Baihaqi et al, 2024; Caldeira et al, 2023). Among the MODM approaches, the following are notable: PB-ROA method, Epoch-Era Analysis (EEA), Mixed Integer Stochastic Linear Programming (MISLPR), Structural Reliability Analysis (SRA), Line Ship Fleet Upgrade Problem (LSFU), and Formal Safety Assessment (FSA). These methods integrate technical and economic dimensions in decision-making, aiming

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to quantify and reduce risk and its associated management cost. For MADM techniques, the most frequently applied are DEMATEL, AHP, TOPSIS, PROMETHEE, VIKOR, and DCM, along with their fuzzy variants. These methods primarily focus on the classification of risk factors and the ranking of alternatives. As such, they are typically limited to the acquisition phase, although they appear more frequently in academic studies.

Economic Risk Assessment Methods

Particular attention is given to economic risk analysis, as it is considered a key dimension in the selection of alternatives due to its direct handling of the costs associated with recognised uncertainties and their management plans. These costs can be estimated independently of technical or schedule-based risk assessments, enabling the classification of management methods and their comparison within alternative analyses. Unlike optimisation techniques, cost risk analysis aims to quantify uncertainty related to the market or expected returns of the target activity. The output is the deviation in revenues or costs of environmental variables and their impact on investment decisions (Mortlock, 2020; Mun, 2021)

Cross-Cutting Support Techniques (Surveys, Comparisons, Expert Judgement)

Techniques such as literature reviews (Fan et al, 2020; Zhihong Li, 2023; Juncheng Tao et al, 2024), survey-based structural equation models (Jeong et al, 2020), and comparative analyses (Iannaccone et al, 2019; Wiekowski, 2019; Dimitrakieva et al, 2021; Sahay et al, 2023), are widely used to quantify, evaluate, and manage risk factors in both acquisition and operational contexts. In addition, expert judgement is consistently applied across all types of risk analysis and throughout the assessment process, playing a critical role in model validation, assumption definition, and scenario interpretation.

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Discussions

The findings highlight the importance of addressing risk analysis in ship acquisition through a multidimensional and integrated approach. Within this context, the technical, economic, schedule, and environmental dimensions must be considered concurrently and with high priority. This holistic perspective enables a better understanding of the threats that may impact the success of a project operating in complex environments, characterized by multiple stakeholders, international regulations, and rapidly evolving technologies.

The risk classification adopted in this study shares similarities with that proposed by the International Council on Systems Engineering (INCOSE), which distinguishes between technical, programmatic, schedule, and cost risks. However, this work introduces a significant distinction by treating the environmental dimension as an independent category, rather than including it as an additional criterion within technical risks, as INCOSE does. This distinction is particularly relevant in the current context of stringent regulatory requirements and increased emphasis on sustainability.

Identified Gaps

One of the main gaps identified in the literature is the limited attention given to risks associated explicitly with the acquisition process or the selection of alternatives. While numerous studies address risks in operational, construction, or maintenance contexts, few focus on the strategic and systemic risks that directly influence acquisition decision- making. The lack of attention to the selection phase, despite its crucial role in determining future vessel performance, cost, and sustainability. represents a critical gap in research. Furthermore, literature exhibits a tendency to prioritise technical risks, marginalising environmental and regulatory risks, despite the growing importance of sustainability in the maritime industry. The absence of focused research on risks according to the type of acquisition, be it newbuild, retrofit, or second-hand purchase, also limits the applicability of current findings to specific acquisition scenarios.

Opportunities for Improvement

The scarcity of studies focused on the alternative selection phase presents a significant opportunity for further research. It is recommended that models, taxonomies, and tools be developed to more effectively integrate the risks associated with each acquisition type. Additionally, there is a clear need for more structured approaches capable of addressing the complexity of emerging risks linked to new technologies, such as alternative propulsion systems (LNG, hydrogen, batteries) and autonomous vessels. These technological advancements introduce novel risk types that remain insufficiently explored in the current literature. It is also essential to improve standardisation in the typology, description, and categorisation of risks, which would facilitate the consolidation of metrics and the comparison of cases ultimately enhancing risk analysis in the selection of ship acquisition alternatives.

Conclusions

The main findings of this systematic review reveal that technical, economic, schedule- related, and environmental risks directly influence the selection of ship acquisition alternatives. The reviewed studies identify a wide array of risks, ranging from operational and design failures to regulatory and market uncertainties, all of which can significantly affect project performance and sustainability. Additionally, methodologies such as Real Options Analysis (PB-ROA), fuzzy logic, and multi-criteria optimisation approaches are highlighted for their ability to support comprehensive assessments of the risks associated with different acquisition alternatives. These methods offer valuable tools for informed decision-making and for reducing uncertainty throughout the vessel’s life cycle.

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Nevertheless, notable gaps and limitations persist in literature, particularly in the alternative selection phase. Few studies explicitly address the strategic and systemic risks specific to this stage. Most work focuses on risk analysis during operation, construction, or maintenance phases, without adequately considering how these risks are interrelated at the initial acquisition stage. Moreover, the absence of a standardised framework for classifying and evaluating these risks limits the ability to apply and compare methodologies consistently across different contexts. The lack of studies that explicitly integrate environmental risks also stands out as a critical gap, especially given the growing emphasis on sustainability in the maritime sector.

Looking ahead, there is a need to advance the development of models and tools capable of addressing these gaps by integrating the various risk dimensions into the selection process of ship acquisition alternatives. It is recommended to establish more comprehensive methodological frameworks that combine both qualitative and quantitative approaches and that can holistically incorporate risks associated with emerging technologies, such as autonomous vessels and alternative propulsion systems. Future research should also focus on the standardisation of methodologies and the enhancement of decision support tools such as multi-criteria decision-making (MCDM) methods, to enable more coherent and robust risk assessments throughout the entire vessel life cycle.

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