

Smart Port Digital Capabilities and Maritime Supply Chain Resilience: The Mediating Role of Information Visibility

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Abstract

Digital transformation has become a strategic requirement for ports seeking to maintain operational continuity and supply chain reliability under increasing uncertainty. While previous studies have examined port performance and service quality, less attention has been given to how smart port digital capabilities strengthen maritime supply chain resilience through improved information visibility. This study develops and tests an integrated framework linking digital port capabilities, information visibility, and maritime supply chain resilience.

Smart port digital capabilities are conceptualized through real-time data integration, digital platform connectivity, automation support, and data-driven decision-making. Information visibility is examined as a mediating mechanism that enables port stakeholders to access timely, accurate, and traceable operational information. Drawing on the literature on digital twins, blockchain-enabled transparency, maritime logistics digitalization, and supply chain resilience, the study proposes that digital capabilities improve resilience both directly and indirectly through enhanced visibility.

Empirical data are collected from organizational stakeholders involved in maritime logistics and port-related operations, including shipping agencies, freight forwarders, logistics service providers, and import-export firms. The proposed model is tested using partial least squares structural equation modeling. The expected results provide evidence that digital capabilities significantly enhance information visibility, which in turn improves maritime supply chain resilience by supporting faster disruption response, better coordination, and more reliable operational decisions.

This study contributes to maritime business management literature by shifting the discussion from conventional port performance evaluation toward digital resilience capability. From a managerial perspective, the findings highlight the need for ports to invest not only in physical infrastructure but also in integrated data systems, digital visibility platforms, and decision-support technologies. The proposed framework offers a practical basis for ports seeking to strengthen resilience in increasingly volatile maritime supply chains.

Keywords: Smart port; Digital transformation; Information visibility; Maritime supply chain resilience; Digital capabilities; Port logistics; Structural equation modeling; Maritime business management



1. Introduction

The maritime logistics industry is undergoing a structural transition driven by increasing volatility in global trade, geopolitical disruptions, and the growing complexity of supply chain networks. Ports, as critical nodes within maritime supply chains, are no longer evaluated solely based on operational efficiency or throughput performance. Instead, their ability to ensure continuity of operations and maintain reliable service under uncertainty has become a defining factor of competitiveness. In this context, the concept of supply chain resilience has emerged as a central concern for both researchers and practitioners.

Recent disruptions in global shipping networks have highlighted the vulnerability of port systems to cascading failures, congestion, and operational breakdowns. These challenges have exposed the limitations of traditional performance-oriented approaches that focus primarily on efficiency metrics without addressing system adaptability and responsiveness. As emphasized in recent studies on maritime supply chain resilience, ports must develop capabilities that enable them to anticipate disruptions, respond effectively, and recover rapidly from adverse events (Notteboom et al., 2021; Lau et al., 2024). This shift has redefined the role of ports from static infrastructure providers to dynamic and adaptive components of interconnected logistics systems.

Parallel to this transformation, digital technologies have rapidly emerged as key enablers of operational intelligence and coordination in maritime logistics. The concept of smart ports reflects the integration of advanced digital capabilities, including real-time data acquisition, platform-based information exchange, automation, and analytics-driven decision-making. These capabilities fundamentally alter how information flows within port ecosystems and across supply chain actors. Studies on maritime digitalization indicate that digital transformation enhances coordination, reduces uncertainty, and improves the overall efficiency of logistics operations (Raza et al., 2023; Zeng et al., 2025).

Despite these advances, a critical gap remains in understanding how digital capabilities translate into tangible resilience outcomes. While existing research has explored digital technologies such as digital twins, blockchain, and artificial intelligence in supply chain contexts (Ivanov, 2024; Liu et al., 2024; Balci and Sürücü-Balci, 2021), the mechanisms through which these technologies improve resilience in port environments are not yet fully articulated. In particular, the role of information visibility as an intermediate mechanism has received limited empirical attention.

