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# Enhancing the implementation of smart ports through data governance and human resource development: Case Study of Tanjung Perak Port, Surabaya, Indonesia

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## Abstract

The transformation of conventional ports into smart ports through the application of the Internet of Things (IoT) faces two main challenges, namely effective data governance and human resource capacity building. This study examines the contribution of data governance and technology integration to the operational efficiency of smart ports, identifies implementation barriers, evaluates their impact on port competitiveness through reducing dwelling time, and develops a progressive policy model that integrates regulatory innovation with human resource development. This study uses a mixed-methods sequential explanatory design, which combines quantitative, qualitative, and regulatory analysis at Tanjung Perak Port, Surabaya. Quantitative data from 48 port workers were analyzed using descriptive statistics. Qualitative data from stakeholder interviews and field observations were analyzed using thematic content analysis. The regulatory analysis examines Indonesia's smart port legal framework through a document review and compares it with Dutch and Singapore regulations to identify harmonization gaps and compliance challenges with international conventions. The implementation of the Terminal Booking System (TBS) has succeeded in reducing dwelling time from four days to two to three days (an increase of more than 25%), with 95.8% of workers reporting reduced workload. AI and data analytics skills. The regulatory analysis reveals that although Indonesia already has adequate smart port regulations, the challenge of harmonizing between existing legal frameworks and international conventions is still ongoing. This research proposes a tripartite policy architecture that integrates regulatory sandbox mechanisms adapted from the financial technology sector, immediate advanced technology training programs, and standardized certifications to bridge the workforce capacity gap.

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## Keywords

Smart ports, Data governance, Human resource development, Internet of things, Regulatory sandbox

## Introduction

As the largest archipelagic country in the world, Indonesia occupies a strategic position in the global maritime trade route, with 40% of the world's shipping routes passing through its waters. However, this maritime potential has not been optimally utilized due to various systemic challenges in the national logistics system. Indonesia's Logistics Performance Index (LPI) ranks 46th globally and 4th in Southeast Asia, behind Singapore, Thailand, and Malaysia. More critically, national logistics costs account for 26% of GDP, far exceeding the global average of 8-10%. This inefficiency directly lowers Indonesia's competitiveness in the global market, considering that the average dwelling time in large ports reaches four days before the implementation of smart ports, well above international best practices of only one to two days.

The urgency of port management innovation is increasingly evident considering that Indonesia, as an archipelagic country, recognizes the urgent need for ports with international standards (Rachmawati & Rastuti, 2023). With 638 large and small ports, the government has positioned maritime transport as a key economic pillar given its significant impact on national and regional supply chains. The maritime sector shows substantial economic significance: contributing 7.9% to national GDP with an annual growth of 12.53%, increasing the volume of export-import trade through improved infrastructure, driving regional economic growth through port infrastructure investments that create jobs and attract foreign investment, as well as generating investment and employment opportunities in related sectors (Dwinovan et al., 2024). Maritime transportation plays a key role in improving the efficiency of Indonesia's ports by optimizing shipping routes, adopting digitalization, and increasing fleet capacity (Li et al., 2025)

The urgency of digital transformation in Indonesian ports is increasingly intensified in the post-pandemic era, as supply chain resilience is very important for economic recovery. Recent studies have shown that the adoption of smart ports through IoT technology, artificial intelligence (AI), and blockchain can significantly improve operational efficiency as well as reduce bureaucratic barriers Modernization of fleets and cargo handling facilities, such as automated container terminals, helps reduce dwelling time and accelerate logistics flows. The development of maritime hubs and collection ports in various strategic areas will distribute logistics burdens more evenly, reduce pressure on major ports, and strengthen Indonesia's competitiveness against countries such as China, Singapore, Malaysia, and Vietnam (Maruf, 2024).

