The Effects of Implementing ISO 42001 AI Management Systems into Autonomous Maritime Operations

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Received on: 10 March 2025 Accepted on: 01 June 2025 Published on: 03 June 2025

ABSTRACT

The integration of Artificial Intelligence (AI) in autonomous maritime operations has significant potential to dramatically alter the industry by enhancing operational efficiency, safety, and compliance. However, the lack of a structured framework to manage AI systems and autonomous maritime operations presents a critical gap, particularly in addressing risks such as inaccuracy, cybersecurity vulnerabilities, and regulatory compliance challenges. This research aims to bridge this gap by investigating the application of International Organization for Standardization (ISO) 42001:2023 standards, focusing on the selection and implementation of specific controls from Annex A.

This research engages a scenario study approach focusing on a particular case study during an ISO 42001:2023 requirements course conducted by Det Norske Veritas (DNV) at the Arab Academy for Science, Technology and Maritime Transport (AASTMT). The selected controls are assessed on their categorization, and their relevance to the maritime operations, and using the Plan-Do-Check-Act (PDCA) model, the research assesses the adequacy of those controls in achieving improvements in governance, risk management, and operational efficiency in autonomous maritime operations.

Key findings demonstrate that ISO 42001:2023 is appropriate in mitigating AI-related risks while ensuring transparency, accountability, and compliance. The research underscores the selected controls' usefulness as regards some critical issues in guidance, decision, and resource management. These outcomes considerably affect how AI management systems can be integrated into the maritime transport industry and serve as a basis for more extensive harmonization and incorporation with the international organization for standardization.

Key-words:
ISO 42001, MASS, AIMS, PDCA, AI risks, Autonomous maritime operations.

INTRODUCTION

AI is among the most disruptive essential components in every information technology-based industry, and it can be a primary contributor to economic growth in the future. And this transformation is being led by the maritime sector through the introduction of autonomous ships. AI facilitates the use of advanced technologies through the development of autonomous vessels, providing unprecedented opportunities for efficiency and innovation with societal and operational challenges that require rigorous management systems and supervision (Joshva et al., 2024).

For example, AI used for automated decisions in autonomous vessels relevant to this use case (e.g., navigation, collision avoidance, and fuel optimization) almost always occurs in an unexplainable manner. These systems can make critical decisions independently and determine actions by themselves, which represents a departure from traditional maritime operations. This opens up a layer of decision-making processes that need special management frameworks that are beyond the capabilities of conventional Information Technology (IT) systems to ensure accountability, safety, and reliability in maritime operations (Zhang et al., 2023). In addition, AI for autonomous vessels relies heavily on data interpretation, knowledge, and machine learning rather than fixed human-coded instructions. This shift enhances flexibility and provides better coverage capabilities, such as the real-time optimization of shipping routes and the prediction of maintenance needs. Yet, it also changes how these systems are developed, justified, and deployed. Maritime organizations not only need to adopt new workflow methods, but they also need to validate their management systems, get safety certifications, and comply with global maritime rules such as those instituted by the International Maritime Organization (IMO) and ISO.

The author delineates the prerequisites for the establishment, implementation, maintenance, and ongoing enhancement of an AI management system in companies operating autonomous vessels. These companies are anticipated to concentrate their application of requirements on attributes that are distinctive to AI. Specific attributes of AI, including its capacity for continuous learning and enhancement, as well as its deficiency in transparency or explainability, may necessitate distinct safeguards if they present heightened concerns relative to conventional practices in maritime operations. Implementing an AI management system to enhance current management frameworks is a strategic choice for companies operating autonomous vessels.

This research paper addresses insight into the standardization and potential advantages of ISO 42001 implementation in the maritime industry and marine AI applications, particularly for companies chartering autonomous and Maritime Autonomous Surface Ships (MASS) vessels. Moreover, it illustrates their specific challenges and advantages and how ISO 42001 adoption can facilitate better management of AI systems onboard MASS ships through their unique problems and prospects. The paper accentuates that solid frameworks need to be in place to guarantee safety, transparency, and compliance whilst utilizing AI to maximize efficiency and innovation with the new application of autonomous maritime technologies.

Background

ISO 42001 is the new standard that allows any management or companies dealing with smart applications to structure and audit their own Artificial Intelligence Management Systems (AIMS), helping to ensure that AI systems are employed and controlled appropriately across various industrial sectors. Mazzinghy et al. (2024) found that the implementation of ISO 42001 in the logistics industry in Brazil was found to bring relevant increases in customer satisfaction, operational efficiency, innovation, competitiveness, and brand image. The standard addresses key challenges, including those related to supply chains and regulatory issues, while making processes smoother and less costly. ISO 42001 certification develops flexible and reliable systems to support the safe use of generative AI tools in the healthcare sector. This way, those tools are designed to integrate seamlessly, which is crucial in a space where many of the current frameworks for product development are lagging (Thiers & Harned, 2024).