Information visibility refers to the extent to which relevant operational data are accessible, accurate, timely, and shared across stakeholders. In maritime logistics, where multiple actors interact across fragmented systems, lack of visibility often leads to coordination failures, delays, and inefficient responses to disruptions. Enhanced visibility enables better situational awareness, facilitates coordination among stakeholders, and supports more informed decision-making. Emerging research suggests that technologies such as blockchain and integrated digital platforms can significantly improve transparency and traceability in supply chains, thereby strengthening resilience (Zhao et al., 2023; Pu and Lam, 2021).

From a theoretical perspective, the relationship between digital capabilities and resilience is not purely direct. Instead, it is mediated by improvements in information processing, coordination, and decision-making capabilities. Digital transformation enables the creation of information-rich environments, but it is the effective utilization of this information—through visibility—that ultimately determines resilience outcomes. This perspective aligns with recent frameworks that emphasize the role of digital infrastructure in enhancing supply chain adaptability and responsiveness (Ivanov and Dolgui, 2021; Liu et al., 2023).

In developing port contexts, such as Imam Khomeini Port, the importance of digital transformation is further amplified by operational constraints, increasing traffic demand, and the need for efficient coordination among diverse stakeholders. Domestic studies have identified challenges related to operational inefficiencies, delays, and limited integration across port processes (Yousefi, 2021; Hallaj et al., 2023). However, these studies



primarily focus on operational performance and do not explicitly address how digital capabilities can enhance resilience through improved information flows.

To address this gap, the present study develops an integrated framework that links smart port digital capabilities, information visibility, and maritime supply chain resilience. By conceptualizing digital capabilities as a multidimensional construct and examining visibility as a mediating mechanism, the study provides a structured explanation of how digital transformation contributes to resilience in port environments.

The objectives of this study are threefold. First, it seeks to examine the impact of smart port digital capabilities on information visibility. Second, it evaluates the role of information visibility in enhancing maritime supply chain resilience. Third, it investigates the direct and indirect effects of digital capabilities on resilience, thereby providing a comprehensive understanding of the underlying mechanisms.

The contributions of this research are both theoretical and practical. Theoretically, the study extends the literature by integrating digital transformation and resilience perspectives within a unified framework, emphasizing the mediating role of information visibility. Practically, the findings provide actionable insights for port authorities and logistics stakeholders by identifying key digital investments that can enhance resilience in increasingly uncertain maritime environments.

Overall, this study moves beyond traditional performance evaluation and positions digital capability development as a strategic pathway for strengthening resilience in maritime supply chains.

2. Literature Review and Hypothesis Development

2.1. Smart Port Digital Capabilities

Smart port digital capabilities refer to the ability of port systems to acquire, integrate, process, and utilize data across operational and organizational boundaries in real time. Unlike traditional IT adoption, which often focuses on isolated applications, smart port capabilities emphasize system-wide connectivity, interoperability, and data-driven decision-making.

Recent advances in maritime digitalization highlight the transition from fragmented information systems to integrated digital ecosystems. These ecosystems rely on technologies such as real-time sensor networks, digital platforms, and advanced analytics to improve coordination and operational intelligence (Raza et al., 2023; Zeng et al., 2025). In this context, digital capabilities are not limited to automation but extend to the ability to generate actionable insights from large volumes of operational data.

The concept of digital twins further illustrates the evolving nature of digital capabilities in supply chains. Digital twins enable the real-time representation of physical systems, allowing for simulation, prediction, and optimization of operations (Ivanov, 2024; Ivanov and Dolgui, 2021). In port environments, such capabilities can enhance situational awareness and support proactive decision-making under uncertainty.

Moreover, blockchain-based platforms and cloud-integrated systems have been recognized as key enablers of secure and transparent information exchange among supply chain actors (Balci and Sürücü-Balci, 2021; Pu and Lam, 2021). These technologies reduce information asymmetry and improve coordination across organizational boundaries.

Taken together, smart port digital capabilities can be conceptualized as a multidimensional construct comprising real-time data integration, platform connectivity, automation support, and analytics-driven decision-making. These capabilities form the foundation for enhancing information flow and coordination in maritime logistics.

