

Towards the Vietnam Port Digital Index: A Conceptual Readiness Framework for Digital Transformation in Emerging Economies

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Abstract: Decision 749/QĐ-TTg identifies logistics as a priority sector in Vietnam’s digital economy strategy toward 2030, placing increasing pressure on seaports to pursue digital transformation. Assessing digital maturity in this setting, however, remains difficult. Most international port digital maturity frameworks are developed for environments characterized by advanced infrastructure, automated data systems, and stable governance arrangements—conditions that are only partially present in Vietnam. This study proposes the Vietnam Port Digital Index as a conceptual readiness framework designed for emerging economies. The framework is developed through a three-stage process comprising literature-informed synthesis, conceptual clustering of capability pillars, and contextual screening against domestic governance and data constraints. Rather than treating technology adoption as a sufficient indicator of maturity, the Vietnam Port Digital Index explicitly incorporates organizational capacity and policy readiness as core analytical dimensions. The framework therefore provides a context-sensitive structure for understanding digital transformation in Vietnamese seaports and establishes a foundation for subsequent empirical operationalization and quantitative assessment.

Keywords: Conceptual framework, digital index, digital maturity, digital transformation, readiness assessment, Vietnam port emerging economies.

1. INTRODUCTION

According to UNCTAD statistics, seaports receive and process more than 80% of global trade goods [1]. Seaports with strong information systems will operate much more efficiently than traditional seaports. Complex operational problems can be easily solved with technologies such as IoT, AI, Big Data and Blockchain [2]. Competitive pressure is the driving force behind countries developing modern port models. Information standardization is a mandatory issue based on the development experience of leading ports in the region such as Rotterdam, Busan and Singapore. Managers at these hubs have made strategic investments in system-level integrated data environments instead of merely optimizing each berth locally [3]. However, the digital transformation landscape still shows significant disparity because not all ports have sufficient resources and conditions to implement it. In recent years, Vietnam has started to accelerate this process under the guiding principle of the National Digital Transformation Program to 2025, orientation to 2030. Decision 749/QĐ-TTg (June 3, 2020) was approved with the main orientation of

comprehensive digital transformation for seaports. In Vietnam, digital transformation has been formally defined as a strategic priority through the National Digital Transformation Program and the Master Plan for the Development of Vietnam’s Seaport System for the period 2021–2030 [4].

Key ports in Vietnam such as Tan Cang – Cat Lai, HICT and Cai Mep – Thi Vai have initially implemented electronic systems to serve port and container management. The remaining seaports still have many limitations and cannot implement the system as expected by the State [5-7]. The immediate goal is to establish an integrated data ecosystem capable of effectively connecting port authorities, customs agencies, shipping lines and logistics service providers. The connection between the Port Operating System (TOS) and external logistics platforms is not yet synchronized. Top Vietnamese ports in digital transformation such as Tan Cang Saigon Corporation are lacking personnel with specialized digital capabilities.

The Vietnamese seaport industry is currently operating but lacks a specific framework to assess its digital maturity level. If managers cannot determine the current

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Table 1. Comparative summary of digital readiness between advanced ports and Vietnamese seaports.

Criterion	Advanced ports	Vietnamese seaports
Digital infrastructure	Large-scale deployment of sensor-based monitoring systems, high levels of equipment automation, and real-time operational data capture.	Digitization remains partial; infrastructure development is uneven across ports, with limited standardization and interoperability.
Data integration	Well-established Port Community Systems enabling continuous data exchange among ports, customs authorities, shipping lines, and logistics operators.	Data integration is largely confined to individual ports or terminals; the absence of national data standards limits cross-actor connectivity.
Smart operations	Use of data-driven applications for planning and control, including automated scheduling, simulation tools, and predictive operational support.	Pilot applications exist in selected terminals, but system-wide adoption and operational integration remain limited.
Cybersecurity	Sector-level cybersecurity frameworks supported by dedicated monitoring units and coordinated risk management mechanisms.	Investment in cybersecurity varies significantly among ports; unified requirements and coordinated protection mechanisms are not yet in place.
Organizational capacity	Availability of specialized digital and data-oriented personnel, supported by adaptive governance structures and flexible decision-making processes.	Persistent gaps in digital skills and institutional arrangements that are not fully aligned with the requirements of digital transformation.

