

Digital Transformation for Enhancing Port Competitiveness, Resilience, and Sustainability: Evidence from Tanjung Perak Port, Surabaya

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Abstract—Digital transformation has become a strategic driver in improving port performance amid increasing pressure on global logistics systems, particularly in relation to efficiency, resilience, and sustainability. This study aims to analyze the role of digital transformation in enhancing port competitiveness, operational resilience, and sustainability at Tanjung Perak Port, Surabaya using a qualitative case study approach. Data were collected from policy documents, operational reports, and observations of digital systems implemented during the 2019–2024 period, and analyzed using thematic content analysis supported by NVivo 14. The findings indicate that digital platform integration contributes to a 20–30% reduction in administrative processing time and improves coordination among stakeholders, thereby strengthening operational competitiveness. However, the impact on operational resilience is not uniform, as its effectiveness decreases in situations requiring cross-institutional coordination due to governance fragmentation. In terms of sustainability, digital transformation provides indirect benefits through reduced vessel waiting time and improved operational efficiency, which potentially lowers fuel consumption and environmental impact. The study concludes that digital transformation functions as an integrative mechanism linking competitiveness, resilience, and sustainability in port operations, but its effectiveness is highly dependent on institutional coordination and governance alignment, indicating that technological adoption alone is insufficient without parallel organizational reform.

Keywords—digital transformation; port; competitiveness; resilience; sustainability.

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I. INTRODUCTION

Tanjung Perak Port holds a strategic position within Indonesia's maritime logistics network as a major gateway supporting national and regional trade flows. In the context of increasing global supply chain volatility, congestion risks, and sustainability pressures, ports are expected to evolve beyond traditional infrastructure-based systems toward digitally enabled, intelligent, and adaptive operational models [1]. According to Notteboom, Pallis, and Rodrigue, modern port competitiveness is increasingly determined by the integration of logistics coordination, governance efficiency, and digital information systems rather than physical capacity alone [2]. This shift highlights the growing importance of digital transformation in shaping port performance.

Recent studies confirm that digital transformation has become a key enabler for improving efficiency, sustainability, and competitiveness in maritime systems. For instance, smart port initiatives leveraging IoT and

integrated data systems have been shown to enhance operational performance and reduce inefficiencies across port processes [3], [4]. Similarly, digitalization in maritime transport has been identified as a driver of service optimization and system integration, particularly in improving coordination among stakeholders [5]. Process-oriented innovations such as smart gate systems further demonstrate that targeted digital interventions can significantly improve operational flow and reduce bottlenecks in port operations [6].

However, despite these advancements, most existing research remains focused on efficiency-oriented outcomes and tends to treat competitiveness, resilience, and sustainability as separate analytical dimensions. Studies on traffic simulation and logistics optimization, for example, primarily emphasize efficiency gains and environmental improvements without fully addressing the systemic interdependencies between operational resilience and institutional governance [7]. Likewise, resilience studies often focus on disruption response mechanisms but do not fully integrate governance coordination as a determining factor [8]. This indicates a conceptual fragmentation in the existing literature.

Furthermore, much of the empirical evidence originates from developed regions with relatively mature institutional frameworks and high levels of digital readiness. Research on smart technologies and optimization models in port digitalization shows strong performance improvements [9]. However, these findings are often context-specific and may not directly translate to developing countries with fragmented governance structures [10], [11]. In contrast, studies in developing maritime systems highlight that organizational transformation and networking capability play a critical

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role in determining the success of digital implementation [12]. This suggests that technological adoption alone is insufficient without institutional and organizational alignment.

In the Indonesian context, studies have begun to explore smart port systems and digital transformation initiatives, particularly in improving operational efficiency through IoT-based systems [13]. Additionally, maturity model assessments of port digitalization in archipelagic countries indicate that uneven digital readiness and institutional variability significantly influence implementation outcomes [14]. However, integrated analysis that simultaneously examines competitiveness, resilience, and sustainability within a single governance framework remains limited. Existing research on integrated port governance systems suggests that alignment between digital systems and institutional coordination is essential for improving logistics performance, yet empirical validation in real operational ports remains limited [15].

