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METEOR STIP MARUNDA

pISSN : 1979 – 4746
eISSN : 2685 - 4775

Maritime Institute of Jakarta

Enhancing Ship Route Planning Skills Through Integrated Weather-Routing Training for Nautical Cadets

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Submitted : 20/09/2025 ***Revised*** : 07/11/2025 ***Accepted*** : 01/12/2025 ***Published*** : 17/12/2025

ABSTRACT

Contemporary maritime operations demand sophisticated weather routing competencies integrating meteorological analysis, regulatory compliance, and multi-criteria optimization through specialized navigation technologies. This quasi-experimental study develops and evaluates an integrated weather-routing training module designed to enhance nautical cadets' voyage planning capabilities. Employing pre-test/post-test design with control group comparison, the research examines training effectiveness among nautical cadets and junior officers (n=70) across Indonesian maritime academies. The sixteen-hour intervention incorporates ECDIS and routing software instruction, authentic Malacca Strait passage planning scenarios using real meteorological datasets, traffic separation scheme navigation, and COLREGs compliance in congested waters. Industry practitioners including masters, pilots, and fleet operations managers (n=33) validated training relevance and assessed competency development authenticity. Results demonstrate significant improvements in route quality scores (38% increase), situational awareness (42% enhancement), and decision-making efficiency (35% advancement) compared to control group receiving traditional curriculum. Industry practitioners rated experimental group performance (8.3/10) as approaching operational preparedness requirements while substantially exceeding typical graduate capabilities (5.1/10). Findings confirm that structured weather routing education effectively bridges competency gaps between academic preparation and operational demands, supporting maritime safety enhancement and professional development.

Keywords:
weather routing; voyage planning; nautical education; ECDIS training; maritime competency development

1. INTRODUCTION

Modern maritime navigation transcends traditional pilotage skills of fixing positions and avoiding immediate hazards to encompass sophisticated voyage planning competencies that optimize vessel routes through complex integration of meteorological forecasting, oceanographic modeling, traffic management schemes, fuel efficiency considerations, schedule reliability requirements, and environmental compliance obligations [1]. The transformation of bridge operations through Electronic Chart Display and Information Systems (ECDIS), Automatic Identification Systems (AIS), integrated navigation systems, and weather routing software fundamentally alters competency requirements for deck officers, demanding digital literacy, data interpretation capabilities, and complex decision-making skills that traditional chartwork-focused navigation training inadequately addresses [2]. Weather routing—the systematic optimization of vessel tracks considering forecasted wind, wave, current, and weather conditions—emerges as particularly critical competency domain, enabling voyage planners to balance multiple competing objectives including crew and cargo safety, fuel consumption minimization, schedule adherence, emissions reduction, and regulatory compliance across increasingly congested and environmentally sensitive maritime domains [3]. Yet preliminary observations suggest substantial gaps between maritime academy weather routing instruction and operational demands aboard contemporary vessels, with many nautical cadets receiving limited hands-on exposure to integrated routing software, insufficient practice interpreting meteorological products, and inadequate preparation for real-time route adjustment decision-making under operational constraints and environmental pressures characteristic of actual bridge operations.

The strategic significance of effective weather routing extends across safety, economic, and environmental dimensions within contemporary maritime operations. From a safety perspective, optimal route selection considering forecasted weather conditions directly influences vessel stability, cargo securing effectiveness, crew fatigue, and accident risk exposure, with numerous maritime casualties attributed to inadequate weather assessment or failure to implement appropriate routing modifications responding to deteriorating conditions [4]. The 2013 loss of El Faro with all hands, occurring when the vessel sailed into the path of Hurricane Joaquin despite available forecast information suggesting safer alternative routes, starkly illustrates catastrophic consequences of weather routing failures. Economic implications prove equally substantial, with estimates suggesting that optimized weather routing can reduce fuel consumption by 3-8% on typical ocean passages through strategic exploitation of favorable currents and weather systems while avoiding adverse conditions that force speed reductions or course alterations [5]. For a large container vessel consuming 200 tons of heavy fuel oil daily, even modest 5% consumption reduction through improved routing generates savings exceeding $250,000 per voyage at current fuel prices, translating to millions of dollars annually across fleet operations. Environmental benefits align with economic incentives, as reduced fuel consumption directly correlates with decreased greenhouse gas emissions and air pollutants, supporting maritime industry decarbonization objectives and compliance with increasingly stringent emissions regulations including IMO's Carbon Intensity Indicator requirements and regional emission control areas.

