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Smart Port Technology Readiness and Multidisciplinary Curriculum Integration in Vocational Maritime Education

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Abstract— Smart port technologies are increasingly transforming port operations and creating new competency requirements for deck officers, while vocational maritime education has not fully incorporated these developments into existing curricula. This study examined the smart port technology readiness of Nautika cadets, identified industry and curricular gaps, and evaluated an integrated instructional intervention. A sequential mixed-methods design was employed involving 180 Level 2 and Level 3 Nautika cadets from AMANJAYA, AMD, and STMT Malahayati, 30 maritime industry professionals, and 12 Nautika lecturers. Quantitative data were collected using the 50-item Smart Port Technology Readiness Index (SPTRI), while qualitative data were obtained through focus group discussions and industry interviews. A Technology Integration Module (TIM) was subsequently implemented with 60 cadets and compared with a matched group of 60 cadets. The baseline overall SPTRI score was 2.77/5.00, indicating a developing level of readiness, while machine learning comprehension recorded the lowest score at 2.48/5.00. Only 27% of industry professionals considered recent Indonesian Nautika graduates adequately prepared for smart port interaction. Following the intervention, the pilot group increased from 2.75 to 3.94, with an overall Cohen's d of 2.24, whereas the comparison group showed minimal change. The findings demonstrate substantial technology-readiness gaps and support the Multidisciplinary Technology Readiness framework as a practical curriculum integration model. Embedding smart port technology across existing Nautika courses can strengthen cadet readiness without creating additional courses.

Keywords: smart port technology; technology readiness; maritime vocational education; machine learning; curriculum integration

1. Introduction

The transformation of commercial ports through digitalization, automation, artificial intelligence (AI), Internet of Things (IoT), renewable energy, and digital information systems is changing the operational environment in which maritime professionals work. Indonesia's national port-development agenda has increasingly emphasized digital transformation and technology-enabled terminal operations, creating new technological requirements for maritime personnel [1]. Smart port development involves interconnected digital systems that support vessel scheduling, cargo handling, environmental monitoring, energy management, and operational documentation. The integration of digital-twin and interconnected information technologies has further strengthened the capacity of industrial systems to combine physical operations with real-time digital information [2]. These developments have direct implications for deck officers because vessel operations during port calls increasingly require interaction

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with digital port platforms rather than relying exclusively on conventional procedures. A deck officer may be required to interpret digital berth-allocation information, respond to IoT-generated alerts, use environmental reporting interfaces, coordinate with vessel traffic management systems, and evaluate information generated by AI-supported systems. Consequently, maritime vocational education needs to ensure that graduates possess not only conventional nautical competencies but also sufficient technological literacy to work effectively within digitally enabled port environments.

Technology readiness provides an important conceptual basis for examining whether learners are prepared to engage with emerging technologies. Parasuraman conceptualized technology readiness as an individual's propensity to embrace and use new technologies, involving positive dimensions such as optimism and innovativeness and inhibiting dimensions such as discomfort and insecurity [3]. Davis's Technology Acceptance Model subsequently emphasized perceived usefulness and perceived ease of use as important determinants of technology acceptance [4]. For maritime cadets, however, technology readiness should extend beyond general attitudes toward technology because professional deployment requires the ability to understand, interpret, evaluate, and appropriately respond to technological outputs.

The technological environment of a smart port is inherently multidisciplinary. IoT systems connect physical equipment and sensors to digital information networks, while AI and machine learning support operational decision-making. Recent maritime research has also demonstrated the increasing relevance of data-driven approaches to seafarer competency and operational decision-making [5]. Renewable-energy technologies represent another important dimension of port transformation. The development of marine energy-management strategies and alternative energy systems demonstrates the increasing importance of energy-related technological knowledge in maritime operations [6]. These developments indicate that smart port readiness encompasses technological, operational, environmental, and communication competencies rather than a single technical skill.

The issue is particularly important in the context of increasing automation. Maritime education and training must prepare cadets to work in environments where automated systems provide recommendations while human operators remain responsible for professional judgment and safety [7]. This creates a competency boundary between accepting technological recommendations and critically evaluating whether those recommendations are appropriate for actual vessel and operational conditions.