Based on these gaps, this study focuses on Tanjung Perak Port, Surabaya, as a representative case of a major Indonesian hub port undergoing digital transformation. The port provides a relevant context due to its relatively advanced digital infrastructure, yet persistent challenges in system integration and cross-institutional coordination. Therefore, this study aims to analyze how digital transformation influences port competitiveness, operational resilience, and sustainability, while also identifying the institutional and operational factors that shape these relationships. By adopting a qualitative case study approach, this research seeks to contribute to a more context-sensitive understanding of port digitalization in developing country settings.

This study contributes to the literature in two main ways. Theoretically, it extends existing port digitalization models by positioning digital transformation as an integrative mechanism linking competitiveness, resilience, and sustainability under governance constraints. Practically, it provides insights for policymakers and port authorities regarding the importance of aligning technological investments with institutional reform and organizational capacity building to ensure consistent operational outcomes.

II. METHOD

2.1 Research Approach

This study uses a qualitative case study approach to look at how digital transformation helps ports become more competitive, resilient and sustainable. The researchers chose this approach because they want to understand how digital transformation actually works in a port not just look at numbers. They want to know how the port is run what policies are, in place and how decisions are made. Other studies that compare ports use numbers but they do not really show how digital transformation is used in each port. That is why a qualitative case study is the way to answer the research questions and get a complete picture of what is happening. Digital transformation is a part of this study and the researchers want to see how it is used in a port so

they can understand how digital transformation helps ports become more competitive, resilient and sustainable.

2.2 Research Design

The research is about Tanjung Perak Port in Surabaya. It looks at how the port's changing with digital technology. We are checking the ports systems and how people use them. This includes services and how people share information. We also look at how the port operates with technology. The analytical variables are conceptually defined as follows:

- (1) how much the port is using technology and what it looks like;
- (2) how well the port operates how strong it is and if it is good, for the environment;
- (3) the rules and policies that affect the port.

This way, the author can see how all these things are connected without thinking they always happen in a line. Tanjung Perak Port is the focus of this research. We want to understand Tanjung Perak Port and its digital transformation.

2.3 Data and Data Sources

The information used is based on what people said and what already exists and it also includes some details about how things work. The information comes from:

- (1) port-level shipping policy documents;
- (2) reports about how Tanjung Perak Port is doing and how well it is performing;
- (3) official documents about putting digital systems in place at the port from 2019 to 2024.

When we were gathering the information we noticed that the documents did not always have the information from year to year so we had to compare them to make sure the story, about the policies and what actually happened made sense.

The time frame we looked at is pretty long which helps us see what happened with digitalization at the port before and after the pandemic sped things up.

2.4 Data Processing and Analysis

Thematic content analysis was used to conduct the data analysis. Primary themes, indicating dimensions of competitiveness, resilience and sustainability, were coded from documents and observational material. The coding process was iterative, with several of the initial categories being revised when re-reading revealed conceptual overlaps between operational efficiency and adaptive resilience. Simple operational indicators such as administrative processing time and service integration were also employed as descriptive markers to assess the plausibility of qualitative findings. This approach helps balance narrative interpretation with evidence of traceable operations.

2.5 Validity and Reliability

To enhance internal validity, this study employs source triangulation, which involves comparing findings across different types of documents and different time periods. Results are discussed in the light of international literature, so that external validity is preserved and readers are able to assess the transferability of findings to other port contexts with similar characteristics. The

coding process is documented systematically and internal audits of thematic consistency are conducted, which enhances the reliability of the analysis. The qualitative approach is not to replicate the study with numbers but a transparent procedure which enables other researchers to follow the analytical logic.

2.6 Ethical Statement and Data Availability

This research did not involve human subjects directly and all data were obtained from publicly available documents and institutional reports. Therefore formal ethical approval was not required. All data sources can be traced to official repositories of the respective institutions and publicly available policy documents. This study follows ethical integrity and data traceability for the sake of analytical credibility and replication.