Although academic attention to smart port development continues to grow, three critical gaps in the literature still significantly limit its practical implementation in developing countries. First, although (Dwinovan et al., 2024)identified regulatory barriers, including regulatory ambiguity and inefficient administrative processes, that hamper Indonesia's maritime potential, existing studies have failed to propose actionable innovation mechanisms, such as the regulatory sandbox framework (I. R. Maruf, 2023). The evolution of port policy but do not synthesize the findings into an

evidence-based model that integrates the sandbox concept that has been successfully implemented in the financial technology sector. This regulatory vacuum prevents the systematic testing of innovations such as the Port Community System, automated gates, and blockchain-based supply chain management before national adoption is made. This creates implementation paralysis, where ports recognize the benefits of digitalization but do not have legal certainty to pursue it.

Second, (Gao et al., 2024)affirm that effective data governance, including data lifecycle management and quality control, is the foundation for IoT effectiveness. However, their conceptual framework lacks empirical testing in Indonesian ports. More critically, these studies ignore the challenges of parallel human resources. While (Zhou, 2006) acknowledge the need for a workforce, empirical evidence quantifying skills gaps and the effectiveness of training programs is still lacking. This dual deficiency creates a sustainability risk where technology investments cannot be fully utilized due to the absence of data protocols and insufficient human capital to operate and maintain the system.

Third, previous studies have used a single-method approach without integrating empirical field data with labor policy and assessment frameworks. Paraskevas et al. (2025) examined innovative port technologies but lacked validation from developing countries, where infrastructure maturity varies widely (Wang, 2024) propose a sophisticated framework but assume readiness that may not exist in resource-constrained environments. These methodological limitations weaken its practical application because technology adoption, regulatory readiness, and human capacity must be assessed simultaneously to formulate realistic implementation strategies for developing countries. To overcome these limitations, this study specifically adopts a mixed-methods sequential explanatory design that integrates empirical field data with policy analysis and workforce capacity assessment simultaneously, resulting in a tripartite framework that has never been operationalized before in the context of Indonesian maritime law.

## *Research Questions*

Based on these gaps, this study answers three fundamental questions:

1. How do data governance strategies and technology integration affect the operational efficiency of Indonesia's smart ports, and what is their measurable impact on dwelling time and productivity?
2. How big is the human resource skills gap in smart port operations, and how does workforce readiness affect the sustainability of implementation?
3. Can the regulatory sandbox framework be adapted from the context of financial innovation to port digitalization, and what kind of policy architecture is needed for progressive implementation in developing countries?

### *Research Objectives*

This study aims to: (1) examine the contribution of data governance and Terminal Booking System (TBS) technology integration to the operational efficiency of smart ports, especially measuring the reduction in dwelling time and productivity increase at Tanjung Perak Port; (2) quantify the workforce skills gap between the competencies required and the existing training program through primary survey data from 48 port workers, in order to identify critical barriers to human resource development; (3) evaluate the implementation of the regulatory sandbox framework for the progressive implementation of smart ports, by drawing lessons from the experience of the financial technology sector; and (4) developing evidence-based policy models that integrate technological readiness, workforce capacity building, and regulatory innovation for the sustainable transformation of smart ports in developing countries.

## Method

This study uses a mixed-methods sequential explanatory approach which was carried out at Tanjung Perak Port, Surabaya, between March and September 2024. This study focuses on two main terminal operators, namely PT Terminal Petikemas Teluk Lamong and PT Terminal Petikemas Surabaya, which are the only terminals with the implementation of an active Terminal Booking System (TBS) during the research period.

### *Research design and data sources*

This study integrates three complementary data sources to ensure comprehensive analysis and methodological triangulation. The researchers collected primary qualitative data through in-depth interviews with key stakeholders, including port management executives, terminal operators, regulatory officials, and technology implementation teams. The researchers obtained primary quantitative data through a structured questionnaire that was distributed to 48 port workers from various operational and departmental levels. Secondary data includes port operational records which include dwelling time statistics, throughput metrics, and Berth Occupancy Ratio (BOR) covering the period before and after the implementation of TBS.