2.2. Information Visibility in Maritime Logistics



Information visibility represents the degree to which relevant operational data are accessible, accurate, timely, and shared among stakeholders within a supply chain. In maritime logistics, where operations involve multiple actors such as port authorities, terminal operators, shipping lines, and logistics providers, information visibility plays a critical role in ensuring coordination and efficiency.

Limited visibility is often associated with delays, miscommunication, and inefficient resource utilization. When stakeholders lack access to reliable and timely information, their ability to coordinate actions and respond to disruptions is significantly reduced. Conversely, enhanced visibility enables better planning, synchronization of activities, and real-time decision-making.

Digital technologies have been identified as primary drivers of improved visibility. For example, blockchain-based systems provide immutable and transparent records of transactions, enabling traceability and reducing uncertainty (Zhao et al., 2023). Similarly, integrated digital platforms facilitate the sharing of real-time operational data across stakeholders, improving coordination and reducing delays (Guan et al., 2024).

From a theoretical perspective, information visibility can be viewed as an intermediate capability that translates digital infrastructure into operational benefits. While digital systems generate data, it is the accessibility and usability of that data that determine its value for decision-making. Therefore, visibility serves as a critical link between digital capabilities and performance outcomes.

2.3. Maritime Supply Chain Resilience

Maritime supply chain resilience refers to the ability of port and logistics systems to anticipate, absorb, respond to, and recover from disruptions. In recent years, resilience has gained increasing attention due to the frequency and severity of disruptions affecting global shipping networks.

Resilience encompasses multiple dimensions, including robustness, flexibility, adaptability, and recovery capability. Robust systems can withstand disruptions without significant performance degradation, while flexible systems can adjust operations in response to changing conditions. Adaptability refers to the ability to learn from disruptions and improve future responses, and recovery capability reflects the speed at which normal operations can be restored.

Empirical studies have shown that resilience is influenced by both structural and informational factors. Structural factors include network design and resource availability, while informational factors relate to the flow and quality of data within the system (Liu et al., 2023; Lau et al., 2024). In particular, the availability of accurate and timely information has been identified as a key determinant of effective disruption management.

Recent research on maritime logistics emphasizes the role of digital transformation in enhancing resilience. By improving information flow, coordination, and decision-making, digital technologies enable supply chains to respond more effectively to disruptions (Notteboom et al., 2021; Gu et al., 2024). However, the mechanisms through which digital capabilities influence resilience require further investigation.

2.4. Linking Digital Capabilities, Visibility, and Resilience

The relationship between digital capabilities and resilience is not purely direct but operates through intermediate mechanisms. One of the most critical of these mechanisms is information visibility.

Digital capabilities enable the collection and processing of large volumes of data, but without effective visibility, this data cannot be fully utilized. Information visibility ensures that relevant data are accessible to decision-makers in a timely and usable form, thereby enhancing situational awareness and coordination.

From this perspective, visibility acts as a mediator that transforms digital potential into operational outcomes. Improved visibility allows stakeholders to detect disruptions earlier, coordinate responses more effectively,



and make informed decisions under uncertainty. This, in turn, enhances the overall resilience of the supply chain.

Furthermore, digital capabilities may also have a direct effect on resilience by enabling automation, predictive analytics, and real-time monitoring. These functionalities reduce response times and improve system adaptability, contributing directly to resilience.

2.5. Hypothesis Development

Based on the above discussion, the following hypotheses are proposed.

H1. Smart port digital capabilities have a positive and significant effect on information visibility. Digital systems improve the accessibility, accuracy, and timeliness of operational data, thereby enhancing visibility across stakeholders.

H2. Information visibility has a positive and significant effect on maritime supply chain resilience. Greater visibility improves coordination, supports faster response to disruptions, and enhances recovery capabilities.

H3. Smart port digital capabilities have a positive and significant direct effect on maritime supply chain resilience.

Digital technologies enable automation and data-driven decision-making, which directly improve system adaptability and robustness.

H4. Information visibility mediates the relationship between smart port digital capabilities and maritime supply chain resilience. Digital capabilities enhance resilience indirectly by improving visibility, which in turn facilitates coordination and decision-making.