2.7 Software Disclosure for Reproducibility

Qualitative data management and analysis processes were performed using NVivo 14 for thematic coding and Microsoft Excel for the organization of descriptive indicators. The application of this software enhances transparency of the analytical process and is consistent with the Open Science and Transparency guidelines of international publishers. Data and coding frameworks are available for academic verification purposes upon reasonable request.

2.8 Methodological Limitations

Some limitations must be mentioned. Firstly, the focus on one port limits the statistical generalisability of findings. Second, reliance on secondary data limits the ability to directly capture the perspectives of field level actors. Third, the quantitative indicators are descriptive and do not intend to infer causality. These limitations leave room for future research with comparative cross-port approaches or the integration of quantitative methods.

III. RESULTS AND DISCUSSION

3.1 Data Presentation and Key Findings

Thematic analysis of policy documents, operational reports and digital system artifacts from 2019-2024 reveals several consistent patterns. First, the use of digital port platforms is associated with a reduction of 20–30% of administrative processing time, particularly in pre-arrival vessel services and inter-agency documents coordination [16]. This result is consistent with internal trends of operational performance in the post-pandemic period [17]. But the gain in efficiency is not homogeneous for all services. Processes that need coordination across institutions display slower rates of improvement.

Second, operational competitiveness shows relatively stable improvement, reflected in reduced service variability and more consistent queue management during peak operational periods. In contrast, operational resilience exhibits non-linear behavior. For routine operational disruptions such as scheduling adjustments and seasonal demand fluctuations, digital systems enhance response speed and coordination. However, in

disruption scenarios that require cross-agency policy alignment, the effectiveness of digital systems decreases significantly. Notably, several advanced digital modules remain underutilized when decision-making involves multiple authorities, indicating a gap between system capability and institutional adoption.

Third, in terms of sustainability, digital transformation contributes indirectly through improved operational efficiency, particularly via reduced vessel waiting times [18]. Although direct emission measurements are not available, operational indicators suggest a likely reduction in fuel consumption due to shorter berthing and queuing durations.

3.2 Analysis and Interpretation of Findings

The findings show that digital transformation acts mainly as a supportive catalyst instead of a standalone solution for improving port performance. The reduction in administrative processing time indicates that digital systems work best when operational processes are standardized and well-defined. On the other hand, in processes that need inter-agency coordination, governance structures significantly influence performance results.

This trend suggests that digital systems improve execution efficiency but do not replace institutional decision-making. The differences in resilience outcomes highlight the varying effects of digital transformation across different operational areas. While some services continuously improve, others stagnate due to differences in institutional readiness, user adoption, and clarity of authority distribution [19].

At Tanjung Perak Port, the current digital setup is fragmented into systems designed for specific functions. Operational platforms like the Port Commercial Service System, the Administrative Information System, and the Integrated Port Information System mainly focus on operational competitiveness. Vessel Traffic Service (VTS) systems are used for monitoring vessels and ensuring navigational safety, while the State Port Information and Performance (SPIP) system helps with sustainability monitoring and risk management. However, these systems operate in silos and have limited interoperability. This fragmentation limits the potential of digital transformation as a unifying mechanism and decreases synergy across port operations [20].

From a theoretical viewpoint, these findings support the idea that the success of digital transformation is shaped more by governance structures and organizational behavior than by technology alone [1],[5]. Therefore, developing an integrated smart port platform is necessary to connect competitiveness, resilience, and sustainability within a unified data and decision-support system. This integration is vital for reducing system fragmentation and improving coordination across port operations [21].