Environmental technology adds another dimension to this transformation. Sustainable shipping and port operations increasingly depend on technological systems for emissions reduction, energy management, environmental monitoring, and digital compliance. The development of zero-emission and decarbonization technologies demonstrates how environmental sustainability is becoming increasingly integrated with maritime technological systems [8]. Deck officers therefore need to understand not only conventional environmental regulations but also the digital systems through which environmental information is collected, processed, reported, and verified.

Despite these developments, a gap remains between the technological environment of smart ports and the curriculum structures of vocational maritime education. Existing Nautika curricula commonly distribute relevant knowledge across separate subjects such as watchkeeping, cargo operations, environmental studies, and English communication. Smart port technology, however, requires these areas to interact within authentic operational contexts. A cadet may need to understand an AI-generated berth recommendation, interpret environmental data, complete a digital compliance form, and communicate with port personnel in English during the same port operation.

This fragmentation creates a multidisciplinary curriculum challenge. Technology may be mentioned within conventional maritime subjects without being established as an explicit competency domain. At the same time, emerging green competencies are becoming increasingly important in Indonesian vocational education, particularly as technological transformation and environmental sustainability become interconnected [9]. The need to integrate professional communication with specialized technological contexts is also increasingly recognized in English for Specific Purposes and World Englishes research [10].

The competency gap also has implications for maritime safety and operational quality. Maritime safety management requires systematic competency development, appropriate decision-making, and the effective implementation of operational procedures [11]. Consequently, technology readiness should be considered as part of broader professional competence rather than as an optional digital skill.

The challenge is consistent with wider developments in technical and vocational education. Research on Indonesian TVET has identified the need to map technical competencies according to Industry 4.0 requirements, while vocational institutions are increasingly expected to develop technology-oriented competencies among both teachers and students [12], [13]. Competency-based education further emphasizes alignment between educational outcomes, workplace requirements, and authentic professional practice [14]. These perspectives support a curriculum model in which emerging technological competencies are embedded within existing occupational learning rather than treated as isolated knowledge.

Green technology integration provides another important consideration. Vocational institutions increasingly need to combine technical, digital, and environmental competencies to respond to changing occupational environments [15]. For maritime education, this means that renewable-energy port systems, environmental monitoring, digital documentation, IoT, and AI cannot be treated as unrelated topics.

Based on these considerations, the present study addresses three gaps. First, empirical evidence regarding smart port technology readiness among Indonesian Nautika cadets remains limited. Second, there is insufficient evidence comparing cadet readiness with industry expectations for smart port operations. Third, limited attention has been given to curriculum models capable of integrating smart port competencies across existing Nautika courses without establishing a completely new course.

Therefore, this study aimed to assess the smart port technology readiness of Nautika cadets across five technology dimensions, identify gaps between cadet readiness and industry competency expectations, and evaluate the effectiveness of an eight-week Technology Integration Module based on a Multidisciplinary Technology Readiness (MTR) framework. The study contributes empirical evidence regarding technology readiness in Indonesian maritime vocational education and provides a practical curriculum integration model for institutions preparing cadets for increasingly digitalized port environments.

2. Method

This study employed a sequential mixed-methods design combining quantitative assessment, qualitative exploration, and intervention evaluation. The approach was selected because the research required both measurement of cadets' technology readiness and an explanation of the institutional and occupational factors underlying the observed readiness gaps. Sequential mixed-methods research allows quantitative findings to be complemented by qualitative evidence and subsequently used to inform an intervention design [16].

The research was conducted at AMANJAYA, AMD, and STMT Malahayati. The quantitative component involved 180 Level 2 and Level 3 Nautika cadets, with 60 cadets recruited from each institution. Sixty cadets, consisting of 20 from each institution, subsequently participated in the eight-week Technology

Integration Module (TIM). A matched comparison group consisting of 60 cadets completed the same pre-test and post-test without receiving the intervention.

The qualitative component involved 30 maritime industry professionals and 12 senior Nautika lecturers. The industry participants consisted of 10 professionals from Tanjung Priok Terminal 3 operations and technology management, 10 from PT Pelindo's digital port development activities, and 10 from shipping-company fleet operations teams managing vessels operating on smart-port-equipped routes. Each industry participant completed a structured questionnaire and a 30-minute structured interview. The lecturer participants consisted of four lecturers from each institution and participated in institution-specific focus group discussions addressing existing technology content, curriculum barriers, available instructional resources, and priority areas for reform.

