IoT Adoption Barriers in Engine Room Monitoring: Experts' and Engineers' Perspectives

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Abstract

Internet of Things sensor networks for engine room monitoring — encompassing real-time vibration analysis, thermal imaging, fuel consumption telemetry, and predictive maintenance platforms — represent one of the most operationally consequential digital transformation applications available to the commercial shipping industry, offering measurable fuel efficiency improvements and unplanned downtime reduction outcomes documented across multiple fleet deployments. Yet the adoption of IoT engine monitoring systems aboard Indonesian-flagged vessels remains substantially below the international fleet average, and the institutional barriers to IoT adoption as perceived and experienced by marine engineering practitioners have not been empirically investigated within the Indonesian maritime context. This study examines IoT adoption barriers in engine room monitoring through a qualitative focus group discussion design with 10 Marine Engineering experts from STIP Jakarta's practitioner community, supplemented by document analysis of current ENG curriculum materials. Four adoption barrier themes were identified: Technical Integration Challenges (dominant, endorsed by all 10 participants), Institutional Readiness and Financial Constraints (strong, endorsed by 9/10), Trust and Data Reliability Concerns (distinct from technical challenges, endorsed by 8/10), and Competency and Training Deficits (endorsed by 9/10 with direct ENG curriculum implications). Cross-referential document analysis confirms that IoT engine monitoring is entirely absent from current STIP Jakarta ENG syllabi. The study contributes the first practitioner-grounded, barrier-typologized account of IoT engine monitoring adoption challenges in the Indonesian maritime engineering context and provides direct implications for ENG curriculum development at STIP Jakarta.

1. Introduction

The engine room of a modern commercial vessel generates continuous streams of operational data — vibration signatures from rotating machinery, thermal profiles from heat exchangers, fuel consumption rates from injection systems, exhaust gas temperature patterns from turbochargers — whose real-time capture, transmission, and analysis through Internet of Things sensor networks enables condition monitoring and predictive maintenance regimes qualitatively superior to the schedule-based and failure-reactive maintenance approaches that have historically dominated commercial marine engineering practice [1]. IoT-enabled engine room monitoring systems connected to shore-based fleet management centers have documented operational benefits including 10–25% reductions in unplanned downtime, measurable fuel efficiency improvements through real-time combustion optimization feedback, and extended component service life through early fault detection that enables corrective action before functional failure occurs [2]. These operational benefits are directly relevant to Indonesia's commercial maritime fleet, where unplanned downtime on domestic inter-island routes generates cascading logistical and social connectivity costs, and fuel consumption optimization contributes directly to the fleet's Carbon Intensity Indicator trajectory under IMO environmental regulatory requirements.

Despite these well-documented benefits, IoT adoption in Indonesian commercial shipping's engine room monitoring practice remains substantially below international commercial shipping norms, particularly among the small and medium-sized domestic shipping companies whose vessels serve the inter-island routes that constitute a large proportion of Indonesian maritime commerce [3]. Understanding why IoT engine monitoring adoption lags behind both its documented performance benefits and international industry peers requires empirical investigation of the adoption barriers as they are experienced and articulated by the marine engineering practitioners who constitute the primary professional user community for these systems — a practitioner perspective that is essential for accurate barrier diagnosis yet largely absent from the existing literature, which has addressed IoT maritime adoption primarily through technology-push framing (what IoT can do) rather than demand-side barrier analysis (what prevents adoption despite demonstrated capability).

Sekolah Tinggi Ilmu Pelayaran Jakarta's Marine Engineering program occupies a directly relevant institutional position in this adoption barrier landscape. STIP Jakarta ENG graduates will enter the marine engineering workforce as junior engineers on vessels whose IoT readiness spans the full range from fully equipped international trading vessels with connected engine monitoring platforms to older domestic tonnage with no IoT capability; their professional formation at STIP Jakarta determines whether they can contribute to IoT adoption decisions and implementation quality or must learn IoT systems entirely through on-the-job experience without educational foundation. Whether the current ENG curriculum prepares graduates for IoT-enabled engineering environments — and what the practitioner community identifies as the primary barriers to IoT adoption that ENG education should address — constitutes the institutional education dimension of the IoT adoption barrier analysis this study provides [4].

