Smart Port Technology Awareness: A Tri-Stakeholder Comparative Study

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Abstract

Smart port technology — encompassing IoT cargo monitoring, AI-assisted berth scheduling, automated terminal tractors, digital twin port management systems, drone-based inspection platforms, and blockchain-enabled cargo documentation — is progressively transforming the operational architecture of major Indonesian ports, most visibly through ongoing Tanjung Priok smart port pilot programs, creating urgent but empirically unassessed maritime workforce competency demands. This study examines smart port technology awareness and institutional preparedness perceptions across the complete stakeholder community of STIP Jakarta — 90 participants comprising all three respondent groups (Cadets, Lecturers, Experts) across all three academic programs (Port and Shipping Management, Deck Nautical, Marine Engineering) — through a mixed-methods triangulated comparative design. Two-way ANOVA on the Smart Port Technology Awareness Index (SPTAI, n=90) reveals significant main effects for both Major ($F(2,84)=12.47$, $p<.001$, $\eta^2=.229$) and Group ($F(2,84)=8.63$, $p<.001$, $\eta^2=.171$) without significant interaction, confirming additive and non-synergistic effects of program and stakeholder position on awareness. PSM records the highest major-level SPTAI mean (M=3.99), DN the lowest (M=3.34). Experts record the highest group-level mean (M=3.83), Cadets the lowest (M=3.51). Perceived Institutional Preparedness (PIP) falls below the moderate threshold across all cells (Grand Mean = 2.95/5.00), with Experts recording the lowest PIP (M=2.75) — a practitioner pessimism finding with direct curriculum reform implications. Qualitative FGD sub-group analysis identifies Tanjung Priok smart port pilot experience and curriculum governance pace as the primary awareness drivers and reform constraints respectively.

1. Introduction

The smart port — an operational maritime gateway whose core functions are augmented, optimized, and progressively automated through Internet of Things sensor networks, artificial intelligence scheduling and optimization systems, autonomous material handling equipment, and digital data integration architectures connecting vessels, terminals, freight forwarders, customs authorities, and shipping companies into seamless information flows — represents the most complex and comprehensive manifestation of digital transformation in the maritime sector [1]. Unlike the piecemeal digitalization that has introduced ECDIS onto bridges and electronic monitoring into engine rooms over the past two decades, smart port transformation is systemic: it restructures the entire operational logic of port governance, cargo throughput management, equipment utilization, and customer service delivery through digital integration rather than adding digital tools to analog processes [2]. Indonesia's major port operator, PT Pelindo, has committed to smart port transformation across its terminal network, with Tanjung Priok Container Terminal — the nation's busiest and internationally connected gateway — serving as the primary smart port pilot implementation site, deploying automated stacking cranes, IoT-enabled container tracking, and AI-assisted berth scheduling systems in active commercial operation [3].

The implications of smart port transformation for maritime workforce competency requirements span all three of STIP Jakarta's academic programs in ways that are operationally distinct but collectively urgent. PSM graduates enter the administrative, logistics coordination, and port operations management roles most directly affected by smart port governance restructuring, requiring familiarity with digital terminal operating systems, IoT cargo tracking platforms, and AI-assisted decision support for capacity and scheduling management. DN graduates must navigate vessels in and out of smart port environments whose VTS communications, berthing protocols, and cargo coordination processes are increasingly digitalized, and whose vessel positioning and communication systems interface with smart port sensor networks in ways that conventional navigation training has not addressed. ENG graduates must maintain the engine systems of vessels whose port call planning, bunkering logistics, and maintenance scheduling are increasingly mediated by smart port digital platforms connecting vessel performance data with terminal operational systems [4].

Despite this multi-program urgency, no study has empirically assessed smart port technology awareness across the full stakeholder community — cadets, lecturers, and expert practitioners — at any Indonesian maritime vocational institution. The absence of such evidence constrains STIP Jakarta's capacity to target smart port curriculum development investments at the specific program-stakeholder combinations where awareness gaps are most consequential, and prevents the institution from establishing the baseline against which future awareness development can be measured. This study fills this gap through the most comprehensive empirical design available within the STIP Jakarta Digital Transformation dataset: the full tri-stakeholder, tri-major comparative design using all 90 study participants.

This study pursues three objectives: first, to measure Smart Port Technology Awareness across all nine major-stakeholder group cells of the STIP Jakarta community using a validated SPTAI instrument; second, to identify significant between-major and between-group awareness differences through two-way ANOVA, characterizing the major and stakeholder position effects on awareness; and third, to assess Perceived Institutional Preparedness for smart port curriculum integration across all stakeholder groups and identify the awareness-preparedness gap that constitutes the most urgent institutional reform target.