The sample of 48 respondents reflects the operational workforce that can be accessed in the two terminals. The findings of this study are not intended as a statistical representation of all Indonesian ports, but rather provide analytical generalizations to the context of equivalent developing countries through the proposed policy framework.

### *Data collection*

Qualitative interviews use purposive sampling to select informants who have first-hand experience in smart port implementation. Semi-structured interview sessions lasted 60-90 minutes, the researcher recorded audio with respondents' consent, and the interviews covered four themes: (1) the technology adoption process and its challenges; (2) adequacy of the regulatory framework; (3) operational impact assessment; and (4)

the need for human resource capacity. The researcher conducted the interview in Indonesian and transcribed it verbatim.

The quantitative survey used convenience sampling with a self-administered questionnaire that measured: (1) demographics and labor experience; (2) the impact of technology adoption; (3) training participation and skills assessment; and (4) future technological readiness. The entire item uses the Likert scale and multiplchoice formats. The researcher conducted a trial questionnaire with five respondents before full distribution to ensure the validity and clarity of the instrument.

### *Data analysis*

Qualitative data through thematic content analysis using NVivo 12, following systematic stages: transcription, initial coding, thematic grouping, and interpretation through constant comparison with the literature. The researcher analyzed quantitative data using SPSS version 26 through descriptive statistics, frequency distribution, percentage calculation, and cross-tabulation. Data triangulation compares findings across interviews, surveys, and operational records to reinforce validity and identify differences that require more in-depth investigation. All research procedures adhere to ethical protocols, including informed consent, confidentiality through anonymization, and institutional approval from port authorities.

## Results and discussion

### *Technology integration and operational efficiency: The impact of data governance on port performance*

Empirical investigations at the Port of Tanjung Perak show that the implementation of the Terminal Booking System (TBS) has resulted in significant operational improvements, validating the potential of smart port technology in the context of developing countries. Field data shows a decrease in dwelling time from four days to two to three days, which represents an increase in cargo processing efficiency of more than 25%. These findings are in line with (Paraskevas et al., 2024), who argue that smart port technologies, particularly digital ordering systems and automated container handling, can reduce bureaucratic barriers and speed up logistics flows. The decrease in dwelling time in Tanjung Perak exceeds international benchmarks that suggest a moderate increase of 15-20%, indicating that Indonesian ports that start from lower basic efficiency levels can achieve more dramatic improvements through early digitalization interventions.

The implementation strategy adopts a phased and multi-terminal approach that focuses on two main container terminals, namely PT Terminal Petikemas Teluk Lamong and PT Terminal Petikemas Surabaya, as pilot locations. This approach is in line with Jahn and (Jahn & Nellen, 2022) who affirm that the development of smart ports requires strategic planning with a phased implementation phase tailored to institutional readiness. Interview data revealed that this phased strategy allows for centralized resource

allocation, intensive stakeholder engagement, and controlled risk management during the initial deployment of the technology. In addition, the adoption of international benchmarking, particularly learning from Singapore's port management practices, demonstrates an awareness of global best practices while adapting to the local context. (Wiko et al., 2023)emphasize the importance of learning from advanced maritime economies, while acknowledging that direct replication may not be appropriate given the differences in institutional capacity and infrastructure maturity.

Data governance has emerged as a success factor that is poorly studied but very critical. Interview data revealed that the effectiveness of FFB depends on accurate and timely data integration across various systems, including customs, trucking companies, and terminal operators. These findings support (Gao et al., 2024), who affirm that data governance frameworks, including lifecycle management, quality control, and interoperability standards, are prerequisites for the performance of IoT ecosystems. However, neither the interview nor survey data show explicit concern for data governance policies in Tanjung Perak, indicating that current successes are vulnerable to scalability challenges. As the expansion of port digitalization includes additional technologies such as blockchain, AI-based predictive analytics, and automated decision-making systems, a robust data governance framework will become increasingly essential.