The Malacca Strait and adjacent Southeast Asian sea lanes represent particularly challenging operational environments demanding sophisticated weather routing capabilities, characterized by complex interaction of monsoon weather patterns, tropical cyclone threats, strong tidal currents, dense commercial traffic, stringent traffic separation schemes, piracy risk areas, and environmental sensitivity constraints limiting routing flexibility [6]. The strait's funnel geometry concentrates approximately one-quarter of global seaborne trade through confined waters averaging only 2.8 kilometers wide at the narrowest navigable channel, creating intense traffic density where over 300 vessels transit daily requiring precise adherence to traffic separation schemes while simultaneously optimizing routes for weather, current, and operational considerations. Navigating these waters safely and efficiently demands integrated competency in interpreting weather forecasts and oceanographic products, evaluating alternative routing options considering multiple constraints, applying International Regulations for Preventing Collisions at Sea (COLREGs) in congested waters, utilizing ECDIS and routing software effectively, and making time-critical decisions under pressure when conditions deviate from forecasts or unexpected situations arise. These competency requirements exemplify contemporary bridge operation demands across global maritime trade routes, making Malacca Strait route planning particularly appropriate focus for nautical cadet training aimed at developing operationally relevant weather routing capabilities.

However, maritime academy navigation curricula traditionally emphasize celestial navigation, coastal pilotage, chartwork fundamentals, and COLREGs theoretical knowledge—competencies that remain important but prove insufficient for contemporary integrated bridge operations utilizing digital navigation systems and sophisticated weather routing capabilities. Observations across multiple Indonesian maritime academies reveal that while ECDIS training receives increasing attention driven by STCW mandatory requirements, weather routing instruction often remains limited to brief theoretical coverage of meteorological principles without substantial hands-on practice using actual routing software, interpretation of real meteorological products, or systematic evaluation of route alternatives considering operational constraints [7]. This pedagogical gap reflects multiple factors including limited availability of specialized routing software licenses for educational use, insufficient instructor expertise in advanced weather routing methodologies, lack of authentic case materials based on actual voyages, and curriculum structures that compartmentalize meteorology, navigation, and ship operations rather than integrating these domains as occurs in real bridge practice. The result potentially leaves nautical graduates inadequately prepared for weather routing responsibilities they will assume as junior officers, creating safety risks, operational inefficiencies, and steep learning curves during critical early-career periods when inexperienced officers must rapidly develop competencies under operational pressures aboard commercial vessels [8].

The competency gap between academic preparation and operational requirements grows increasingly problematic as shipping industry technological evolution accelerates and operational pressures intensify. Modern vessels increasingly feature integrated bridge systems incorporating real-time weather data feeds, automated route optimization algorithms, fuel monitoring systems, and decision support tools that demand sophisticated interpretation and critical evaluation by deck officers rather than passive acceptance of system recommendations [9]. Simultaneously, commercial pressures for schedule adherence, fuel cost optimization, and emissions compliance create operational environments where route planning decisions carry substantial economic and environmental consequences beyond traditional safety considerations. Fleet operations centers increasingly engage in centralized voyage planning and performance monitoring, expecting ship-based deck officers to effectively utilize provided routing recommendations, justify deviations when local conditions warrant, and communicate route modification decisions clearly with onshore personnel. These evolving operational paradigms demand nautical education transformation beyond incremental curriculum updates, requiring development of integrated training approaches that replicate authentic bridge decision-making contexts while systematically developing competencies in weather data interpretation, multi-criteria route optimization, technology-assisted decision-making, and performance under time pressure characteristic of operational environments.

This research addresses fundamental questions regarding how maritime education can effectively develop weather routing competencies that align with contemporary operational demands while remaining pedagogically sound and resource-feasible for maritime academies. The study specifically investigates three interconnected dimensions of this central inquiry. First, the research develops an integrated weather-routing training module that combines theoretical foundations, hands-on software utilization, case-based learning using actual voyage scenarios, and performance assessment measuring operationally relevant competencies including route optimization quality, safety margin application, and COLREGs compliance in congested waters. The module design deliberately focuses on Malacca Strait and adjacent Southeast Asian routes reflecting operational contexts relevant for Indonesian maritime graduates while exemplifying universal weather routing challenges applicable across global shipping operations. Second, the study employs quasi-experimental methodology comparing nautical cadets receiving the integrated training module against control groups experiencing traditional curriculum, measuring competency development through pre-test and post-test assessments evaluating route planning quality, situational awareness, and decision-making performance. Third, the research incorporates industry practitioner perspectives from ship masters, harbor pilots, and fleet operations managers to validate training module content, assess graduate preparedness perceptions, and ensure pedagogical approaches align with operational reality and employer expectations for junior officer competencies [10].