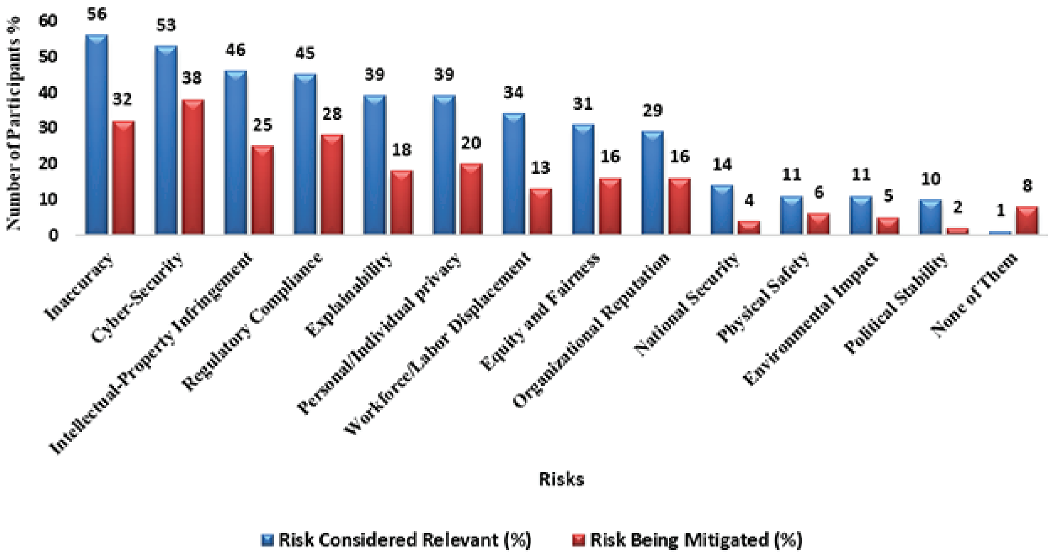

Figure 1. Generative AI-related risks that organizations consider relevant and are working to mitigate. Source: Chui et al., 2023

In a recent survey, as shown in Figure (1), published by McKinsey & Company, involving 1,684 participants from organizations, a significant gap was found regarding the preparedness of companies for risks associated with generative AI tools. This survey carried out from April 11 - 21, 2023, explains the amount of effort required to ensure safety for key risks, which include cybersecurity dissatisfactions, regulatory compliance issues, and inaccuracies. The percentages in the figure do not total 100 percent because the participants could select multiple risks, either relevant or currently addressed when managing them. The extensive nature of AI-related threats demonstrates their multi-faceted characteristics since many of these threats exist without proper solutions, thus exposing most of the industry to unprepared risk (Digital Insurer, 2023).

Inconsistency is the leading cited risk in generative AI, but only 32% of businesses prevent this risk. These risks take form in autonomous maritime operations, such as undependable decision-making in maneuverings, navigational defects, and potential safety issues. Moreover, cyber threats, which were reported by 38% of respondents, are particularly pertinent in the maritime transport and technology sector since AI systems' vulnerabilities can lead to disruptions in operations or compromise sensitive data. These findings may necessitate implementing a systematic risk management strategy as per ISO 42001:2023 guidelines to mitigate effectively technical and organizational risks. Maritime organizations can improve their readiness for these hazards by incorporating continuous improvement mechanisms like the PDCA cycle, which will result in safer and more dependable AI-led operations (Chui et al., 2023). This research would establish the basis for the secure and effective implementation of autonomous vessels and promote innovation in maritime operations.

METHODOLOGY

This specific research approach, as shown in Figure (2), is a thorough investigation of the deployment of AIMS in maritime autonomous operations. The research is structured concerning the ISO 42001:2023 framework and could focus on selecting and implementing 10 specific controls, out of 39 in Annex A, that relate to key aspects of AI governance, risk management, and operational effectiveness. The study consists principally of a documentary analysis of the ISO 42001:2023 standard, along with a survey of relevant academic literature, industry reports, and scenarios of case studies within the maritime domain. Using this approach ensures both theoretical and practical aspects of implementing AI systems in autonomous maritime operations.

The research also identifies risks, including cybersecurity vulnerabilities and accuracy and compliance deficiencies, and links them to the selected controls. Integrated Case Study Scenario During the requirements course for ISO 42001:2023 conducted by DNV at AASTMT from 24th-27th of December 2024. Twenty-six experts (including the author) evaluated the implementation of selected controls in the context of autonomous AI maritime operations. The case studies were created to explore scenarios in which AI systems are adopted for management-critical maritime functions, operational management, decision engineering, and navigational duties.