Assessments of existing digital application systems reveal diverse readiness with significant scalability implications. The data shows that 40% of respondents rated their app's mastery in the good category, while 30% rated it quite well, resulting in a positive rating of 70%. However, 20% rated their mastery somewhat lacking, and 10% rated it poorly, indicating that nearly a third of port operations still face serious constraints (Paraskevas et al., 2024) assert that uneven digital capabilities across port networks create systemic vulnerabilities, as supply chain efficiency depends on consistent performance across interconnected nodes. This distribution shows a substantial digital readiness gap and requires differentiated intervention strategies. (Priadi, 2022) argues that the optimization of intelligent technology for sustainable maritime transportation requires not only the application of technology, but also continuous capacity building so that workers can take full advantage of the system's functionality. The distribution of the mastery of the application indicates that the current utilization only reflects the realization of a part of the available digital capabilities.

### *Human resource capacity gap: Magnitude and sustainability implications*

Survey data from 48 port workers reveals a paradoxical situation that threatens the sustainability of smart port transformation. While 95.8% of respondents reported reduced workload or positive changes after the implementation of TBS, with 37.5% experiencing a significant reduction in workload and 58.3% reporting a slight reduction, critical capacity gaps emerged simultaneously. In addition, 83.3% of workers experienced an increase in working hours through greater flexibility (37.5%) or more

regular scheduling (45.8%), indicating that technology adoption improved worker well-being and operational order.

However, the survey results revealed that 62.5% of respondents have not participated in any specific development program, although 58.3% of them identified advanced technology training in artificial intelligence and data analytics as their key capacity building needs. This condition represents a serious misalignment between the skills needs that have been identified and the availability of training programs. (Zhou, 2006) assert that advanced digital systems, such as the federated Digital Twin framework, require workforce competencies in data interpretation, system monitoring, and problem-solving, i.e. skills that cannot be assumed to exist, but must be systematically developed through targeted training interventions.

This gap is even more alarming when considering the readiness of future technologies. Although 83.3% of respondents expressed confidence in adapting to future technologies, with 37.5% very prepared and 45.8% ready for continuous learning, this optimism does not necessarily translate into actual capabilities without institutional support for capacity building. (Gao et al., 2024) argue that human resource capacity is a critical driving factor for effective data governance in an IoT-enabled port environment, and warns that technology adoption without parallel workforce development creates operational vulnerabilities.

Comparative analysis with international benchmarks confirms the urgency of addressing this problem. The Port of Singapore maintains a 95% workforce certification rate for digital port technology, the Port of Rotterdam achieves advanced technology readiness of 90%, and the Port of Shanghai reports a digital literacy rate of 85% among port workers. On the other hand, the findings in Tanjung Perak showing that only 4.1% of workers have smart port technical certifications indicate that Indonesia is far behind global standards. This gap, if not addressed immediately, will limit Indonesia's ability to move beyond basic digitalization towards a sophisticated smart port ecosystem and integrate advanced AI, blockchain, and analytics.

Training needs profiles provide actionable insights for policy interventions. Beyond the dominant need for advanced technology training (58.3%), respondents identified a need in soft skills and communication (20.8%), leadership and management (16.7%), as well as international port certification (4.2%). This diversity indicates that a comprehensive workforce development program must address the broader technical competencies as well as professional skills, which are needed for a collaborative and technology-mediated work environment. (M. Maruf, 2026) emphasized that digital transformation in maritime law enforcement and port operations requires not only technical skills, but also regulatory literacy and cross-functional collaboration.

A moderate level of application proficiency indicates that workers have acquire (Perkovič et al., 2024) basic operational skills through informal on-the-job learning or minimal initial training. However, they do not have the systematic capacity development

to achieve proficient levels of use. This pattern is consistent with Pwho evaluated the performance of Indonesia's logistics system and found that policy implementation often emphasizes infrastructure deployment while underinvesting in the human capital development required for effective system use. The Tanjung Perak data provides empirical confirmation of this policy imbalance, which shows that the availability of technology does not automatically result in optimal utilization without a sustained capacity building program.