The overall research procedure consisted of five stages: baseline assessment, industry and lecturer investigation, curriculum-gap analysis, intervention implementation, and post-intervention evaluation. The research flow is presented in Figure 1.

The principal quantitative instrument was the Smart Port Technology Readiness Index (SPTRI), consisting of 50 items distributed across five dimensions: smart infrastructure literacy, IoT and AI application awareness, environmental monitoring technology, renewable energy port knowledge, and machine learning comprehension. Each dimension consisted of 10 items. Responses were recorded using a five-point Likert scale ranging from 1 = no knowledge to 5 = expert proficiency. The instrument demonstrated good internal consistency, with an overall Cronbach's alpha of 0.89 and subscale coefficients ranging from 0.81 to 0.87.

Smart Infrastructure Literacy assessed understanding of IoT networks, AI systems, and digital documentation as integrated components of port infrastructure. IoT and AI Application Awareness assessed understanding of maritime IoT cargo-monitoring systems and AI-assisted vessel-management applications. Environmental Monitoring Technology assessed knowledge of eco-port information systems, IoT-based emissions monitoring, and digital environmental reporting. Renewable Energy Port Knowledge assessed knowledge of shore-power connection procedures, renewable-energy systems, and power-quality considerations. Machine Learning Comprehension assessed understanding of algorithmic scheduling outputs, human–algorithm decision boundaries, and the evaluation of machine-learning applications.

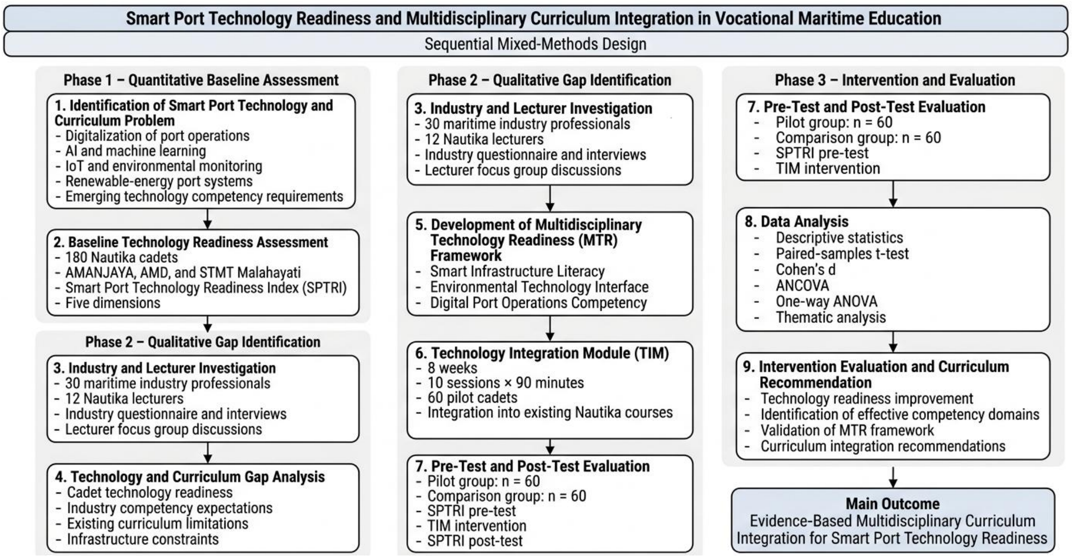

Figure 1. Research Flowchart of the Sequential Mixed-Methods Study

SPTRI scores were interpreted using five categories: 4.20–5.00 = Expert, 3.40–4.19 = Proficient, 2.60–3.39 = Developing, 1.80–2.59 = Beginner, and 1.00–1.79 = No knowledge.

The Technology Integration Module consisted of 10 sessions of 90 minutes delivered over eight weeks. The module was based on the Multidisciplinary Technology Readiness framework and distributed smart-port technology content across existing Nautika courses. Smart infrastructure literacy was integrated into watchkeeping and bridge resource management instruction. Environmental technology was integrated into environmental studies and cargo operations. Digital port operations competency was integrated into English Communication using authentic smart-port documentation and operational communication materials.

