Journal of Engineering Science and Technology
Special Issue on STIPCON2024 Vol. 20, No. 5 (2025) 11 - 18

INNOVATIVE TRAINING METHODS FOR MARITIME MANAGEMENT EFFECTIVENESS: A META-ANALYTIC APPROACH

SUBAGIYO[1], JUNAIDI[1], APRIL GUNAWAN MALAU[1], LAELY[2], MEILINASARI NURHASANAH HUTAGAOL[1]

[1]STIP Jakarta, Jl. Marunda Makmur Cilincing, Jakarta, Indonesia
[2]Universitas Linggabuana PGRI Sukabumi, Jl. Pramuka II No.10, Sukabumi, Indonesia
*Corresponding Author: aprilgunawan22@gmail.com

Abstract

The maritime industry is rapidly transforming through digitalization, automation, and evolving regulatory frameworks, necessitating a shift in training practices. This study applies a meta-analytic approach to evaluate the effectiveness of innovative training methods in enhancing maritime management outcomes. Thirteen empirical studies published between 2015 and 2024 were selected using PRISMA guidelines and assessed using a random-effects model. The analysis yielded a robust overall effect size (ES = 0.83, 95% CI [0.79, 0.88]), highlighting the positive impact of methods such as simulation-based training, augmented reality (AR), and virtual reality (VR). However, high heterogeneity ($I^2 = 97.23\%$) and a significant Egger's test ($p < .001$) suggest publication bias and variability in implementation contexts. These findings underscore the effectiveness of digital and immersive learning strategies while calling for tailored, context-specific approaches. This study contributes to maritime education by identifying impactful training technologies and recommending strategic collaboration between stakeholders to ensure sustainable workforce development.

Keywords: Innovative training methods, Maritime management effectiveness, Meta analysis, PRISMA.

1. Introduction

The maritime industry is vital to global trade and economic development, requiring effective management to navigate its complexities. Rapid technological advancements and evolving regulations have rendered traditional training insufficient, highlighting the need for innovative approaches. Digital and simulation-based learning address digitalization and the demand for non-technical skills like team coordination and decision-making [1]. Techniques such as augmented reality (AR) and virtual reality (VR) effectively prepare professionals for highly technological environments [2]. Leadership and crew resource management training further enhance safety and efficiency [3]. These innovative methods improve technical skills while fostering adaptive management cultures crucial for the industry's future.

This research aims to systematically analyse training methodologies in maritime management to identify best practices that enhance training outcomes and industry performance. The maritime sector faces challenges such as integrating advanced technologies and developing non-technical skills, requiring innovative training approaches. Autonomous shipping technologies, for instance, demand programs that address shifting roles for seafarers [4], while onboard training grounded in cognitive apprenticeship is essential for skill development [5]. Simulator-based training enhances technical and decision-making skills in controlled settings [6], and digital learning platforms offer modernization opportunities to align education with industry demands [7]. By examining case studies and empirical evidence, this study provides actionable recommendations for designing adaptive, tailored training programs to meet the sector's evolving needs.

This analysis highlights the effectiveness of current maritime training practices while exploring emerging technologies transforming education in the sector. Advancements in virtual reality (VR) and augmented reality (AR) provide immersive, cost-effective simulations that enhance competency development [8]. Automation and digital tools improve seafarers' adaptability to technological changes, underscoring the need for continuous training [9]. Digital innovations like blockchain for secure transactions and IoT-based systems demonstrate the potential of technology to streamline operations and optimize training methodologies [10]. Stakeholder collaboration is emphasized for aligning training with evolving industry needs and regulatory requirements [11]. These findings aim to bridge theory and practice, equipping maritime professionals with the skills to succeed in an increasingly complex industry.

By identifying key competencies and aligning educational outcomes with real-world challenges, this study aims to create a roadmap for future training programs that enhance both individual performance and organizational success in the maritime sector. Competency-based education has proven effective in standardizing training across operational and management levels, ensuring that professionals are well-prepared to meet safety and operational demands [12]. Moreover, the integration of digital competencies and authentic assessment strategies is critical in preparing educators and students for evolving industry needs, particularly in the era of digitalization [13, 14]. This comprehensive approach will not only ensure that maritime education remains relevant but also foster innovation and adaptability among practitioners. For example, the adoption of simulation-based learning and digital tools has significantly enhanced decision-making skills

and preparedness in maritime training programs [2]. By addressing these evolving challenges and aligning training initiatives with global standards, the maritime sector can cultivate a skilled and resilient workforce capable of responding to the dynamic demands of the industry while maintaining compliance with regulatory requirements [15].

