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Maritime Education and Training: A Simulation-Based Approach for Enhancing Ship Electric Load Management Competency Through Emergency Scenario Familiarization

R. Karimpour & M. Figari
University of Genova, Genova, Italy

ABSTRACT: As ship automation advances, maritime training must adapt to ensure proficiency in manual operations during automation failures. Traditional Maritime Education and Training (MET) lacks standardized, simulator-based assessments for critical tasks such as manual generator synchronization, leading to skill gaps in high-risk scenarios.
This study evaluates the effectiveness of high-fidelity engine room simulators in improving situational awareness, cognitive load management, and decision-making under stress. A Simulation-Based Training (SBT) framework using the Wärtsilä TechSim engine room simulator was implemented at the University of Genoa (UNIGE), aligning with the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW) (Reg. III/1, Section A-III/1; Reg. I/14). Pre- and post-training assessments, simulator logs, and instructor observations demonstrated significant improvements in synchronization execution time, fault diagnosis, and emergency response efficiency.
However, the absence of structured, simulator-driven competency assessments in MET limits objective skill measurement and training effectiveness. Drawing insights from aviation competency models, this study proposes a structured assessment framework to standardize competency verification, enhance training methodologies, and better equip seafarers for automation-driven ship operations.

1 INTRODUCTION

1.1 *Background and Rationale for Maritime Education and Training (MET)*

The increasing automation and complexity of shipboard electrical systems demand a shift in Maritime Education and Training (MET) toward structured, competency-based approaches. Traditional MET methods, reliant on classroom instruction and limited onboard exposure, often can not provide high-risk scenario training, particularly for critical operations like manual generator synchronization and emergency power management. Onboard training is further constrained by operational priorities, safety concerns, and the likelihood of real-life fault scenarios, limiting trainees' ability to develop manual skills and quick decision-making under pressure [1], [2].

In a study on e-learning, Chen, Bai, and Xiao proposed in 2017, the use of e-learning to advance the traditional maritime education. Similarly, Goerlandt in 2020 highlighted the role of maritime simulators in providing controlled environments for familiarization with safety-critical operations [3], [4]. These simulators allow for the breakdown of complex scenarios to focus on specific skills, including leadership, teamwork, software proficiency, and hardware operation. As a complementary solution to traditional onboard training, high-fidelity Simulation-Based Training (SBT) offers a scalable and cost-effective alternative, with the potential to significantly reduce operational costs.

Simulation-based training has emerged as a transformative approach, offering a controlled, immersive environment for developing proficiency in fault diagnosis, synchronization execution, and emergency response efficiency [5], [6]. High-fidelity engine room simulators replicating complex shipboard systems enable structured, repeatable simulations that enhance situational awareness, decision-making, and crisis management [7], [8].

While the 2010 Manila Amendments to the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW) mandated the use of simulators for specific training areas, including navigation, engine operations, and resource management, however, the absence of fully standardized evaluation protocols has hindered consistent and systematic adoption of simulator-based assessments across Maritime Education and Training (MET) institutions. This inconsistency affects training quality, competency verification, and regulatory alignment. Recognizing these challenges, the International Maritime Organization (IMO) initiated a comprehensive review of the STCW Convention and Code [6].

1.1.1 *Regulatory alignment and the need for standardized assessments*

The IMO stipulates that officers must demonstrate proficiency in electrical systems, including generator synchronization and load management. The STCW Convention (Reg. III/1, Section A-III/1) mandates competence in electrical load management and generator synchronization for electro-technical and engineer engineer officers, ensuring safe power system operation. Additionally, STCW Reg. I/14 emphasizes training for operational safety and efficiency, including synchronization during onshore power supply (OPS) connections [9]. However, without standardized simulator-based competency assessments, the full potential of SBT remains underutilized. This study evaluates the effectiveness of structured SBT in:

- Enhancing electrical load management and generator synchronization skills using high-fidelity simulators, and
- Developing situational awareness and decision-making capabilities, aligning with STCW Regulation I/14 and emphasizing safety-focused training methodologies.

1.1.2 *Bridging MET gaps through structured SBT*

SBT enhances technical proficiency and emergency preparedness, yet maritime education (MET) lacks structured competency evaluations, unlike aviation, which mandates recurrent simulator assessments every 6–12 months A structured SBT framework in MET can address gaps in ship electric load management and manual generator synchronization, critical tasks requiring precision and rapid decision-making [10], [11].

Table 1 highlights aviation’s competency-based framework, which enhances safety and operational readiness through standardized SBT. Unlike aviation's ICAO-mandated simulator assessments, STCW lacks recurrent training requirements. Adopting a structured SBT model in MET could improve emergency preparedness and decision-making, aligning maritime training with STCW standards [12], [13].

Table 1. Comparison of Aviation vs. Maritime Simulator Training Frameworks [12] , [13], [10].

