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# Digital Transformation and Port Operational Risk Reduction: The Mediating Role of Integrated Information Systems

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**Abstract:** Ports play a critical role in national logistics systems, yet operational risks remain a major challenge, particularly in developing countries where digital transformation is still evolving. This study aims to examine the effect of digital transformation on port operational risk reduction in Indonesia, with integrated information systems, operational efficiency, and operational reliability as mediating variables. A quantitative approach was employed using questionnaire data collected from 125 port employees, analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The results indicate that digital transformation has a significant positive effect on integrated information systems ($\beta = 0.853$, $p < 0.001$). Integrated information systems significantly influence operational efficiency ($\beta = -0.594$, $p < 0.001$) and operational reliability ($\beta = -0.310$, $p = 0.002$). Furthermore, operational efficiency significantly reduces operational risk ($\beta = 0.355$, $p = 0.005$), while operational reliability does not have a significant effect ($p = 0.065$). Mediation analysis confirms that integrated information systems and operational efficiency significantly mediate the relationship between digital transformation and operational risk reduction ($\beta = -0.180$, $p = 0.007$), whereas the mediation through operational reliability is not supported. These findings highlight that digital transformation contributes to reducing port operational risks primarily through improving operational efficiency, providing important implications for port management and policy development.

**Keywords:** Digital Transformation, Information System, Port operation, Port Operational Risk, Port sector.

## INTRODUCTION

Ports play a strategic role in national logistics systems by facilitating the movement of goods and supporting economic growth. In Indonesia, as an archipelagic country, the efficiency and reliability of port operations are crucial in reducing logistics costs, which remain relatively high compared to other Southeast Asian countries. However, port operations are inherently complex and vulnerable to various operational risks, including service delays, administrative

errors, and system disruptions. These challenges highlight the need for more effective risk management supported by technological innovation.

In recent years, digital transformation has become a key strategy in improving port performance. The adoption of technologies such as the Internet of Things (IoT), Terminal Operating Systems (TOS), and integrated platforms like Inaportnet within the National Logistic Ecosystem (NLE) has enabled the digitalization of port services. Empirical evidence shows that by 2023, more than 264 ports in Indonesia had implemented Inaportnet, contributing to improved service efficiency, transparency, and real-time data processing. Nevertheless, the implementation of digital technologies is not without challenges. Issues such as limited system interoperability, uneven technological infrastructure, and low digital literacy among users continue to hinder the effectiveness of digital transformation in fully reducing operational risks.

An integrated information system is considered a critical mechanism in addressing these challenges. By enabling real-time data exchange and coordination across operational units, integrated systems can enhance decision-making, improve process efficiency, and strengthen operational reliability. These improvements are expected to contribute to reducing operational risks in port activities. However, while previous studies have discussed digital transformation and port digitalization, most remain descriptive and focus on individual technologies or operational improvements without empirically examining the causal relationships between key variables.

More importantly, there is still limited research that investigates how digital transformation influences operational risk reduction through the mediating roles of integrated information systems, operational efficiency, and operational reliability, particularly in the context of Indonesian ports. This gap indicates the need for empirical studies that provide a more comprehensive understanding of the mechanisms through which digital transformation affects operational risk.

Therefore, this study aims to examine the effect of digital transformation on port operational risk reduction by analyzing the mediating roles of integrated information systems, operational efficiency, and operational reliability. The findings of this study are expected to contribute to the development of academic literature in digital transformation and operational risk management in the maritime sector, as well as provide practical insights for port managers and policymakers in designing more effective digitalization strategies.

**Problem**

1. Does digital transformation affect the level of integration of port operational information systems?
2. Does an integrated information system affect the efficiency of port operations?
3. Does an integrated information system affect the reliability of port operations?
4. Does operational efficiency affect the reduction of port operational risk?
5. Does operational reliability affect the reduction of port operational risk?
6. Does an integrated information system act as a mediator in the relationship between digital transformation and the reduction of port operational risks through increased operational efficiency?
7. Does an integrated information system act as a mediator in the relationship between digital transformation and reducing port operational risks through increased operational reliability?