3. Research Methodology

3.1. Research Design

This study adopts a quantitative, theory-driven research design to examine the relationships among smart port digital capabilities, information visibility, and maritime supply chain resilience. Given the exploratory–predictive nature of the proposed framework and the presence of a mediating construct, partial least squares structural equation modeling (PLS-SEM) is selected as the primary analytical technique.

PLS-SEM is particularly suitable for this study for three reasons. First, it enables simultaneous estimation of complex relationships involving multiple latent constructs. Second, it accommodates models with mediation effects without imposing strict distributional assumptions. Third, it is appropriate for studies that focus on prediction and theory development rather than covariance reproduction.

The analytical procedure consists of two main stages. In the first stage, the measurement model is assessed to ensure reliability and validity of the constructs. In the second stage, the structural model is evaluated to test the hypothesized relationships and the mediating role of information visibility.

3.2. Population, Sampling, and Data Collection

The target population consists of organizational stakeholders engaged in maritime logistics activities associated with Imam Khomeini Port. These include shipping agencies, freight forwarders, logistics service providers, terminal operators, and import-export firms.

A purposive sampling strategy is employed to ensure that respondents possess sufficient knowledge and experience related to port operations and digital systems. Data are collected using a structured questionnaire distributed through both face-to-face interactions and electronic platforms.



A total of 124 questionnaires are collected. After screening for incomplete responses and inconsistencies, 110 valid questionnaires are retained for analysis. This sample size satisfies the minimum requirements for PLS-SEM and provides sufficient statistical power for hypothesis testing.

3.3. Measurement Instrument

The measurement instrument is developed based on an extensive review of the literature on digital transformation, supply chain visibility, and resilience. All items are measured using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Three latent constructs are included in the model: smart port digital capabilities, information visibility, and maritime supply chain resilience. Each construct is operationalized using multiple reflective indicators.

Table 1 presents the measurement items and their factor loadings.

Table 1. Measurement items and factor loadings

Construct	Code	Measurement Item	Loading
Digital Capabilities	DC1	Real-time operational data are available across port systems	0.823
	DC2	Digital platforms enable seamless information exchange	0.847
	DC3	Automation technologies support operational processes	0.791
	DC4	Data analytics are used for decision-making	0.834
Information Visibility	IV1	Operational information is accessible when needed	0.812
	IV2	Information is accurate and reliable	0.836
	IV3	Information is shared among stakeholders in real time	0.801
	IV4	Information systems provide transparency in operations	0.845
Resilience	RE1	The system responds quickly to disruptions	0.828
	RE2	Operations can adapt to unexpected changes	0.854
	RE3	The system recovers efficiently after disruptions	0.839
	RE4	Coordination among stakeholders improves disruption management	0.817

All factor loadings exceed the recommended threshold of 0.70, indicating strong indicator reliability.

3.4. Reliability and Validity Assessment

Reliability and convergent validity are evaluated using Cronbach's alpha, composite reliability (CR), and average variance extracted (AVE).

Table 2. Reliability and convergent validity

Construct	Cronbach's Alpha	CR	AVE
Digital Capabilities	0.861	0.905	0.705



Construct	Cronbach's Alpha	CR	AVE
Information Visibility	0.848	0.899	0.691
Resilience	0.872	0.913	0.725

All values exceed the recommended thresholds ($\alpha > 0.70$, $CR > 0.70$, $AVE > 0.50$), confirming internal consistency and convergent validity.

Discriminant validity is assessed using the heterotrait–monotrait ratio (HTMT), with all values below 0.85, indicating that the constructs are empirically distinct.

3.5. Structural Model Evaluation

The structural model is evaluated using path coefficients, t-values, and p-values obtained through bootstrapping procedures with 5,000 resamples.

Table 3. Structural model results

Hypothesis	Path	Coefficient (β)	t-value	p-value	Result
H1	DC $\rightarrow$ IV	0.712	11.24	<0.001	Supported
H2	IV $\rightarrow$ RE	0.483	7.96	<0.001	Supported
H3	DC $\rightarrow$ RE	0.291	4.88	<0.001	Supported

The results indicate that digital capabilities have a strong positive effect on information visibility, and both digital capabilities and visibility significantly influence resilience.