Aspect	Aviation Training	Maritime Training
Regulatory Standard	International Civil Aviation Organization Competency-Based Training & Assessment	STCW Competency-Based Training
Simulator Use	Mandatory recurrent simulator assessments	Limited simulator assessments in MET
Frequency	Pilots must complete simulator assessments every 6-12 months	Seafarers are not regularly assessed in simulator environments
Assessment Standardization	Highly structured evaluation protocols	Lacks globally standardized simulator assessments
Instructor Certification	Requires recurrent simulator-based instructor training	Varies widely between MET institutions

Addressing competency assessment gaps, particularly in ship electric load management and emergency power coordination, remains crucial for modern maritime education and training. By standardizing simulator-based evaluations within STCW frameworks, maritime institutions can ensure effective skill transferability, enhanced decision-making, and improved safety outcomes in automation-driven ship operations.[1]

The following section defines the research objectives and outlines how the study builds upon existing simulation-based training models for MET practices.

1.2 *Research Objectives and Contributions*

This study examines the pedagogical value of simulation-based training (SBT) in shipboard electrical systems, focusing on enhancing crisis response, technical accuracy, and adaptability in a risk-free atmosphere. By addressing real-world challenges such as generator synchronization and fault diagnosis, SBT provides a structured framework for developing essential competencies. In particular, the study explores how manual synchronization of a diesel generator to the ship's electrical switchboard can improve seafarers' ability to manage automation failures effectively.

1.2.1 *Research question*

How effective are high-fidelity engine room simulators in enhancing MET, particularly in developing technical proficiency, decision-making skills, and emergency response capabilities?

[1] While a wide range of standardized simulators exists for deck and communication training (e.g., ARPA, GMDSS, ECDIS, high-voltage), this study focuses specifically on engine room simulators and does not attempt to evaluate simulator use in all maritime domains.

1.2.2 *Key research objectives*

To comprehensively investigate this question, the study explores the following key research objectives:

1. Assess the impact of structured engine room simulation training on task execution efficiency.
2. Measure competency development through performance metrics and participant feedback.
3. Evaluate decision-making improvements in ship manual power management(generator synchronization) scenarios.

This study advances simulation-based training (SBT) research by providing empirical validation of its effectiveness in ship electric load management and manual generator synchronization—a critical yet underexplored competency. Unlike prior studies relying on self-reported outcomes, this research integrates quantitative performance metrics (pre/post-test analysis) with qualitative evaluations (instructor assessments, trainee feedback) to measure decision-making, fault diagnosis, and execution accuracy.

Aligning SBT with STCW-mandated competencies (Reg. III/1, I/14), this study benchmarks structured simulator debriefing against aviation competency models, addressing a gap in maritime training. By identifying fidelity limitations in ship engine room simulators, it underscores the need for standardized, recurrent training to enhance skill transferability, operational readiness, and safety in automation-driven ship systems.

1.3 *Methodology*

After Chapter 1, which highlighted the need for simulation-based training (SBT) in maritime education (MET) due to the limitations of traditional methods and emphasized structured competency training for shipboard electrical systems, Chapter 2, this study employs a Systematic Scoping Literature Review (SSLR) methodology to examine relevant research on simulation-based training in MET [10].

1. The initial stage of the literature review involved compiling a research pool through Google Scholar searches using targeted keywords, including "familiarization with ship machinery via simulators," "added value of ship simulators in maritime education," "performance metrics in ship simulator training," "pedagogical approaches to cadet training with simulators," "advantages and limitations of ship simulator-based education," "simulating engine room emergency scenarios," and "measuring the effectiveness of simulator-based training.". In the second step, the review process continued with an initial pool of forty selected studies, which were filtered through three stages:
2. Title Screening: Exclusion of seven studies due to duplication or irrelevance.
3. Abstract and Conclusion Scan: Removal of five studies based on predefined Inclusion and Exclusion Criteria (Studies were selected based on inclusion criteria: publications since 2010 (aligning with the Manila amendments to STCW 2010), research on simulation-based training for ship electrical systems, manual generator synchronization, electrical load management, and empirical studies on situational awareness in maritime emergencies. Studies without empirical data or validation methodologies and non-English papers without translations were excluded. This ensured the inclusion of relevant, high-quality sources.
4. Full-Text Review: A further two studies were excluded after a detailed methodological and thematic evaluation.

Finally, after applying these filtering stages, twenty six references were reviewed and used for this study. As illustrated in Figure 1, this research follows a Systematic Scoping Literature Review (SSLR) approach, which outlines the inclusion and exclusion process used for selecting studies. These references are listed at the reference list at the end of this article.

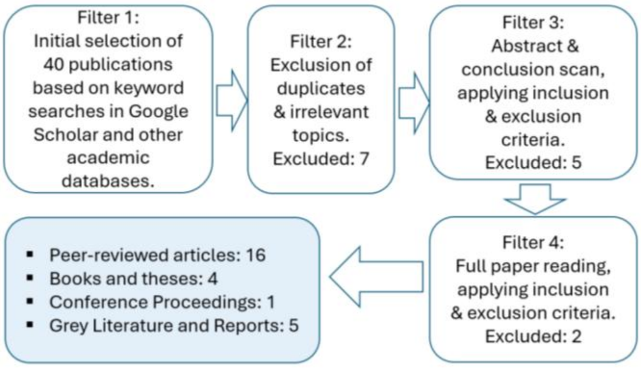

Figure 1. Systematic Scoping Literature Review (SSLR).

