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Effectiveness of STCW Standards in Navigating Digital Transformation Challenges in the Shipping Sector

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Abstract

The effectiveness of the global International Convention on Standards of Training, Certification and Watchkeeping (STCW) framework remains critically uncertain amidst the rapid digital transformation (AI, IoT) in the maritime industry. This study utilized a rigorous qualitative approach involving Cross-Group Comparisons among Maritime Education and Training (MET) Lecturers, Shipping Company Experts, and Experienced Seafarers (N=30) via semi-structured interviews. The findings show that the overall effectiveness is Very Good, largely attributed to proactive, company-specific training that successfully bridges immediate gaps in e-navigation and digital logbook proficiency. However, a significant Simulator-Reality Dissonance was found regarding troubleshooting Automated Ship Systems, and Regulatory Lag was confirmed in integrating practical Cybersecurity competence (rated Moderate). The research concludes that economic motivation drives localized competence, yet this fragmentation poses risks to operational consistency and increases administrative burden, challenging social sustainability. Recommendations urge the formalization of successful local Standard Operating Procedures (SOPs) into the STCW Code and targeted investment in diagnostic simulation training.

Keywords: *STCW, Digital Transformation, Maritime Competence, Cybersecurity, Seafarer Training.*

1. INTRODUCTION

The global maritime industry, often referred to as the backbone of international trade, is currently navigating an unprecedented convergence of global imperatives: decarbonization, automation, and digital transformation [1]. This triple threat disruption signals a paradigm shift from traditional seafaring to a highly technological and data-driven operational environment. Yet, while the physical infrastructure of shipping the vessels, ports, and logistics chains is rapidly evolving with the integration of Artificial Intelligence (AI), the Internet of Things (IoT), and Big Data Analytics, the human element remains subject to a global standard established decades ago: the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), first adopted in 1978 [2] This contrast between the rapid technological evolution and the relatively rigid regulatory framework creates a compelling and critical point of inquiry for the future of maritime economic and social development.

The engaging hook that draws the attention of researchers and industry practitioners lies precisely in this tension: the world's most critical industry relies on a global human competency standard, the effectiveness of which is increasingly questioned in the face of technology that was unimaginable when the standard was conceived. While the STCW Convention, particularly after the significant 2010 Manila Amendments, has successfully served as the fundamental safeguard for competence, safety, and pollution prevention for generations of seafarers, its core tenets were built upon a foundation of manual navigation, conventional propulsion, and paper-based record-keeping. Today, watchkeeping officers, like the researcher, are no longer solely engaged in manual seamanship; they are simultaneously data analysts, cybersecurity first responders, and system operators managing complex e-navigation suites and digital logbooks [3]. The shift from physical to digital risk management is profound, requiring cognitive skills related to situational awareness in automated environments rather than purely reactive, physical maneuvers. This

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transformation is not merely about using a new tool; it is a change in the fundamental nature of the job, a shift that is pivotal to the maritime economy's ability to sustain its efficiency gains.

The background information for this study is rooted in the overwhelming evidence of digital adoption across the logistics and shipping sector. On the economic front, digital transformation promises massive efficiency improvements, enabling just-in-time deliveries, optimized bunkering, and predictive maintenance, directly impacting operational costs and profitability. Studies on port operations, for instance, highlight how automation and digital systems enhance operational resilience and economic output, even during periods of global crisis [4]. However, the success of these multi-billion-dollar investments in Smart Ship Systems and shore-side integration hinges entirely on the competency of the crew operating, troubleshooting, and maintaining them. Without adequate human competence, these sophisticated systems designed to eliminate human error paradoxically introduce new vectors for critical failure, particularly in the domain of cybersecurity and data integrity.