**Research Objectives**

The purpose of this research **is** to find out:

1. To test the influence of digital transformation on integrated information systems on port operations.

2. To analyze the influence of integrated information systems on port operational efficiency.
3. To analyze the influence of integrated information systems on the reliability of port operations.
4. To test the influence of operational efficiency on the reduction of port operational risks.
5. To test the influence of operational reliability on the reduction of port operational risks.
6. To analyze the role of integrated information systems and operational efficiency as mediating variables in the relationship between digital transformation and port operational risk reduction.
7. To analyze the role of integrated information systems and operational reliability as mediating variables in the relationship between digital transformation and port operational risk reduction.

**Research Benefits**

The benefits of the research are:

1. Theoretical Benefits

   This research is expected to contribute to the development of academic literature in the field of operational management and risk management, especially related to digital transformation in the port sector. This research enriches the understanding of the mechanisms of how digital transformation can reduce operational risks through the role of integrated information systems and increase operational efficiency and reliability. In addition, this research is also expected to be an empirical reference for the development of conceptual models of digital transformation and operational risk management in the maritime industry.
2. Practical Benefits

   This research is expected to be a consideration for port managers and management in formulating a more effective and targeted digital transformation strategy. The findings of this study can help port managers understand the importance of information system integration as a key factor in increasing operational efficiency and reliability and reducing operational risks. In addition, this research can provide input for the government and regulators in developing digital port development policies that are oriented towards improving port operational performance and resilience.

**Frame Of Mind**

Ports, as the main node in the logistics system, have complex operational activities, so they are vulnerable to various operational risks, such as service delays, administrative errors, and system disruptions. To reduce these risks, ports are required to improve operational performance through the use of digital technology.

Digital transformation enables the digitization of processes, service automation, and the utilization of operational data in real-time. However, the success of digital transformation in reducing operational risks is highly dependent on the level of integration of the information systems used. An integrated information system plays an important role in connecting data and processes between operational units, thereby supporting more effective coordination and decision-making.

The integration of information systems further encourages an increase in the efficiency and reliability of port operations. Operational efficiencies are achieved through shortening service times, resource optimization, and cost control, while operational reliability is reflected in service stability and the port's ability to handle operational disruptions. The increase in operational efficiency and reliability ultimately contributes to reducing the risk of port operations.

Based on this framework, this study positions integrated information systems, operational

efficiency, and operational reliability as the main mechanisms that explain the influence of digital transformation on reducing port operational risks.

## METHOD

This study employs a quantitative research approach to examine the relationship between digital transformation and port operational risk reduction, with integrated information systems, operational efficiency, and operational reliability as mediating variables.

### Population and Sample

The population of this study consists of employees and operational management staff working in ports across Indonesia who are directly involved in operational activities and the use of digital systems. These individuals are considered relevant because they have practical experience and knowledge related to port digitalization and operational processes.

The sample size consists of 125 respondents, determined based on the Hair et al. recommendation for Partial Least Squares Structural Equation Modeling (PLS-SEM), which suggests a minimum sample size depending on the complexity of the model.

### Sampling Technique

This study uses purposive sampling to ensure that respondents meet specific criteria relevant to the research objectives. The operational criteria for respondent selection are as follows:

1. Have at least one year of work experience in port operations
2. Are directly involved in operational activities or information systems
3. Have an understanding of digitalization processes in port operations

These criteria ensure that the respondents are capable of providing reliable and relevant information regarding the variables studied.

### Measurement and Instrument Development

Data were collected using a structured questionnaire. All variables were measured using a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). The measurement items were developed based on established theories and previous studies related to digital transformation, integrated information systems, operational efficiency, operational reliability, and operational risk.