Three objectives guide this investigation: first, to identify and characterize the primary IoT adoption barrier categories in engine room monitoring as articulated by STIP Jakarta's ENG expert community through systematic focus group discussion; second, to examine the cross-barrier relationships and compound effects that explain why IoT adoption barriers are collectively more constraining than any individual barrier alone; and third, to assess the ENG curriculum implications that the identified barrier typology generates for STIP Jakarta's IoT-related instructional content development.

1.1 Theoretical Framework

This study draws on two theoretical frameworks that together provide the analytical architecture for expert-grounded IoT adoption barrier analysis in a maritime vocational education institutional context. Rogers' [5] Diffusion of Innovations theory provides the foundational conceptual vocabulary for understanding why technologically demonstrated innovations like IoT engine monitoring systems encounter adoption resistance despite their documented advantages, identifying five attributes that determine adoption rate — relative advantage, compatibility, complexity, trialability, and observability — and positioning adoption barriers as conditions that suppress one or more of these attributes below the threshold required for adoption to occur within a given professional or organizational community. Applied to IoT engine monitoring on Indonesian commercial vessels, Rogers' framework generates specific barrier hypotheses: complexity may be elevated relative to marine engineering workforce training baseline; compatibility with existing vessel electrical and network infrastructure may be low on older tonnage; and trialability may be limited by the capital investment required for IoT sensor installation before operational benefits can be observed.

The technology-organization-environment (TOE) framework [6], developed to explain organizational technology adoption decisions across technological, organizational, and environmental dimensions simultaneously, provides the second theoretical pillar, establishing that IoT adoption barriers do not reside exclusively in the technology itself but in the interaction between technology characteristics, organizational capacity and culture, and the environmental conditions — regulatory, competitive, market — shaping adoption incentives. For Indonesian domestic shipping companies contemplating IoT engine monitoring adoption, this framework predicts that organizational financial constraints and competitive market structure — not technical inadequacy of the IoT systems themselves — may constitute the most binding adoption barriers in the specific institutional context this study addresses.

2. Research Method

This study employed a qualitative focus group discussion design supplemented by curriculum document analysis, conducted at STIP Jakarta from August 2025 to March 2026 as part of the institution's Digital Transformation assessment. The expert FGD design was selected because the study's objectives require the practitioner-grounded, experientially anchored barrier characterization that professional expert discourse generates and that survey-based barrier rating scales cannot provide with comparable contextual richness and specificity [7].

The participant population comprised 10 Marine Engineering experts from STIP Jakarta's practitioner network, satisfying three selection criteria: minimum 10 years of operational marine engineering experience, direct experience with onboard monitoring and maintenance management systems in commercial maritime contexts, and either direct recruitment or supervision of STIP Jakarta ENG graduates in engineering roles. The n=10 expert sample is the design-specified data slice for this paper within the STIP Jakarta Digital Transformation dataset, consistent with established expert FGD design norms where practitioner knowledge depth rather than sample size breadth is the appropriate quality criterion for barrier identification research [7].

A single extended focus group discussion was conducted across two sessions of approximately 90 minutes each, using a semi-structured protocol organized around three analytical domains: expert assessment of current IoT engine monitoring deployment status and adoption rates within their professional networks and experience; systematic barrier identification across technical, organizational, institutional, and competency dimensions; and assessment of STIP Jakarta ENG curriculum's current preparation of graduates for IoT-enabled engine room environments. Document analysis of all 10 ENG core module syllabi examined the presence, depth, and integration quality of IoT-relevant learning outcomes. Thematic analysis [8] was applied to FGD transcripts following Braun and Clarke's six-phase procedure, with cross-referential integration of thematic findings with document analysis results. Member checking was conducted with two expert participants via follow-up email [9].

3. Results and Discussion

3.1 FGD Thematic Analysis: Four IoT Adoption Barrier Themes

Systematic thematic analysis of the FGD transcript corpus generated four distinct adoption barrier themes, each representing a qualitatively different category of constraint on IoT engine monitoring adoption in Indonesian maritime engineering contexts. Table 1 presents these themes alongside their participant endorsement rates, characteristic sub-barriers, and document analysis triangulation findings.