The existing knowledge base confirms a growing competency gap within the maritime workforce. While academic literature has explored the need for Digital Literacy across various professional fields, the specific application within the highly regulated and safety-critical environment of seafaring remains under-analyzed [4]. Current STCW requirements mandate proficiency in specific equipment (like ECDIS and ARPA), but they often lack the systemic, foundational digital skills necessary for managing the holistic digital environment of a modern vessel a capability crucial for maintaining the efficiency and safety that the maritime economy demands. This is compounded by the ethical and social management challenges of crew well-being, where digital tools can increase administrative burden or blur the lines between work and rest, issues that the STCW framework, focused on minimum safe manning, must eventually address.

The central focus of this research, therefore, emerges from the critical uncertainty surrounding the efficacy of the current regulatory framework in the face of this technological wave. The core research problem is that the effectiveness of the existing STCW framework in robustly preparing seafarers for the immediate and future demands of the modern, digitally-driven operational environment remains critically uncertain, potentially jeopardizing both marine safety standards and the economic viability of shipping operations. This uncertainty manifests as a palpable skills-perception dissonance between what training institutions teach, what ship managers require, and what seafarers practically encounter at sea.

This problem statement leads directly to the central research question: What is the effectiveness of current STCW Standards in responding to the competency challenges posed by digital transformation in the shipping sector, particularly concerning the practical digital competence of watchkeeping officers? To provide an effective, critical, and comprehensive answer, the research will pursue the following specific objectives, to analyze the current adaptation mechanisms of the STCW framework, including its associated training and certification procedures, in addressing the requirements for proficiency in modern digital tools such as e-navigation systems, digital watchkeeping systems, and electronic logbooks.

To identify and critically evaluate the key factors that influence the effectiveness of STCW standards' implementation concerning the Digital Competence of Seafarers in the digital era, focusing on the friction between training curriculum and real-world ship operations (Margaretha et al., 2024). To develop a conceptual framework or set of actionable recommendations for maritime training institutions and regulatory bodies to enhance the STCW curriculum, thereby ensuring its continuous relevance to the rapidly evolving technological landscape and fostering the social sustainability of the maritime workforce.

The rationale and motivation for this research are multi-faceted, serving both academic and practical stakeholders within the maritime community. Academic Significance: The study offers significant academic contribution by moving beyond simple descriptive studies of technological adoption. It positions the STCW Standard as the primary independent variable (regulatory framework) against the dependent variables of Seafarer Competence and Operational Efficiency within the context of Digital Transformation. This approach facilitates the development of a novel conceptual model that can be utilized by future researchers to assess regulatory lag in other safety-critical, highly digitized industries. Furthermore, by employing a Systematic Literature Review (SLR) complemented by qualitative analysis, this research aims to identify true theoretical and empirical gaps, contributing to the establishment of a robust Maritime Digital Competency Framework. Socio-Economic Significance: From a social management and economic development perspective, the research is critical. Indonesia, as an archipelagic state, relies

heavily on a competent seafaring workforce to maintain its global trade links and national logistics. A failure to adapt STCW means that Indonesian seafarers risk becoming marginalized in a highly competitive global market due to skill deficiencies. The research findings will provide direct and actionable recommendations to enhance Seafarer Employability: By clarifying necessary digital skills, training providers can better prepare graduates for modern vessels, safeguarding the long-term career viability of the seafaring profession [6]. Improve Operational Safety: By understanding where the STCW standard fails to mitigate new digital risks (e.g., in Human-System Integration and Cybersecurity), regulatory bodies can proactively prevent casualties and economic loss related to human-technology interaction. Promote Social Sustainability: Addressing the social dimension of digital transformation such as the potential for increased stress, isolation, or administrative burden from new technology is vital. The research will provide insights into how training can be better managed to support seafarer well-being and long-term career satisfaction.

Motivation (Personal Context): The primary motivation stems directly from the researcher's practical experience as a 3rd Officer on a Kapal Niaga (Merchant Vessel). This unique professional vantage point provides an intrinsic understanding of the friction points: the strict adherence to paperwork-based STCW protocols coexisting with complex, often poorly integrated, digital systems. This lived experience necessitates a critical academic investigation to formalize and address the practical challenges faced by watchkeepers globally, transitioning from anecdotal observations to evidence-based reform proposals.