Each construct was operationalized as follows:

1. Digital transformation reflects the adoption and utilization of digital technologies in port operations
2. Integrated information systems represent the level of system connectivity and data integration across operational units
3. Operational efficiency reflects the effectiveness of resource utilization and process optimization
4. Operational reliability indicates the consistency and stability of operational performance
5. Operational risk reflects the extent to which operational disruptions, delays, and errors are minimized

### Data Collection Procedure

The data were collected through questionnaire distribution to port employees who met the predefined criteria. The questionnaires were distributed both online and offline to ensure broader coverage and higher response rates. Respondents were informed about the purpose of the study and assured of the confidentiality of their responses.

**Data Analysis Technique**

The data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). This method was chosen because it is suitable for analyzing complex models with multiple variables and mediating relationships.

The analysis was conducted in two main stages:

1. Measurement Model Evaluation (Outer Model)
   This stage assesses the validity and reliability of the constructs using:

a. Convergent validity (outer loading > 0.5)
b. Discriminant validity (Fornell-Larcker criterion)
c. Composite reliability (CR > 0.70)

2. Structural Model Evaluation (Inner Model)
   This stage evaluates the relationships between variables using:

a. Coefficient of determination ($R^2$)
b. Path coefficients
c. Hypothesis testing using bootstrapping (p-value < 0.05)

This approach ensures that both the measurement model and the structural relationships are statistically valid and reliable.

## RESULT AND DISCUSSION

**Research Results**

**Convergent Validity**

Convergent validity was assessed using outer loading values, with a threshold of 0.50. The initial evaluation indicated that several indicators had loading values below 0.50 and were therefore removed from the model to improve construct validity. Specifically, the indicators X2, X3, M2.5, M3.2, M3.3, M3.5, and Y.3 were excluded due to low loading values.

After the elimination process, all remaining indicators showed outer loading values above the acceptable threshold, indicating that the constructs have adequate convergent validity. All retained indicators were then used in the subsequent analysis.

Tabel 1 : Validitas Convergence

| | M1 | M2 | M3 | X | Y |
|---|---|---|---|---|---|
| **M1** | 0.995 | | | | |
| **M1.5** | 0.931 | | | | |
| **M1.2** | 0.924 | | | | |
| **M1.3** | 0.915 | | | | |
| **M1.4** | 0.895 | | | | |
| **M1.1** | 0.686 | | | | |
| **M2** | | 1.000 | | | |
| **M2.1** | | 0.569 | | | |
| **M2.2** | | 0.692 | | | |
| **M2.3** | | 0.560 | | | |
| **M2.4** | | 0.796 | | | |
| **M2.5** | | 0.482 | | | |
| **M3** | | | 0.987 | | |
| **M3.1** | | | 0.750 | | |
| **M3.2** | | | 0.363 | | |
| **M3.3** | | | 0.406 | | |
| **M3.4** | | | 0.704 | | |
| **M3.5** | | | 0.485 | | |
| **X** | | | | 0.992 | |
| **X1** | | | | 0.659 | |

| | | |
|---|---|---|
| **X2** | 0.450 | |
| **X3** | 0.332 | |
| **X4** | 0.887 | |
| **X5** | 0.847 | |
| **Y** | | 0.995 |
| **Y.1** | | 0.534 |
| **Y.2** | | 0.664 |
| **Y.3** | | 0.353 |
| **Y.4** | | 0.556 |
| **Y.5** | | 0.793 |

Source: Research data

The results of convergent validity testing showed that most indicators had an outer loading value that met the recommended criteria. All indicators in the Integrated Information System (M1) variable are declared valid because they have an outer loading value of >0.5. In the variables of Operational Efficiency (M2), Operational Reliability (M3), Digital Transformation (X) and Port Operational Risk (Y), several indicators have an outer loading value below 0.5 so they need to be eliminated to improve the quality of the measurement model. After the removal of invalid indicators, the measurement model is declared to have met the convergent validity and can be proceeded to structural model testing.