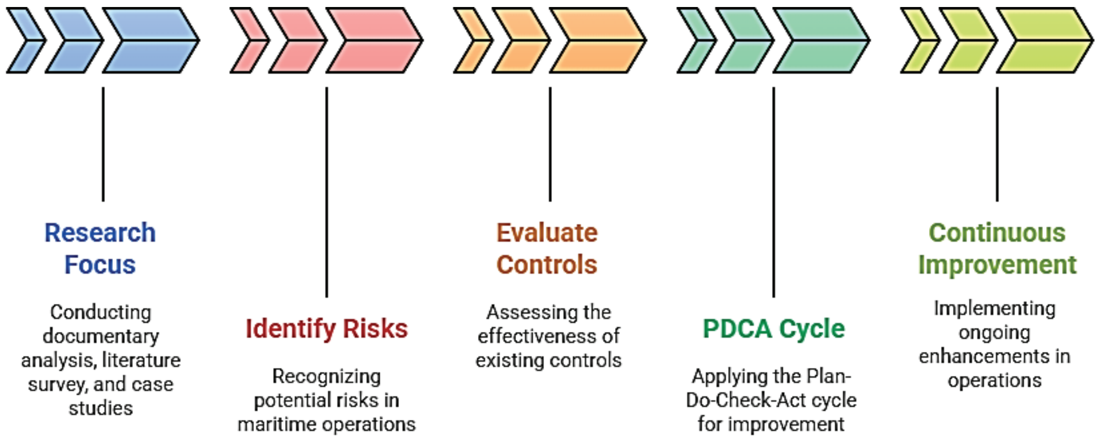

Figure 2. Implementing ISO 42001:2023 in Autonomous Maritime Operations

Also, an established framework, the PDCA cycle, was used to structure the evaluation process and create a structured approach for continuous improvement regarding the implementation of AI systems. PDCA cycle, in turn, established a clear pattern for designing, implementing, measuring, and improving AI systems. Such analysis diligently addressed operational issues, like navigation hazards and adherence to regulatory norms. It provides an analytical overview of existing AI management practices that the maritime industry is taking up to measure controls of ISO 42001:2023. This study investigates the utility of these behaviors in risk management and performance enhancement while staying within the confines of regulatory compliance. This also serves to thoroughly study the research objectives, enthusing sound contributions for the deployment and enhancement of AIMS in the marine transport sector.

This compilation of studies affords a systematic investigation of the adoption status of AIMS for the implementation of autonomous maritime operations. Aligning with the ISO 42001:2023 framework, the research is structured around the selection and implementation of 10 specific controls (out of a total of 39) within Annex A, focusing on critical facets of AI governance, risk management, and operational effectiveness.

ISO 42001:2023 AIMS STRUCTURE OVERVIEW

ISO and the International Electrotechnical Commission (IEC) constitute a specialized framework for global standardization. National organizations that are members of ISO or IEC engage in the formulation of International Standards via technical committees formed by the respective organization to address specific areas of technical activity. ISO and IEC technical committees cooperate in areas of shared interest. Various international organizations, both governmental and non-governmental, collaborate with ISO and IEC in this endeavor (ISO/IEC 27001:2022).

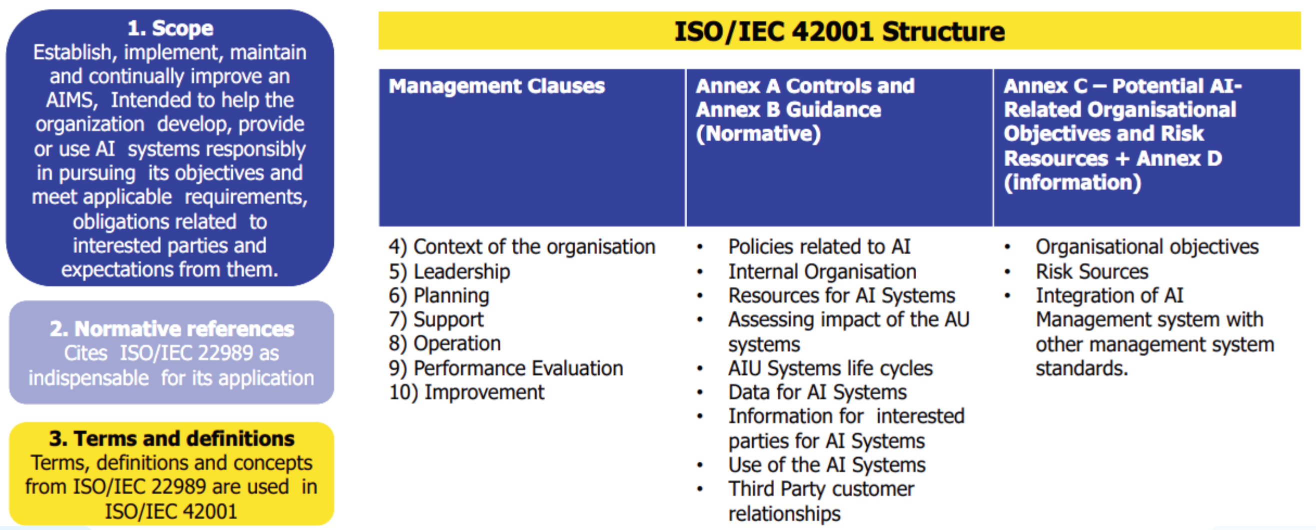

Figure 3. ISO 42001 structure

ISO 42001, as shown in Figure (3), is the inaugural ISO standard for AIMS. It offers a scalable framework for organizations engaged in the development and/ or utilization of AI. Similar to other ISO Management Systems. The standards are adaptable to the swiftly changing expectations regarding AI governance across all sectors, including maritime transport. The standard offers a framework for the AIMS compliance evaluation, necessitating that organizations exhibit their comprehension of the contexts in which they implement AI technology. This entails identifying the impacted stakeholders and evaluating the technology's risks and potential consequences. The standard mandates a clear delineation of the organizational structure for design decision-making, accountability assignment, operationalization of AI implementation, local effectiveness evaluation, and deployment monitoring (ISO/IEC, 2023).