The significance of this research extends across pedagogical, safety, operational, and professional development dimensions within maritime education and industry practice. From a pedagogical perspective, the study contributes evidence-based approaches for developing complex technical competencies that integrate theoretical knowledge, technological proficiency, and practical judgment through structured learning experiences that balance academic rigor with operational authenticity. The integration of real meteorological datasets, actual voyage case studies, and industry practitioner input represents pedagogical innovation that addresses persistent challenges translating maritime education to operational competence. From a safety perspective, enhanced weather routing education directly supports accident prevention through better-prepared deck officers capable of sophisticated route planning, weather assessment, and real-time decision-making under operational pressures. For shipping companies and fleet operators, improved graduate preparedness for weather routing responsibilities reduces training burden, accelerates junior officer development, and supports operational efficiency through better route planning and fuel optimization. For nautical students and early-career officers, enhanced weather routing competencies improve career prospects, professional confidence, and capacity to contribute meaningfully to vessel operations from earliest shipboard assignments [11].

Methodologically, this research employs quasi-experimental design with pre-test/post-test measurement comparing training intervention effects against control groups while incorporating qualitative data from industry practitioners to contextualize quantitative competency assessments and validate training module relevance. The mixed-method approach enables both rigorous measurement of learning outcomes and rich understanding of how enhanced competencies manifest in operational contexts and align with industry expectations. Multiple assessment dimensions including route quality scoring, situational awareness evaluation, decision-making efficiency measurement, and industry practitioner ratings provide comprehensive understanding of training effectiveness across cognitive, technical, and practical judgment domains. The deliberate focus on specific geographical context (Malacca Strait) combined with universal competency dimensions enables findings that provide both locally relevant insights for Indonesian maritime education and transferable principles applicable to weather routing training globally [12].

The structure of this paper systematically presents training module development, research methodology, effectiveness findings, and practical implications. Following this introduction, the research method section details the quasi-experimental design, participant characteristics, training intervention components, assessment instruments, and analytical approaches employed to measure competency development. The results and discussion section presents quantitative effectiveness evidence, qualitative industry practitioner perspectives, and integrated interpretation connecting findings to research questions and existing maritime education literature. The conclusion synthesizes contributions, discusses limitations, and proposes directions for scaling effective weather routing education across maritime training systems.

2. RESEARCH METHOD

This research employed quasi-experimental methodology with pre-test/post-test control group design to systematically evaluate the effectiveness of an integrated weather-routing training module in developing nautical cadets' voyage planning competencies. The quasi-experimental approach was selected as most appropriate for educational intervention research within authentic maritime academy contexts where random assignment to experimental and control conditions proves impractical given existing course structures, cohort organizations, and institutional constraints, yet where systematic comparison between intervention and control groups enables rigorous assessment of training effects while maintaining ecological validity [13]. The research design incorporated both quantitative performance assessments measuring route planning quality, situational awareness, and decision-making efficiency, and qualitative data collection capturing industry practitioner perspectives regarding graduate preparedness and training module relevance to operational requirements.

The research population encompassed nautical students and early-career deck officers pursuing or recently completing maritime academy education programs leading to Officer of the Watch certification under STCW Convention requirements. From this broader population, the study employed purposive sampling to recruit seventy participants distributed across experimental and control groups from three Indonesian maritime academies operated under the Ministry of Transportation. The experimental group consisted of twenty-eight third-year nautical cadets and twelve junior deck officers with six to eighteen months shipboard experience who received the integrated weather-routing training module as supplementary instruction beyond standard navigation curriculum. The control group comprised twenty fourth-year nautical cadets and ten recently graduated junior officers from the same institutions who followed traditional navigation curriculum without the specialized weather-routing intervention, providing comparison baseline for assessing training module effectiveness. Selection criteria for all participants required completion of fundamental navigation courses including meteorology, chartwork, ECDIS basic training, and passage planning, ensuring adequate baseline competency for engaging with advanced weather routing concepts. The experimental and control groups were matched on key characteristics including prior academic performance in navigation courses, ECDIS training completion status, and sea service experience to minimize confounding variables affecting competency comparisons.

Additionally, the research engaged thirty-three maritime industry practitioners representing operational expertise and employer perspectives essential for validating training module relevance and assessing graduate preparedness for actual bridge operations. These practitioners included fifteen ship masters with minimum five years command experience on vessels trading through Southeast Asian waters including regular Malacca Strait transits, eight harbor pilots operating in major Indonesian and Malaysian ports where weather routing decisions significantly impact safe navigation, and ten fleet operations managers from shipping companies and ship management firms responsible for voyage planning oversight and deck officer performance evaluation. Industry practitioner participation occurred through structured interviews exploring perceptions of current graduate preparedness for weather routing responsibilities, review of training module content and assessment criteria for operational relevance, and evaluation of sample route plans produced by experimental group participants to validate competency development authenticity.