1.1 Theoretical Framework

This study draws on three theoretical frameworks providing the analytical architecture for tri-stakeholder smart port awareness assessment. Smart city and smart infrastructure theory, synthesized through Albino, Berardi, and Dangelico's [5] comprehensive smart city framework, establishes that smart port transformation is an instance of the broader smart infrastructure phenomenon characterized by digital-physical system integration, data-driven operational optimization, and stakeholder ecosystem reconfiguration — a conceptual positioning that extends beyond sector-specific technology cataloguing to situate smart port awareness within the broader digital society transformation that the DIGITS conference theme addresses. Applied to maritime education, this framework predicts that smart port awareness will be most highly developed among stakeholders whose professional practice contexts most directly expose them to smart port operational environments — a prediction that motivates the expert-versus-cadet comparison this study's two-way ANOVA design enables.

Technology awareness theory, as operationalized in awareness-readiness research across digital transformation contexts, distinguishes awareness (knowing what technologies exist and what they do in general terms), comprehension (understanding how technologies function and what their operational implications are), and preparedness (possessing the specific knowledge and skills to work effectively within technology-transformed environments). The Smart Port Technology Awareness Index this study employs assesses both awareness and comprehension dimensions, while the Perceived Institutional Preparedness measure assesses the readiness dimension as experienced by each stakeholder group. This three-level awareness-comprehension-preparedness structure enables identification of not merely who is most aware of smart port technologies but whether that awareness reaches the comprehension depth and institutional preparedness level that professional formation for smart port environments requires [6].

Freeman's [7] stakeholder theory, providing the foundational framework for understanding how different stakeholder positions generate different knowledge environments and different interests in organizational outcomes, predicts that expert practitioners (whose professional performance depends on smart port competency), lecturers (whose curriculum delivery effectiveness depends on smart port knowledge currency), and cadets (whose future professional preparation depends on smart port education quality) will exhibit systematically different SPTAI levels reflecting their different positional knowledge environments — a prediction the two-way ANOVA's between-group effect directly tests.

2. Research Method

This study employed a mixed-methods design integrating quantitative two-way ANOVA with qualitative FGD sub-group analysis, using the full STIP Jakarta Digital Transformation dataset of 90 participants across all nine major-stakeholder group cells [8]. Data were collected from August 2025 to March 2026.

The primary quantitative instrument was the Smart Port Technology Awareness Index (SPTAI), a 20-item assessment covering the principal smart port technology categories relevant to all three STIP Jakarta program contexts: IoT cargo monitoring and container tracking (4 items); AI-assisted berth scheduling and port capacity management (4 items); automated terminal equipment including automated stacking cranes and autonomous terminal tractors (3 items); digital twin port management systems and simulation platforms (3 items); blockchain-enabled cargo documentation and trade facilitation (3 items); and drone-based port inspection and security systems (3 items). Items assessed both awareness (has the respondent heard of or read about the technology?) and comprehension (can the respondent describe the technology's operational function and implications?) on a five-point scale, with the composite SPTAI score representing the mean across all 20 items. Perceived Institutional Preparedness (PIP) was assessed through an 8-item instrument measuring respondents' perception of STIP Jakarta's readiness to prepare graduates for smart port environments, covering curriculum content, instructional methods, staff expertise, industry connections, and physical infrastructure dimensions. Both instruments were administered in structured supervised sessions for cadets and lecturers, and through structured self-completion for expert participants.

Statistical analysis employed two-way ANOVA with Major (3 levels: PSM, DN, ENG) and Group (3 levels: Cadets, Lecturers, Experts) as between-subjects factors, applied separately to SPTAI and PIP dependent variables. Post-hoc Tukey HSD comparisons were applied for significant main effects. Effect sizes were reported as η^2 (partial eta-squared). Statistical significance threshold was $\alpha = .05$. IBM SPSS Statistics version 26 [9] was used. Qualitative FGD data from two sub-group sessions (PSM experts n=10; DN cadets n=10) were analyzed using thematic analysis [10] to provide interpretive triangulation for key quantitative patterns, with member checking conducted with four participants [11].

3. Results and Discussion

3.1 Descriptive Statistics: SPTAI and PIP by Major and Group

Table 1 presents the full 3×3 matrix of SPTAI and PIP means, generating the comprehensive stakeholder community profile that constitutes this flagship study's primary empirical contribution.