Table 2. Comparative summary of digital readiness between advanced ports and Vietnamese seaports.

Ports	Strategic focus of digitalization	Key digital initiatives	Operational outcomes (illustrative)	Analytical implication
Port of Rotterdam	Port-wide coordination through shared data	Port-call optimization platforms; port-wide data services	Improved schedule reliability; reduced vessel waiting time; better utilization of nautical infrastructure	Shift from terminal-level optimization to system-wide coordination
Port of Singapore	Integration of automation and centralized digital control	Automated yard and quay systems at Tuas Port; centralized operations control	Multi-million TEU throughput achieved in early phases; scalability toward >60 million TEUs	Digital integration as a core operational requirement at scale
Port of Busan	Smart-port platforms and analytical capability	Digital twin-based logistics platforms; real-time data integration across terminals and hinterland	Enhanced simulation, flow analysis, and planning; support for remote operations	Digital maturity combines technology deployment with organizational capability

state of development, it will be very difficult to build an effective digital transformation roadmap.

The Vietnam Port Digital Index (VPDI) was developed through the qualitative synthesis of recognized smart port models. Simultaneously, feasibility studies were conducted in relation to domestic operating conditions and policies. The resulting index comprises five core pillars and 15 component indicators. These can be applied by policymakers to assess digital maturity and provide input for strategic planning.

Table 1 presents a synthesized analytical contrast between advanced ports and Vietnamese seaports, serving as an analytical framing device rather than a quantitative benchmarking exercise. The advanced port characteristics are derived from established international literature and benchmark cases in Section 2, while the Vietnamese port characteristics are empirically elaborated in Section 3.

2. THEORETICAL BACKGROUND AND RESEARCH METHODOLOGY

2.1. Theoretical background

Digital transformation at advanced ports is a process of building system-level coordination capacity rather than deploying isolated digital tools. Automation creates managerial and operational value only when embedded in integrated data environments that enable centralized control. Real-time data links infrastructure, operations, and decision-making across the port system.

Management effectiveness therefore depends on digital coherence at the system level, not on individual technologies. Digital maturity develops through staged alignment among technological capability, data integration, and organizational coordination [8-12].

The digital transformation processes of ports like Rotterdam, Singapore, and even Busan offer valuable lessons for Vietnam. The biggest current obstacles for Vietnamese ports are likely economic and technological. Results from the PESTLE analysis indicate that limited investment budgets hinder the deployment of advanced technologies [13].

2.2. Literature foundations for the VPDI framework

The literature review matrix (Table 3) identifies five recurring content groups in studies on smart ports and digital transformation assessment frameworks [14-17]. Research on leading ports and international benchmarking frameworks consistently emphasizes the contribution of technical factors to operational efficiency and reliability.

A lack of consistency emerges in how these factors are addressed across the literature. International benchmarking frameworks, including CPPI, concentrate mainly on technical indicators and operational data that can be directly measured. Resilience-oriented studies, by contrast, demonstrate that technological efficiency alone is insufficient to ensure system continuity or effective recovery following disruptions.

Greater explanatory weight is placed on organizational

Table 3. Literature review matrix supporting the VPDI pillars.