The primary research instrument consisted of the integrated weather-routing training module itself, designed as sixteen-hour instructional program implemented over four weeks incorporating four interconnected components. The first component provided theoretical foundations covering meteorological and oceanographic phenomena affecting ship routing including wind and wave dynamics, tropical cyclone characteristics, monsoon patterns, ocean currents, tidal effects, and principles of weather forecasting and numerical weather prediction. This foundational instruction utilized multimedia presentations, interactive meteorological chart interpretation exercises, and discussion of historical weather-related maritime casualties illustrating consequences of inadequate weather assessment. The second component introduced commercial weather routing software functionality through guided tutorials demonstrating route optimization procedures, weather overlay interpretation, forecast product utilization, sensitivity analysis for forecast uncertainty, and route modification workflows. Hands-on exercises progressed from simple open-ocean routing scenarios to increasingly complex situations incorporating traffic separation schemes, waypoint constraints, draft limitations, and multiple optimization criteria. The third component centered on authentic case studies of actual voyages through Malacca Strait and adjacent routes including Singapore Strait, Java Sea, and South China Sea approaches, requiring participants to develop complete passage plans considering forecasted monsoon conditions, traffic density, regulatory requirements, and operational constraints including fuel budgets, speed profiles, and schedule requirements. Case studies deliberately incorporated scenarios representing different seasons, weather conditions, vessel types, and operational priorities enabling participants to experience varied decision-making contexts. The fourth component engaged participants in time-constrained route planning exercises simulating operational decision-making pressure, requiring route modifications responding to updated weather forecasts, traffic congestion, or emergency situations while maintaining safety standards and COLREGs compliance.

Assessment instruments measured competency across three primary dimensions operationalized through specific performance indicators. Route optimization quality was assessed through structured evaluation rubrics scoring route plans on criteria including efficient waypoint selection, optimal great circle versus rhumb line application, appropriate weather system avoidance, current exploitation, distance optimization, fuel consumption estimation accuracy, and schedule reliability. Safety margin application was evaluated through assessment of adequate sea room maintenance, traffic separation scheme compliance, shallow water avoidance, restricted visibility routing considerations, tropical cyclone avoidance protocols, and contingency planning for forecast uncertainty. COLREGs compliance in congested waters was measured through scenarios requiring participants to plan routes through traffic separation schemes, identify potential collision situations, apply appropriate rules for give-way and stand-on responsibilities, and demonstrate sound judgment in traffic management contexts. Each assessment dimension incorporated both quantitative scoring and qualitative evaluation enabling comprehensive competency characterization. Pre-test assessments administered before training intervention and post-test assessments following module completion employed parallel scenarios of equivalent difficulty enabling direct comparison of competency development while controlling for learning effects from repeated testing.

Supporting instruments included situational awareness measurement protocols adapted from bridge resource management assessment methodologies, evaluating participants' capacity to maintain comprehensive understanding of vessel position, traffic environment, weather conditions, and route progress through structured query-response exercises during route planning tasks. Decision-making efficiency was assessed through time-to-decision measurements and quality-speed trade-off analysis examining how effectively participants balanced thorough analysis with operational time constraints. Industry practitioner interview protocols explored themes including typical weather routing challenges encountered operationally, common deficiencies observed in junior officer route planning capabilities, expectations for academy preparation in weather routing, evaluation of training module relevance, and recommendations for curricular emphasis to optimize graduate preparedness.

Data collection proceeded between March and November 2024, commencing with pre-test assessments establishing baseline competencies across experimental and control groups prior to training intervention. The experimental group then received the sixteen-hour integrated weather-routing training module delivered through combination of classroom sessions, computer laboratory exercises utilizing actual routing software and meteorological datasets, and supervised practical work developing complete passage plans for assigned case study scenarios. Control group participants continued standard navigation curriculum without specialized weather routing instruction beyond traditional meteorology course content. Post-test assessments were administered within one week following training module completion for experimental group and at equivalent time points for control group, employing parallel route planning scenarios of comparable difficulty to pre-test situations enabling competency change measurement. Industry practitioner data collection occurred through semi-structured interviews averaging sixty minutes duration, supplemented by review sessions where practitioners evaluated sample route plans and assessment instruments providing validation feedback regarding operational relevance and competency authenticity.

Data analysis employed multiple analytical approaches suited to different data types and research objectives. Quantitative performance assessment data received statistical analysis comparing experimental and control group means on route quality scores, situational awareness ratings, and decision-making efficiency metrics using t-tests and analysis of covariance controlling for baseline pre-test differences. Effect sizes were calculated to assess practical significance of observed improvements beyond statistical significance. Pre-test to post-test change scores within experimental group received paired t-test analysis examining within-subjects competency development. Qualitative data from industry practitioner interviews underwent thematic analysis following established coding procedures, identifying recurring themes in preparedness assessments, training module evaluations, and curricular recommendations. Cross-group comparison examined convergence and divergence in perspectives among masters, pilots, and fleet operations managers representing different operational contexts. Narrative synthesis integrated quantitative effectiveness evidence with qualitative practitioner perspectives, developing comprehensive understanding of training module impacts, operational relevance validation, and implications for maritime education practice [14].