Investing in targeted training programs, advanced digital tools, research and development, and partnerships with educational institutions is essential for building a sustainable and innovative maritime industry. Simulator-based training, digital transformation initiatives, and the integration of green technologies enhance operational efficiency, address emerging challenges like automation and digitalization, and minimize environmental impacts [16, 17]. Collaboration among industry stakeholders, governments, and academia drives innovation, fostering sustainable practices and climate resilience, particularly at coastal ports [18]. The adoption of alternative fuels like green hydrogen, renewable energy technologies, and smart logistics solutions further supports decarbonization and compliance with international regulatory targets [19]. Incorporating these advancements into training and operations ensures the workforce is prepared for regulatory shifts, improves safety outcomes, and strengthens performance [20, 21]. These efforts position the maritime sector as a leader in environmental stewardship, attracting investment and talent while paving the way for a competitive, sustainable, and greener future for generations to come [17, 22].

The maritime industry is vital for global trade, economic growth, and environmental sustainability. As automation, digitalization, and regulations evolve, there's a growing need for skilled professionals who can handle technical and operational challenges. Traditional training methods are often inadequate for rapid technological changes and non-technical skills like leadership and teamwork. Innovative approaches using immersive technologies such as simulation, AR, and VR are transforming maritime education by providing interactive, safe, and cost-effective training. The sector is also shifting towards digital fluency and sustainability, prompting a revaluation of conventional training models. This study conducts a meta-analysis of maritime training methods to evaluate their effectiveness in improving management and inform training policies. It aims to provide data-driven insights for developing adaptable maritime training programs across different organizations and regions.

Below are the research questions:

a) Does the reliability of the questionnaire affect research on innovative training methods and maritime management effectiveness?

b) How valid and accurate are innovative training methods and maritime management effectiveness questionnaires in various studies?

2. Method

This meta-analysis shows that innovative training methods, such as simulation, virtual and augmented reality, and digital platforms, significantly improve maritime management skills (ES = 0.83). These methods enhance technical and non-technical abilities like decision-making, teamwork, and adaptability, which are vital in high-risk maritime environments. However, high heterogeneity (I^2=97.23%) indicates variability across different contexts, suggesting training

should be tailored to specific organizational and learner needs. While the publication bias analysis suggests strong findings, some effects may be underreported, highlighting the need for transparency in future research.

The PRISMA flow diagram in Fig. 1 demonstrates how this meta-analysis chose papers. Keyword searches for creative training and marine management generated 675 results (500 Crossref and 175 Scopus). After removing 405 duplicates, 270 unique records were evaluated, with 225 discarded based on publication year (2015-2024), document type, and accessibility, leaving 50 articles for eligibility assessment. The full-text evaluation eliminated 37 non-training and marine management papers, leaving 13 high-quality studies. This thorough, open procedure uses systematic review and meta-analysis best practices to ensure findings reliability and validity.

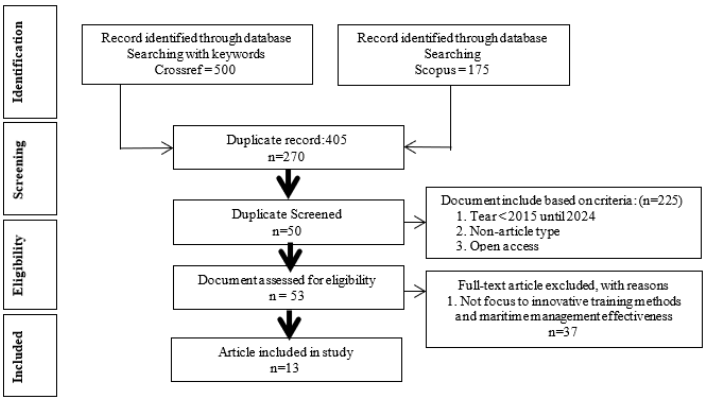

Fig. 1. Prisma model.