AI RISKS IN AUTONOMOUS MARITIME OPERATIONS

To avoid risks and ensure that AI integration into self-governing vessels is safe and effective, several moves need to be taken. A major concern relates to potential internal system failures, particularly due to the lack of backup or redundancy in autonomous systems operating within such environments. The Risk Analysis for Maritime Autonomous and Intelligent System (RA4MAIS) approach handles this by targeting risk reduction from the design stage, which makes the systems more resilient (Lee & Lee, 2024).

On another note, there is complexity in human-AI interaction that can cause accidents. This becomes even more important as crew members shift into supervisory roles where they may over-rely on AI or not trust it enough (Khan et al., 2023). Network-based Human-Autonomy Risk Management System (Net-HARMS), among other methods, analyzes specific tasks as well as general risks for identifying potential failure points when autonomous operations are involved (Koimtzoglou et al., 2024). It becomes difficult to conduct traditional risk assessments, especially with highly autonomous systems, because there is little real-world data or precedents available. That's where newer approaches, such as simulations and digital twins, become useful here. This is especially applicable in uncertain situations that may arise at any given time. (Menges & Rasheed, 2024). Furthermore, environmental circumstances like bad weather or rough seas can add to operational risks; hence, AI must have flexible systems that can be adaptable during operation.

Cybersecurity is something that has become a growing concern. Hackers are now targeting autonomous systems with the aim of interfering with their navigation, communication, and propulsion systems (Bondarev et al., 2024). As the emphasis on digitalization increases within autonomous maritime operations, the threat of cyberattacks capable of stopping activities or endangering safety becomes more important. As such, there is an effort to create more secure protocols consistent with international standards (Koo et al., 2024). Efforts to incorporate ISO 42001 standards are helping bridge the gap in AI governance through the promotion of transparency, accountability, and adoption, respectively, all of which are essential for the maritime sector.

INTEGRATING AIMS INTO AUTONOMOUS MARITIME OPERATIONS

The use of AI in the maritime industry has resulted in substantial enhancements in seamanship capabilities, safety levels, and eco-friendliness, which further drive the growth of the maritime business. AI-aided ship management can be readily seen in its applications, such as routing optimization, equipment predictive maintenance, and decision support capabilities, which are important for the evolution of maritime automatization (Joshva et al., 2024). The coming MASS Code developed by the International Maritime Organization indicates that safeguarding AI-integrated systems is critical, and adequate risk management solutions such as RA4MAIS are justified on the basis of the anticipated triad of risks stemming from AI to be performed and from AI's reliability and safety (Lee & Lee, 2024). In addition, AI shifts industries from polluting sources of energy to clean sources by managing emissions and optimizing energy utilization, which aids in achieving the environmental strategy of any sector. (Durlik et al., 2024).

AI and machine learning tools form predictive maintenance, which boosts fault detection and maintenance planning, which is critical for autonomous vessels (Simion et al., 2024). Also, AI-based intrusion detection systems and network automation are important for mitigating cybersecurity threats, particularly if operated in extreme external conditions such as those required of autonomous ships (Ibokette et al., 2024). The effective introduction of ISO 42001 in the autonomous maritime domain will envisage measures like risk mitigation, adaptable policies like sustainability measures, predictive maintenance, and cybersecurity frameworks, along with facilitating cooperation between marine and technology sectors to drive innovation and make sure new legislative measures are adopted.

