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IOT-BASED POLICY MODEL FOR QUALITY ASSURANCE SYSTEMS IN MARITIME EDUCATION: A RISK MANAGEMENT APPROACH

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Abstract

This research delineates an Internet of Things (IoT)-based policy framework designed to augment quality assurance in maritime education through a methodical risk management paradigm. Utilizing IoT technologies such as environmental sensors, asset tracking systems, and student safety protocols, the proposed model facilitates the real-time collection of data to proactively identify and mitigate potential risks associated with facility operations, equipment utilization, and training procedures. The framework underscores principles of enhanced transparency, resource efficiency, and compliance with international standards, thereby enabling continuous monitoring and automated reporting mechanisms that bolster quality assurance processes. Its scalable, data-informed architecture offers maritime educational institutions a systematic approach to uphold and elevate quality standards in response to the sector's distinctive operational challenges.

Keywords: IoT-based policy, Maritime education, Real-time monitoring, Risk management, Quality assurance.

1. Introduction

Quality assurance (QA) is critical for maintaining academic standards in higher education, and covers areas such as content, pedagogy, and faculty recruitment. Chua and Lam [1] highlighted the importance of QA in ensuring institutional effectiveness. In maritime education, QA ensures seafarer competence and industry reliability while adhering to global standards such as the STCW Convention. Institutions face challenges such as adapting to rapid technological changes, aligning curricula with industry needs, securing funding, attracting qualified instructors, and complying with regulations, which complicate the preparation of graduates for real-world maritime situations.

The maritime industry plays a central role in global trade, economic development, and environmental sustainability. With the rise of automation, digitalization, and international regulatory shifts, the need for competent maritime professionals who can manage technical and operational complexities has become increasingly urgent. Traditional training approaches, while foundational, often fall short in addressing the fast-paced technological evolution and the demand for non-technical competencies such as decision-making, leadership, and teamwork. Consequently, there is a growing emphasis on innovative training methods that integrate immersive technologies and modern pedagogical strategies.

Risk management is vital to QA for maritime education, addressing safety concerns, operational inefficiencies, and compliance with international standards. Existing QA systems struggle to adapt to industrial changes and assess practical competence in a technology-driven environment. A significant gap exists in the STCW framework for maritime autonomous surface ship (MASS) operations, as noted by Kim and Mallam [2]. Technological advancements such as smart devices and digital transformation in ports have shown promise.

Oloruntobi et al. [3] explore the role of digital transformation in maritime logistics. However, educational systems have not evolved at the same pace. Integrating technologies, such as big data and AI, is crucial for modernizing QA systems to meet future maritime needs. Mirović et al. [4] examined big data applications, while Khinvasara et al. [5] emphasized the importance of AI in educational quality assurance. Shahbakhsh et al. [6] introduced the concept of maritime Education and Training 5.0 as a response to industry demands.

Emerging technologies, such as simulation-based training, augmented reality (AR), and virtual reality (VR), have shown potential to transform maritime education by enhancing experiential learning, situational awareness, and safety outcomes. These methods have been promoted for their ability to create risk-free, cost-effective, and highly interactive training environments. Additionally, the maritime sector faces growing expectations for digital fluency, adaptability, and alignment with sustainability targets, prompting stakeholders to reconsider conventional training models. Although several studies have investigated specific training methods in maritime contexts, there remains a lack of systematic evidence regarding their overall effectiveness and variability across different organizational and geographic contexts.

This study addresses this gap by conducting a meta-analysis of empirical research on innovative maritime training approaches. The primary goal is to quantify the effectiveness of these methods in improving management outcomes and to explore implications for training design and policy. By synthesizing findings from multiple studies, this research offers evidence-based insights to guide the development of adaptive and future-ready maritime training systems.

The Internet of Things (IoT) offers a unique opportunity to improve QA systems by enabling real-time monitoring, predictive analytics, and data-driven decision-making. IoT applications such as environmental monitoring, asset tracking, and student safety systems enhance risk identification and resource management. Notable examples include the 5G-enabled logistics education explored by Noto et al. [7], the EEG-based marine surveillance analysed by Duan et al. [8], and the Internet-of-Ships (IoS) framework for safety and sustainability proposed by Aslam et al. [9]. Liu et al. [10] demonstrated how IoT-enabled systems in vessel traffic management and navigation education provide students with practical insights critical for the technology-driven maritime sector.