3. Analysis and Interpretation of the Results

Table 1 presents a meta-analysis of 13 studies (k = 13) using a random-effects model, revealing a robust overall effect size with an intercept estimate of 0.833 (SE = 0.0236, 95% CI: 0.786–0.879, Z = 35.2, $p < 0.001$). The analysis shows moderate between-study variability ($\tau^2 = 0.0067$, $\tau = 0.082$) and substantial heterogeneity ($I^2 = 97.23\%$), indicating that over 97% of the variance is due to true heterogeneity rather than sampling error. The significant Q statistic ($Q = 343.341$, df = 12, $p < 0.001$) and H^2 value (36.084) further confirm this variability, underscoring the appropriateness of a random-effects model to account for diverse effect sizes across studies.

Table 1. Reliability generalization.

Random-Effects Model (k=12)							
	Estimate	**se**	**Z**	**p**		**CL Lower Bound**	**CL Upper Bound**
Intercept	0.833	0.0236	35.2	< .001		0.786	0.879
Heterogeneity Statistics							
Tau	**Tau²**	**I²**	**H²**	**R²**	**df**	**Q**	**p**
0.082	0.0067 (SE= 0.003)	97.23%	36.084	.	12.000	343.341	< .001

Note Tau^2 Estimator: Restricted Maximum-Likelihood

Table 2 summarizes the publication bias assessment, employing multiple statistical methods to evaluate potential bias in the meta-analysis. The Fail-Safe N, calculated as 203,574 ($p < .001$), indicates exceptional robustness, as it would require over 203,000 null studies to nullify the meta-analytic findings, suggesting low susceptibility to publication bias. Kendall's Tau (-0.359, $p = 0.100$) shows a non-significant trend toward asymmetry, providing limited evidence of bias.

However, Egger's Regression test (-3.693, $p < .001$) detects significant asymmetry, potentially indicating publication bias or small-study effects. These findings highlight the robustness of the results but underscore the need for cautious interpretation, considering possible biases or unmeasured heterogeneity. Overall, while the Fail-Safe N indicates robustness of the findings, the significant Egger's Regression suggests potential asymmetry that warrants further exploration. It is recommended to supplement these results with visual inspection of a funnel plot and consider sensitivity analyses to evaluate the impact of potential bias on the conclusions of the meta-analysis.

Table 2. Publication bias assessment.

Test Name	Value	P
Fail-Safe N	203574.000	< .001
Kendalls Tau	-0.359	0.100
Egger's Regression	-3.693	< .001

Note. Fail-safe N Calculation Using the Rosenthal Approach

Creative training improves marine management, says this meta-analysis. The substantial pooled effect size (ES = 0.83, 95% CI [0.79, 0.88]) shows that simulation-based learning, virtual and augmented reality, and digital platforms build technical and non-technical competencies. These foster decision-making, cooperation, and adaptation in high-risk, technology-driven maritime environments. Training outcomes vary across contexts due to company culture, instructional design, and technical infrastructure ($I^2 = 97.23\%$).

Customizing maritime training programs for individuals and institutions is crucial. Standardized training frameworks may fail unless adjusted to end users' contextual preparation and capabilities. Publishing bias analysis yields mixed results. While the high Fail-Safe N value (203,574, $p < .001$) indicates strong findings, the significant Egger's regression suggests possible small-study effects or underreporting of non-significant data. This encourages cautious interpretation and future reporting transparency.

4. Discussion

This meta-analysis highlights the significant impact of innovative training methods on enhancing maritime management, with a pooled effect size of 0.83 (95% CI [0.79, 0.88]), demonstrating the effectiveness of simulation-based learning, virtual reality (VR), augmented reality (AR), and digital platforms. These methods improve decision-making and technical competencies [8], while also fostering non-technical skills like teamwork and adaptability, essential in high-technology environments [2]. However, substantial heterogeneity ($I^2 = 97.23\%$) indicates variability in training outcomes due to differences in implementation, study designs, and contextual factors like organizational culture and technological readiness [5]. This emphasizes the need for tailored approaches that address

specific organizational needs and learner profiles to maximize the effectiveness of training interventions.