MRT
ISSN 2812-5622
http://dx.doi.org/10.21622/MRT.2025.04.1.1253

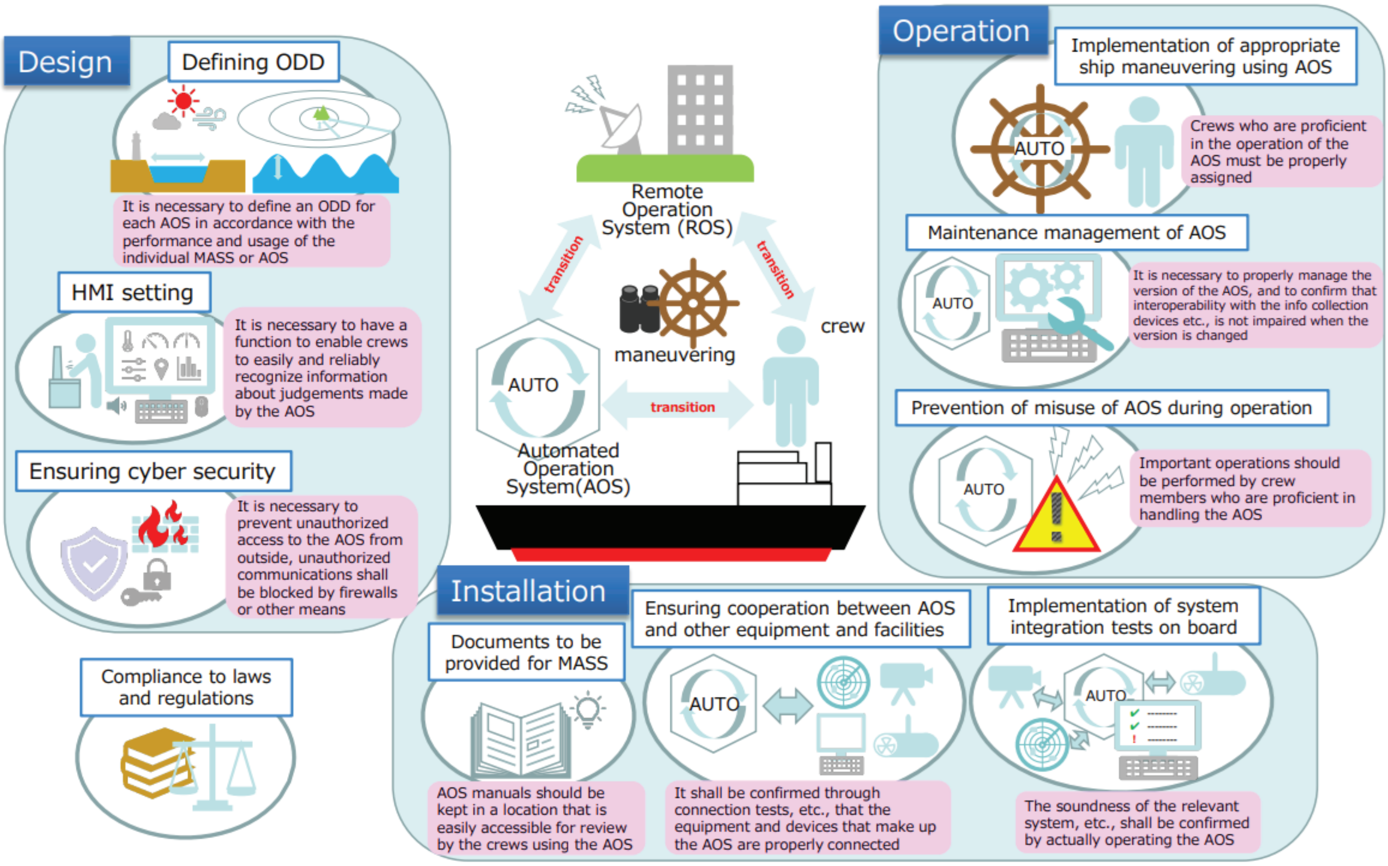

Figure 4. Key considerations for AOS in maritime operations

The ISO 42001 AI management systems are beneficial for the safety, reliability, and effectiveness of Automated Operation Systems (AOS) throughout their lifespan when integrated into autonomous maritime activities, as seen in Figure (4). Concerning codes and standards in ISO 42001, which are sorted into comprehensive definitions, parameters are required for AOS to ensure boundaries are agreed on during the designing phase. While remaining human-machine interfaces, HMIs are designed for optimal transparency and explainability in the final decision of AI. The use of firewalls and secure communication systems prohibits the unauthorized access of AOS, which complies with ISO standards. In the installation stage, all systems and interfaces are thoroughly documented and validated with system integration tests, making sure that all meet technical compliance and legal requirements. Similarly, during operation, it is sought to assign employees who are skilled in the effective management and functionality of an AOS to prevent misuse and perform regular system updates as recommended by ISO 42001 standards. Using the other existing layers, the comprehensive framework creates a uniform approach to the effective management of the risks of AI operations within the structure of the maritime sector.

Figure (4) in this work shows how ISO 42001 AI management system integration into autonomous maritime operations improves the safety, reliability, and efficiency of AOS during their lifecycle. During the design stage, the Operational Design Domain (ODD) is established in accordance with ISO 42001 that clearly defines performance boundaries and usage of AOS, while Human-Machine Interfaces (HMIs) are fine-tuned to provide AI explanations and enhance visual transparency. The installation phase includes protection from unauthorized access using firewalls as well as secure communication channels as required by ISO. The system needs to be fully integrated, tested, and documented by the system so that it interfaces with other systems onboard in accordance with regulatory requirements and technical specifications. Besides, the AOS maintenance responsibility should be assigned to some designated personnel according to this standard; these designated personnel should prevent misuse of AOS and keep it up to date (Vries et al., 2022). This integrative approach encourages a risk-based approach for AI-related activities across the maritime transport sector, always ensuring workplace safety alongside operational excellence in service delivery quality.

STRATEGIC PLANNING FOR AI RISK MANAGEMENT

The first step in strategic planning of autonomous maritime operations is the identification and mitigation of risk and opportunity for AI systems. ISO 42001 clause 6 requires a systematic evaluation of the internal and external issues that affect an organization's objectives (ISO/IEC, 2023). Nature and nurture – Environmental variability, operational failures, cyber threats, as well as innovation, efficiency, and sustainability, to name but a few, maritime organizations need to identify risks and opportunities through a comprehensive risk assessment process. Simulation-based assessments and a digital twin are tools that act as key means of identification of such risks and opportunities and help organizations mitigate the potential impact of risks on their operations whilst optimizing outcomes (Koimtzoglou et al., 2024).