VPDI pillars (Level 1)	Evidence from leading port practices	International assessment frameworks	Resilience-oriented theoretical insights	Frequency
I. Digital Infrastructure	Advanced ports deploy integrated digital infrastructure combining sensors, IoT, and Digital Twin technologies to monitor and optimize physical assets.	CPPI and related indices emphasize the quality of physical infrastructure and supporting ICT systems.		2
II. Data Integration / Interoperability	Evidence from leading ports indicates that data generates value only when it is shared and interoperable across actors within the port ecosystem.	IAPH and international standards prioritize Single Window mechanisms, data standardization, and system interoperability.	Data visibility is identified as a foundational capability for system resilience.	3
III. Intelligent Operations	Automation and data analytics are used to support planning, coordination, and adaptive responses to operational variability.		Adaptive capacity and operational flexibility are emphasized as key determinants of recovery performance.	2
IV. Cybersecurity and Data Safety	Digitalization and OT-IT integration increase systemic risk, requiring advanced ports to treat cybersecurity as a strategic function.	IAPH has issued dedicated guidelines on cybersecurity and data protection in port systems.	Cybersecurity is regarded as a prerequisite for maintaining supply chain integrity.	3
V. Organizational / Policy Capacity	Successful cases show that digital transformation is closely tied to institutional coordination and digital ecosystem governance.		Resilience theory emphasizes community capacity, institutional readiness, and coordination quality rather than technology alone.	2

coordination capacity, policy mechanisms, and adaptive capability. These elements determine whether digitalization produces sustained operational benefits rather than isolated efficiency gains. The contrast between performance-oriented benchmarks and resilience-based analyses reveals a structural weakness in prevailing assessment models, where non-technical dimensions are treated as peripheral rather than integral to digital maturity.

The limitation becomes particularly visible in port systems undergoing transformation in emerging economies. Human resource constraints, governance arrangements, and cybersecurity readiness frequently shape digital transformation outcomes more strongly than the availability of technology. Integrating technical capabilities with organizational capacity therefore becomes a necessary step, forming the theoretical foundation for defining the five pillars of the VPDI framework.

2.3. Consolidation of international criteria into conceptual clusters

Table 4 summarizes how international models approach port digital capabilities as an inter-organizational system [17-21]. Digital maturity is not the result of applying a single technology, but rather a process of accumulating governance and coordination capabilities at the port community level. Boullauzan's argument is that mapping international criteria to VPDI should reflect the capability structure, rather than simply copying the technology portfolio.

Studies on Digital Twin show that the value of enhanced automation does not lie in the digital model itself. Digital Twin is merely an expensive simulation tool if not directly linked to real-time data and operational decision-making mechanisms. Automation is not treated as a standalone technological attribute within

the VPDI. Klar shows that digital twin and automation technologies deliver limited operational value when they are not linked to real-time data streams and decision-making processes. Digital infrastructure and intelligent operational capability are treated as separate analytical domains rather than being collapsed into a single technology pillar.

Data integration determines whether digital capability translates into operational performance. Liu and his crew demonstrates that ports with high levels of data interoperability maintain throughput more effectively during major disruptions, while fragmented systems generate isolated data environments that weaken coordination among actors. Within the VPDI, emphasis is therefore placed on substantive connectivity rather than on the formal presence of information systems.

Cybersecurity capacity extends beyond technical safeguards. Senarak documents that vulnerability increases as operational technology systems expand without corresponding organizational preparedness. Hasan investigations shows that adaptive and resilient capacity exerts a stronger influence on system continuity than static defenses when communication structures are disrupted. Accordingly, cybersecurity criteria are embedded within both data protection and organizational capacity dimensions of the framework.

2.4. Positioning VPDI relative to international and regional port digital maturity approaches

This study positions the Vietnam Port Digital Index (VPDI) within the existing landscape of port digital assessment by comparing the measurement logics embedded in international approaches, rather than by enumerating indices by region.

One dominant stream consists of performance-based quantitative benchmarks, exemplified by the World Bank's Container Port Performance Index (CPPI). CPPI

Table 4. International criteria clusters and their linkages to vpdi pillars.