The publication bias assessment provides mixed insights, with a large Fail-Safe N (203,574, $p < .001$) suggesting robust meta-analytic results, but a significant Egger's Regression result (-3.693, $p < .001$) raising concerns about potential bias or small-study effects, as previously noted in rapidly evolving fields like maritime management [21]. These findings call for cautious interpretation and the use of sensitivity analyses to validate conclusions. Additionally, the results underscore the need to address emerging challenges in maritime training, such as the integration of autonomous technologies and digitalization [7]. Autonomous shipping requires tailored training for new roles and responsibilities [4], while sustainable practices, including green technologies and alternative fuels, highlight the importance of continuous professional development to align with evolving industry demands [23].

Stakeholder collaboration plays a crucial role in designing effective maritime training programs, with partnerships between academia, industry, and regulatory bodies driving innovation and aligning training with industry needs [17]. While this meta-analysis highlights the transformative potential of innovative methods such as emerging technologies and collaborative approaches, it is limited by reliance on published studies, potentially excluding valuable unpublished insights. High heterogeneity among studies further emphasizes the need to explore moderating factors like demographics, delivery methods, and technology adoption rates. Future research should assess the long-term impacts of these methods on maritime management and operational outcomes, providing a basis for sustainable training strategies that address the complexities of an increasingly technological maritime industry.

These findings have practical implications. Maritime education should prioritize immersive learning technologies and stakeholder collaboration for relevance and scalability. Continuous professional development must keep pace with automation, environmental regulations, and digital innovations. Despite consolidating key insights, the meta-analysis has limitations like small sample size and limited grey literature access, suggesting a need for further research. Future studies should examine factors such as delivery method, location, and learner demographics, and longitudinal research could offer a deeper understanding of training effectiveness in maritime contexts.

5. Conclusion

This meta-analysis underscores the critical role of innovative training methods, such as simulation-based training, augmented reality (AR), virtual reality (VR), and digital platforms, in enhancing maritime management by improving technical and non-technical skills like teamwork and decision-making. While significant heterogeneity highlights the need for tailored, context-specific solutions, potential publication bias calls for cautious interpretation and further sensitivity analyses.

The findings emphasize aligning training with trends in digitalization, automation, and sustainability, requiring collaboration among industry, education, and regulatory stakeholders to build a resilient, skilled workforce. Future research should explore the long-term impacts and moderating factors of these interventions to ensure their sustained effectiveness and adaptability in addressing evolving maritime challenges.

6. Recommendations for Future Research

Demography, organizational contexts, and delivery methods should be studied to identify appropriate maritime management training conditions. To evaluate how novel approaches affect maritime operations performance and sustainability, longitudinal studies are needed. Training programs should include AI, machine learning, and blockchain. Research should encourage green technologies, energy-efficient practices, and non-technical abilities like leadership and teamwork for safety and decision-making to accomplish sustainability goals. To address publication bias, scalable solutions involve Gray literature, rigorous techniques, and business, academic, and regulatory collaboration. With established assessment metrics, international comparisons and learner-centred techniques can improve training design and efficacy. This will lead to targeted, effective training initiatives to build a resilient maritime workforce for future issues.