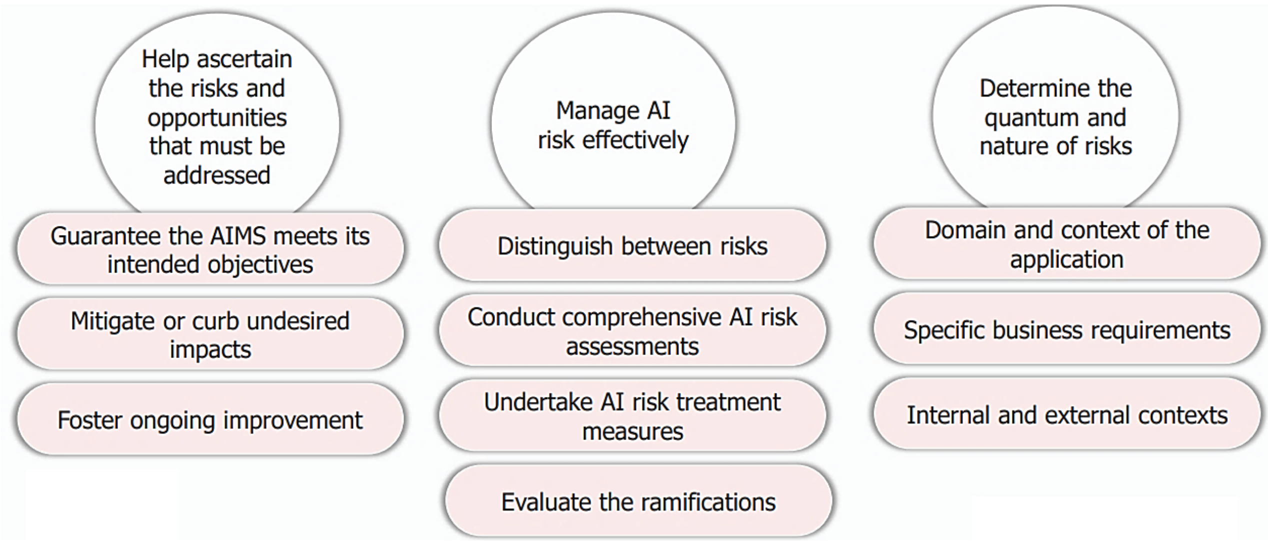

Figure 5. AI Risk Management Framework

Figure (5) shows that the management of risks arising from AI activities is central to ISO 42001's strategic planning framework. Discerning and distinguishing types of risks, assessing their magnitude, and instituting specific controls are important for organizations (ISO/IEC, 2023). For instance, predictive maintenance systems and route optimization systems are some of the solutions that can be employed in addressing challenges like cyber security risks as well as non-compliance with regulations (Joshva et al., 2024). Not only do these practices ensure that functional alignment exists between AI management systems toward organizational objectives, but they also prevent any negative effects. Organizations can develop accountability, safety, and reliability in their respective autonomous cases if they have strong risk management processes.

ANALYSIS OF SELECTED CONTROLS (CASE STUDY)

In this scenario, 10 out of 39 commands mobilized in Annex A of ISO 42001:2023 are elected by professionals during AASTMT course attendance for use in autonomous maritime operations. These controls were selected in a way that meets the purposes of the most important risks and opportunities within compliance with the standards' requirements. The selected controls are assessed based on their categorization, relevance to maritime operations, and selection criteria codes, as may be observed in Table (1).

Table 1: Selected controls and criteria for Autonomous Maritime Operations

Categorization Code	Description
DIE (Data Integrity and Ethics)	Ensuring data accuracy, reliability, and ethical sourcing for trustworthy AI systems.
TAA (Transparency and Accountability Assurance)	Promoting transparency and establishing accountability in AI governance.
HIP (Human Interaction and Participation)	Emphasizing human oversight and involvement in AI systems.
RMA (Risk Management Assessment)	Systematically identifying, analyzing, and addressing AI-related risks.

PDD (Policy Development and Documentation)	Developing and maintaining policies to govern AI systems effectively.
ETE (End-to-End Testing and Evaluation)	Ensuring rigorous testing and evaluation throughout the AI system lifecycle.
CRM (Compliance and Regulatory Management)	Ensuring adherence to legal, regulatory, and industry standards.

Table (2) below presents an overview of various controls excerpted from ISO 42001:2023 Annex A to be used in autonomous maritime operations. This selection among the 39 available ones demonstrates a strategic approach to responding to major risks and opportunities inherent in running AI systems.

Table 2: Analysis of 10 selected controls for Autonomous Maritime Operations

ISO 42001:2023 Controls	Sec.	Control	Current Control	Selected Controls and Reasons for Selection						
				DIE	TAA	HIP	RMA	PDD	ETE	CRM
Policies Related to AI	B.2.2	AI Policy	Y	X	X	X			X	
	B.2.3	Alignment with other Organizational Policies	Y	X		X				
	B.2.4	Review of the AI Policy	Y	X		X				
Internal Organization	B.3.2	AI Roles and Responsibilities	Y	X	X	X				X
	B.3.3	Reporting of Concerns	Y		X	X				X
Resources for AI Systems	B.4.2	Resource Documentation	Y	X			X			X
	B.4.3	Data Resources	Y	X	X			X		X
	B.4.4	Tooling Resources	Y				X			X
	B.4.5	System and Computing Resources	Y	X			X			X
	B.4.6	Human Resources	Y						X	X

THE PDCA APPROACH IN AUTONOMOUS MARITIME AI OPERATIONS

The PDCA approach, with its cyclic nature, is best suited for continuous improvement and matches the life cycle of AIMS well in autonomous shipping operations. This one is very appropriate for these procedures since it ensures that AI system implementation follows a continuous improvement process that covers the lifecycle of AI systems to guarantee governance, accountability, and operational excellence (Xu et al., 2023). Furthermore, as the agile PDCA offers an integral structure to orient multiple human teams in academia (engineers, data scientists, maritime operation managers) linked to a common goal, it is flexible and adaptable to the complex maritime domain (Ouyang & Cheng, 2019). The four stages of PDCA, as shown in Figure (6) outlined below, are aligned with the key objectives in implementing AIMS in autonomous maritime operations and the processes for achieving these objectives.