Table 1. IoT Adoption Barrier Themes: FGD Analysis and Document Triangulation (n = 10 Experts)

Theme	Endorsement	Core Sub-Barriers	Curriculum Coverage
1. Technical Integration Challenges	10/10	Legacy vessel electrical architecture incompatibility; limited onboard network bandwidth for continuous data transmission; sensor installation requiring classification society approval; cybersecurity vulnerability of IoT-connected engine systems	2/10 ENG syllabi passing reference to digital monitoring tools only
2. Institutional Readiness and Financial Constraints	9/10	Capital investment threshold beyond small operator capacity; lack of shore-based fleet management center infrastructure; absence of ROI calculation guidance for domestic route vessel operators; regulatory uncertainty about IoT data ownership and liability	0/10 ENG syllabi
3. Trust and Data Reliability Concerns	8/10	Sensor failure history creating false positive maintenance alerts; algorithmic maintenance recommendation confidence calibration; liability for IoT-driven maintenance decisions that prove incorrect; resistance among experienced engineers to algorithmic override of manual judgment	0/10 ENG syllabi
4. Competency and Training Deficits	9/10	ENG graduates lacking IoT system commissioning and calibration knowledge; absence of data interpretation training for sensor telemetry outputs; no familiarity with predictive maintenance analytics platforms in formal education	0/10 ENG syllabi

All four IoT adoption barrier themes are entirely or substantially absent from current STIP Jakarta ENG curriculum, confirming that the competency dimension of IoT adoption barriers is being reproduced rather than addressed by the formal engineering education program.

3.2 Theme 1: Technical Integration Challenges

Technical Integration Challenges emerged as the most universally endorsed barrier (10/10 participants), but its characterization by expert practitioners introduced important nuances not captured by generic IoT adoption barrier frameworks. The dominant technical integration challenge identified by participants was not the sophistication of the IoT technology itself — which expert engineers assessed as well within the capability range of trained marine engineers to operate — but the architectural incompatibility between IoT sensor networks' continuous data transmission requirements and the electrical and network infrastructure of Indonesian domestic fleet vessels, the majority of which were constructed before IoT engine monitoring architectures existed and are not equipped with the network bandwidth, power distribution modifications, or classification-approved sensor installation pathways that retrofitting IoT systems requires.

A secondary technical integration challenge of specific analytical interest was the cybersecurity dimension: seven of 10 expert participants raised the cybersecurity exposure created by connecting engine room IoT systems to shore-based fleet management platforms as a distinct technical adoption concern separate from installation complexity. "Once you open a data pipeline from the engine room to a shore server, you've created a network access pathway that didn't exist before. If that pathway is not properly secured, you've potentially created an access route into shipboard systems that can affect critical machinery control. We don't have clear protocols for securing IoT engine monitoring connections, and that uncertainty itself is a barrier to adoption for responsible operators." This cybersecurity-IoT intersection, connecting IoT adoption to the maritime cyber risk management concerns that IMO Resolution MSC.428(98) addresses, highlights a compound technical barrier that the existing IoT maritime adoption literature has not yet fully engaged [10].

3.3 Theme 2: Institutional Readiness and Financial Constraints

The Institutional Readiness and Financial Constraints theme (9/10 endorsement) captures the organizational-level adoption barriers that the TOE framework [6] identifies as frequently the most binding adoption constraints in small and medium enterprise contexts — the organizational category that describes the majority of Indonesian domestic shipping operators within whose fleets STIP Jakarta ENG graduates most commonly serve in early-career positions. Expert participants consistently distinguished the capital investment barrier — sensor hardware, installation, platform licensing — from the organizational capacity barrier: the absence of the shore-based fleet management center infrastructure, data analytics staffing, and IT support capacity that IoT engine monitoring's operational model requires alongside the onboard hardware. "The IoT sensor is only the visible part of the system. The invisible part is the shore-based infrastructure that processes the data and turns it into maintenance recommendations. Small Indonesian domestic operators don't have that invisible part, and the sensor without it is just an expensive temperature gauge."