The instructional materials included publicly available smart-port documentation, simulated machine-learning scheduling outputs, digital environmental reporting forms, and vessel power-management documentation. The use of authentic and simulated materials was intended to provide technology-literacy experiences despite the limited availability of dedicated smart-port training infrastructure.

Data collection was conducted in three periods. Baseline quantitative assessment was conducted from April to September 2025. Industry interviews and lecturer FGDs were conducted from July to September 2025. The intervention was implemented from October 2025 to January 2026. The pilot group completed the SPTRI before and after the intervention, while the matched comparison group completed the same assessments without participating in the module.

Descriptive statistics were used to calculate means and standard deviations. One-way ANOVA was used to examine differences among institutions. Paired-samples t-tests and Cohen's d were used to evaluate within-group changes. ANCOVA was used to compare post-test outcomes between the intervention and comparison groups while controlling for baseline SPTRI scores. Statistical procedures followed established approaches for educational and social-science data analysis [17].

Qualitative data from industry interviews and lecturer FGDs were analyzed thematically. Thematic analysis was used to identify recurring competency requirements, curriculum barriers, infrastructure constraints, and priorities for curriculum integration. Particular attention was given to environmental and energy-related technology because the transition toward more sustainable maritime operations is increasingly associated with energy-efficiency and decarbonization requirements [18].

3. Results and Discussion

The baseline SPTRI results are presented in Table 1. The overall combined score was 2.77/5.00, placing the participating cadets in the Developing category. AMANJAYA recorded the highest overall score at 2.97, followed by STMT Malahayati at 2.77, while AMD recorded 2.58, corresponding to the upper end of the Beginner category.

The lowest combined score was found for machine learning comprehension ($M = 2.48$), which was the only dimension classified as Beginner. Environmental monitoring technology recorded the highest score ($M = 2.92$), followed by smart infrastructure literacy ($M = 2.90$), renewable energy port knowledge ($M = 2.82$), and IoT and AI application awareness ($M = 2.74$).

Table 1. Smart Port Technology Readiness Index Baseline Scores (n = 180)

SPTRI Dimension	AMANJAYA M (SD)	AMD M (SD)	STMT Malahayati M (SD)	Combined M (SD)
Smart Infrastructure Literacy	3.08 (0.88)	2.72 (0.94)	2.91 (0.91)	2.90 (0.91)

SPTRI Dimension	AMANJAYA M (SD)	AMD M (SD)	STMT Malahayati M (SD)	Combined M (SD)
IoT and AI Application Awareness	2.94 (0.91)	2.54 (0.98)	2.74 (0.94)	2.74 (0.95)
Environmental Monitoring Technology	3.12 (0.86)	2.72 (0.92)	2.92 (0.88)	2.92 (0.89)
Renewable Energy Port Knowledge	3.02 (0.89)	2.62 (0.96)	2.82 (0.92)	2.82 (0.93)
Machine Learning Comprehension	2.68 (0.96)	2.28 (1.04)	2.48 (0.99)	2.48 (1.00)
SPTRI Overall	2.97	2.58	2.77	2.77

The relatively higher environmental-monitoring score may be associated with the presence of conventional environmental and MARPOL-related content in Nautika education. However, conceptual knowledge of maritime environmental regulation does not necessarily provide the technological literacy required to operate digital environmental-monitoring and reporting systems. This distinction is important because modern maritime environmental management increasingly depends on digital data collection and technology-supported monitoring.

The machine-learning result is more concerning because algorithm-supported scheduling and decision systems increasingly influence vessel and port operations. The low score suggests that cadets may encounter algorithmic outputs without sufficient preparation to understand their meaning, limitations, or appropriate relationship with professional judgment. This is consistent with previous research emphasizing the need to adapt maritime education to increasing automation and changing human–technology relationships.

Differences among the three institutions were statistically significant for all five dimensions, with all $F(2,177) > 3.84$ and $p < .024$. AMANJAYA consistently recorded the highest scores, while AMD recorded the lowest scores. The institutional variation suggests that existing curriculum exposure, learning resources, or instructional practices may influence technology readiness. The industry assessment provided additional evidence regarding the practical significance of the readiness gap. The results are shown in Table 2.