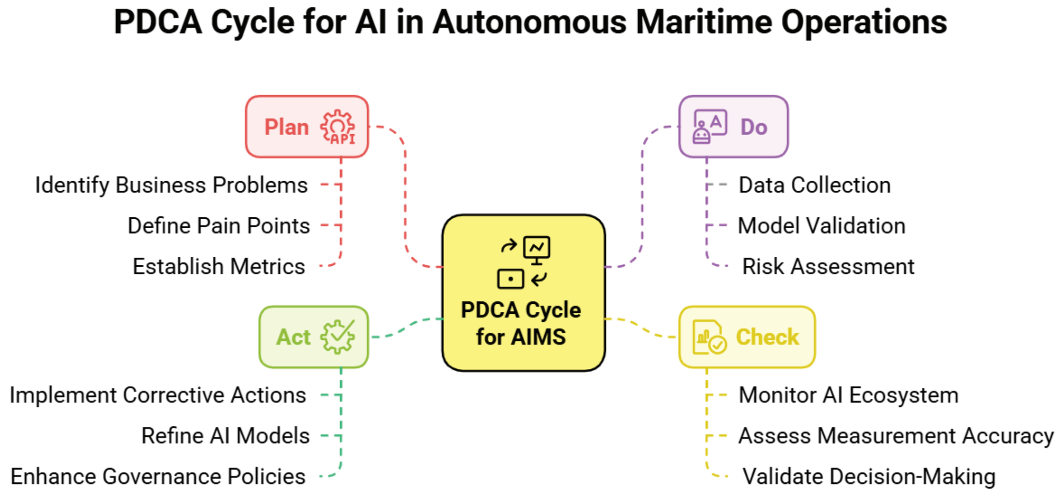

Figure 6. PDCA approach to improving the AI Maritime Autonomous Operation

Plan: Establishing a Clear Roadmap for Improvement

The first stage, **"Plan,"** involves defining the business problem and setting clear objectives for AI improvement projects. In the maritime context, this includes engaging technical and operational teams to define the challenges associated with autonomous vessels, such as safety risks, navigation inefficiencies, and compliance gaps. Key planning activities include:

- Align technical challenges like algorithmic performance with maritime operational objectives such as safety, environmental sustainability, and route optimization.

- Establish improvement goals for AIMS, such as reducing operational risks or enhancing system transparency.

- Identify metrics to assess the AI system's performance, such as fuel efficiency improvements or enhanced predictive maintenance capabilities.

- Determine the financial, physical (e.g., computing infrastructure), and human resources (e.g., maritime engineers and AI specialists) required to implement improvements.

Do: Implementation and Execution

The **"Do"** phase focuses on executing the planned actions to improve the AIMS. For autonomous maritime operations, this includes:

- Managing maritime-specific data, such as weather patterns, vessel performance, and navigational data.

- Monitoring how the AI model performs against its intended functions, such as real-time decision-making in route optimization or collision avoidance.

- Assessing the extent to which identified risks, such as cybersecurity threats or algorithmic bias, align with real-world performance.

- Ensuring the AI model achieves its intended objectives, such as reducing downtime through predictive maintenance or improving fuel efficiency.

Check: Verification and Monitoring

The **"Check"** phase ensures that the AIMS operates as intended by verifying both governance and technical dimensions. In the maritime context, this involves two key components:

- Evaluate whether the AIMS governance mechanisms, such as AI policies, risk management processes, and compliance measures, are functioning effectively. Questions include:
    - *Is the AI policy updated and aligned with maritime regulations?*
    - *Are the KPIs and metrics for assessing AIMS alignment producing reliable results?*

- Analyze the algorithm's behavior to ensure technical robustness. Questions include:
    - *Is the trained AI model achieving the accuracy and reliability metrics identified during the planning phase?*

- *Are there any issues in algorithm performance, such as navigation errors or inefficiencies, that require action?*

Act: Continuous Feedback and Improvement

The final stage, **"Act,"** involves taking corrective and improvement actions based on the insights from the "Check" phase. For maritime operations, this includes:

- Addressing gaps in governance, such as updating risk management policies or improving communication channels between maritime and AI teams.

- Refining the AI model to improve its accuracy and efficiency, such as optimizing route planning algorithms or enhancing the system's ability to adapt to dynamic environmental conditions.

- Creating a continuous feedback mechanism to ensure that lessons learned from system performance and governance are integrated into future iterations of the AIMS.

DISCUSSION AND FINDING

The review of the ISO 42001:2023 controls highlights the role each control has in addressing the issues that encompass autonomous maritime operations. While attending to policies, organizational arrangements, and resource management, selected controls promote governance, operational effectiveness, and compliance in the organization. In this regard, the structured procedure ensures safe and ethical deployment of AI however, it instills the need to not only be transparent and reliable but also adhere to standardization practices. This paper will analyze each control individually demonstrating the pragmatism of its implementations.