Methodology Overview: This study adopts a sequential, mixed-methods approach, beginning with a Systematic Literature Review (SLR) to map the existing landscape of STCW, digital competence, and maritime technology. The initial SLR will be followed by a focused Qualitative Field Study designed to capture the nuanced, real-world perspectives of key stakeholders. This qualitative analysis will be instrumental in achieving the research objectives by gathering primary data from the people who design, deliver, and execute the STCW mandate.

The qualitative data collection will target three strategic population groups: Maritime Education and Training (MET) Lecturers/Curriculum Developers, Shipping Company Management/Experts (Operational & HR), and Experienced Watchkeeping Seafarers (including 3rd Officers). This diverse sample ensures a comprehensive understanding of the problem from the perspective of the regulator/trainer, the employer, and the end-user. The analysis will proceed through a rigorous Thematic Analysis, categorizing data into key themes such as Competency Development Gaps and Sustainability Themes (both environmental and social). Crucially, Cross-Group Comparisons will be conducted to identify consensus or dissonance across the three groups, highlighting where training perception diverges from operational reality. Finally, a Narrative Synthesis will integrate all findings both from the initial SLR and the qualitative data to construct a cohesive, evidence-based argument that explains the current effectiveness (or ineffectiveness) of STCW in the digital age, thereby fulfilling the central aim of the research.

2. RESEARCH METHODOLOGY

This research adopts a rigorous Qualitative Approach following an initial Systematic Literature Review (SLR) to ensure that the findings are grounded in both theoretical understanding and real-world perspectives. This methodology is indispensable for studying the effectiveness of STCW standards in the digital era, as effectiveness is not merely a quantitative measure but a nuanced perception of skill relevance, organizational culture, and regulatory compliance. Qualitative inquiry allows for an in-depth exploration of the "how" and "why" behind the identified competency gaps, transporting the critical on-the-ground information from key maritime stakeholders into academic data.

The Population and Samples for the qualitative phase are strategically chosen to represent the entire STCW ecosystem, which governs training, certification, and employment, thereby ensuring maximal transferability and comprehensiveness of the data. The research specifically targets three distinct groups: first, Maritime Education and Training (MET) Lecturers and Curriculum Developers, who establish the training content; second, Shipping Company Management and Technical Experts (from Operational and Human Resources departments), who define the skill requirements for employment and witness operational performance; and third, Experienced Watchkeeping Seafarers, specifically targeting Deck Officers, including the 3rd Officer rank, who serve as the end-users of the technology and the direct recipients of the STCW-mandated training. The urgency in sampling these specific groups lies in addressing the pervasive skill-perception dissonance: the potential difference between the competence promised by a certificate (Lecturers' perspective) and the competence needed for safe, digitized watchkeeping (Company

Experts and Seafarers' perspective) [7]. By focusing on these populations, the research can accurately chart where the STCW framework is effective and where it lags in preparing the digital seafarer.

The primary Research Instrument employed is a Semi-Structured In-Depth Interview Protocol, designed to elicit rich, explanatory narratives concerning the implementation of STCW and the integration of digital competence. The Independent Variable in this qualitative structure is the Digital Transformation/Technology Adoption Rate (measured by the complexity of systems like e-navigation and automated ship systems encountered). The Dependent Variable is the Effectiveness of STCW Implementation (measured by the perceived relevance of training to modern challenges). The interview protocol develops Indicators for these variables, such as: curriculum relevance to cybersecurity principles, proficiency in managing digital logbook integrity, and organizational support for continuous professional development. Supporting instruments include document analysis of company safety management systems and training manuals. Data collection will adhere to strict ethical guidelines, beginning with informed consent and ensuring anonymity. Data saturation will serve as the critical stopping criterion, confirming that no new themes or perspectives are emerging across the samples [8].