Technology readiness was considered essential or highly important for deck officer appointments by 78% of industry respondents. However, only 27% considered recent Indonesian Nautika graduates adequately prepared for smart-port interaction. The lowest competency assessment concerned machine-learning scheduling outputs, with only 21.3% of professionals considering graduates adequately prepared.

The alignment between the industry assessment and the SPTRI results is notable. Machine-learning comprehension was the lowest cadet-readiness dimension and simultaneously the weakest graduate competency identified by industry professionals. This convergence suggests that the identified readiness gap has direct occupational relevance rather than representing only an academic concern.

Table 2. Industry Professional Technology Competency Assessment (n = 30)

Assessment Item	Rating (%)
Technology readiness essential/highly important for deck officer appointments	78
Recent Indonesian Nautika graduates adequately prepared for smart-port interaction	27
Graduates understand and correctly use machine-learning scheduling outputs	21.3
Graduates can execute shore-power connection without additional training	43.3
Graduates complete eco-port information reporting accurately without support	31
Graduates respond appropriately to IoT alerts	38.7

Industry interviews identified several operational difficulties. Four of the 10 Tanjung Priok Terminal 3 managers reported situations in which deck officers interpreted AI-supported berth-allocation recommendations as fixed mandatory instructions rather than recommendations subject to professional judgment. Six managers reported shore-power connection delays associated with unfamiliarity with vessel-side power-management transition procedures. Three managers identified errors in eco-port reporting related to the use of conventional paper-based environmental logs rather than digital terminal interfaces.

These findings highlight an important distinction between technology access and technology competence. A professional may be able to receive a digital instruction but still lack the competency required to evaluate it appropriately. This is particularly important in maritime operations, where automated recommendations must remain subordinate to safety considerations and professional responsibility.

The lecturer FGDs identified three recurring barriers. The first was the treatment of technology as supplementary rather than as an explicit competency domain. All 12 lecturers indicated that emerging technologies were generally introduced as examples within conventional technical subjects rather than as competencies with defined learning outcomes and assessment criteria. This approach may provide cadets with awareness but is unlikely to produce systematic technology literacy.

The second barrier was the disciplinary separation of smart-port competencies. Smart infrastructure involves digital and communication technologies, environmental monitoring involves environmental science, shore power involves energy and marine-engineering knowledge, and digital cargo operations involve operational management. Existing course structures distribute these domains across different subjects without a formal mechanism for integration.

The third barrier was limited access to smart-port infrastructure. Lecturers reported insufficient access to smart-port simulation systems, IoT training modules, environmental reporting platforms, and shore-power training facilities. However, the intervention demonstrated that meaningful technology-literacy development can begin through authentic documentation and simulated digital environments. The post-intervention results are presented in Table 3.

The pilot group demonstrated substantial improvement across all five dimensions. Overall SPTRI increased from 2.75 to 3.94, representing a gain of 1.19 points and an overall Cohen's d of 2.24. This represents a very large intervention effect.

Table 3. Pre-Test and Post-Test SPTRI Scores for the Pilot and Comparison Groups

SPTRI Dimension	Pilot Pre M	Pilot Post M	Gain	Cohen's *d*	Comparison Pre M	Comparison Post M
Smart Infrastructure Literacy	2.88 (0.90)	3.92 (0.76)	1.04	1.7	2.91 (0.89)	2.94 (0.88)
IoT and AI Application Awareness	2.72 (0.94)	3.88 (0.78)	1.16	1.88	2.76 (0.93)	2.78 (0.93)
Environmental Monitoring Technology	2.90 (0.88)	3.96 (0.74)	1.06	1.74	2.93 (0.87)	2.95 (0.87)
Renewable Energy Port Knowledge	2.80 (0.92)	3.98 (0.78)	1.18	1.92	2.84 (0.91)	2.87 (0.91)
Machine Learning Comprehension	2.46 (0.99)	3.94 (0.80)	1.48	2.24	2.50 (0.99)	2.53 (0.99)
SPTRI Overall	2.75	3.94	1.19	2.24	2.79	2.81

Machine-learning comprehension produced the largest absolute gain, increasing by 1.48 points from 2.46 to 3.94, with d = 2.24. Renewable energy port knowledge increased by 1.18 points (d = 1.92), IoT and AI application awareness increased by 1.16 points (d = 1.88), environmental monitoring technology increased by 1.06 points (d = 1.74), and smart infrastructure literacy increased by 1.04 points (d = 1.70).