Chapter 3 evaluates simulation-based training (SBT) for manual generator synchronization using the Wärtsilä TechSim simulator. Fourteen students from the University of Genoa(UNIGE) participated in theoretical instruction, simulator exercises, and structured debriefing. Performance was assessed through pre/post-tests, simulator logs, and instructor observations, measuring accuracy, decision-making, and fault diagnosis. A mixed-methods approach integrated quantitative metrics with qualitative feedback.

Chapter 4 examines the impact of SBT under a specific condition, confirming significant competency gains in technical proficiency, situational awareness, and decision-making. Chapter 5 with discussion and comparison with existing literature critically analyzes these findings against prior research. Finally, the conclusion chapter highlights SBT's effectiveness in ship electrical load management, advocating for structured simulator training. See Figure 2.

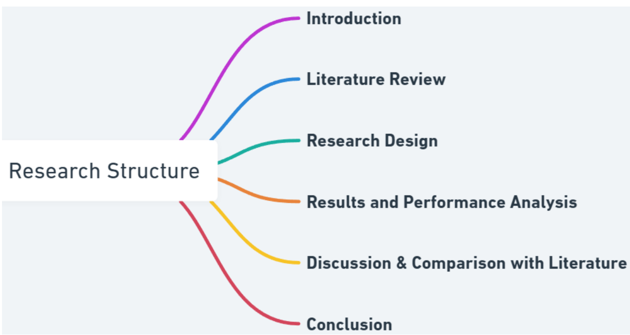

Figure 2. Research Structure and Framework.

2 LITERATURE REVIEW: THEORETICAL FOUNDATIONS OF SIMULATOR-BASED TRAINING IN MET

Building on the Chapter 1, this chapter presents a structured literature review of selected references to establish the theoretical foundations of Simulation-Based Training (SBT) in MET. The review systematically identifies key aspects of SBT relevant to maritime competency development, focusing on three core areas: task execution efficiency (Section 2.1), competency assessment through performance metrics and feedback (Section 2.2), and decision-making improvements in engine room emergencies (Section 2.3). By analyzing empirical studies on simulator fidelity, structured assessments, and cognitive adaptability, this chapter explores SBT within STCW competency frameworks, emphasizing its role in enhancing maritime training outcomes.

2.1 *Impact of Structured Engine Room Simulation Training on Task Execution Efficiency*

Simulator-based training (SBT) in Maritime Education and Training (MET) has gained prominence as an effective method for skill acquisition, addressing the limitations of traditional classroom instruction and onboard training [14]. Previous studies have demonstrated the effectiveness of ship navigation simulators in replicating high-pressure communication scenarios and distress protocols, enhancing practical communication skills in maritime operations [7]. High-fidelity engine room simulators to a high-respect replicate real-world operational challenges, allowing trainees to develop proficiency in executing complex technical procedures with improved efficiency. Some research indicates that structured simulator scenarios enhance competency outcomes, skill retention, and task execution accuracy, with simulator-trained participants exhibiting an increase in technical precision and a reduction in response time during emergency operations [5], [15].

The effectiveness of structured simulator training hinges on realism, or fidelity, which ensures the simulation environment aligns with operational and educational objectives [2]. Advanced immersive simulators, such as full-mission maritime systems, integrate high-fidelity simulations with digital learning tools, fostering technical proficiency in manual generator synchronization, electrical load management, and emergency fault diagnosis [12]. Furthermore, the integration of augmented reality (AR) and virtual reality (VR) enhances engagement and learning outcomes, reducing dropout rates and promoting skill development [16]. Despite these advancements, standardization in MET competency assessments remains insufficient, highlighting the need for structured evaluation protocols [13].

2.2 *Competency Development Through Performance Metrics and Participant Feedback*

Competency acquisition in MET is traditionally assessed through theoretical exams and limited onboard evaluations, which fail to measure real-world proficiency [13]. As illustrated in Figure 3, engine room simulators—which replicate power distribution networks, electrical system failures, and generator synchronization procedures—offer a controlled environment for maritime students to develop and demonstrate their technical competencies [17].

Studies indicate that simulator-trained participants achieve significantly higher success rates in executing generator synchronization procedures compared to their initial attempts, underscoring the efficacy of structured competency development [5]. However, existing STCW-aligned MET training frameworks lack structured simulator-based assessment protocols, limiting the ability to measure practical competency effectively. Unlike aviation, where recurrent simulator assessments are mandatory, maritime competency evaluations rely heavily on theoretical testing, failing to account for emergency scenario performance. Furthermore, while structured emergency drills exist, particularly in safety management systems, the assessment of individual performance during such scenarios remains inconsistent across MET institutions [18].