Criteria Cluster	Representative Concepts in International Models	Mapped VPDI Pillar(s)
A. Advanced Automation and Digital Operational Technologies	AI-enabled scheduling, Autonomous Operations, Large-scale Digital Twin, High-density IoT sensor deployment	I. Digital Infrastructure / III. Intelligent Operations
B. Data Integration & System Standardization	Mature Port Community Systems (PCS), API/EDI data-exchange standards, visibility and synchronization platforms	II. Data Integration & Interoperability
C. Resilience, Continuity Planning & Cybersecurity	Operational robustness, redundancy mechanisms, contingency planning, cybersecurity controls	IV. Cybersecurity & Data Safety / V. Organizational & Policy Capacity
D. Organizational Capacity & Soft Governance Factors	Digital skill readiness, agile governance, institutional capacity, change-management systems	V. Organizational & Policy Capacity

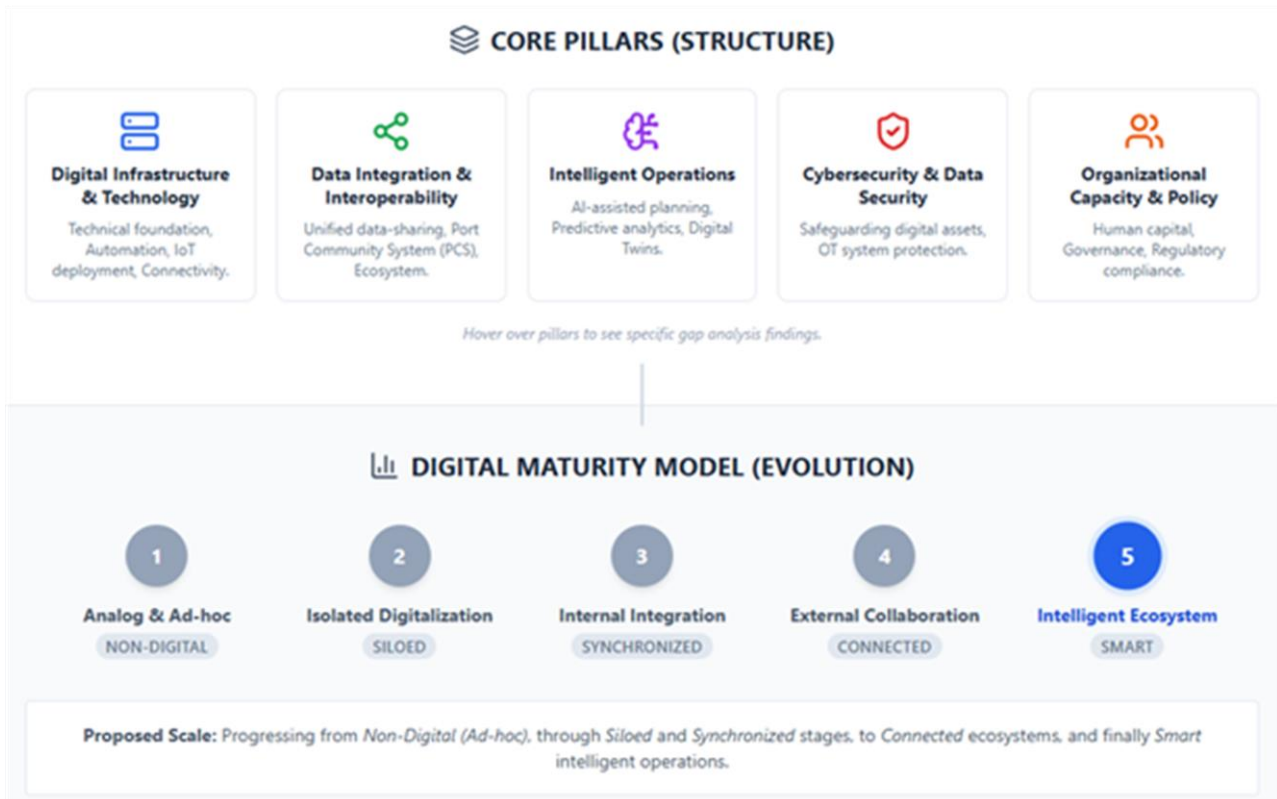


Fig 1. VPDI – Structured framework & maturity model.