The regulatory uncertainty sub-barrier — specifically, the absence of clear guidance on data ownership and liability for IoT-driven maintenance decisions that prove incorrect — was raised by six of 10 participants as a distinctive constraint with no parallel in conventional maintenance practice. When a chief engineer makes a maintenance decision based on manual inspection and that decision proves incorrect, professional liability is straightforwardly assigned. When an IoT platform makes an algorithmic maintenance recommendation and a chief engineer follows it with negative consequences, the professional liability pathway is unclear — an uncertainty that some expert participants identified as creating rational caution about IoT adoption independent of their technical assessment of system capability.

3.4 Theme 3: Trust and Data Reliability Concerns

The Trust and Data Reliability theme (8/10 endorsement) emerged as the analytically most distinctive finding of the study, representing a barrier category that is qualitatively different from the technical and financial constraints in themes 1 and 2 and that standard adoption barrier frameworks have not highlighted for the maritime engineering expert community specifically. Multiple participants described direct experiences of IoT sensor false positive alerts — maintenance recommendations generated by sensor anomalies attributable to sensor fouling, calibration drift, or installation vibration rather than actual machinery fault — that had created operational disruption without corresponding equipment failure, producing a trust deficit that persisted as an adoption barrier even after the false positive cause was identified and rectified. "I had three chief engineers tell me they switched off the alert notifications on their engine monitoring platforms because the false positive rate was so high that the alerts had become noise. When the alert becomes noise, the system has become worse than nothing — it creates complacency about the alerts that do mean something."

This trust deficit is theoretically significant because it represents a Rogers [5] compatibility failure of a specific type not addressed by standard diffusion theory: the IoT system is technically compatible with the vessel's machinery, but the data quality experience that early adoption has produced is incompatible with the reliability standards that experienced marine engineers apply to maintenance decision-making information. Addressing this barrier requires not merely better sensor technology but better calibration protocols, clearer confidence interval communication in algorithmic recommendations, and transparency about the historical accuracy rates of specific predictive maintenance algorithms in comparable vessel configurations — institutional knowledge requirements that currently have no home in STIP Jakarta's ENG curriculum.

3.5 Theme 4: Competency and Training Deficits

The Competency and Training Deficits theme (9/10 endorsement) is the most directly ENG curriculum-relevant finding of the study, documenting expert assessment that STIP Jakarta ENG graduates lack the IoT system commissioning, sensor telemetry interpretation, and predictive maintenance analytics platform competency that IoT-enabled engine room environments require. Document analysis confirms this assessment: 0 of 10 ENG core module syllabi contain learning objectives or assessed tasks specifically addressing IoT system operation, data interpretation, or predictive maintenance analytics, and only 2 syllabi contain even passing references to digital monitoring tools — references that address conventional bridge/engine monitoring systems without engaging IoT connectivity, remote analytics, or algorithmic maintenance recommendation interpretation [4].

Figure 1 presents the integrated IoT adoption barrier model, synthesizing the four themes into a conceptual representation of how technical, institutional, trust, and competency barriers interact as a compound adoption constraint system rather than independent parallel barriers.