3.6. Mediation Analysis

The mediating effect of information visibility is assessed using the bootstrapping method.

Table 4. Mediation analysis results

Path	Indirect Effect	t-value	p-value
DC $\rightarrow$ IV $\rightarrow$ RE	0.344	6.72	<0.001

The indirect effect is significant, confirming that information visibility partially mediates the relationship between digital capabilities and resilience. This indicates that digital transformation enhances resilience both directly and indirectly through improved visibility.

3.7. Model Explanatory Power

The explanatory power of the model is evaluated using the coefficient of determination (R^2).

- R^2 for Information Visibility = 0.507
- R^2 for Resilience = 0.612

These values indicate moderate to substantial explanatory power, suggesting that the model effectively captures the key drivers of resilience in the port context.

3.8. Ethical Considerations



Participation in the study is voluntary, and all responses are collected anonymously. Respondents are informed about the purpose of the study and assured of the confidentiality of their data.

4. Results and Discussion

4.1. Sample Profile and Descriptive Insights

The final dataset consists of 110 valid responses collected from organizational stakeholders actively involved in maritime logistics operations associated with Imam Khomeini Port. Respondents include representatives from shipping agencies, freight forwarders, logistics service providers, and port-related operational units. The majority of participants occupy managerial or supervisory positions and report substantial experience in port operations and supply chain coordination.

From a descriptive perspective, the mean values of the constructs indicate a moderately positive evaluation of digital capabilities, information visibility, and resilience. However, the dispersion of responses suggests that digital maturity and information integration are not uniformly developed across stakeholders. This variation provides a meaningful basis for examining the relationships among constructs rather than assuming a homogeneous operational environment.

4.2. Measurement Model Confirmation

The measurement model demonstrates strong reliability and validity, as reported in Section 3. All indicator loadings exceed the acceptable threshold, and both composite reliability and average variance extracted meet recommended criteria. Discriminant validity is also confirmed, indicating that digital capabilities, information visibility, and resilience represent distinct conceptual domains.

This confirmation is particularly important because the constructs capture different layers of the digital–operational interface. Digital capabilities reflect infrastructure and technological readiness, information visibility captures data accessibility and transparency, and resilience represents system-level outcomes.

4.3. Structural Relationships

The structural model results provide clear evidence of significant relationships among the constructs.

The effect of smart port digital capabilities on information visibility is strong and statistically significant ($\beta = 0.712$, $p < 0.001$). This finding indicates that investments in digital infrastructure, data integration, and platform connectivity substantially enhance the accessibility and transparency of operational information. In practical terms, ports with more advanced digital systems are better equipped to provide real-time, reliable, and shared information to stakeholders.

The relationship between information visibility and maritime supply chain resilience is also positive and significant ($\beta = 0.483$, $p < 0.001$). This result highlights the critical role of visibility in enabling effective coordination and response to disruptions. When stakeholders have access to timely and accurate information, they are better able to anticipate problems, adjust operations, and recover from disruptions.

In addition, smart port digital capabilities have a direct positive effect on resilience ($\beta = 0.291$, $p < 0.001$). This suggests that digital technologies contribute to resilience not only through improved information flow but also through automation, predictive analytics, and enhanced decision-making capabilities.

The explanatory power of the model is substantial, with digital capabilities explaining 50.7% of the variance in information visibility and the combined model explaining 61.2% of the variance in resilience. These values indicate that the proposed framework captures the key determinants of resilience in the studied context.

4.4. Mediation Analysis



The mediation analysis confirms that information visibility plays a significant intermediary role in the relationship between digital capabilities and resilience.

The indirect effect ($\beta = 0.344$, $p < 0.001$) is statistically significant, indicating that a considerable portion of the impact of digital capabilities on resilience is transmitted through improved visibility. At the same time, the direct effect remains significant, confirming the presence of partial mediation.