Figure 3. Generator Panels of a Dual-Fuel Tanker Ship on Wärtsilä Engine Room Simulator at UNIGE

To address this gap, structured competency evaluations integrating performance metrics, standardized assessment criteria, and instructor-led debriefing are essential. Research supports that post-training evaluations incorporating real-time feedback mechanisms enhance competency retention and practical skill development [19]. Moreover, eye-tracking and verbal response analysis methods utilized in offshore well control training demonstrate measurable improvements in system failure mitigation, further validating the need for performance-based competency assessments in maritime training [20].

2.3 *Decision-Making Improvements in Ship Engine Room Emergency Scenarios*

Effective decision-making under pressure is critical for maritime safety, particularly in emergency engine room scenarios. Situational awareness (SA) is essential for diagnosing and mitigating electrical system failures and generator malfunctions. Research highlights the role of structured Simulation-Based Training (SBT) in enhancing SA and improving fault diagnosis, contributing to more efficient decision-making in emergency situations [21]. Blended learning models integrating simulator training with digital case studies enhance cognitive adaptability and problem-solving efficiency [12].

Structured Simulation-Based Training (SBT) enhances diagnostic accuracy and supports adaptive decision-making in maritime training [2]. Research highlights its role in improving performance and cognitive adaptability under complex operational conditions. However, standardized metrics quantifying decision-making error reduction in emergency drills require further empirical validation [11], [22]. Moreover, maritime training lacks adaptive crisis components found in aviation. Over-reliance on automated decision-support systems necessitates structured situational awareness training to enhance critical thinking [8], [10].

Given that SA-related errors account for 71% of maritime incidents [21], instructor-led training, including scenario execution and debriefing, which is aligned with the requirements of the STCW education, is essential for improving emergency preparedness [23]. Standardized simulator-based assessments in MET would enhance decision-making, safety, and operational efficiency in engine room management. The following chapter details the research methodology used to assess simulator-based competency acquisition in shipboard electrical systems.

3 RESEARCH DESIGN AND EXPERIMENTAL APPROACH TO SIMULATOR-BASED TRAINING

Based on the valuable insights gained from the systematic scoping literature review in previous chapter, an experimental approach designed in this research to simulator-based training is presented in Figure 4.

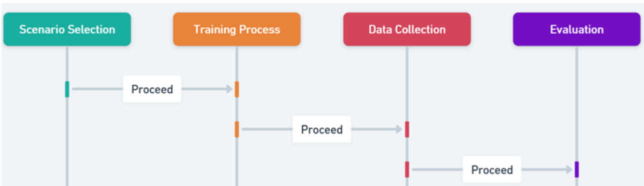

Figure 4. Research Design and Experimental Approach to Simulator-Based Training Evaluation

3.1 *Scenario Selection*

Title of Scenario: " Manual Generator Synchronization in Emergency Conditions (Triggered by Failure or Non-Operational Status of Automatic Synchronization)".

Manual synchronization is a fundamental skill for ship engineers and officers, ensuring the stability and safety of the ship's electrical system. Although synchronization is typically handled automatically by PLC-based systems, understanding and executing manual synchronization remains critical for engineers during automation failure or emergency scenarios. By focusing on this scenario, the study aligns with real-world demands, where improper synchronization can lead to system instability, electrical faults, or even fires. This scenario enhances technical proficiency and prepares trainees for both routine and emergency operations in high-pressure situations. This approach directly supports competency-based training frameworks in Maritime Education and Training (MET), as outlined in STCW guidelines, by bridging the gap between theoretical knowledge and practical, real-life application.

Objective: Train participants to manually synchronize two generators to obtain safe and stable operational conditions.

Simulator: This study was conducted at the the Department of Electrical, Electronic, Telecommunications Engineering, and Naval Architecture (DITEN) of the University of Genoa, using the Wärtsilä TechSim engine room simulator that is considered a full-mission engine room simulator. It is designed to replicate the complex systems and operations of a real ship's engine room, providing a highly realistic training environment for maritime professionals. The simulator covers a wide range of scenarios, including power management, machinery operations, failure handling, and emergency procedures, making it a comprehensive tool for developing technical and operational competencies.

The Wärtsilä TechSim simulator used in this study replicates a modern tanker's electrical switchboard with a high level of realism, providing user interfaces and synchro panels nearly identical to those on real vessels. This fidelity enhances skill transfer and situational familiarity. Wärtsilä TechSim is widely used in maritime training institutions and by shipping companies to ensure that trainees and crew members are well-prepared for real-world challenges in engine room operations [24]. Within the scope of this exercise, the simulator accurately modeled a modern tanker ship's electrical system. This training platform enables participants to practice manual generator synchronization, power distribution, and response procedures in a controlled environment. See Figure 5.