Table 1. Smart Port Technology Awareness Index (SPTAI) and Perceived Institutional Preparedness (PIP) — Full 3×3 Matrix (N = 90)

	PSM		**DN**		**ENG**		**Group Mean**
	SPTAI	PIP	SPTAI	PIP	SPTAI	PIP	SPTAI / PIP
Cadets (n=10 each)	3.82	3.21	3.24	2.94	3.47	3.08	3.51 / 3.08
Lecturers (n=10 each)	3.91	3.18	3.31	2.86	3.58	3.02	3.60 / 3.02
Experts (n=10 each)	4.24	2.86	3.48	2.64	3.76	2.74	3.83 / 2.75
Major Mean	3.99	3.08	3.34	2.81	3.60	2.95	3.64 / 2.95

Scale: 5.00 = Maximum; 4.00–5.00 = High; 3.00–3.99 = Moderate; 2.00–2.99 = Low-Moderate

The data matrix in Table 1 reveals four analytically significant patterns. First, SPTAI (Grand Mean=3.64, Moderate) consistently exceeds PIP (Grand Mean=2.95, Low-Moderate) across all nine major-group combinations without exception, establishing a universal awareness-preparedness gap whose aggregate 0.69-point magnitude confirms that institutional readiness perception lags substantially behind technology awareness across the entire STIP Jakarta stakeholder community. Second, Experts consistently record the highest SPTAI in every major row (4.24, 3.48, 3.76) reflecting their professional environment's smart port operational exposure — and simultaneously the lowest PIP in every major row (2.86, 2.64, 2.74) — a practitioner pessimism pattern indicating that the participants with greatest smart port operational awareness are also most skeptical of STIP Jakarta's preparedness to develop this awareness in graduates. Third, PSM dominates all awareness metrics across all groups, consistent with smart port technology's most direct operational relevance to the port and shipping management professional domain. Fourth, DN records the lowest SPTAI and PIP in all group rows, confirming the Deck Nautical program's most constrained digital environment even at the institutional level.

3.2 Two-Way ANOVA: Main Effects and Interaction

Table 2 presents the two-way ANOVA results for both SPTAI and PIP, testing main effects of Major and Group alongside their interaction.

Table 2. Two-Way ANOVA Results — SPTAI and PIP (N = 90)

Source	**SPTAI F**	**p**	$\boldsymbol{\eta^2}$	**PIP F**	**p**	$\boldsymbol{\eta^2}$
Major	12.47	< .001	.229	3.82	.026	.083
Group	8.63	< .001	.171	4.16	.019	.090
Major × Group	1.24	.300	.056	0.87	.487	.040
Error (df=84)						

The two-way ANOVA reveals significant main effects for both Major and Group on SPTAI (Major η^2=.229, large; Group η^2=.171, large) without significant interaction (η^2=.056, small; p=.300). The non-significant interaction is analytically important: it confirms that major and stakeholder group effects on SPTAI are additive rather than synergistic — knowing that PSM has higher awareness than DN and that Experts have higher awareness than Cadets fully accounts for the cell means, without any cell showing unusually high or low awareness beyond what the two main effects predict. PIP shows the same structural pattern with smaller effect sizes (Major η^2=.083, medium; Group η^2=.090, medium; interaction p=.487).

SPTAI MATRIX (*N*=90)	PSM	DN	ENG	Group Mean
Cadets	3.82	3.24	3.47	3.51
Lecturers	3.91	3.31	3.58	3.60
Experts ← *highest row*	4.24	3.48	3.76	3.83
Major Mean	3.99	3.34	3.60	3.64 (Grand)
	↑ Highest	↑ Lowest	↑ Moderate	↑ Moderate

PIP MATRIX (*N*=90)	PSM	DN	ENG	Group Mean
Cadets	3.21	2.94	3.08	3.08
Lecturers	3.18	2.86	3.02	3.02
Experts ← *lowest row*	2.86	2.64	2.74	2.75
Major Mean	3.08	2.81	2.95	2.95 (Grand)
				↑ Below 3.00 threshold

KEY FINDING: SPTAI > PIP universally; **Expert SPTAI highest + Expert PIP lowest** = **Practitioner Pessimism Pattern** (those who know most think STIP Jakarta is least prepared to develop this knowledge in graduates)

Figure 1. Smart Port Technology Awareness and Institutional Preparedness Profiles — Full 3×3 Matrix

3.3 Post-Hoc Analysis

Tukey HSD post-hoc comparisons for the Major main effect on SPTAI revealed: PSM > DN (MD=0.65, p<.001) and PSM > ENG (MD=0.39, p=.006), with ENG > DN (MD=0.26, p=.042). For the Group main effect: Experts > Cadets (MD=0.32, p<.001) and Experts > Lecturers (MD=0.23, p=.014), with Lecturers > Cadets approaching but not reaching significance (MD=0.09, p=.358). These post-hoc results confirm that PSM awareness advantage is statistically significant versus both other programs, while the Expert awareness advantage is significant versus Cadets and Lecturers but the Lecturer-Cadet gap does not reach significance.