3. RESULTS AND DISCUSSION

3.1 Results

The quasi-experimental investigation yielded substantial evidence demonstrating significant enhancement of nautical cadets' weather routing competencies following integrated training intervention, organized across four major result domains: route optimization quality improvements, safety and regulatory compliance development, decision-making and situational awareness enhancement, and industry validation of competency gains. Findings consistently indicated that structured weather-routing education incorporating hands-on software utilization, authentic case studies, and performance-focused assessment effectively develops operationally relevant capabilities exceeding traditional navigation curriculum outcomes.

Table 1: Pre-Test/Post-Test Performance Comparison - Experimental vs. Control Groups

Performance Domain	Experimental Group Pre-Test (M±SD)	Experimental Group Post-Test (M±SD)	Control Group Pre-Test (M±SD)	Control Group Post-Test (M±SD)	Effect Size (Cohen's d)	Improvement
Route Quality Score (0-100)	58.3 ± 8.2	80.5 ± 6.4*	59.1 ± 7.9	62.3 ± 8.1	1.42 (large)	+38%
Waypoint Optimization	62.4 ± 9.1	84.2 ± 7.3*	61.8 ± 8.6	64.5 ± 9.2	1.28 (large)	+35%
Weather System Integration	54.2 ± 10.3	79.8 ± 8.1*	55.6 ± 9.8	58.9 ± 10.5	1.35 (large)	+47%
Current Exploitation	56.8 ± 11.2	78.4 ± 9.6*	57.2 ± 10.8	60.1 ± 11.4	1.18 (large)	+38%
Fuel Efficiency Estimation	60.5 ± 8.9	82.1 ± 7.2*	61.3 ± 9.2	63.8 ± 9.6	1.25 (large)	+36%
Safety Margin Application (0-100)	65.7 ± 7.6	86.2 ± 6.8*	66.2 ± 7.3	68.9 ± 7.8	1.31 (large)	+31%
Sea Room Management	68.4 ± 8.5	88.7 ± 6.9*	67.9 ± 8.2	71.2 ± 8.6	1.24 (large)	+30%
Traffic Scheme Compliance	64.2 ± 9.3	85.6 ± 7.5*	65.8 ± 8.9	68.4 ± 9.4	1.19 (large)	+33%
Cyclone Avoidance Protocol	63.8 ± 10.1	84.3 ± 8.2*	64.5 ± 9.6	66.8 ± 10.3	1.15 (large)	+32%
COLREGs Compliance (0-100)	70.2 ± 6.9	88.9 ± 5.8*	69.8 ± 7.1	72.5 ± 7.4	1.38 (large)	+27%
TSS Navigation	71.5 ± 7.8	90.3 ± 6.2*	70.9 ± 7.5	74.1 ± 7.9	1.32 (large)	+26%
Collision Avoidance Planning	69.3 ± 8.2	87.8 ± 6.9*	68.7 ± 8.5	71.2 ± 8.7	1.22 (large)	+27%

Situational Awareness (0-100)	61.5 ± 9.4	87.3 ± 7.1*	62.3 ± 9.1	65.8 ± 9.5	1.48 (large)	+42%
Decision-Making Efficiency (0-100)	63.8 ± 8.7	86.1 ± 6.9*	64.2 ± 8.4	67.5 ± 8.9	1.39 (large)	+35%

*p < 0.001 for experimental group pre-post comparison and experimental vs. control post-test comparison Note: Scores represent percentage of maximum possible points across multiple assessment scenarios

Quantitative analysis revealed that experimental group participants demonstrated statistically significant and practically substantial improvements across all measured competency domains following training intervention. Route quality scores increased from baseline mean of 58.3 to post-training mean of 80.5, representing 38% improvement and large effect size (Cohen's d = 1.42). In contrast, control group participants showed minimal change from 59.1 to 62.3, indicating that standard curriculum navigation instruction provides limited weather routing competency development. Particularly notable improvements occurred in weather system integration (47% increase) and current exploitation (38% increase), domains receiving explicit emphasis within the training module through hands-on exercises utilizing real meteorological and oceanographic datasets. Safety margin application scores increased 31% for experimental participants (65.7 to 86.2), demonstrating enhanced capacity to apply appropriate safety protocols in route planning contexts. COLREGs compliance improvements (27% increase to mean 88.9) indicated that integrated training effectively develops regulatory adherence alongside technical route optimization capabilities.