The Collection of Data process is designed to be critically reflective. The interview steps move from broad, contextual questions about the impact of digital transformation on the maritime economy to specific, critical questions about the STCW framework. For instance, questions will challenge the seafarers' perceived competency in handling system failures in automated watchkeeping systems, while experts will be asked about the economic consequences of skill deficiencies. This critical step ensures that the data collected transcends anecdotal evidence, rigorously linking the study's variables and indicators to the lived experiences and professional judgments of the respondents, thereby validating the urgency of the research inquiry.

Data Analysis will follow a systematic and multi-layered procedure, commencing with transcription and familiarization. The initial stage involves Thematic Analysis, where all data are coded and categorized into overarching themes. Two primary themes will dominate: Competency Development (addressing the type, quality, and delivery of training for digital skills) and Sustainability (examining the longterm impact on the maritime workforce, including social management, career progression, and environmental compliance via technology). Following this, a crucial step involves Cross-Group Comparisons, where the coded data from the three distinct populations (Lecturers, Experts, Seafarers) are systematically compared and contrasted. This comparative analysis is vital for identifying areas of agreement (consensus on critical skill gaps) and dissonance (disagreement on solutions or perceived effectiveness), providing robust triangulation [9]. Finally, a Narrative Synthesis will be constructed, developing a cohesive, academic, and critical narrative that translates the individual voices and categorized data into a comprehensive explanation of the STCW framework's effectiveness. This synthesis will not merely present the findings but will analyze the perspectives of the people interviewed, connecting their experiences to broader implications for maritime safety, economic development, and social management policy in the digital era.

3. RESULT AND DISCUSSION

This section presents the findings from the qualitative phase of the research, which followed the initial Systematic Literature Review (SLR). The analysis focuses on data collected from three strategic population groups Maritime Education and Training (MET) Lecturers, Shipping Company Experts (Operational/HR), and Experienced Watchkeeping Seafarer to critically evaluate the effectiveness of the STCW framework in the context of digital transformation. Contrary to the common assumption of widespread regulatory failure, the aggregated results demonstrate overall very good effectiveness and well-efficiency in adapting to the immediate challenges of digital adoption within the study's scope. The effectiveness is particularly high where local, agile adaptations have compensated for the slower pace of global regulatory reform.

3.1. Data Presentation : The Effectiveness Scorecard

The core of the findings is synthesized in the Implementation Effectiveness Scorecard (Table 1), which quantifies the qualitative data collected via the Semi-Structured In-Depth Interview Protocol. The scoring reflects the consensus derived from the Cross-Group Comparisons among the three stakeholder groups, with **"Very Good"** signifying high perceived relevance of STCW-mandated training (the Dependent Variable) to the demands of the Digital Transformation (the Independent Variable).

Tabel 1. Evectiveness Scorecard

Indicator	Group Consensus (N=30)	Analysis and Interpretation	Score
Curriculum Relevance to e-Navigation Proficiency	MET Lecturers, Company Experts, and Seafarers reported high satisfaction with existing ECDIS/ARPA modules, noting the early integration of these systems into STCW standards provided a strong foundation[10]	High effectiveness due to pre-emptive regulatory action in the 2010 Manila Amendments, creating a robust, established module for core electronic navigation competence.	Very Good
Proficiency in Managing Digital Logbook Integrity	Near-unanimous agreement that seafarers are competent in using digital logbooks, though moderate concern remains regarding data integrity protocols and the ability to detect tampering (Cybersecurity-lite).	High efficiency driven by company-specific Standard Operating Procedures (SOPs) rather than explicit STCW mandates; competence is primarily procedural rather than systemic.	Very Good
		‘Abstrak’	
Training Adaptability to Automated Ship Systems (ASS)	Mixed results, with high scores from MET Lecturers (due to simulator use) but lower confidence from Seafarers regarding troubleshooting ASS failures in real-time.	Effectiveness is perceived as strong for system operation, but weaker in diagnostic and non-routine problem-solving, indicating a need for more advanced, scenario-based simulation training.	Good
Organizational Support for Continuous Digital Professional Development	Company Experts reported high investment, while Seafarers reported moderate accessibility, citing time and resource constraints during watches.	High motivation/investment from the employer side (economic motivation) but implementation friction on the social management side (crew well-being/workload).	Very Good
Cybersecurity Principles Integration	Low consensus and moderate satisfaction across all groups. Currently perceived as an add-on course rather than a core competency integrated into watchkeeping routines.	Low effectiveness, confirming a major regulatory lag. Competence is primarily theoretical, not embedded in practical risk management (IMO, 2022).	Moderate
Overall Effectiveness of STCW in Digital Readiness	Consensus Score: 4.2/5.0	The high overall score suggests that the localized, industry-driven responses have successfully bridged many immediate digital gaps, compensating for the global STCW framework’s incremental pace.	Verry Good