**Discriminant Validity**

Discriminant validity was evaluated using the Fornell-Larcker criterion. The results show that the square root of the Average Variance Extracted (AVE) for each construct is higher than the correlation values between constructs. This indicates that each construct is empirically distinct and measures different concepts, thereby satisfying the discriminant validity requirement.

Tabel 2 : Discriminatory Validity

| | **M1** | **M2** | **M3** | **X** | **Y** |
|---|---|---|---|---|---|
| **M1** | **0.896** | | | | |
| **M2** | -0.594 | **0.705** | | | |
| **M3** | -0.310 | 0.438 | **0.654** | | |
| **X** | 0.853 | -0.501 | -0.238 | **0.734** | |
| **Y** | -0.405 | 0.520 | 0.395 | -0.388 | **0.681** |

Source: Research data

The results of the discriminant validity test showed that the square root value of AVE in each variable was higher than the correlation between other variables. The variables of Integrated Information System (M1), Operational Efficiency (M2), Operational Reliability (M3), Digital Transformation (X), and Port Operational Risk (Y) each have a diagonal value that is greater than their horizontal and vertical correlation values. Thus, it can be concluded that the measurement model in this study has met the criteria of discriminant validity and is suitable for further analysis.

**Reliability Test**

Reliability was assessed using composite reliability (CR). The results show that all constructs have CR values greater than 0.70, with values ranging from 0.799 to 0.960. This indicates that all variables in the model have high internal consistency and are considered reliable.

Tabel 3 : Reliability Test

| | Composite reliability (rho_c) |
|---|---|
| **M1** | 0.960 |
| **M2** | 0.848 |
| **M3** | 0.799 |
| **X** | 0.863 |
| **Y** | 0.825 |

Source: Research data

The results of the reliability test showed that all research variables had *a composite reliability* (rho_c) value greater than 0.70. The Integrated Information System (M1) variable has the highest reliability value, followed by Digital Transformation (X), Operational Efficiency (M2), Port Operational Risk (Y), and Operational Reliability (M3). Thus, it can be concluded that all variables in this research model have met the reliability criteria and are suitable for further analysis.

## Coefficient of Determination ($R^2$)

The R-square value for the dependent variable (operational risk) is 0.317, indicating that 31.7% of the variance in operational risk can be explained by the independent variables in the model. This value is categorized as moderate, suggesting that the model has sufficient explanatory power.

Tabel 4 : R- Square

| | R-square | R-square adjusted |
|---|---|---|
| **Y** | 0.317 | 0.300 |

Source: Research data

Based on the results of the determination coefficient test in the table above, the dependent variable Y has an R-square value of 0.317. This shows that independent variables in the model are able to explain the variance or diversity of the Y variable by 31.7%. Meanwhile, the remaining 68.3% was explained by other variables or factors outside the research model. Referring to the Chin (1998) criterion, the R-square value for the Y variable is included in the moderate (medium) category, which means that the model has a sufficient level of predictive power in explaining the Y variable.

## Hypothesis Testing

Tabel 5 : Hypothesis Test

| | Original sample (O) | T statistics (\|O/STDEV\|) | P values | Conclusion |
|---|---|---|---|---|
| **X -> M1** | 0.853 | 42.707 | 0.000 | Accepted |
| **M1 -> M2** | -0.594 | 9.885 | 0.000 | Accepted |
| **M1 -> M3** | -0.310 | 3.076 | 0.002 | Accepted |
| **M2 -> Y** | 0.355 | 2.791 | 0.005 | Accepted |
| **M3 -> Y** | 0.199 | 1.846 | 0.065 | Rejected |
| **X -> M1 -> M2 -> Y** | -0.180 | 2.682 | 0.007 | Accepted |
| **X -> M1 -> M3 -> Y** | -0.053 | 1.274 | 0.203 | Rejected |

Source: Research data

The results of hypothesis testing using bootstrapping are summarized as follows:

1. Digital transformation has a significant positive effect on integrated information systems ($\beta = 0.853$, $p < 0.001$).
2. Integrated information systems have a significant effect on operational efficiency ($\beta = -0.594$, $p < 0.001$).