TABLE 1.
COMPARATIVE ANALYSIS OF FINDINGS AND LITERATURE

Finding	Literature Compared	Similarity/Difference	Possible Explanation	Policy Implication
20-30% reduction in administrative processing time	Notteboom & Rodrigue (2022)	Consistent	Data integration speeds up execution	Prioritize pre-arrival services
Stable improvement in operational competitiveness	Li et al. (2025)	Consistent	Service reliability improves	Standardize core modules
Uneven resilience outcomes	Zheng Chang et al. (2025)	Different	Gaps in cross-authority governance	Establish policy coordination mandates
Indirect environmental impact	Koritarov (2024)	Consistent	Reduced vessel waiting time	Target waiting-time reduction
Advanced modules underutilized	Basulo-Ribeiro & Pimentel (2024)	Partially aligned	Organizational readiness gap	Process-based training

3.3 Comparison with Prior Literature

Table 1 summarizes the comparison between findings from Tanjung Perak Port and relevant literature. The observed 20 to 30% reduction in administrative processing time aligns with results from Notteboom and Rodrigue [2]. They highlight that digital integration improves efficiency by enhancing logistics coordination. This connection shows that digitizing processes mainly provides measurable gains when applied to standardized procedures, especially in documentation and pre-arrival coordination systems.

Stable improvements in operational competitiveness match Li et al. [10], who point out that smart technologies improve service reliability through system optimization. This suggests that gains in competitiveness in digitalized port environments largely come from consistent system performance and the level of automation in everyday workflows. In this context, digital transformation helps stabilize service delivery rather than just speeding up isolated processes.

However, the different resilience outcomes observed here contrast with findings from Zheng Chang et al. [8]. They report more uniform resilience improvements where there is stronger governance integration. This difference highlights the important role of coordination among institutions in shaping resilience outcomes, particularly in areas where decision-making is shared among multiple agencies. It shows that resilience in port systems is not just a technological result; it's a capability that depends on governance and requires structured cooperation among agencies.

Regarding sustainability, the indirect environmental benefits found in this study agree with Koritarov et al. [3], who note that reduced vessel waiting time lowers

environmental impact through better operational efficiency. This reinforces the idea that improvements in environmental performance at ports often stem from operational optimization rather than direct efforts to target environmental issues.

Additionally, the underuse of advanced digital modules partly aligns with Basulo-Ribeiro and Pimentel [6]. They emphasize that how ready an organization is plays a significant role in how effective digital gate systems are. This finding suggests that having advanced technology doesn't automatically ensure efficiency, as both institutional readiness and user adaptation are crucial for determining actual system performance.

Overall, the analysis shows that while digital transformation consistently boosts operational efficiency and competitiveness, its effects on resilience and sustainability depend more on the context and are strongly influenced by governance structures and organizational readiness.

3.4 Theoretical Implications

The findings suggest that port digitalization models need improvement by including interactions between competitiveness, resilience, and sustainability. Current models that see these dimensions as separate could oversimplify how ports really work.

The results support the idea that digital transformation acts as a way to connect different elements, influenced by governance structures and organizational behavior [22]. While technology offers operational ability, how institutions are set up decides how well this ability is used. This shows the need to consider governance when looking at the results of digital transformation in port systems.