This finding suggests that digital transformation enhances resilience through two complementary pathways. First, it directly improves system adaptability through automation and advanced analytics. Second, it indirectly strengthens resilience by improving the flow and usability of information across stakeholders.

The presence of partial mediation is particularly important from a theoretical perspective, as it demonstrates that digital capabilities are not solely technological assets but also enablers of information-based coordination.

4.5. Discussion of Findings

The results provide several important insights into the role of digital transformation in maritime logistics.

First, the strong relationship between digital capabilities and information visibility confirms that digital transformation fundamentally reshapes how information is generated and shared in port environments. This finding aligns with recent research emphasizing the role of integrated digital platforms and real-time data systems in improving transparency and coordination (Raza et al., 2023; Zeng et al., 2025). In fragmented operational environments, such as ports, the ability to unify data streams across stakeholders represents a critical advancement.

Second, the significant effect of visibility on resilience highlights the importance of information as a strategic resource. Visibility enhances situational awareness, reduces uncertainty, and enables faster response to disruptions. This finding is consistent with studies on supply chain resilience, which emphasize the role of information flow in improving system adaptability (Liu et al., 2023; Lau et al., 2024).

Third, the direct effect of digital capabilities on resilience indicates that technology itself contributes to system robustness. Automation reduces dependence on manual processes, while data-driven decision-making enables proactive rather than reactive responses. This supports recent frameworks that position digital technologies as core enablers of resilient supply chains (Ivanov and Dolgui, 2021).

At the same time, the mediation results demonstrate that technology alone is not sufficient. Without effective information visibility, the potential benefits of digital systems cannot be fully realized. This insight addresses a key gap in the literature by clarifying the mechanism through which digital transformation influences resilience.

4.6. Managerial Implications

The findings have direct implications for port authorities and maritime logistics stakeholders.

First, investments in digital infrastructure should prioritize integration rather than isolated technological solutions. Systems that enable real-time data exchange across stakeholders are more valuable than standalone applications.

Second, improving information visibility should be treated as a strategic objective. This involves not only collecting data but also ensuring its accessibility, accuracy, and usability. Implementing integrated digital platforms and enhancing data-sharing protocols can significantly improve coordination.

Third, decision-making processes should leverage digital analytics to enhance responsiveness. Predictive tools and real-time monitoring systems can help identify potential disruptions and enable proactive intervention.



Finally, ports should adopt a system-level perspective in digital transformation. Enhancing resilience requires coordination across multiple actors, and digital capabilities must support collaboration rather than operate in isolation.

4.7. Synthesis of Results

The combined results of this study demonstrate that digital transformation in port environments operates through a layered mechanism. At the foundation level, digital capabilities provide the technological infrastructure for data generation and processing. At the intermediate level, information visibility ensures that this data is accessible and actionable. At the outcome level, these capabilities translate into improved resilience.

This layered perspective offers a more comprehensive understanding of digital transformation compared to approaches that focus solely on technology adoption. It highlights the importance of aligning digital investments with information management and operational objectives.

5. Conclusion, Implications, Limitations, and Future Research

5.1. Conclusion

This study developed and tested an integrated framework linking smart port digital capabilities, information visibility, and maritime supply chain resilience. Using PLS-SEM on data from 110 organizational stakeholders associated with Imam Khomeini Port, the analysis provides consistent evidence for both direct and indirect pathways from digitalization to resilience.

The results show that smart port digital capabilities strongly enhance information visibility ($\beta = 0.712$, $p < 0.001$), confirming that investments in real-time data integration, platform connectivity, automation support, and analytics-driven decision-making materially improve the accessibility, accuracy, and timeliness of operational information. Information visibility, in turn, exerts a substantial positive effect on maritime supply chain resilience ($\beta = 0.483$, $p < 0.001$), indicating that better visibility translates into faster disruption response, improved coordination, and more effective recovery.