measures quayside efficiency using vessel time in port and container handling productivity derived from AIS-based operational data [22-23]. Its scope is intentionally restricted to time-based outputs experienced by container ship operators, while dimensions such as digital infrastructure, software capability, organizational coordination, hinterland connectivity, costs, and safety culture are excluded from the index [24]. CPPI therefore captures operational outcomes, not the digital or organizational inputs that produce those outcomes.

This distinction matters in developing contexts. Evidence from Vietnam shows that operational performance can be achieved through labor-intensive coordination and manual procedures rather than through advanced digital systems. National surveys report that 90.5% of logistics and port-related enterprises remain at early stages of digitalization, with dominant reliance on basic tools such as spreadsheets and very limited adoption of specialized systems including TOS, WMS, or automated equipment [25-26]. Under these conditions, high performance scores do not reliably indicate digital maturity, limiting the diagnostic value of output-based benchmarks for guiding digital transformation.

A second stream comprises digital maturity and smart port models, primarily developed in advanced port systems in Europe and East Asia. These models emphasize capability-based indicators such as system interoperability, real-time data integration, automation, and Digital Twin deployment [27]. They embed strong assumptions regarding data readiness and institutional maturity, typically presuming continuous, standardized, and automated data flows across port actors, as well as stable governance arrangements that support inter-organizational data sharing and coordinated decision-making [28]. Such assumptions underpin both qualitative maturity staging and quantitative scoring schemes in smart port and resilience-oriented studies.

The direct transfer of either approach to Vietnam is constrained by a pronounced asymmetry of readiness. Empirical and policy evidence indicates that digital transformation in Vietnam’s port and logistics sector is driven primarily by regulatory mandates and administrative compliance, rather than by organically integrated port community ecosystems [29-30]. Data infrastructures remain fragmented, API-based interconnections are limited, and organizational

Table 5. Vietnam port digital index (VPDI) framework.

Pillar	Code	Indicator	Description & Measurement focus
I. Digital Infrastructure and technology	I.1	Smart Gate & Connectivity Coverage	The extent of industrial network coverage (4G/5G/Fiber) and the use of automated identification technologies (OCR/Rfid) at gates that are connected to operational systems and reduce manual data entry.
	I.2	IoT & Sensor Deployment	The proportion of frontline handling equipment (cranes, forklifts) equipped with IoT sensors and connected to operational monitoring systems for real-time status visibility.
	I.3	Equipment Automation Level	The degree of automation in handling equipment, ranging from manual operation to semi-automated or fully automated systems that support consistent and repeatable processes.
II. Data Integration & Interoperability	II.1	Data Standardization & Digitization	The level of transition from manual data handling to standardized digital data formats that enable structured storage and exchange across systems.
	II.2	Internal Interoperability	The capability for seamless data sharing across internal functional units (operations, billing, technical) without reliance on manual re-entry or isolated databases.
	II.3	External Ecosystem Connectivity	The extent of automated and standardized data exchange with external stakeholders, including Customs through the National Single Window, shipping lines, and logistics service providers.
III. Intelligent Operations	III.1	Advanced TOS Capabilities	The capability of the Terminal Operating System to support automated or rule-based yard and berth planning rather than functioning solely as a transaction recording tool.
	III.2	Real-time Monitoring & Operational Decision Support	The availability of real-time operational visibility and the use of data to support timely operational decision-making.
	III.3	Predictive Analytics & Operational Optimization	The use of analytical or algorithm-based tools to anticipate cargo flows, support equipment routing, and mitigate congestion risks.
IV. Cybersecurity & Data Safety	IV.1	IT/OT Network Segmentation	The implementation of logical or physical separation between Information Technology and Operational Technology networks to limit cross-domain cyber exposure.
	IV.2	Data Protection Mechanisms	The presence and enforcement of data backup procedures, access controls, and protection mechanisms to safeguard critical operational and client data.
	IV.3	Incident Response & Recovery Readiness	The existence of tested incident response and recovery procedures supported by defined organizational roles and coordination mechanisms.
V. Organizational Capacity & Policy	V.1	Digital Human Capital Readiness	The proportion of the workforce trained in digital operational systems and the ability to adapt to new digital tools and workflows.
	V.2	Leadership Commitment & Digital Strategy	The degree of executive commitment reflected through resource allocation and the existence of a documented digital transformation strategy.
	V.3	Governance Agility & Policy Alignment	The capacity of internal governance arrangements to adapt processes and ensure alignment with evolving digital business and regulatory requirements.