3.2. Thematic Analysis: Drivers of Success and Failure

The Thematic Analysis identified the qualitative reasons behind the high (Very Good) and moderate (Moderate) scores, categorized under Competency Development and Sustainability. The analysis of the perspectives (Lecturers, Experts, Seafarers) provides the necessary critical depth.

Tabel 2. Drivers of Success and Failure

Indicator	Sub-Theme	Analysis and Interpretation	Score
Competency Development	Proactive Local Adaptation	Company Experts and Seafarers strongly agreed that the high scores in e-navigation and digital logbook were largely due to company-specific training and SOPs developed rapidly by shipping firms in response to economic demands for efficiency.	Consensus:Localmarket mechan outpaced global regulation. demonstrates high agility by industry.
Competency Development	Simulator-Reality Disconnect	MET Lecturers lauded the use of simulators for Automated Ship Systems (ASS). However, Seafarers indicated a critical dissonance (Palinkas et al., 2015) between the controlled simulator environment and the stress of troubleshooting system failures at sea, particularly regarding sensor data anomalies—an issue highlighted in intelligent ship risk assessments [11]	Dissonance: Training perception (Good) clashes with operational reality (Moderate to Low for troubleshooting).
Sustainability	Economic Efficiency vs. Social Manageme nt	Company Experts prioritized the economic returns of digital systems (e.g., predictive maintenance). Seafarers acknowledged the efficiency but highlighted negative social management impacts, such as increased administrative burden and blurry work-rest boundaries due to continuous digital communication and reporting.	Dissonance: High economic efficiency (Kim et al., 2021) is achieved at the expense of social sustainability (seafarer well-being).

3.3. Thematic Analysis: Drivers of Success and Failure

The central research question asked: What is the effectiveness of current STCW Standards in responding to the competency challenges posed by digital transformation? The findings, with an overall effectiveness score of "Very Good," partially contradict the widely held critical assumption that the regulatory framework has failed entirely.

The high scores demonstrate that the STCW framework, through its inherent flexibility that allows Part A and B of the Code to be implemented and augmented by flag states and companies, is effective in adapting to the challenges. Specifically, the study confirms that adaptation mechanisms are functioning (RQ 1), but these mechanisms are often localized and industry-driven, rather than being formal, top-down revisions of the convention itself. The core of STCW (e.g., collision avoidance competence) remains robust, and the digital competence gaps are being filled by rapid, company-funded training modules designed to secure economic performance (Margaretha et al., 2024).

However, the findings critically reveal that this effectiveness is uneven. The "Moderate" score for Cybersecurity Integration directly indicates a failure of the current STCW standards to fully mitigate new digital risks. The existing IMO Guidance on maritime cyber risk management (2022), while available, has not yet been translated effectively into a mandatory, rigorous, and practical competency requirement, leaving a significant safety vulnerability.

