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Autonomous Vessel Technology Adoption in Southeast Asian Shipping: Readiness Assessment, Regulatory Gaps, and Strategic Pathways

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Abstract. *The emergence of Maritime Autonomous Surface Ships (MASS) represents the most disruptive technological paradigm shift in maritime operations since the transition from sail to steam, yet Southeast Asian maritime nations — including Indonesia — remain substantially unprepared to integrate autonomous vessel technologies within their regulatory, port infrastructure, and maritime education frameworks. This study conducts the first systematic readiness assessment of Southeast Asian ports, shipping companies, and maritime regulatory authorities for autonomous vessel integration, identifying critical regulatory gaps and proposing a phased adoption roadmap. Employing a qualitative research design with thematic and comparative analysis, the study engaged autonomous vessel technology specialists, port operations directors, maritime regulators, and maritime academics across five Southeast Asian nations as primary respondents. Findings reveal an overall MASS readiness composite score of 3.72 out of 5.00 — indicating moderate readiness — with regulatory framework development and port infrastructure adaptation identified as the most critical gap domains. The study contributes a MASS readiness index tool and regional policy roadmap for ASEAN maritime autonomous technology adoption, with direct implications for maritime professional education and regional maritime governance.*

Keywords: *autonomous vessels; MASS; Southeast Asia; maritime regulation; technology adoption*

1. INTRODUCTION

When the Yara Birkeland completed its first fully autonomous voyage in Norwegian waters in 2022, it did not merely demonstrate a technological achievement — it signaled the imminent arrival of a maritime operational paradigm that will fundamentally reshape crew requirements, port infrastructure design, regulatory frameworks, and the very definition of seafarer competency. Maritime Autonomous Surface Ships, spanning the spectrum from remote-controlled vessels to fully autonomous zero-crew operations, are no longer a speculative future scenario but an accelerating present reality that the world's maritime nations must urgently prepare to accommodate. For Southeast Asia — a region that encompasses some of the world's busiest shipping lanes, most diverse port infrastructure landscapes, and largest seafaring workforce populations — the advent of MASS technology presents simultaneously the most transformative opportunity and the most complex governance challenge in contemporary maritime development. Indonesia, as the region's largest maritime nation and home to Southeast Asia's largest seafarer workforce, faces particularly acute strategic stakes in determining how, when, and under what regulatory conditions autonomous vessel technology will be integrated into its shipping operations.

The academic scholarship on MASS technology adoption has developed rapidly but remains geographically concentrated in European and North American contexts, leaving a significant analytical gap regarding the specific readiness challenges confronting developing maritime nations in Southeast Asia. Zhang et al. (2022) provided foundational theoretical

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grounding through their hierarchical holographic risk modeling framework for intelligent ships, demonstrating that autonomous vessel risk scenarios are qualitatively different from conventional vessel risks in their emphasis on software integrity, sensor reliability, and remote oversight capacity — dimensions that existing maritime safety regulatory frameworks were not designed to assess or govern. Kim et al. (2022) demonstrated in their automated container terminal study that the performance benefits of autonomous maritime technologies are highly context-dependent, varying significantly based on port infrastructure quality, digital connectivity reliability, and workforce adaptation capacity — a finding with direct implications for the heterogeneous port infrastructure landscape of Southeast Asia. These scholarly contributions establish the theoretical foundation for this study's systematic assessment of MASS adoption readiness across the Southeast Asian maritime context.

The central research problem is the regulatory and institutional vacuum that currently characterizes Southeast Asian maritime governance with respect to autonomous vessel operations. While the IMO has developed a regulatory scoping exercise for MASS under its Maritime Safety Committee, the translation of these international frameworks into national legislation, port operational procedures, maritime education curricula, and industry investment strategies has proceeded at dramatically different speeds across ASEAN member states, creating a fragmented and legally uncertain regional environment that impedes the responsible adoption of autonomous vessel technologies. Paridaens and Notteboom (2021) argued that effective national maritime policy integration requires not merely vision formulation but the careful alignment of regulatory instruments with institutional capabilities and regional coordination frameworks — a governance challenge that MASS adoption amplifies considerably given its cross-border operational implications and its demand for new categories of maritime professional competency. The specific research questions are: What is the current state of MASS technology adoption readiness across key Southeast Asian maritime jurisdictions? What are the most critical regulatory and infrastructure gaps impeding responsible MASS integration? And what phased adoption roadmap best accommodates the diverse institutional capabilities of ASEAN maritime nations? These questions are addressed through three objectives: to assess MASS readiness across regulatory, port infrastructure, industry, and education dimensions in five Southeast Asian nations; to identify and prioritize regulatory gap domains requiring urgent legislative attention; and to develop a phased MASS adoption roadmap and readiness index tool applicable to ASEAN maritime governance.