preparedness frequently lags behind technological ambition. These structural conditions undermine the applicability of data-intensive scoring logics and advanced maturity assumptions embedded in international models.

Against this backdrop, VPDI is positioned as a conceptual readiness assessment framework, not as a quantitative benchmarking tool. Drawing directly on the reviewed empirical and policy evidence, VPDI makes Organizational Capacity and Policy explicit analytical pillars. These dimensions, often treated as implicit preconditions in international models, are critical determinants of whether digital transformation initiatives are feasible and sustainable in emerging port systems. By foregrounding these foundations, VPDI bridges the gap between global digital maturity concepts and the structural realities shaping Vietnam's port sector.

2.5. Methodological framework development process

This subsection clarifies the methodological logic underlying the development of the Vietnam Port Digital Index (VPDI) as a conceptual readiness framework. Rather than introducing a new empirical research protocol, it explicates the analytical reasoning through which the framework architecture is derived. Consistent

with established practice in conceptual research on complex socio-technical systems, methodological transparency is achieved through a three-stage process: literature-informed synthesis, conceptual clustering and contextual adaptation.

Phase 1: Literature-informed synthesis

The analytical grounding of VPDI draws on a targeted synthesis of peer-reviewed studies indexed in major academic databases, including Scopus and Web of Science, complemented by Google Scholar to capture policy-oriented and emerging conceptual work. The analytical scope focuses on recurrent thematic clusters in the literature on smart ports, digital transformation, Digital Twin systems, port resilience, and digital governance. No rigid temporal cut-off is imposed, as the objective is conceptual coverage and theoretical consolidation rather than chronological trend analysis. This integrative approach is particularly appropriate for addressing heterogeneous and fragmented bodies of literature, as it enables the extraction of higher-order analytical structures rather than the exhaustive enumeration of empirical findings [31].

Within this scope, indicators are analytically derived through iterative comparison across existing frameworks,

with emphasis placed on underlying capability domains rather than isolated technologies or surface-level performance metrics. The synthesis therefore prioritizes recurring functional constructs that explain how digitalization operates at the system level, allowing dispersed empirical insights to be consolidated into a coherent analytical structure.

Phase 2: Conceptual clustering logic

The resulting conceptual clustering logic, articulated in Section 2.3 and Table 4, demonstrates how internationally derived criteria are consolidated into coherent capability clusters. Digital maturity is treated not as the outcome of individual technology deployment, but as the accumulation of coordination capacity at the port-community level. Accordingly, advanced automation and Digital Twin applications are analytically differentiated rather than collapsed into a single technological category. Digital infrastructure and intelligent operations are treated as distinct domains, reflecting evidence that automation and simulation technologies deliver limited operational value when they are not embedded within real-time data environments and operational decision-making mechanisms [32].

In a similar vein, data integration and interoperability are emphasized as substantive connectivity capacities rather than as the formal presence of information systems. This distinction reflects the role of interoperability in enabling coordination, information sharing, and adaptive responses across multiple port actors, and reinforces the treatment of data integration as a foundational capability rather than a derivative technical attribute.