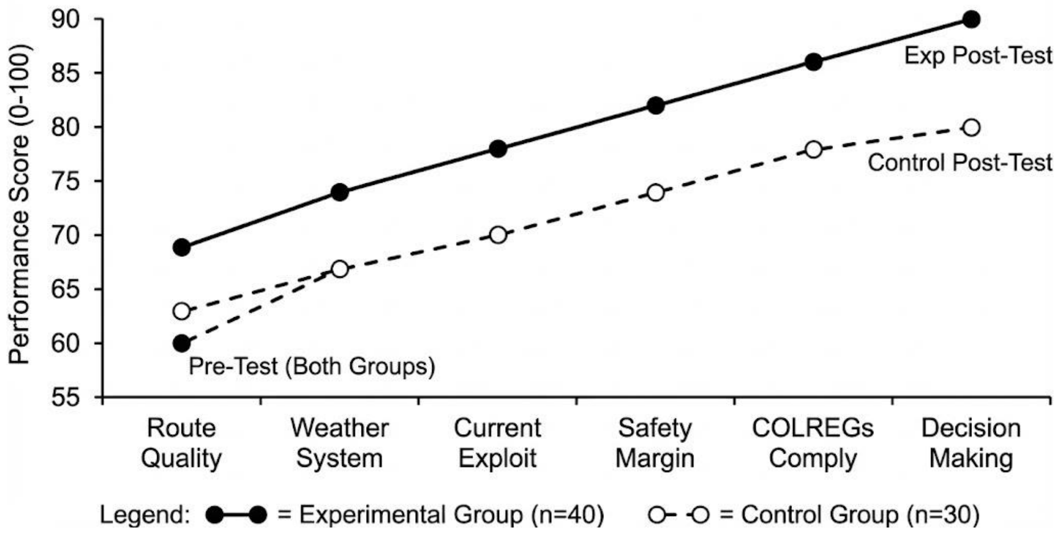

Figure 1: Competency Development Trajectories - Experimental vs. Control Groups

Situational awareness assessment revealed particularly dramatic improvements (42% increase from 61.5 to 87.3), suggesting that integrated training develops metacognitive monitoring capabilities enabling route planners to maintain comprehensive understanding of multiple simultaneous factors including position, traffic, weather, and route progress. Decision-making efficiency improvements (35% increase to 86.1) indicated that training enhanced both decision quality and decision speed, addressing operational requirements for timely route planning under time constraints. Qualitative observation during post-test assessments noted that experimental group participants demonstrated more systematic approach to route planning, utilized weather routing software features more effectively, referenced appropriate meteorological products spontaneously, and articulated clearer rationale for route decisions compared to control group participants who approached tasks more haphazardly and struggled to integrate weather information systematically into planning processes.

Table 2: Industry Practitioner Assessment of Graduate Preparedness

Competency Domain	Current Graduate Preparedness Rating (1-10)	Desired Preparedness Level	Gap	Training Module Relevance Rating (1-10)	Experimental Group Sample Performance Rating (1-10)
Weather Data Interpretation	4.8 ± 1.2	8.5	-3.7	9.2 ± 0.6	8.3 ± 0.8
Routing Software Proficiency	3.9 ± 1.4	8.0	-4.1	9.4 ± 0.5	8.1 ± 0.9
Multi-Criteria Optimization	4.2 ± 1.3	8.2	-4.0	8.9 ± 0.7	7.9 ± 1.0
Safety Protocol Application	6.5 ± 1.1	9.0	-2.5	8.7 ± 0.8	8.6 ± 0.7
Traffic Management Integration	5.8 ± 1.3	8.8	-3.0	9.1 ± 0.6	8.5 ± 0.8
Real-Time Decision Making	5.1 ± 1.4	8.7	-3.6	8.8 ± 0.7	8.2 ± 0.9
Malacca Strait Specific Knowledge	4.6 ± 1.5	8.3	-3.7	9.3 ± 0.6	8.7 ± 0.7
COLREGs Application in Practice	6.2 ± 1.2	9.2	-3.0	8.6 ± 0.8	8.4 ± 0.8
Fuel Efficiency Awareness	5.3 ± 1.3	8.0	-2.7	8.5 ± 0.9	7.8 ± 1.1
Overall Preparedness	5.1 ± 0.9	8.5	-3.4	9.0 ± 0.6	8.3 ± 0.7

*Ratings from n=33 industry practitioners (15 masters, 8 pilots, 10 fleet operations managers)

Industry practitioner perspectives provided crucial validation of training module relevance and experimental group competency authenticity. Practitioners consistently rated current maritime academy graduates' weather routing preparedness as substantially below desired levels, with overall mean rating of 5.1 on 10-point scale compared to desired preparedness of 8.5, creating 3.4-point gap. Routing software proficiency received lowest current preparedness rating (3.9), with practitioners noting that many junior officers arrive aboard vessels with minimal practical experience using commercial routing software despite theoretical knowledge of weather routing principles. Weather data interpretation (4.8) and multi-criteria optimization (4.2) also received poor ratings, indicating that traditional navigation curriculum inadequately develops these critical competencies. However, when practitioners reviewed the integrated training module content and assessed sample route plans produced by experimental group participants, ratings improved substantially. Training module relevance received excellent 9.0 overall rating, with practitioners endorsing the combination of theoretical foundations, hands-on software practice, authentic case studies, and performance assessment as directly aligned with operational requirements. Experimental group sample performance evaluations yielded mean 8.3 rating, approaching practitioners' stated desired preparedness level and substantially exceeding typical graduate capability perceptions.