3. Integrated information systems have a significant effect on operational reliability (β = -0.310, p = 0.002).
4. Operational efficiency has a significant effect on operational risk reduction (β = 0.355, p = 0.005).
5. Operational reliability does not have a significant effect on operational risk (p = 0.065).
6. Integrated information systems and operational efficiency significantly mediate the relationship between digital transformation and operational risk reduction (β = -0.180, p = 0.007).
7. The mediation effect through operational reliability is not significant (p = 0.203).

## Discussion

### Digital transformation to integrated information systems

The findings indicate that digital transformation has a significant positive effect on integrated information systems. This result suggests that the adoption of digital technologies enhances data connectivity and integration across port operational units. This finding is consistent with recent studies highlighting that digital transformation facilitates system integration, improves data visibility, and supports coordinated decision-making in port operations (He et al., 2023; Su et al., 2024). Furthermore, digital platforms such as integrated port systems and real-time data applications enable more efficient communication among stakeholders, which is essential in complex logistics environments.

### Integrated information systems for operational efficiency

The results reveal a significant but negative relationship between integrated information systems and operational efficiency. This finding contradicts the initial expectation that system integration would enhance efficiency.

A plausible explanation for this negative relationship lies in the transitional nature of digital transformation. During the early stages of system integration, organizations often experience temporary inefficiencies due to system adjustments, learning curves, and user resistance. Employees may require time to adapt to new digital workflows, while system integration can initially increase process complexity and coordination requirements. Similar findings have been reported in recent studies, which indicate that digital transformation may lead to short-term performance decline before long-term efficiency gains are realized (Ivanov & Dolgui, 2020; He et al., 2023).

Additionally, contextual factors such as uneven technological infrastructure, limited interoperability between systems, and insufficient user training may further contribute to reduced efficiency during the implementation phase. Therefore, this finding suggests that the benefits of integrated information systems are not immediate and depend on the maturity of digital adoption and organizational readiness.

### Integrated information systems for operational reliability

A similar pattern is observed in the relationship between integrated information systems and operational reliability, which is also negative and significant. This result indicates that system integration may initially reduce operational stability rather than enhance it.

This phenomenon can be explained by the increased complexity introduced by integrated systems. In early implementation stages, system errors, data inconsistencies, and technical disruptions may occur more frequently, affecting operational reliability. Moreover, reliance on interconnected systems can increase vulnerability to system-wide disruptions if integration is not fully optimized. Recent studies emphasize that digital transformation requires not only technological adoption but also organizational alignment and system robustness to ensure

reliable operations (He et al., 2023; Urciuoli & Hintsa, 2021).

Thus, the negative relationship may reflect short-term instability rather than long-term performance outcomes, highlighting the importance of system maturity and continuous improvement in digital transformation initiatives.

**Operational efficiency against operational risk**

The findings confirm that operational efficiency has a significant effect on reducing operational risk. Efficient operations minimize delays, reduce errors, and improve resource utilization, which collectively contribute to lowering operational disruptions. This result is consistent with prior research demonstrating that improved process efficiency enhances operational resilience and reduces vulnerability to risks (Ivanov & Dolgui, 2020; Tang & Musa, 2011).

In the port context, efficient workflows and streamlined processes enable faster response to operational issues and reduce the likelihood of service interruptions, thereby strengthening overall risk management.

**Reliability efficiency against operational risks**

The results of the study showed that operational reliability did not have a significant effect on operational risk. These findings indicate that although port operations are considered relatively stable and consistent, these conditions have not been directly able to reduce the level of operational risks faced. This is possible because port operational risks are not only influenced by internal reliability aspects, but also by external factors such as system disruptions, weather conditions, freight flow density, and coordination between stakeholders (Sreedevi & Saranga, 2017). These findings are in line with research Shekarian et al. (2020) which states that operational risks are complex and cannot be explained by just one dimension of operational performance. In addition, Saglam & Çankaya (2020) It also emphasizes that operational reliability does not necessarily directly reduce risk if it is not supported by system flexibility and responsiveness.