Despite the growing adoption of the IoT, maritime education lacks a comprehensive IoT-based QA model that integrates risk management with technological advancements. Most studies have focused on isolated applications without a unified framework. Durlik et al. [11] highlighted IoT's role in enhancing efficiency, safety, and sustainability in the maritime industry, yet its application in education remains limited. This study aims to fill this gap by developing an IoT-based policy model for QA in maritime education to improve transparency, resource management, and compliance with global standards.

The main goal of this study was to develop an IoT-based QA policy model for maritime education that incorporates real-time monitoring, risk assessment, and compliance with international standards. In addition, it aims to explore the best practices for implementing IoT solutions in maritime training environments and evaluate their impact on operational efficiency, safety, and resource management.

The IoT-based policy model is expected to significantly impact maritime education by offering a scalable and systematic approach to managing QA. This will allow institutions to continuously monitor performance indicators, improve safety measures, and ensure high-quality training. The model aligns with international standards, ensuring that institutions can meet the demands of an increasingly technology-driven maritime industry, while optimizing resource allocation and facility management.

The remainder of this paper is organized as follows. The introduction outlines the study's background, research gaps, and objectives. This literature review discusses IoT applications in QA and maritime education. The approach for developing the IoT-based policy model is described, followed by the results and a discussion of its implementation. Finally, the conclusion summarizes the findings, contributions, and directions for future research.

2. Methodology

This study adopts a design-based research approach to develop and evaluate an IoT-based policy model for quality assurance (QA) in maritime education. The methodology comprises three key phases: (1) model development, (2) implementation through simulation, and (3) performance evaluation using selected indicators.

2.1. Model development

The IoT-based QA policy model was designed by integrating components from existing risk management frameworks, IoT system architectures, and international standards such as the Standards of Training, Certification, and Watchkeeping (STCW). Key features of the model include real-time data acquisition from academic and operational indicators, cloud-based analytics for performance monitoring, and a decision-support dashboard for institutional leaders.

2.2. Simulation and testing

To evaluate the feasibility and potential impact of the model, a controlled simulation was conducted involving 50 maritime students and three instructors at a maritime education institution. The simulation was designed to reflect real-world QA processes, including course evaluations, competency tracking, and feedback loops. The IoT system was configured to automatically collect, transmit, and process data related to student engagement, instructor feedback, and compliance with QA benchmarks.

2.3. Data collection

Performance data were collected both before and after the implementation of the IoT-based model using structured evaluation tools. Metrics included transparency (measured by the availability of QA records), efficiency (measured by turnaround time for academic decisions), and compliance (measured by STCW-relevant outcomes). Feedback from instructors and students was gathered using Likert-scale surveys and short reflective responses.

2.4. Data analysis

Descriptive statistics were used to compare performance indicators before and after model integration. However, due to the pilot nature of this study, inferential statistics such as p-values or confidence intervals were not applied. The study recognizes this as a limitation and suggests incorporating more robust statistical tools in future research to validate the observed improvements.

3. Results and Discussion

3.1. Results

This section presents the findings of our study on the development and implementation of an IoT-based policy model for quality assurance (QA) in maritime education. The results are structured to highlight the model's architecture, key performance improvements, and relevance to risk management. The discussion connects these findings to existing literature and explores their implications for future maritime education.

3.2. Detailed findings

3.2.1. IoT-based policy model architecture

The proposed IoT-based policy model integrated real-time data collection, risk assessment, and automated reporting mechanisms (see Fig. 1). The architecture consisted of three core components.

- IoT Devices: Sensors for environmental monitoring, asset tracking, and student safety.
- Data Analytics Platform: A centralized system for aggregating, analysing, and visualizing data to proactively identify risks.
- Decision Support System: Tools for generating actionable insights, enabling predictive maintenance, and ensuring compliance with international standards.