In contrast, the comparison group demonstrated only 0.02–0.03-point improvements across dimensions. ANCOVA, controlling for baseline SPTRI, demonstrated significant post-test differences between the pilot and comparison groups across all five dimensions, with all $F(1,117) > 18.4$, $p < .001$, and $\eta^2 > .14$.

The results indicate that the TIM was associated with substantial improvements in technology readiness. The magnitude of the improvement in machine-learning comprehension is particularly important because this was the weakest baseline competency. The finding suggests that targeted instruction can produce substantial improvements in domains where previous exposure is limited.

The intervention also provides evidence supporting the MTR framework as a curriculum integration strategy. Rather than introducing a new standalone smart-port course, the framework distributes technology competencies across existing subjects. Smart infrastructure literacy can be incorporated into watchkeeping and bridge resource management. Environmental technology can be incorporated into environmental studies and cargo operations. Digital port operations can be incorporated into English Communication.

The English Communication component is particularly valuable because smart-port operations involve extensive use of English-language digital documentation and professional communication. Authentic operational texts can simultaneously develop language proficiency and technological literacy. This integrated approach supports the development of specialized professional communication competencies while reducing the risk that technology education becomes isolated from operational practice.

The findings also have implications for green maritime education. Renewable-energy port knowledge and environmental monitoring should not be treated as separate sustainability topics but as operational technology competencies. Shore-power systems, digital emissions reporting, and environmental data platforms represent the intersection of energy management, environmental responsibility, and maritime operations.

The intervention further demonstrates that limited physical infrastructure does not necessarily prevent initial smart-port technology education. The module used authentic documentation, simulated machine-learning outputs, digital reporting forms, and existing vessel-system documentation. Nevertheless, this should not be interpreted as evidence that simulation infrastructure is unnecessary. Dedicated smart-port simulation facilities would remain important for developing higher-order procedural competencies, decision-making, and realistic operational responses.

The practical implication is that maritime vocational institutions can adopt a staged curriculum strategy. Initial technology literacy can be introduced using authentic digital documentation and simulated operational scenarios. Subsequent learning can incorporate interactive simulation of IoT alerts, automated vessel scheduling, environmental reporting, and shore-power procedures. Finally, industry collaboration and workplace-based learning can provide direct exposure to operational smart-port systems.

4. Conclusion

This study demonstrates a substantial gap between the technological requirements of smart-port operations and the current technology readiness of Nautika cadets. The baseline assessment of 180 cadets produced an overall SPTRI score of 2.77/5.00, indicating a Developing level of readiness, while machine-learning comprehension recorded the lowest score at 2.48/5.00, within the Beginner category. The industry assessment reinforced the finding, with only 27% of professionals considering recent Indonesian Nautika graduates adequately prepared for smart-port interaction, while 78% considered technology readiness essential or highly important for deck officer appointments.

The eight-week Technology Integration Module produced substantial improvements across all five dimensions. The pilot group's overall SPTRI increased from 2.75 to 3.94, with an overall Cohen's d of 2.24. Machine-learning comprehension showed the largest improvement, increasing by 1.48 points. In contrast, the comparison group showed only minimal changes, while ANCOVA confirmed significant differences between the intervention and comparison groups after controlling for baseline readiness.

The principal scientific contribution of this study is the empirical identification of smart-port technology readiness as a multidimensional competency requirement in vocational maritime education. The practical contribution is the Multidisciplinary Technology Readiness framework, which provides a curriculum integration mechanism for embedding smart-port competencies within existing Nautika courses.

The findings recommend that maritime vocational institutions prioritize machine-learning literacy, IoT and AI applications, digital environmental monitoring, renewable-energy port operations, and technology-supported professional communication. Institutions should initially integrate these competencies into existing courses and progressively strengthen them through simulation, industry collaboration, and workplace-based learning.

The broader significance of the study lies in supporting the transition toward maritime education that is digitally competent, environmentally responsive, and aligned with emerging occupational requirements. Strengthening technology readiness among Nautika cadets can contribute to graduate employability, safer human–technology interaction, improved operational performance, and more sustainable maritime operations.

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