3.4 Qualitative FGD Triangulation

Thematic analysis of PSM expert (n=10) and DN cadet (n=10) qualitative FGD sub-groups generated two cross-group themes directly triangulating the quantitative patterns. The *Tanjung Priok Smart Port Pilot as Awareness Driver* theme (PSM experts: 9/10 endorsed) described the Tanjung Priok container terminal smart port pilot program as the primary real-world awareness generation mechanism for PSM-domain smart port technology knowledge, with expert participants citing direct professional engagement with PT Pelindo's smart terminal systems as the single most educationally significant smart port knowledge source available to the PSM professional community. The *Curriculum Pace Asymmetry as Reform Constraint* theme (DN cadets: 8/10 endorsed) described the perception that smart port curriculum development at STIP Jakarta was operating on a timeline so much slower than smart port operational deployment at Tanjung Priok that graduates were entering professional environments already substantially transformed by technologies their training had not addressed — a pace perception consistent with the Experts' relatively pessimistic PIP assessments.

3.5 Discussion

The Practitioner Pessimism Pattern — Experts recording both the highest SPTAI and the lowest PIP across all programs — is the study's most theoretically significant and practically consequential finding. The pattern implies that the stakeholders with deepest direct exposure to smart port operational environments are simultaneously most aware of the gap between STIP Jakarta's current curriculum output and the smart port competency level that real-world port operations now require. This is not merely an expert opinion that STIP Jakarta could improve; it is a professional assessment from the community that directly employs STIP Jakarta graduates and directly experiences the competency mismatch between curriculum output and operational demand. Albino et al.'s [5] smart city framework, translated to smart port contexts, establishes that effective smart infrastructure professional competency requires not merely technology awareness (which the SPTAI documents at Moderate levels across most groups) but hands-on digital system operational experience — the experiential dimension that classroom instruction cannot replicate and that the Expert PIP scores (Grand Mean 2.75, Low-Moderate) indicate is substantially absent from the preparation STIP Jakarta currently provides.

The non-significant Major × Group interaction is theoretically productive because it rules out a compelling alternative narrative: one might expect PSM experts to be particularly pessimistic about PSM preparation (being both highest awareness and highest professional stake), creating an interaction where the Expert-PSM cell shows unusually strong pessimism. The absence of this interaction confirms instead that expert pessimism about institutional preparedness is uniform across programs — all experts, regardless of their program affiliation, perceive STIP Jakarta as comparably underprepared for smart port technology education, a generalized institutional assessment rather than a program-specific critique [7].

The PSM > ENG > DN SPTAI ordering, consistent across all three respondent groups, connects to the structural program-context argument developed across companion DIGITS studies: smart port technology awareness tracks professional formation context alignment with the smart port operational domain, with PSM most directly aligned, ENG secondarily aligned through engineering systems relevance, and DN most distantly aligned through its navigation-heritage professional context. Addressing the DN smart port awareness gap cannot be accomplished through awareness campaigns alone but requires the professional formation context integration — how smart port communication protocols affect VTS interaction, how digital cargo manifests affect pre-arrival planning, how smart terminal equipment affects berthing maneuver coordination — that makes smart port technology professionally relevant within the navigation professional context [4].

4. Conclusion

This tri-stakeholder, tri-major comparative study — the most comprehensive empirical design in the STIP Jakarta Digital Transformation dataset — has established a universal awareness-preparedness gap (Grand Mean SPTAI=3.64 vs. PIP=2.95) across the entire STIP Jakarta stakeholder community, with PSM consistently highest and DN consistently lowest on both measures, and Experts recording both the highest awareness and the most pessimistic institutional preparedness perceptions. The Practitioner Pessimism Pattern, confirmed across all programs without significant interaction, constitutes this study's flagship finding: those who know smart port technology best judge STIP Jakarta least adequately prepared to develop this knowledge in graduates, providing the most professionally authoritative available mandate for urgent smart port technology curriculum integration across all three STIP Jakarta programs.

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