### *Adaptation of the regulatory sandbox: Policy architecture for progressive smart port implementation*

The successful phased implementation in Tanjung Perak provides an empirical foundation to adapt the regulatory sandbox to the digitalization of the port. Maruf et al. (2023, 2024) and Rachmawati et al. (2023) identified regulatory uncertainty as the main obstacle to the comprehensive implementation of smart ports in Indonesia. The Tanjung Perak case shows that controlled experimentation at specific terminals, combined with systematic monitoring and stakeholder collaboration, can generate evidence to scale innovation while managing risk. This is in line with the principles of the regulatory sandbox that have (Rachmawati, 2020)been successfully implemented in the financial technology sector, where limited-scale testing precedes full regulatory integration. However, the study reveals that the current implementation takes place without a formal sandbox framework. The institutionalization of the sandbox mechanism through explicit regulatory instruments can accelerate replication to 638 Indonesian ports by providing legal certainty and risk mitigation structures.

This research proposes a three-tier policy architecture for regulatory sandbox adaptation. First, short-term priorities (zero to six months) focus on intensive advanced technology training programs in AI and data analytics. These programs target 58.3% of workers who identify these needs and implement them through a bootcamp format with hands-on practice and vendor collaboration. Second, medium-term priorities (six to twelve months) address the need for soft skills development and leadership affecting 37.5% of respondents, with an emphasis on communication, collaboration, and supervisory competencies for technology-mediated work environments. Third, long-term priorities (one to two years) aim to build a continuous learning platform with self-paced modules, regular updates that are in line with technological evolution, and integration with career development pathways. This phased approach balances urgency with resource constraints typical of developing countries.

The findings of this study indicate that the regulatory sandbox framework should include explicit requirements for workforce capacity development. (Rachmawati & Rastuti, 2023) trace the evolution of port policy but do not link regulatory innovation to human capital investment. The study argues that the criteria for sandbox participation should include mandatory training programs to ensure that technology testing takes place in the context of an adequately prepared workforce. This integration addresses a sustainability concern revealed from the data: that technological success without

human capital investment in parallel creates a fragile system that is vulnerable to knowledge loss and operational disruption.

The heterogeneity of application mastery among respondents reveals variations in digital readiness potential at the organizational or terminal level. Given that the study focused on two major terminals, the distribution may reflect differences in implementation schedules, training intensity, or levels of management support across different facilities. This variation reinforces the importance of a gradual, multi-terminal approach. The variation also confirms that the success of replication depends on the standardization of not only the application of the technology, but also the companion training protocols and user support systems. (Rachmawati & Rastuti, 2023) examines Indonesia's maritime infrastructure development strategy and argues that technological modernization must be accompanied by strengthening institutional capacity to ensure sustainable outcomes.

The Tanjung Perak case shows that the transformation of smart ports in developing countries cannot simply replicate advanced economic models, but must adapt to different institutional contexts, infrastructure, and capacities. This research validates an adaptive benchmarking approach that learns from international best practices while acknowledging local constraints and opportunities. These findings support the argument of (Dwinovan et al., 2024) that Indonesia's unique geography, institutional structure, and development stages require contextualized innovation strategies. The successful phased and multi-terminal implementation in Tanjung Perak offers a replicable model for many Indonesian ports at various stages of development. This model provides an empirical foundation for a progressive national policy framework, which accommodates heterogeneity while driving systematic progress towards a smart port ecosystem.