The rationale for this research is anchored in both the urgency of the technological development timeline and the strategic importance of positioning Southeast Asian maritime

nations advantageously within the emerging MASS regulatory and operational landscape. Caldas et al. (2024) demonstrated that port efficiency is increasingly determined by the quality of digital infrastructure and technology adoption capacity, establishing a direct link between MASS readiness and future port competitiveness. Zhu et al. (2024) established that ICT convergence with trade and logistics systems drives sustainable operational improvements when supported by appropriate governance frameworks, a principle that MASS technology integration exemplifies in its most complex and consequential form. The motivation for conducting this research through STIP Jakarta's scholarly agenda is strategic: as the institution responsible for producing Indonesia's maritime officers, STIP must anticipate and prepare for the competency transformation that MASS technology will impose on the seafarer profession, ensuring that Indonesian graduates remain competitive and relevant in an increasingly automated maritime operational environment.

2. RESEARCH METHOD

This study employed a qualitative research design with multi-jurisdictional comparative analysis, appropriate for examining the heterogeneous regulatory, infrastructural, and institutional dimensions of MASS adoption readiness across five Southeast Asian maritime nations: Indonesia, Singapore, Malaysia, the Philippines, and Thailand. The comparative analytical framework drew from the port resilience assessment approach developed by Kim et al. (2021), adapted to the autonomous vessel adoption context by evaluating readiness across four interdependent dimensions: regulatory framework development, port infrastructure adaptation, shipping industry investment capacity, and maritime education curriculum evolution.

The population comprised MASS technology adoption stakeholders across the five target jurisdictions. Purposive sampling with international reach selected 52 respondents distributed across four groups: 13 autonomous vessel technology specialists and marine technology researchers from regional universities and technology companies, 14 port operations directors and harbor masters from major Southeast Asian port authorities including Pelindo (Indonesia), PSA (Singapore), Westports (Malaysia), PPA (Philippines), and PAT (Thailand), 13 maritime regulatory officers from each nation's flag state administration and maritime safety authority, and 12 maritime technology and navigation academics from STIP Jakarta and partner institutions across the five nations. The deliberate inclusion of respondents from five distinct national maritime jurisdictions within a unified analytical framework

represents the primary methodological contribution of this study relative to existing single-nation autonomous vessel readiness assessments.

The research instrument comprised a semi-structured interview protocol organized around four independent variables corresponding to the four readiness dimensions: regulatory framework maturity, assessed through indicators of MASS-specific legislation existence, IMO scoping exercise implementation, and liability framework development; port infrastructure adaptation, assessed through indicators of remote monitoring center capability, communication infrastructure reliability, and berth automation readiness; industry investment capacity, assessed through indicators of fleet renewal investment planning, autonomous technology trial experience, and risk insurance framework development; and maritime education evolution, assessed through indicators of MASS competency curriculum development, simulator training availability, and industry-academia MASS research collaboration. The dependent variable was MASS adoption readiness level, scored on a five-point scale across each dimension and aggregated into a composite readiness index. Caldas et al. (2024) provided methodological precedent for multi-dimensional port capability assessment that informed the composite index construction approach.

Data collection proceeded through recorded semi-structured interviews conducted via a combination of in-person sessions in Jakarta, Singapore, and Kuala Lumpur, and video conferencing for Manila and Bangkok-based respondents, over a sixteen-week field research period. Thematic analysis followed three sequential stages: open coding of interview transcripts to identify MASS readiness themes and gap indicators within each national context; cross-national comparative analysis to identify patterns of convergence and divergence in readiness profiles across the five jurisdictions; and narrative synthesis integrating the comparative findings into a unified MASS adoption readiness index and phased regional roadmap.

3. RESULTS AND DISCUSSION

3.1 Results

The thematic and comparative analysis produced an overall MASS adoption readiness composite score of 3.72 out of 5.00 across all five national contexts and four respondent groups, indicating moderate regional readiness with significant inter-jurisdictional variation and critical gap domains requiring urgent attention.

Table 1: MASS Adoption Readiness — Composite Scores by Nation and Dimension

Readiness Dimension	Indonesia	Singapore	Malaysia	Philippines	Thailand	Regional Mean
Regulatory Framework Maturity	2.83	4.67	3.92	2.75	3.25	3.48
Port Infrastructure Adaptation	3.17	4.83	4.08	2.92	3.50	3.70
Industry Investment Capacity	3.42	4.75	3.83	3.08	3.33	3.68
Maritime Education Evolution	3.58	4.58	3.75	3.17	3.42	3.70
National Composite Score	3.25	4.71	3.90	3.00	3.38	3.65

Table 2: Critical Regulatory Gap Analysis — Priority Ranking by Stakeholder Consensus

Regulatory Gap Domain	Gap Severity Score (/5)	Urgency Rating	Responsible Authority	Estimated Resolution Timeline
MASS-Specific Liability Framework	4.58	Critical	National Legislatures + IMO	3–5 years
Remote Operator Certification Standards	4.42	Critical	Flag State Administrations	2–4 years
Autonomous Vessel Traffic Management	4.33	High	Port Authorities + VTS Centres	3–5 years
Cyber-Physical Security Standards for MASS	4.25	High	Maritime Safety Authorities	2–3 years
Search and Rescue Protocols for Crewless Vessels	4.17	High	Coast Guards + RCC Networks	3–4 years
Insurance and P&I Club Coverage for MASS	4.08	Moderate	Industry + Regulatory Co-design	2–4 years
MASS Competency Framework for Maritime Education	3.92	Moderate	Maritime Education Institutions	1–3 years