Policies Related to AI

In this category, a basis for preventing the effective governance of AI systems is constructed. For example, ***B.2.2*** AI Policy, under DIE, TAA, HIP, and CRM, is selected to make sure the policy framework behind the use of AI is ethical, transparent, and accountable. An AI policy helps make maritime operations clearer relationally through its provision of clarity in regard to governance and makes sure systems are being managed responsibly and in line with regulatory requirements. The relative DIE chosen for ***B.2.3***: Alignment with Organizational Policies also aligns with the integration of AI-specific policies with broader organizational goals so as to maintain coherence across governance. ***B.2.4*** DIE and HIP marks also review the AI Policy and demonstrate the importance of the regular reviewing of AI policies, in line with the evolution of the challenges, involving effective human oversight in maritime operations.

Internal Organization

It is important for managing AI systems to have clear roles and mechanisms for accountability. DIE, TAA, HIP, and CRM select roles for accountability and transparency under the ***B.3.2*** AI Roles and Responsibilities as selected roles. This control is an important coordination tool in maritime operations for such critical situations where system malfunction or cyber threat occurs. In addition, TAA, HIP, and CRM support ***B.3.3***, AI Reporting of Concerns, which creates channels for employees to report problems associated with AI. To enable real-time monitoring and continuous safe deployment of AI systems in maritime environments, proactive reporting is necessary for identifying and resolving potential risks in such operations.

Resources for AI Systems

In the AI-driven maritime systems protocol, proper resource management is vital for guaranteed operation and compliance. DIE, RMA, and CRM ***B.4.2*** Resource Documentation: Make certain that all the resources are documented well for regulatory audits and can support operation continuity. Like this, ***B.4.3*** Data Resources, selected under DIE, TAA, and CRM, is concerned with engaging with the best data critical for navigation, decision-making, and predictive analysis in maritime operations. Further, ***B.4.4*** Tooling Resources (selected with RMA and CRM) provides that appropriate tools are available to lower risks and augment the robustness of AI systems. In that sense, ***B.4.5*** System and Computing Resources, chosen in DIE, RMA, and CRM, indicate the importance of having available computational infrastructure in real time to process data in the dynamic marine environment. Last, ***B.4.6*** Human Resources listed under ETE and CRM stresses the need for professionally skilled personnel responsible for AI system overseeing, monitoring, and advancement in order to guarantee both operational safety and operation effectiveness.

The preservation of AI systems is self-explanatory; however, HIP, RMA, PDD, and ETE emphasize human interaction, capture risk assessment, policy development, and system testing. The utilization of 10 out of the 39 controls provided by ISO 42001 Annex A helps create a solid foundation that ensures transparency and dependability aligned with Marine Regulations, which subsequently helps with the secure and efficient application of AI within the maritime transport and technology sector.

CONCLUSION

The rapid advancement of AI in the maritime transport sector, particularly through autonomous ship operations, introduces significant challenges regarding AI risk management. Without proper frameworks, these challenges could compromise trust, transparency, and safety in an industry that already operates under high-stakes conditions. This study explored the implementation of ISO 42001:2023 as a dedicated AI management standard and demonstrated its effectiveness in addressing the unique risks and governance issues associated with integrating AI into MASS. Through the application of 10 critical controls from Annex A and the PDCA model, ISO 42001 was shown to provide a proactive and adaptive framework tailored to AI's dynamic nature.

According to the research, ISO 42001 meets the key gap left by earlier management standards in terms of AI-specific advice on issues such as transparency, human oversight, traceability, and risk management. Compared to ISO 9001 or ISO 27001, it is closer to what shipping companies using AI in the context of autonomous systems may need. Significant benefits to operational availability, as well as ethical alignment, continuous improvement, and regulatory preparedness in the increasingly complex maritime environment, are identified by ISO 42001. The safe evolution of autonomous shipping relies on developing robust AI management systems, and one such system is ISO 42001. Since AI decisions are increasingly influencing safety-critical scenarios, it is necessary for organizations to be ready to have accountability, mitigate the percentage of failures, and foster stakeholder trust.

In an era where autonomous maritime operations are reshaping the maritime industry, embracing AI governance standards is no longer optional. ISO 42001 sets the foundation for a safer, smarter, and more sustainable maritime future. Continued collaboration between regulators, technologists, and maritime stakeholders will be crucial in refining and expanding these systems. Future research should investigate how ISO 42001 can be harmonized with IMO regulations and how it performs across different levels of vessel autonomy, helping to future-proof the maritime industry.

RECOMMENDATION

- Foster community toward AI experts, marine structural engineers, and regulatory agents to promote holistic management of AI systems

- It is recommended that these ISO 42001 controls be incorporated into maritime organizations' management processes to manage AI-specific risks, strengthen governance, and align themselves with the international regulatory regime.

- Use the PDCA approach to iteratively track, assess, and enhance AI systems to ensure they stay consistent with organizational goals and operational needs.

- Support personnel at all levels to understand the requirements of ISO 42001:2023 and the operational implications of AI systems, and to lean into a culture of ethical AI use and risk awareness.

- Investigate further the application of ISO 42001:2023, which controls various maritime sectors and harmonization with other standards/frameworks.

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