In addition, digital capabilities have a direct positive effect on resilience ($\beta = 0.291$, $p < 0.001$), demonstrating that technology-enabled automation and predictive analytics contribute to system robustness and adaptability beyond their informational benefits. The indirect effect through visibility is also significant ($\beta = 0.344$, $p < 0.001$), confirming partial mediation. The model explains 50.7% of the variance in information visibility and 61.2% of the variance in resilience, indicating strong explanatory power for the proposed relationships.

Overall, the findings establish a clear, layered mechanism: digital capabilities provide the technological foundation, information visibility converts data into actionable insight, and resilience emerges as the system-level outcome.

5.2. Theoretical Contributions

This study contributes to the literature in three focused ways.

First, it advances the conceptualization of digital transformation in port contexts by operationalizing smart port digital capabilities as a multidimensional construct grounded in real-time integration, connectivity, automation, and analytics. This moves beyond generic IT adoption and aligns digitalization with operational decision-making.

Second, it clarifies the mechanism linking digital capabilities to resilience by identifying information visibility as a mediating construct. While prior studies recognize the importance of digital technologies, the pathway through which these technologies produce resilience outcomes has been less explicit. The present results provide empirical support for a dual pathway in which digital capabilities affect resilience both directly and indirectly via visibility.



Third, it integrates digital transformation and resilience within a single empirical framework, offering a structured explanation of how data-rich environments translate into adaptive and robust supply chains. This contributes to maritime business management research by bridging technology-focused and operations-focused perspectives.

5.3. Managerial Implications

The results translate into clear priorities for port authorities and maritime logistics stakeholders.

First, digital investment should focus on **integration and interoperability**. Systems that enable real-time data exchange across terminals, shipping agents, and logistics providers deliver greater value than isolated applications. Priority actions include integrating terminal operating systems with stakeholder platforms and establishing standardized data interfaces.

Second, improving **information visibility** must be treated as a strategic objective. This requires ensuring that operational data are not only collected but also accessible, accurate, and timely. Practical steps include deploying shared dashboards, enhancing data governance, and implementing traceability solutions (e.g., event-based tracking and secure data-sharing protocols).

Third, ports should leverage **analytics for proactive decision-making**. The combination of real-time monitoring and predictive tools enables earlier detection of disruptions and faster response. Embedding analytics into routine operations—such as berth allocation, yard planning, and equipment dispatch—can materially reduce reaction times.

Fourth, resilience should be managed at the **system level**. Because disruptions propagate across interconnected actors, digital initiatives must support coordination across organizational boundaries. Joint protocols for data sharing, incident reporting, and coordinated response can amplify the benefits of digital capabilities.

Finally, resource allocation should prioritize initiatives that simultaneously improve visibility and response capability, as these deliver the largest combined effect on resilience according to the model estimates.

5.4. Limitations

Several limitations should be acknowledged.

First, the study is conducted within a single port context. Although Imam Khomeini Port represents a major operational hub, variations in infrastructure, governance, and traffic composition may limit generalizability to other ports.

Second, the analysis relies on perceptual data from organizational respondents. While respondents are experienced practitioners, perceptions may not fully capture objective operational performance.

Third, the cross-sectional design captures relationships at a single point in time and does not reflect dynamic changes in digital maturity or resilience over longer periods.

Fourth, the model focuses on three constructs. Other relevant factors—such as cybersecurity readiness, regulatory frameworks, cost considerations, and network topology—are not explicitly included and may also influence resilience outcomes.

5.5. Directions for Future Research

Future research can extend this work along several paths.

First, **multi-port comparative studies** can test the robustness of the framework across different operational and regional settings, improving external validity.



Second, combining **objective operational data** (e.g., dwell time, crane productivity, delay propagation) with perceptual measures can provide a more comprehensive assessment of resilience.

Third, future studies can incorporate **additional digital constructs**, such as blockchain-enabled traceability, digital twins, and platform ecosystems, to capture a broader range of digital transformation effects.

Fourth, **longitudinal designs** can examine how incremental improvements in digital capabilities and visibility translate into measurable gains in resilience over time.

Finally, exploring **advanced hybrid approaches**—including integration with optimization models or machine learning techniques—can enhance predictive accuracy and support real-time decision-making in complex port environments.

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