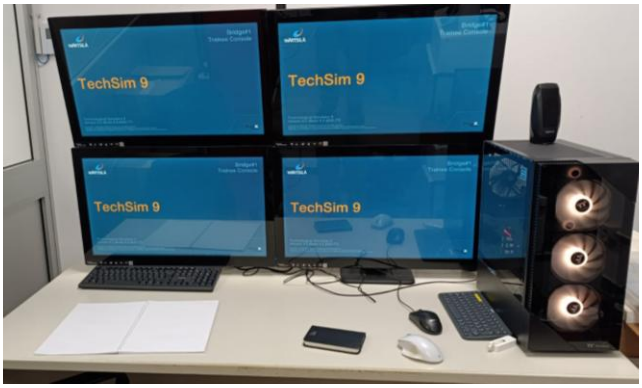

Figure 5. The trainee station of the engine room simulator at UNIGE

Instructors: The primary instructor holds a Chief Engineer Certificate of Competency and has over 10 years of seagoing experience on cargo ships. He also holds postgraduate degrees, with research focused on Shoreside Electricity (SSE) and ship-generator synchronization. Certified in Training for Trainers and Assessors through the Use of Simulators by Wärtsilä, he ensures high-quality simulator-based training. The exercise was supervised by the Head of Maritime Science and Technology, a full professor at the University of Genoa (UNIGE), who is also certified in

Training for Trainers and Assessors through the Use of Simulators.

Participant selection: This study involved fourteen participants from the University of Genoa, comprising two, third-year Maritime Science and Technology students, and twelve master's-level Naval Architecture students. While all participants had a foundational understanding of ship electrical systems, none had prior hands-on experience with generator synchronization using simulators, making them an ideal test group for assessing the effectiveness of structured simulation-based training (SBT). The gender distribution was balanced, ensuring diverse perspectives in training effectiveness.

However, it should be noted that this study is limited by the relatively small sample size (n=14), drawn from a single institution, which may constrain the generalizability of the findings. Additionally, the study does not include long-term retention analysis or performance tracking in real-world onboard scenarios. Future studies involving larger, more diverse participant groups and longitudinal data collection are recommended to validate and extend these results.

3.2 *Training Process*

Experimental setup and training process: The training methodology was designed to follow a structured and progressive approach, ensuring optimal competency development through a combination of theoretical familiarization, hands-on simulator exercises, instructor-led demonstrations, and debriefing sessions. Due to the availability of a single trainee simulator station for students and an instructor station for monitoring, participants were organized into small groups of 2–3 individuals. Prior to the practical sessions, participants were provided with a comprehensive training manual. This manual covered essential theoretical concepts related to ship electrical systems and generator synchronization. It included detailed technical specifications of a tanker ship, step-by-step synchronization procedures tailored for the Wärtsilä TechSim simulator, and operational protocols for both standard and emergency scenarios.

The training process was divided into distinct phases, each with specific activities, durations, and key learning outcomes, as summarized in the following table:

Table 2. Experimental Setup and Training Process

Phase	Activity	Time	Learning Outcome
1-Theoretical Familiarization	Self-study on simulator concepts	1 hour	Understanding fundamentals
2-Simulator Introduction	Instructor synchronization demonstration	30 mins	System familiarization
3-Initial Simulation Exercise	First synchronization test	15 mins	Baseline performance assessment
4-Demonstration Phase	Instructor-guided demonstration	30 mins	Correct synchronization procedures
5-Second Simulation Exercise	Second synchronization test with feedback	15 mins	Performance improvement
6-Debriefing & Analysis	Reviewing results and feedback	15 mins	Reinforcing learning

Generator synchronization procedure: Generator synchronization on ships involves matching the electrical parameters of multiple generators before connecting them to a common bus bar, enabling load sharing and ensuring the proper operation of the ship's electrical system.

As illustrated in Figure 6, key parameters for synchronization include voltage, frequency, phase angle, and phase sequence. Proper synchronization is crucial for load sharing, system stability, and safety, as it prevents overloading, electrical faults, and potential fires. The synchronization process involves adjusting the generator speed to match frequency, using voltage regulators to match voltage, and employing tools like synchroscopes or synchronization lamps to align phase angles [25]. Generator Synchronization Process:

[Adjust Generator Speed] → [Match Voltage&Frequency] → [Check Phase Sequence] → [Align Phase Angle] → [Close Circuit Breaker]

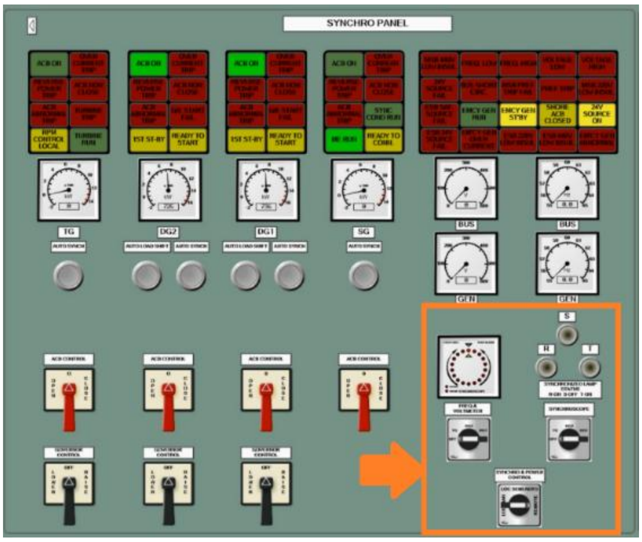

Figure 6. Synchro Panel of a Tanker Ship Simulator used for generator synchronization, highlighting the synchroscope.