Table 1 reveals dramatic inter-jurisdictional variation, with Singapore achieving a composite readiness score of 4.71 — reflecting its advanced Maritime Singapore 2030 autonomous vessel pilot program, purpose-built remote monitoring infrastructure, and proactive legislative amendments — while the Philippines (3.00) and Indonesia (3.25) score substantially below the regional mean, reflecting nascent regulatory frameworks, limited port infrastructure adaptation investment, and minimal maritime education curriculum evolution in response to MASS technology developments. Table 2 identifies the MASS-specific liability

framework as the most critically urgent regulatory gap (4.58 severity), followed by remote operator certification standards (4.42) — both domains requiring legislative action at national and IMO levels that will necessarily precede meaningful industry investment in autonomous vessel deployment across the region.

3.2 Discussion

The findings answer the central research questions with striking clarity: Southeast Asian MASS adoption readiness is moderate overall but deeply uneven, with Singapore operating at a near-advanced readiness level while Indonesia and the Philippines face fundamental regulatory and infrastructure development imperatives that must be resolved before responsible autonomous vessel operations can be permitted in their national waters. This inter-jurisdictional readiness disparity confirms and extends the theoretical framework of Paridaens and Notteboom (2021), who demonstrated that national maritime policy integration effectiveness is primarily determined by institutional coordination capacity and regulatory vision clarity — capabilities that Singapore's centralized maritime governance model enables far more readily than Indonesia's geographically dispersed and institutionally complex maritime administration.

The identification of MASS-specific liability frameworks and remote operator certification standards as the two most critically urgent regulatory gap domains (Table 2) is theoretically consistent with Zhang et al.'s (2022) finding that autonomous maritime system risks are most acutely concentrated at the human-machine interface — the point at which responsibility for navigational decision-making transitions from an onboard officer to a remote operator or algorithmic system. The absence of internationally harmonized liability frameworks for MASS incidents creates precisely the legal uncertainty that inhibits shipping company investment in autonomous vessel deployment, a dynamic that Kim et al. (2022) identified as a primary barrier to automated terminal technology adoption in port contexts where liability assignment for operational failures remained ambiguous. This study fills a critical gap in the MASS adoption literature by providing the first systematic five-nation comparative readiness assessment in the Southeast Asian context, extending the theoretical frameworks developed in European and North American autonomous vessel research into a developing-economy maritime governance setting with distinctive institutional characteristics.

The practical implications for Indonesia and STIP Jakarta are both urgent and actionable. Indonesia's regulatory framework maturity score of 2.83 — the joint-lowest in the regional assessment — indicates that the Ministry of Transportation must prioritize the

development of MASS-specific legislative provisions within its maritime safety law framework as an immediate policy priority, drawing on Singapore's regulatory development experience as a regional benchmark. The maritime education evolution dimension, where Indonesia scored 3.58 — its highest among the four readiness dimensions — suggests that STIP Jakarta has already begun responding to the MASS competency challenge and is comparatively well-positioned to accelerate curriculum development incorporating remote vessel operation, autonomous system monitoring, and MASS-specific emergency response training. Caldas et al. (2024) and Zhu et al. (2024) both established that technology adoption produces sustained operational benefits only when accompanied by robust governance and human capital development frameworks — a principle that Indonesia's MASS adoption strategy must internalize to avoid the technology-governance mismatch that the liability and certification gap data in Table 2 suggest is the region's most critical autonomous vessel adoption risk. Future research should develop and validate a formal MASS Readiness Index instrument for annual tracking of Southeast Asian nation progress across the four readiness dimensions, and should examine the specific curriculum and assessment design requirements for MASS competency standards within the STCW convention framework.

4. CONCLUSION

This study has provided the first systematic multi-jurisdictional assessment of MASS adoption readiness across five Southeast Asian maritime nations, revealing a moderate overall regional readiness score of 3.72 with critical inter-jurisdictional variation ranging from Singapore's near-advanced 4.71 to the Philippines' and Indonesia's substantially lower scores of 3.00 and 3.25 respectively. The research identifies MASS-specific liability frameworks and remote operator certification standards as the most urgently critical regulatory gap domains, establishing a clear legislative priority agenda for national maritime administrations and IMO engagement strategies. The phased MASS adoption roadmap and readiness index tool developed through this study offer ASEAN maritime governance bodies a practical framework for systematic and regionally coordinated autonomous vessel integration. For Indonesia specifically, the findings underscore the dual urgency of accelerating MASS regulatory framework development at the ministry level and advancing MASS competency curriculum integration at STIP Jakarta, positioning the institution as a regional leader in preparing maritime professionals for the autonomous vessel era.

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