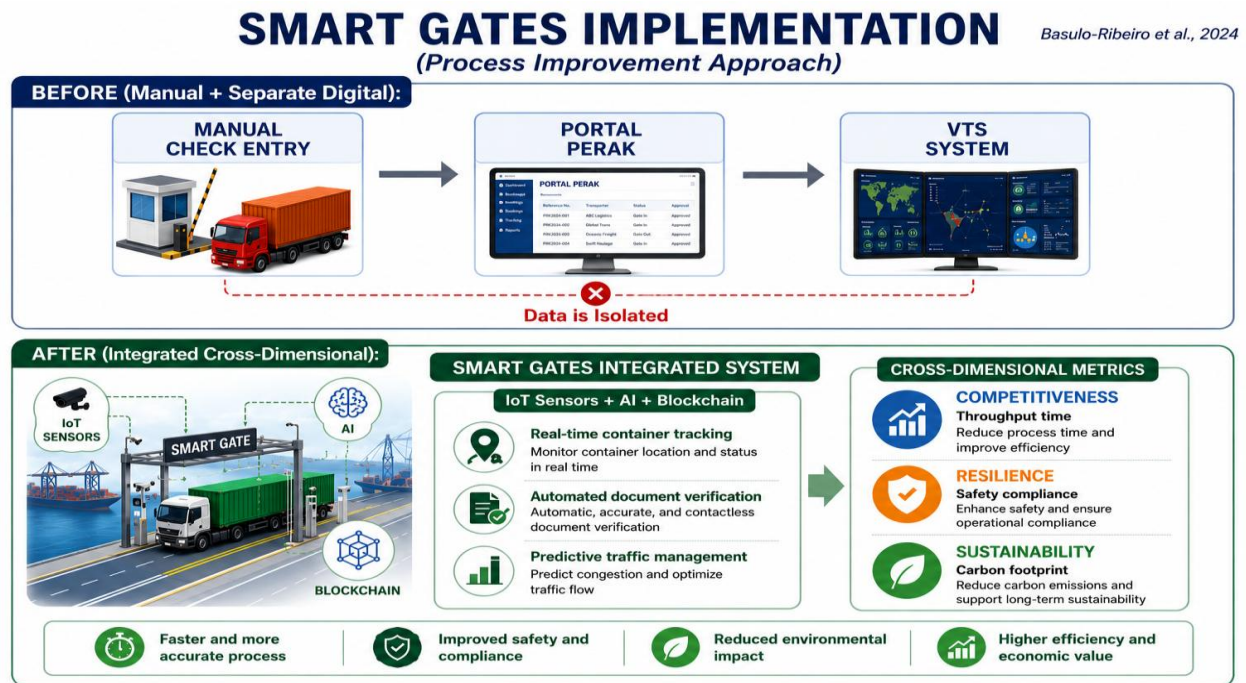


Figure 1. Smart Gates Implementation

Source: Author (2026).

3.5 Practical and Policy Implications

From a policy perspective, digital transformation initiatives should be part of larger institutional reform programs instead of being treated as separate technological investments. Key priorities for implementation include: (i) establishing mandates for integrated port services across agencies, (ii) standardizing data exchange methods among institutions, and (iii) changing training approaches from system-based methods to process-based capacity building. Policy evaluation should focus on performance consistency across operational areas rather than just looking at system adoption metrics. This way, digital transformation can drive efficiency improvements as well as support long-term system resilience and sustainability [6], [23].

3.6 Robustness and Sensitivity

The robustness of findings is backed by cross-source triangulation among policy documents, operational reports, and system artifacts. The results remain consistent when looking at different indicators like service time variability. While the qualitative approach does not include statistical testing, stable patterns across various data sources add to the credibility of the findings.

Some relationships are sensitive to the institutional context, especially in cases of cross-agency collaboration. This sensitivity is seen as a natural feature of governance-related digital transformation rather than a limitation of the methods used. [24].

3.7 Limitations and Directions for Future Research

This study has limitations due to its single-case design and reliance on secondary data sources. This affects how broadly the findings can be applied to different port settings. Future research should consider

comparative studies involving multiple ports or mixed-methods approaches that include quantitative performance measures. Additionally, using direct environmental indicators like emissions data would enhance sustainability assessments and allow for more accurate evaluations of the impacts of digital transformation in maritime logistics systems [25].

IV. Conclusion

This study looked at how digital transformation affects the competitiveness, resilience, and sustainability of Tanjung Perak Port in Surabaya. The findings show that digital transformation positively impacts port competitiveness, especially by making administrative processes more efficient and service performance more reliable. However, these improvements do not occur evenly across all operational processes.

For operational resilience, the results reveal a mixed effect of digital transformation. Digital systems improve response capabilities during regular operational disruptions, but they are less effective in situations that need coordination between different institutions. This indicates that resilience relies more on governance and institutional readiness than on technology alone.

In terms of sustainability, digital transformation offers indirect benefits by improving operational efficiency, especially by reducing vessel waiting times, which may lower environmental impacts. Still, these benefits depend on how consistently operations are carried out and how well systems are used by all stakeholders.

Overall, the study concludes that digital transformation acts as an integrative factor that influences competitiveness, resilience, and sustainability in port operations. However, its success heavily relies on governance structures, institutional coordination, and organizational capacity. This shows that simply adopting

technology is not enough without also strengthening institutions to ensure consistent improvement across various areas.

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