References

1. Nikolov, B. (2023). Maritime cybersecurity education and training at Nikola Vaptsarov Naval Academy. *Педагогика*, 95(6 s), 48-55.
2. Hopcraft, R. (2021). Developing maritime digital competencies. *IEEE Communications Standards Magazine*, 5(3), 12-18.
3. Wahl, A.M.; and Kongsvik, T. (2018). Crew resource management training in the maritime industry: A literature review. *WMU Journal of Maritime Affairs*, 17(3), 377-396.
4. Meštrović, T.; Pavić, I.; Maljković, M.; and Androjna, A. (2024). Challenges for the education and training of seafarers in the context of autonomous shipping: Bibliometric analysis and systematic literature review. *Applied Sciences*, 14(8), 3173.
5. Mori, Y.; and Manuel, M.E. (2023). An exploration of the theoretical foundations of onboard seafarer training: A systematic review of the literature. *TransNav*, *International Journal on Marine Navigation and Safety of Sea Transportation*, 17(4), 913-928.
6. Tusher, H.M.; Nazir, S.; Ghosh, S.; and Rusli, R. (2023). Seeking the best practices of assessment in maritime simulator training. *TransNav*, *International Journal on Marine Navigation and Safety of Sea Transportation*, 17(1), 105-114.
7. Konon, N. (2022). Prospects for modern maritime education and training practices in terms of distance learning. *Shipping & Navigation*, 33(1), 54-66.
8. Mallam, S.C.; Nazir, S.; and Renganayagalu, S.K. (2019). Rethinking maritime education, training, and operations in the digital era: Applications for emerging immersive technologies. *Journal of Marine Science and Engineering*, 7(12), 428.
9. Aguilar, R.J.; Arcolar, W.C.; Calmerin, C.E.D.; Dupa, R.R.; Fabila, E.P.; Laplana, P.; and Ortencio, K.A. (2024). Navigating change: The role of 21st century technological innovations on seafarers' professional lives. *International Journal of Research and Innovation in Social Science*, VIII (VI), 1730-1741.
10. Pattikawa, M.M. (2023). *The impact of the Covid*-19 *pandemic on inter-European maritime and aviation trade flows.* Utrecht University.

11. Campos, C.; Castells-Sanabra, M.; and Borén, C. (2024). Conceptualization of the era of autonomous shipping within maritime education and training framework. *Proceedings of the MT'*24. 10th *International Conference on Maritime Transport*, Barcelona School of Nautical Studies, Barcelona, Spain, 5-7.
12. Martes, L. (2020). Best practices in competency-based education in maritime and inland navigation. *TransNav*, *International Journal on Marine Navigation and Safety of Sea Transportation*, 14(3), 557-562.
13. Yuen, K.F.; Tan, L.; and Loh, H.S. (2022). Core competencies for maritime business educators in the digital era. *Frontiers in Psychology*, 13, 915980.
14. Baldevarona, G.; San Miguel, A.; Bentulan, E.; and F. Cerbito, A. (2024). Exploring the interplay of authentic assessment and instructor competencies in enhancing industry readiness in maritime education. *Asia Pacific Journal of Advanced Education and Technology*, 3(3), 29-40.
15. Sijabat, P.S.; Simanjuntak, M.B.; Mudakir, Putrawan, B.K.; and Lumingkewas, M.S. (2024). Empowering literacy in maritime education: Strategies and professionalism alignment. *Meteor STIP Marunda*, 17(1), 42-50.
16. Talabi, A.T.O. (2019). Innovative use of technology in the maritime sector for sustainable environment. *SSRN Electronic Journal*, 1-18.
17. Saether, E.A.; Eide, A.E.; and Bjørgum, Ø. (2021). Sustainability among Norwegian maritime firms: Green strategy and innovation as mediators of long-term orientation and emission reduction. *Business Strategy and the Environment*, 30(5), 2382-2395.
18. Morris, L.L. (2020). Stakeholder collaboration as a pathway to climate adaptation at coastal ports. *Maritime Policy & Management*, 47(7), 953-967.
19. Koo, K.Y.; Rødseth, Ø.J.; Lislebø, G.; and Ulvensøen, J.H. (2024). Harmonizing maritime innovation: Enhancing international and national standardization in intelligent ship transport systems. *Journal of Physics*: *Conference Series*, 2867(1), 012023.
20. Simanjuntak, M.B.; Rafli, Z.; and Utami, S.R. (2024). Enhancing maritime education for ocean sustainability: A multidisciplinary approach. *BIO Web of Conferences*, 106, 02006.
21. Demirel, E. (2020). Maritime education and training in the digital era. *Universal Journal of Educational Research*, 8(9), 4129-4142.
22. Aboul-Dahab, K.M. (2021). The readiness of the maritime education for the autonomous shipping operations. *SSRN Electronic Journal*.
23. Oksana, P.; and Olexiy, A. (2022). Greening of the maritime transport process. *Electronic Scientific Journal Intellectualization of Logistics and Supply Chain Management* #13 2020, 1(13), 34-54.