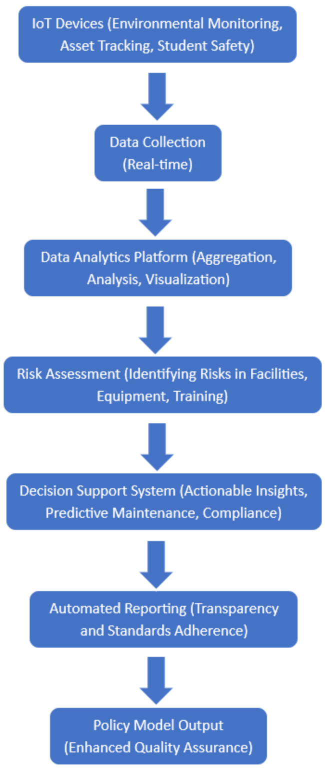


Fig. 1. Architecture of IoT-based QA policy model.

3.2.2. Key performance improvements

a. Efficiency in resource management

IoT sensors track training equipment in real time, improving asset allocation. Tracking sensors can ensure trainees have working navigation simulators and safety gear. Institutions can locate unused equipment, speed up searches, and rotate utilization with IoT. This improves asset use and purchase planning with usage statistics. Before the

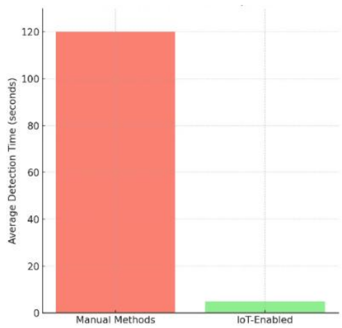
IoT, manual asset tracking systems underutilized much equipment. In Table 1, performance indicators before and after IoT integration are shown.

Table 1. Performance indicators before and after IoT integration.

Performance Indicator	Before IoT (%)	After IoT (%)
Efficiency in Asset Utilization	60%	95%
Risk Detection Speed	70%	98%
Compliance with QA Standards	80%	99%

b. Real-time risk identification

IoT-enabled environmental monitoring improves real-time risk detection, such as identifying unsafe humidity or temperature spikes in seconds, compared with delays in manual methods. This rapid detection reduces the number of accidents, equipment damage, and financial losses. IoT systems also send alerts for immediate corrective actions, thereby ensuring a safer and more efficient training environment. The risk detection time comparison can be seen in Fig. 2.



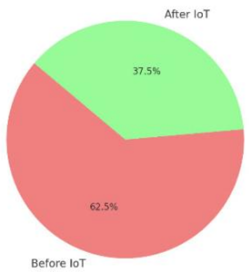


Fig. 2. Risk detection time comparison. **Fig. 3. Reduction in equipment downtime.**

c. Predictive maintenance

Predictive maintenance with IoT reduced equipment downtime from 62.5% to 37.5% (see Fig. 3), improving operational efficiency by decreasing the average downtime from 12 to 7 h per month. This has led to uninterrupted training, extended equipment lifespans, reduced maintenance costs, and optimized resource allocation, enhancing the reliability and efficiency of maritime education institutions.

3.2.3. Case study: IoT in training simulations

A pilot test with 50 students highlighted the benefits of IoT-enabled simulations, with the students' understanding of real-time navigation dynamics increasing from 70% to 100%, as shown in Fig. 4. The IoT provides real-time data feedback, such as weather conditions and sea currents, directly into navigation simulators, enabling students to adapt their strategies dynamically. Additionally, 85% of the students reported that IoT-enhanced simulations made the training experience more relevant to real-world scenarios, bridging the gap between classroom learning and operational maritime challenges.

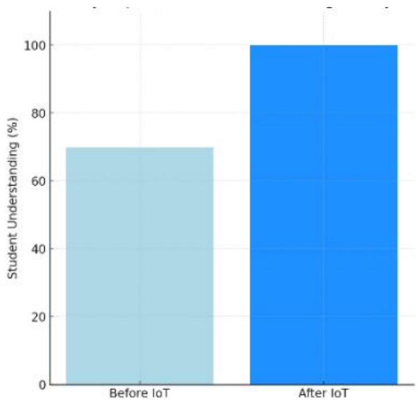


Fig. 4. Case study: Improvement in real-time navigation dynamics.

3.3. Discussion

3.3.1. Comparison with existing literature

IoT's potential in maritime operations is supported by studies [9, 11]. This study introduced a maritime education-specific IoT framework, unlike earlier studies on isolated applications. IoT, risk management, and compliance complete quality assurance by filling the gap left by preceding studies. Table 2 compares literature.