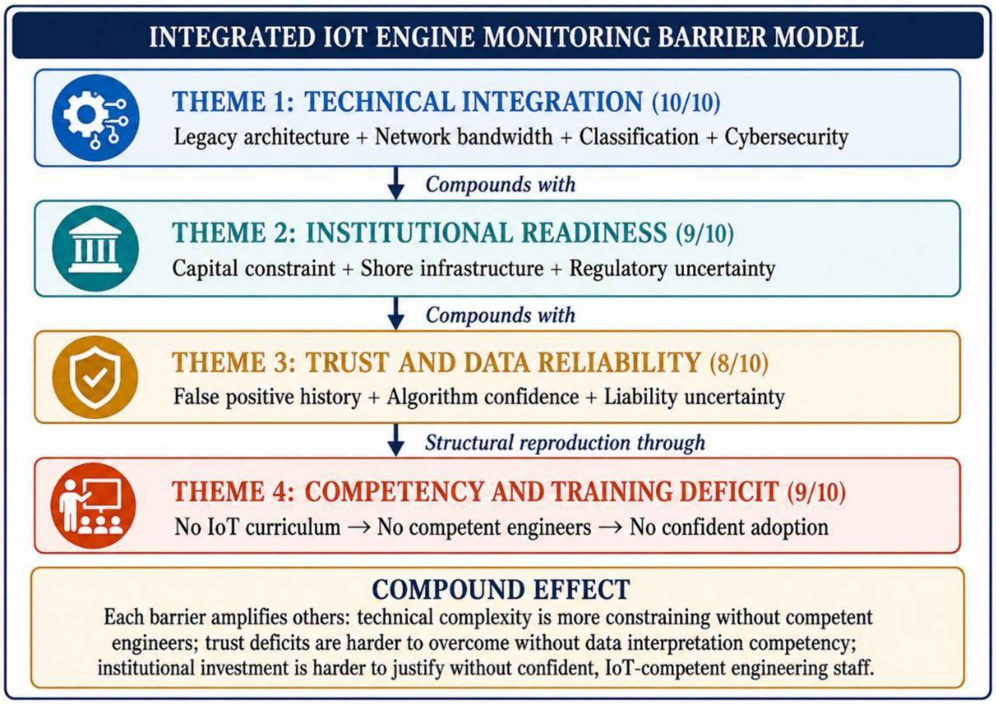

Figure 1. Integrated IoT Engine Monitoring Adoption Barrier Model (n = 10 ENG Experts)

3.6 Discussion

The four-barrier thematic structure generated by this study advances the IoT maritime adoption literature in two analytically specific ways. First, it empirically documents the Trust and Data Reliability barrier as a distinct and consequential adoption constraint category that is not reducible to technical capability limitation or financial constraint — a barrier whose existence in the expert community's professional experience reflects a historically specific pattern of early IoT deployment producing false positive alert experiences that have created lasting credibility deficits for algorithmic maintenance recommendations among experienced marine engineers. This finding extends Rogers' [5] diffusion of innovations framework by identifying observability's negative complement — the observation of system failures or false positives — as a barrier mechanism that the original framework's positive observability construct does not capture and that the maritime IoT deployment history has generated specifically for the expert engineering community most positioned to advocate for broader adoption.

Second, the compound barrier model in Figure 1 — in which technical, institutional, trust, and competency barriers interact and amplify each other — provides a more accurate diagnostic framework for IoT adoption barrier policy than barrier lists that treat each constraint as independently addressable. Expert participants' accounts consistently described compound constraint experiences: the technical integration challenge is more overwhelming without competent engineers who understand IoT system architecture; the trust deficit is harder to overcome without data interpretation training enabling practitioners to distinguish genuine fault signals from sensor noise; the institutional investment case is harder to make without confidence in available engineering workforce IoT competency [11]. This compound structure implies that piecemeal barrier-removal strategies — addressing only financial constraints through subsidized IoT hardware, for example — are likely to produce disappointing adoption outcomes because the remaining compound barriers suppress adoption even when one constraint is removed.

The ENG curriculum implication of Theme 4's findings is specific and actionable. The complete absence of IoT learning objectives from all 10 current ENG syllabi, combined with expert consensus assessment that STIP Jakarta ENG graduates lack IoT commissioning, telemetry interpretation, and predictive maintenance analytics competency, establishes a curriculum reform need directly comparable to the big data competency gap documented in the companion PSM expert validation study (DIGITS Paper 3) — with the important addition that in the ENG context, the competency gap is a barrier to industry-wide IoT adoption rather than merely an individual graduate career limitation [12].

4. Conclusion

This study has identified and characterized four IoT engine monitoring adoption barrier themes — Technical Integration Challenges, Institutional Readiness and Financial Constraints, Trust and Data Reliability Concerns, and Competency and Training Deficits — through expert focus group discussion with 10 Marine Engineering practitioners at STIP Jakarta, revealing a compound barrier structure in which each barrier amplifies the constraining effect of the others. The Trust and Data Reliability theme emerges as a distinctive contribution to the IoT maritime adoption literature, documenting false positive alert experiences as a persistent adoption barrier that technical improvement alone cannot resolve. Document analysis confirms that 0 of 10 ENG syllabi address IoT engine monitoring competency, establishing the curriculum reform gap that the Competency and Training barrier theme identifies as directly institutionally remediable. These findings contribute the first practitioner-grounded, barrier-typologized account of IoT engine monitoring adoption challenges in Indonesian maritime engineering practice and provide STIP Jakarta's ENG curriculum development with specific, expert-validated content priorities for IoT integration.

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