Figure 6 illustrates the setup where trainees perform manual generator synchronization exercises using the Wärtsilä TechSim engine room simulator. The simulation displays key electrical parameters—voltage, frequency, and phase—of both the running and incoming generators, guiding trainees through the synchronization process before closing the circuit breaker. As shown in Figure 7, the black knob on the generator governor control is used for fine-tuning the incoming generator's parameters to match those of the running generator. Once synchronization is achieved, the red circuit breaker knob is engaged, allowing the synchronized generators to share the kilowatt (kW) load efficiently [25].

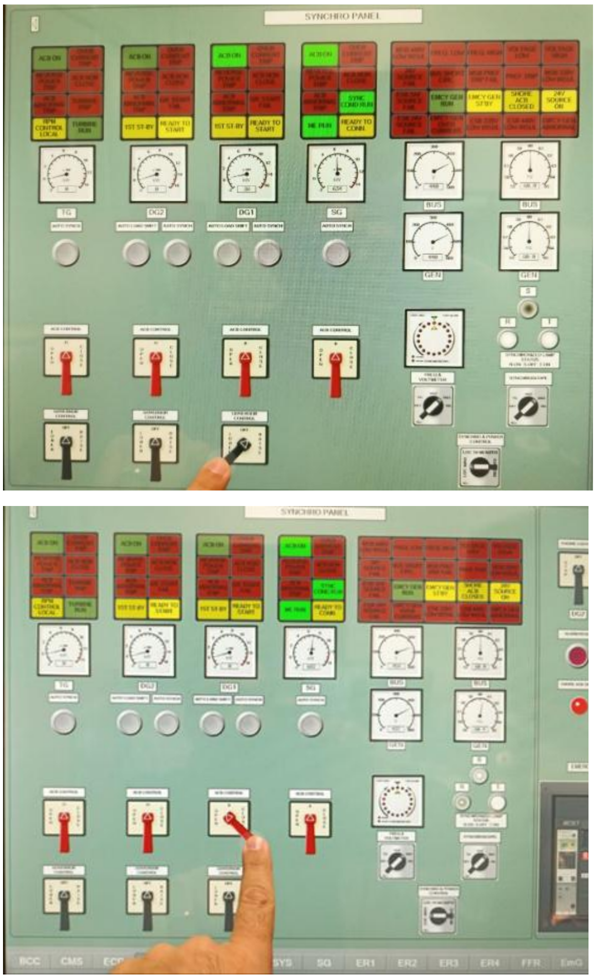

Figure 7. a) Adjusting Parameters (voltage, frequency, phase) of the Incoming Generator; b) Closing the generator's circuit breaker for load sharing.

This training scenario familiarizes participants with essential shipboard electrical load management procedures, emphasizing manual generator synchronization. Trainees must precisely align the electrical voltage, frequency, and phase angle to ensure stable load distribution and system reliability. By completing this exercise, they develop a foundational understanding of synchronization principles, gaining the technical competence and confidence necessary for more complex emergency operations. The controlled simulator environment reinforces skill acquisition before progressing to fault diagnosis and troubleshooting scenarios.

3.3 *Data Collection*

Data Collection, performance metrics, and post-simulation assessment: A comprehensive mixed-methods approach was employed to evaluate the effectiveness of simulator-based training (SBT) in decision-making efficiency and crisis management skills. The assessment framework integrated quantitative and qualitative measures, ensuring a holistic analysis of participants' performance before, during, and after training. Below Table 3 provides a clear distinction between quantitative and qualitative measures, helping quickly to grasp the approach for data collection, performance metrics, and post-simulation assessment.

Table 3. Data collection, performance metrics, and post-simulation assessment

Evaluation Category	Specific Measure	Purpose	Assessment Approach
Quantitative Measures:	Pre-/Post-Training Assessments	Evaluate competency improvements	Knowledge & procedure
	Performance Metrics	Measure speed, accuracy, and fault resolution	Simulator logs & recorded execution data
	Performance Analysis	Review response times, teamwork, and decision-making	Simulator task observations
	Simulator Log Analysis	Identify execution strengths and weaknesses	Analysis of recorded system responses
Qualitative Measures:	Instructor Observations	Assess decision-making, stress handling, and teamwork	Structured instructor evaluations
	Instructor Feedback	Improve procedural accuracy and adaptive response	Expert recommendations post-simulation
	Trainee Feedback Surveys	Assess realism, engagement, and applicability	Responses & group interviews
	Best Practices Discussion	Reinforce synchronization & fault-handling strategies	Post-simulation trainee-instructor reviews

By integrating real-time performance tracking with structured debriefing, this method provided empirical validation of SBT's effectiveness in maritime competency development.

The evaluation of the findings of this experimental approach is presented and explained in the next section.