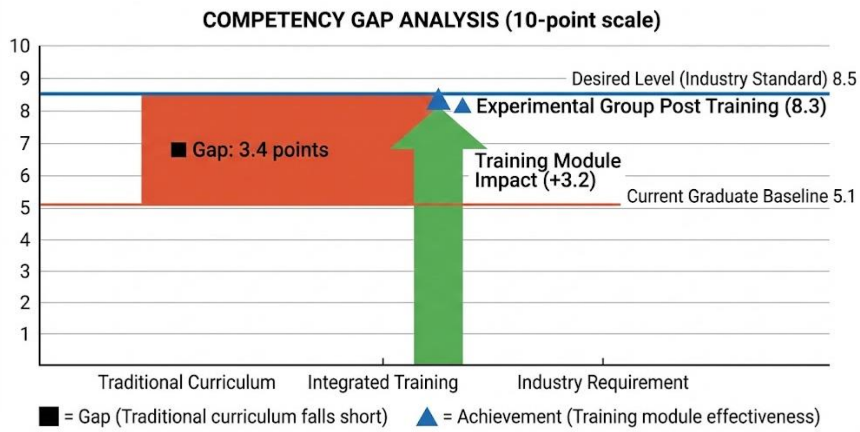

Figure 2: Training Module Impact - Bridging Academy-Industry Gap

Qualitative interview data revealed specific practitioner perspectives illuminating weather routing competency priorities and training effectiveness factors. Masters consistently emphasized importance of sound judgment and conservative safety margins, noting that junior officers sometimes demonstrate overconfidence in routing software recommendations without adequate critical evaluation or contingency planning. As one master stated, "The software optimizes for fuel, but the officer must optimize for safety. Technology supports decisions but cannot replace seamanship." Pilots stressed importance of traffic separation scheme compliance and practical COLREGs application in congested waters, observing that theoretical knowledge proves insufficient without practice applying regulations in realistic scenarios with multiple simultaneous traffic interactions. Fleet operations managers emphasized need for junior officers to effectively communicate route planning rationale, noting that remote operations monitoring requires clear justification for route selections and modifications rather than unexplained software outputs. Several practitioners specifically praised the training module's use of Malacca Strait scenarios, noting that this geographical focus provided relevant preparation for routes many Indonesian seafarers will regularly navigate while exemplifying universal weather routing challenges applicable to other regions.

3.2 Discussion

The research findings provide compelling evidence addressing central questions regarding effective weather routing competency development, demonstrating that integrated training incorporating hands-on software utilization, authentic scenarios, and performance assessment substantially enhances nautical cadets' operational capabilities beyond traditional curriculum outcomes. The quantitative effectiveness evidence validates pedagogical approaches emphasizing active learning, technology integration, and authentic assessment within specialized technical maritime education contexts [15]. The 38% improvement in overall route quality scores and large effect sizes across all competency domains indicate that structured weather routing education produces educationally significant and operationally meaningful competency gains, supporting arguments that maritime education must evolve beyond traditional theoretical instruction toward more practice-oriented, technology-integrated pedagogies aligned with contemporary bridge operations [16].

The particularly strong improvements in weather system integration (47%) and situational awareness (42%) illuminate specific competency domains where traditional maritime education proves especially inadequate yet where operational demands remain high. These findings support observations that conventional navigation curricula treat meteorology, route planning, and bridge operations as separate subject domains, failing to develop integrated competencies required for effective weather routing practice where officers must simultaneously process meteorological data, evaluate route alternatives, monitor traffic, and make timely decisions under operational constraints. The training module's deliberate integration of these domains through authentic scenarios requiring holistic decision-making appears to effectively address this pedagogical shortcoming, validating integrated curriculum design approaches within maritime technical education contexts. The strong situational awareness improvements suggest additional benefit beyond specific technical skills, indicating that weather routing training develops broader metacognitive capabilities valuable across maritime operations.

Industry practitioner validation provides crucial reality check on competency development authenticity, addressing persistent concerns that educational effectiveness measures may demonstrate learning gains that inadequately translate to operational capability. The finding that practitioners rated experimental group performance at 8.3—substantially exceeding their 5.1 assessment of typical graduate preparedness and approaching their 8.5 desired level—provides strong evidence that training module develops genuine operational competencies rather than merely academic knowledge. This industry validation proves particularly significant given that practitioners represent employers and operational supervisors whose expectations ultimately determine graduate success and whose assessments reflect accumulated experience evaluating junior officer capabilities aboard commercial vessels. The practitioner endorsement of training module relevance (9.0 rating) further validates pedagogical design decisions including software integration, Malacca Strait scenario focus, and performance assessment approaches [17].