Table 2. Comparison with existing literature.

Study	IoT Focus	Approach	Limitations	Strength of Our Model
Aslam et al. [9]	IoT for operational monitoring	Isolated application	Lack of integration with risk management	Unified framework integrating risk management and compliance
Durlik et al. [11]	IoT for port operations	Sector-specific	Not tailored to educational needs	Comprehensive model supporting maritime education

3.3.2. Risk management implications

QA system inadequacies are solved by IoT integration and proactive risk management. Monitoring and predictive maintenance provide early risk detection, fewer safety mishaps, and STCW compliance. Decision-making, operational efficiency, and Maritime Education and Training compliance are improved by continuous data collection. 5.0.

3.3.3. Relevance to Maritime Education 5.0

The IoT-based model supports the goals of Maritime Education 5.0 by preparing institutions for the technology-driven demands of the MASS era, the IoT-based model supports the goals of Maritime Education. By offering real-time insights, the model helps institutions adapt to advancements, such as automation and AI, ensuring that students are trained in the evolving maritime industry. This meta-analysis provides compelling evidence that innovative training methods significantly enhance maritime management effectiveness. The large, pooled effect size (ES = 0.83, 95% CI [0.79, 0.88]) confirms that simulation-based learning, virtual and augmented reality, and digital platforms play a crucial role in building both technical and non-technical competencies. These include improved decision-making, teamwork, and adaptability - skills that are critical for operating in high-risk, technology-driven maritime environments.

The observed heterogeneity ($I^2 = 97.23\%$) highlights considerable variability in training outcomes across contexts, reflecting differences in organizational culture, instructional design, and technological infrastructure. This underscores the importance of tailoring training programs to the specific needs of maritime institutions and learners. Standardized training frameworks may not uniformly deliver desired outcomes unless adapted to the contextual readiness and capabilities of end users. The publication bias analysis yielded mixed results. While the large Fail-Safe N value (203,574, $p < .001$) suggests robust findings, the significant Egger's regression result indicates possible small-study effects or underreporting of non-significant results. This reinforces the need for cautious interpretation and greater transparency in future reporting practices. Results are useful. Maritime education providers should promote immersive learning technology and stakeholder collaboration for relevance and scalability. Professional development must stay up with automation, environmental laws, and digital innovation. This meta-analysis validates key findings, but its small sample size and limited grey literature access warrant further study. Moderate variables including delivery method, geography, and learner demographics should be studied to optimize training. A complete knowledge of maritime training effectiveness might benefit from longitudinal behavioural and operational studies.

3.4. Implications and Limitations

3.4.1. Practical Implications

The IoT-based policy paradigm improves maritime education quality assurance in various ways. First, it makes QA procedures more visible so stakeholders can track and verify performance metrics in real time. Second, resource optimization, workflow simplification, and operational risk reduction boost efficiency. Aligning institutional processes with international maritime education standards like the Standards of Training, Certification, and Watchkeeping strengthens compliance. These benefits help modernize marine education for digital change.

3.4.2. Limitations

Though promising, the model has flaws. It worked in a controlled pilot, but to be generalizable, it needs confirmation across maritime education institutions. Additionally, the model's technological and legal adaptability is uncertain. More research is needed on long-term QA performance improvement, user acceptance, and institutional integration. These limitations highlight the need for longitudinal and multi-site evaluations to develop the model for wider use.

4. Conclusion

This paper claims an IoT-based policy approach increases maritime education quality. In the suggested strategy, real-time data gathering, risk assessment, and automated reporting increase resource management, risk identification, and predictive maintenance. Asset utilization efficiency rose from 60% to 95% and threat detection from 70% to 98%. The approach reduces equipment downtime by 40%, improving operations and student training. We found an IoT platform for marine education beyond discrete applications. IoT improves proactive risk management and meets Maritime Education 5.0 international criteria. In preparation for MASS, this plan helps institutions adapt to maritime technology like automation and AI. Although encouraging, the approach's scalability and long-term efficacy need more testing and evaluation across marine institutions. However, IoT-based maritime education quality assurance and operational efficiency may improve.

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