4 RESULTS AND PERFORMANCE ANALYSIS OF SIMULATOR-BASED TRAINING

This section presents the study's findings based on a structured evaluation aligned with the research objectives. The assessment process began with a pre-test measuring execution time and fault diagnosis accuracy to establish a performance baseline. During the simulation phase, real-time data from the Wärtsilä TechSim logs were analyzed to capture improvements in synchronization accuracy, error rates, and response times. Instructors then evaluated procedural adherence and decision-making using a standardized 1–5 scale. Finally, post-test assessments and participant feedback were used to validate gains in operational accuracy, fault diagnosis efficiency, and situational awareness. This approach discusses the effectiveness of Simulation-Based Training (SBT) in enhancing both technical proficiency and emergency response capabilities in ship electrical load management.

4.1 *Simulator Log Analysis for Assessing SBT Task Execution Efficiency*

To assess the impact of structured simulator-based training (SBT) on task execution efficiency, key performance indicators such as synchronization execution accuracy, fault recognition response times, and synchronization error rates were analyzed. Simulator log data revealed significant improvements post-training. Synchronization execution accuracy increased from 0% to 95%, indicating enhanced precision. Fault recognition response times improved notably, reducing the average diagnostic response to three to four minutes. Additionally, synchronization error rates decreased substantially, reflecting greater operational accuracy in manual generator synchronization. Therefore, the findings confirm that SBT effectively enhances technical proficiency and decision-making efficiency, reinforcing its value in ship power management training.

4.2 *Measuring Competency Development Through Performance Metrics and Participant Feedback*

4.2.1 *Pre-Test and Post-Test Evaluations of Competency Acquisition*

The pre-test and post-test assessments demonstrated significant improvements in synchronization execution time, decision-making accuracy, and fault diagnosis efficiency following simulator-based training. Before training, most participants struggled to complete manual synchronization within the designated fifteen-minute timeframe. After training, execution time was reduced by nearly 50%, reflecting greater proficiency and confidence.

Decision-making accuracy also improved notably. Initially, only one-quarter of the trainee groups successfully completed synchronization tasks without errors. Post-training results showed 100% completion, indicating enhanced procedural adherence and situational awareness. Similarly, fault diagnosis efficiency increased, with all trainees successfully identifying and resolving system faults after training, compared to only half before.

As shown in Figure 8, these findings confirm the effectiveness of simulator-based training in maritime education, demonstrating its role in enhancing technical precision, decision-making, and problem-solving skills in ship electrical load management.

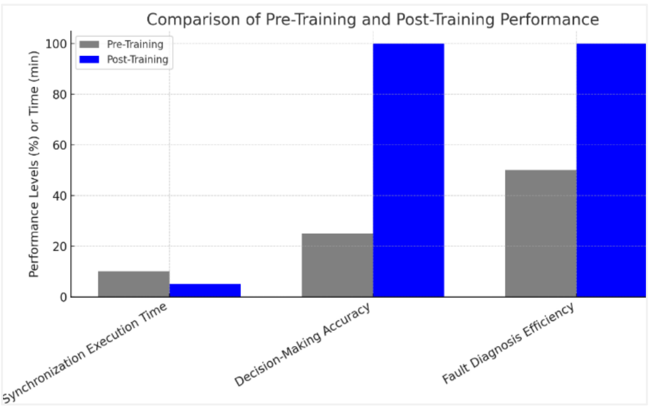

Figure 8. Performance metrics: Pre-test and post-test evaluations of competency acquisition

These results confirm that structured training significantly enhances competency development by improving procedural accuracy and operational efficiency.

4.2.2 *Performance Metrics for Competency Evaluation*

To further quantify competency development, performance metrics captured by the simulator logs were analyzed. These metrics provide an objective measure of skill acquisition, including:

– Execution accuracy and task completion: Significant improvements in task completion rates, reflecting enhanced procedural adherence.
– Problem-solving and fault recognition: Reduction in fault recognition response time, showcasing improved situational awareness and competency in identifying electrical system malfunctions.
– Error reduction in synchronization procedures: Post-training results demonstrate increased technical proficiency, with near-total elimination of synchronization errors.

These performance indicators support the point that simulator-based training leads to measurable improvements in technical competency.

4.2.3 *Trainee Feedback on Simulator-Based Training Effectiveness*

Trainees highlighted the realistic replication of maritime operations as a key advantage of simulator-based training, allowing them to bridge theoretical knowledge with practical application. Many reported increased confidence in performing critical tasks such as manual generator synchronization and fault management, attributing this to the structured learning environment that enabled risk-free experimentation and problem-solving. Participants suggested enhancements, including more complex scenarios to refine skills in diverse conditions, enhanced real-time feedback mechanisms for better learning reinforcement, and structured debriefing sessions to strengthen the integration of theory with practice. These insights underscore the pedagogical value of simulator-based training, reinforcing its role in competency development and decision-making proficiency in maritime education.

4.3 *Evaluating Decision-Making Improvements in Ship Engine Room Emergency Scenarios*

Instructor-led evaluations assessed situational awareness, cognitive load management, and real-time decision-making efficiency in high-pressure maritime scenarios. Initial assessments revealed gaps in trainees' ability to anticipate and recognize critical faults, but post-training evaluations demonstrated marked improvements in fault identification and resolution.