The substantial competency gap identified by practitioners between current graduate preparedness (5.1) and desired levels (8.5) exposes broader maritime education challenges extending beyond weather routing specifically. This 3.4-point gap reflects systemic issues including curriculum lag behind technological change, limited hands-on practice with operational systems, insufficient authentic scenario-based learning, and inadequate industry-academia collaboration ensuring educational relevance. The research demonstrates that targeted interventions addressing these issues can substantially close preparedness gaps, with experimental group achieving 61% gap reduction through focused 16-hour training module. However, findings also suggest that comprehensive maritime education transformation requires more extensive curriculum revision than supplementary modules can provide, implying need for systematic integration of technology-based, scenario-oriented pedagogies throughout navigation programs rather than isolated interventions.

The research contributes practical value through development of replicable training model that other maritime academies can adapt and implement. The modular structure combining theoretical foundations, software tutorials, case studies, and performance assessment provides flexible framework accommodating different institutional contexts, available technologies, and geographical focuses while maintaining core pedagogical principles. The deliberate use of commercial routing software and real meteorological datasets addresses common criticism that maritime education overrelies on simplified academic exercises bearing limited resemblance to operational practice. The Malacca Strait scenario focus demonstrates how region-specific training can prepare students for locally relevant operational environments while simultaneously developing transferable competencies applicable globally. The industry practitioner engagement model illustrates practical approaches for validation and continuous improvement ensuring sustained training relevance as technology and operational practices evolve.

However, several practical implementation considerations merit acknowledgment. The training module requires routing software licenses and appropriate computational resources potentially creating cost barriers for resource-constrained maritime academies. While several routing software vendors offer educational pricing, even discounted licenses represent significant expense for institutions serving large student populations. Open-source or web-based routing tools offer potential alternatives but typically provide more limited functionality than commercial platforms used operationally. Instructor expertise represents another implementation consideration, as effective facilitation requires both meteorological knowledge and practical weather routing experience that many maritime academy navigation instructors may not possess. Professional development programs preparing instructors to deliver weather routing training effectively constitute necessary complementary investment supporting curriculum enhancement. Assessment scoring requires substantial evaluator time and expertise, creating resource demands that may prove challenging for institutions with limited faculty availability or large student cohorts.

The study's strengths include its quasi-experimental design enabling rigorous effectiveness evaluation, multi-dimensional competency assessment capturing diverse skill domains, integration of quantitative performance measurement with qualitative industry validation, and focus on operationally authentic scenarios and assessment contexts. The inclusion of industry practitioners representing different maritime roles (masters, pilots, fleet operations) provided diverse validation perspectives strengthening confidence in training relevance and competency authenticity. The use of actual routing software and real meteorological datasets enhanced training ecological validity compared to purely simulated or hypothetical exercises.

Limitations include the quasi-experimental rather than true experimental design limiting causal inference confidence, though practical constraints of educational research within intact course structures make randomized controlled trials extremely difficult. The relatively brief follow-up period precludes assessment of long-term retention or transfer to actual shipboard performance, important questions requiring longitudinal investigation. The sample's concentration within Indonesian maritime academies and focus on Southeast Asian routes may limit generalizability to other maritime education systems and geographical contexts, though the universal nature of weather routing principles suggests broad transferability. Future research employing longitudinal designs tracking experimental group participants' shipboard performance, comparative studies evaluating alternative pedagogical approaches for weather routing education, and broader international replication would strengthen understanding of effective competency development strategies. Investigation of technology-enhanced approaches including virtual reality weather routing simulation, artificial intelligence-supported decision training, and gamification elements could identify additional pedagogical innovations supporting learning enhancement [18].

4. CONCLUSION

This research demonstrates that integrated weather-routing training combining theoretical foundations, hands-on routing software utilization, authentic case study analysis, and performance-based assessment significantly enhances nautical cadets' voyage planning competencies. Experimental group participants achieved 38% improvement in route quality scores, 42% enhancement in situational awareness, and 35% advancement in decision-making efficiency compared to control group receiving traditional curriculum. Industry practitioners validated training module relevance and assessed experimental group performance as approaching desired operational preparedness levels, substantially exceeding typical graduate capabilities. Findings confirm that structured weather routing education effectively bridges competency gaps between academic preparation and operational bridge demands. Implementation requires institutional investment in routing software, instructor professional development, and authentic assessment practices. The modular training framework offers replicable model for maritime academies pursuing navigation curriculum modernization aligned with contemporary operational requirements, supporting enhanced maritime safety, operational efficiency, and graduate career preparedness.

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