The group of 30% who consider their technological mastery somewhat lacking or poor should be the main target of immediate intervention to minimize the digital divide between ports. This group likely faces multiple challenges, including limited prior technology exposure, inadequate initial training, insufficient ongoing support, or limited resources that prevent dedicated learning time. Policy interventions should include extended remedial training programs and hands-on practice, peer mentoring systems that pair proficient users with struggling peers, as well as enhanced technical support mechanisms to provide real-time problem-solving assistance. Without targeted attention to this group, the digital divide risks widening further as more sophisticated technologies are deployed, potentially creating a two-tier port system where capable facilities continue to thrive while struggling facilities are further lagging behind.

## Conclusion

The Terminal Booking System has successfully reduced the dwelling time from four days to two to three days, which represents an increase in efficiency of more than 25%. This achievement exceeds international benchmarks by 15 to 20%, thus validating that

Indonesian ports that start from lower basic efficiency can achieve more substantial improvements through early digitalization interventions. Nonetheless, the study identified a critical gap: the effectiveness of FFB depends on accurate and timely data integration between customs, trucking companies, and terminal operators, yet explicit data governance policies are not yet available in Tanjung Perak. This condition indicates that operational success is currently vulnerable to scalability challenges as the digitization of ports moves towards blockchain, AI-based predictive analytics, and automated decision-making systems. These technologies require data lifecycle management, quality control, and strong interoperability standards. This study confirms that a data governance framework is a prerequisite for the sustainable performance of the IoT ecosystem, but Indonesian ports have not systematically institutionalized it despite the initial technological successes.

This study quantifies the paradoxical situation in workforce readiness. While 95.8% of workers reported operational improvements and 83.3% experienced better working hours after the implementation of FFB, 62.5% have not participated in any specific development programs. Simultaneously, 58.3% identified advanced training in artificial intelligence and data analytics as their key capacity building needs. This misalignment between the needs of recognized skills and the available training infrastructure directly threatens the sustainability of implementation. In addition, only 4.1% of workers have smart port technical certification, compared to 95% at the Port of Singapore, 90% at the Port of Rotterdam, and 85% at the Port of Shanghai, which shows that Indonesia is far behind global standards. An assessment of digital application systems revealed that while 70% demonstrated adequate basic proficiency, 30% rated their competence somewhat lacking or poor, creating a digital readiness gap between ports that risks widening with the adoption of advanced technology. Early digitalization succeeded through minimal training and on-the-job learning, but further progress towards a sophisticated smart port ecosystem will face serious capacity constraints without substantial investment in workforce development infrastructure. This confirms that the adoption of technology without the development of human capital in parallel creates operational vulnerabilities and fragile systems.

The successful implementation of the gradual and multi-terminal in Tanjung Perak focusing on PT Terminal Petikemas Teluk Lamong and PT Terminal Petikemas Surabaya as pilot locations demonstrates the principle of controlled experimentation that is analogous to the regulatory sandbox in the financial technology sector. However, this implementation took place without a formal sandbox framework, so the institutionalization of the sandbox mechanism through explicit regulatory instruments could accelerate its replication to 638 Indonesian ports. The study proposes a three-tier policy architecture that integrates short-term priorities (zero to six months) that focus on intensive advanced technology training for 58.3% of workers who need AI and data analytics skills, medium-term priorities (six to twelve months) that address soft skills development and leadership for 37.5% of respondents, and long-term priorities (one to

two years) that build learning platforms sustainable with the integration of career development. Sandbox participation criteria should include mandatory training programs to ensure technology testing takes place in the context of adequate workforce readiness. The transformation of smart ports in developing countries cannot directly replicate advanced economic models, but rather requires contextualized innovation strategies that take into account institutional, infrastructure, and capacity constraints. The case of Tanjung Perak provides an empirically-based model for adaptive and progressive progress towards a smart port ecosystem.

This research has several limitations. A sample of 48 workers from two terminals in Tanjung Perak limited statistical generalization directly to Indonesia's broader port system. Further research needs to extend the empirical base to additional port terminals and categories to validate the proposed policy framework on a national scale. Longitudinal studies that track workforce competency development and regulatory sandbox outcomes after formal implementation will further strengthen the evidence base of this research.

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