Participants also showed enhanced cognitive load management, effectively processing multiple information sources while reducing response time to system failures. Before training, many relied on trial-and-error decision-making, whereas post-training assessments indicated that 100% of participants followed structured decision-making processes, adhering to standard operational procedures. Key findings highlight significant improvements in crisis management skills, knowledge application, and adaptability. Trainees exhibited better task prioritization under stress, improved teamwork and communication in electrical load management scenarios, and a notable reduction in decision-making errors. These results reinforce the effectiveness of simulator-based training in strengthening operational resilience and informed decision-making in high-risk maritime environments.

5 DISCUSSION AND COMPARISON WITH EXISTING LITERATURE

High-fidelity simulators are recognized for improving seafarer competency, situational awareness, and emergency decision-making [7] [5]. Prior studies indicate that structured simulator-based training enhances fault diagnosis accuracy and reduces decision-making errors in maritime operations [2] [15]. Our study extends this by integrating quantitative performance metrics with qualitative instructor insights, offering a more comprehensive evaluation than studies relying solely on self-reported outcomes.

Previous research has primarily emphasized technical proficiency in simulator-based training [8], while this study highlights the role of structured scenario-based debriefing in enhancing cognitive adaptability and skill retention. This approach is well established in aviation and has been applied in maritime simulation training, as discussed in structured simulator debriefings (Chapter 4.3). Our findings align with Bogusławski et al., who emphasize post-scenario reflections as key to optimizing procedural execution and long-term learning [18].

As also summarized in Figure 9, structured simulator-based training, when combined with targeted debriefing, significantly enhances:

- Crisis management and decision-making – Improved situational awareness and team coordination, aligning with STCW requirements [23] [6], with measurable performance gains in operational readiness.
- Skill transferability and learning retention – Empirical evidence confirms improved post-training task accuracy and faster execution times, further supporting the role of structured debriefing in adaptive learning, as demonstrated by Hjelmervik et al. and Hontvedt [2] [26].
- Cognitive workload optimization – High cognitive load initially led to errors in high-stress scenarios like manual generator synchronization, but structured training improved adaptability and reduced mistakes, as highlighted in the research of Hjelmervik et al. [2].

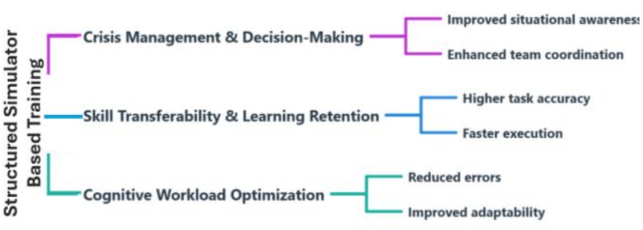

Figure 9. Key findings of this research aligned with the existing discussed literature

Our findings reinforce structured simulator training and debriefing as essential in maritime education, providing empirical evidence for its impact on competency development, knowledge retention, and decision-making efficiency.

While the simulator-based environment provided significant training value, it should be noted that it does not necessarily capture all real-world complexities, including rare but high-impact issues such as excitation problems and reactive power disparities. Furthermore, future simulator-based scenarios may incorporate more frequently encountered electrical issues such as excitation anomalies and load imbalance.

6 CONCLUSION

This study provides empirical evidence that Simulation-Based Training (SBT) significantly improves technical proficiency, decision-making accuracy, and situational awareness in ship electric load management. This study combines performance data with structured instructor feedback, offering a holistic view of trainee competency—an approach not thoroughly explored in existing literature.

The results reflect the study's original objectives by demonstrating clear improvements in task execution efficiency, competency development, and decision-making under emergency conditions. The ship engine room simulator demonstrated measurable gains in generators synchronization execution time, fault diagnosis, and manual emergency response efficiency. Evaluation criteria—such as execution accuracy, fault diagnosis response time, and procedural adherence—were consistently applied using simulator log data, instructor assessments, and pre/post-test comparisons, ensuring a structured and transparent performance analysis. By integrating structured simulator-driven training, participants developed adaptive cognitive skills, enhancing their ability to handle manual generator synchronization and emergency power transitions—competencies underrepresented in traditional MET.

Despite its advantages, integrating SBT into STCW-mandated training faces challenges. The absence of standardized simulator-based competency assessments limits formal skill evaluation, unlike aviation, where structured simulator assessments occur at fixed intervals. Additionally, simulator fidelity constraints restrict the full replication of real-world operational variability and stressors, affecting skill transferability.

Financial and infrastructural barriers further hinder accessibility. High-end simulators offer immersive learning but remain costly, limiting adoption in resource-constrained institutions. A scalable approach, including cloud-based platforms and modular training models, could expand accessibility while ensuring training quality. Cross-platform STCW-aligned competency assessments would promote standardized training outcomes.

Building on the current findings, future research may aim to integrate AI-driven performance analytics to further personalize simulation-based training (SBT) feedback. Additionally, developing a standardized rubric for simulator-based competency assessments across institutions could ensure greater consistency and comparability. Expanding this research to include cross-institutional cohorts would help validate the effectiveness of SBT on a larger scale.

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