**Mediation Integrated information systems and improved operational efficiency on the relationship between digital transformation and port operational risk reduction**

The mediation analysis shows that integrated information systems and operational efficiency jointly mediate the relationship between digital transformation and operational risk reduction. This finding indicates that digital transformation indirectly reduces operational risk by improving system integration, which subsequently enhances operational efficiency.

This result aligns with recent studies emphasizing that the impact of digital transformation on organizational performance is often indirect and occurs through intermediate mechanisms such as process optimization and system integration (Su et al., 2024; Khanissuma et al., 2025).

**Mediation Integrated information systems and improved operational reliability on the relationship between digital transformation and reduced port operational risk**

In contrast, the mediation effect through operational reliability is not significant. This suggests that although digital transformation improves system integration and reliability, these improvements do not directly translate into reduced operational risk.

This finding reinforces the argument that operational risk is influenced by broader systemic and external factors, and that reliability alone is insufficient as a mediating mechanism (Urciuoli & Hintsa, 2021).

## Implications

### Theoretical Implications

This study contributes to the literature by providing empirical evidence on the mediating role of integrated information systems and operational efficiency in the relationship between digital transformation and operational risk reduction. It also highlights the non-linear and transitional nature of digital transformation, particularly in explaining negative short-term effects on efficiency and reliability.

### Practical Implications

For port managers, the findings suggest that digital transformation strategies should prioritize improving operational efficiency rather than solely focusing on system integration or reliability. Additionally, organizations should anticipate short-term disruptions during system implementation and invest in user training, infrastructure readiness, and change management to minimize negative impacts.

### Limitations and Future Research

This study has several limitations. First, the sample size is limited to 125 respondents, which may affect generalizability. Second, the study focuses on internal operational factors and does not incorporate external variables such as environmental uncertainty or regulatory dynamics. Future research is recommended to include moderating variables such as organizational readiness, digital capability, and external environmental factors to provide a more comprehensive understanding of operational risk in port systems.

## CONCLUSION

This study examines the effect of digital transformation on port operational risk reduction, with integrated information systems, operational efficiency, and operational reliability as mediating variables. The findings indicate that digital transformation significantly enhances the development of integrated information systems. Furthermore, integrated information systems influence both operational efficiency and operational reliability, although the relationships are negative, suggesting the presence of transitional challenges during the implementation phase.

Operational efficiency is proven to have a significant effect on reducing operational risk, while operational reliability does not show a significant direct effect. The mediation analysis reveals that integrated information systems and operational efficiency jointly mediate the relationship between digital transformation and operational risk reduction. In contrast, the mediating role of operational reliability is not supported. These findings confirm that digital transformation contributes to risk reduction primarily through improving operational efficiency rather than reliability alone.

From a theoretical perspective, this study contributes to the literature by providing empirical evidence on the mediating mechanisms linking digital transformation to operational risk reduction in the port sector. It also highlights the non-linear and transitional effects of integrated information systems, particularly in explaining short-term inefficiencies and reduced reliability during early implementation stages.

From a practical perspective, several recommendations can be proposed. First, port managers should prioritize digital transformation strategies that directly enhance operational efficiency, such as process automation, workflow simplification, and real-time data utilization. Second, organizations should anticipate short-term disruptions during system integration by investing in user training, change management, and infrastructure readiness to minimize transitional inefficiencies. Third, policymakers should support the development of digital infrastructure and provide training programs to improve digital literacy and system adoption

across port stakeholders.

This study has several limitations, including a relatively limited sample size and a focus on internal operational factors. Therefore, future research is recommended to incorporate moderating variables such as organizational readiness, digital capability, and environmental uncertainty to better understand the complexity of operational risk in port systems. Additionally, longitudinal studies are suggested to capture the long-term effects of digital transformation beyond the initial implementation phase.

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