3.4. Meaning, Importance, and Filling Academic Gaps

The primary importance of this finding lies in shifting the narrative of maritime regulatory debate. Previous literature often lamented the slowness of the IMO, creating a generalized perception of failure (Fernández Otoya et al., 2024). This research, however, demonstrates that regulatory lag

does not equate to complete competence failure; rather, the robust, economically-motivated response from the global shipping industry has created a functional, albeit fragmented, system of digital competency assurance.

This study fills a crucial academic gap by utilizing a Cross-Group Comparison methodology, which provides the necessary critique lacking in many large-scale surveys. The dissonance identified between the MET Lecturers' confidence in simulator training and the Seafarers' operational struggles with troubleshooting Automated Ship Systems is a novel finding. It moves beyond merely reporting a skill gap to identifying the source of the training friction—specifically, the fidelity and the practical application of non-routine problem-solving exercises in existing STCW-mandated simulation courses. This unique approach, informed by the researcher's practical experience as a 3rd Officer, is a significant strength of the research, ensuring that the data transports authentic operational urgency into academic discourse.

3.5. Practical Implications and Future Research

The findings carry profound practical implications for immediate action in maritime social management and economic policy:

Standardization of Local Wins: Given the high effectiveness of company-developed training for digital logbooks and e-navigation, regulatory bodies should initiate a process to standardize these successful local programs. Formalizing these practices into the STCW framework (e.g., as mandatory company-specific familiarization) would ensure consistency across the fleet and prevent the competency level from fluctuating based on the employer’s economic capacity.

Investment in Diagnostic Skills: The moderate score for ASS troubleshooting necessitates immediate investment in advanced, scenario-based simulation training focused purely on diagnostic skills and managing sensor data ambiguity, rather than routine operations. This is a critical risk mitigation measure aligned with intelligent ship risk evaluation (Zhang et al., 2022).

Prioritizing Social Management: The identified dissonance regarding the Sustainability theme demands a policy review of work-rest hours and administrative burden. Digital efficiency must not lead to the erosion of seafarer well-being. Companies must implement digital tools that streamline, not complicate, administrative tasks to ensure the social sustainability of the maritime workforce.

The primary limitation of this research is its reliance on the subjective perceptions captured through qualitative interviews, regardless of the rigor of the triangulation process. Therefore, future research should: Quantify the Dissonance: Employ a quantitative study (survey design) to measure the magnitude of the simulator-reality disconnect by comparing the self-assessed confidence of seafarers versus objective performance scores in non-routine, complex digital failure scenarios. Deep Dive into Cybersecurity: Conduct a dedicated thematic analysis focusing solely on the "Moderate" scoring area, exploring the specific barriers (regulatory, educational, budgetary) preventing the effective integration of Cybersecurity competence into core STCW training modules [15]. Economic Impact of Skill: Develop an econometric model to directly link the identified competence levels (e.g., proficiency in predictive maintenance systems) to quantifiable economic outcomes (e.g., reduction in unscheduled downtime, fuel consumption efficiency), thereby providing a tangible return-on-investment justification for further STCW reform.

By integrating the strong, positive qualitative findings with a critical examination of the remaining friction points, this research successfully provides a robust, evidence-based roadmap for enhancing the STCW framework to meet the complex demands of the digital maritime economy.

4. KESIMPULAN

This research concludes that the STCW framework demonstrates an overall very good effectiveness (Consensus Score: 4.2/5.0) in responding to immediate digital challenges, largely due to proactive, economically-driven adaptation by shipping companies that standardize e-navigation and digital logbook procedures locally. However, this effectiveness is fundamentally uneven. The study identified a critical Simulator-Reality Dissonance regarding troubleshooting Automated Ship Systems and confirmed a significant Regulatory Lag in integrating practical Cybersecurity competence (rated Moderate). Consequently, while economic efficiency is maintained, this localized adaptation introduces risks and sacrifices social sustainability through increased administrative workload. Future STCW reforms must formalize these proven industry SOPs and prioritize targeted investment in advanced diagnostic simulation to secure long-term safety and seafarer well-being.

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