Phase 3: Contextual screening and feasibility filtering

A critical methodological component of VPDI is the screening of internationally derived criteria against conditions empirically observable in Vietnam's port and logistics system. The objective of this phase is not to benchmark Vietnamese ports against advanced smart ports, but to align indicator selection with realistic maturity levels and implementation capacity. Evidence synthesized from national logistics reports indicates persistent constraints in interoperability, investment capacity, and digitally skilled human resources. Under such conditions, indicators associated with late-stage digital maturity such as fully autonomous decision-making or large-scale real-time Digital Twin deployment are either excluded or reformulated to reflect readiness-oriented conditions [33-34]

This contextual adaptation logic is further informed by resilience-oriented research, which demonstrates that deeper technological integration may increase systemic vulnerability when organizational preparedness and policy coordination lag behind technological ambition. Studies on port resilience and cybersecurity show that institutional readiness, communication protocols, and governance arrangements exert a stronger influence on system continuity than static technical safeguards alone. Accordingly, cybersecurity-related criteria within VPDI are analytically integrated with organizational and policy capacity dimensions, rather than being treated as an isolated technical pillar [35-36].

Conclusion on scaling, reliability, and validation

At the conceptual stage, VPDI defines indicator levels using an ordinal capability maturity logic rather than numerical scoring rules or Likert-type measurements. This approach conceptualizes digital transformation as progression through qualitatively distinct stages of readiness, focusing on institutionalized capabilities and coordination conditions rather than continuous performance outcomes. Issues of reliability, validity, and indicator weighting are therefore intentionally positioned beyond the scope of the present conceptualization phase. These aspects are addressed through a clearly defined empirical operationalization pathway, including expert elicitation to establish content validity, inter-rater agreement during pilot applications to assess reliability, and multi-criteria decision analysis techniques to support weighting and construct validity.

This staged separation between conceptual framework development and empirical validation is consistent with established methodological practice in complex system research, where defining a coherent analytical architecture is treated as a prerequisite for subsequent measurement and testing [37-38].

3. RESULTS AND DISCUSSIONS

Table 5 presents the structure of the Vietnam Port Digital Index (VPDI) and its associated indicators. To improve analytical clarity and practical relevance, the following subsections (3.1–3.5) discuss each pillar in turn, clarifying its conceptual scope, grounding its rationale in empirical observations from Vietnam, and indicating how the corresponding indicators may be examined in applied settings.

3.1. Digital infrastructure and technology

Digital infrastructure constitutes the foundational layer of port digitalization, encompassing network connectivity, automated identification technologies, and equipment-level automation that enable real-time data capture and operational visibility. It defines the baseline conditions upon which higher-order digital coordination and intelligence can emerge.

In Vietnam, limitations in digital infrastructure continue to constrain the depth of port digitalization. Evidence from the Vietnam Logistics Report indicates that 90.5% of logistics enterprises remain at basic levels of digital adoption, while 55.4% consider existing technological infrastructure inadequate for effective transformation. Performance data from the Container Port Performance Index further reveal vessel turnaround times of approximately 0.8–0.9 days at Vietnamese ports, compared with around 0.34 days in Japan and 0.62 days in China. These figures suggest that terminal-level investment, when not embedded within broader digital connectivity, delivers only limited competitive gains [39].

Within VPDI, these constraints are reflected in Pillar I indicators (I.1–I.3), which capture connectivity coverage, sensor deployment, and equipment automation. In practice, assessment of these indicators may draw on infrastructure audits to verify network availability and technical reviews to confirm whether automated identification and sensing technologies are effectively

integrated into operational systems.

3.2. Data integration and interoperability

Data integration and interoperability describe the extent to which operational information is standardized, shared, and exchanged seamlessly across internal port functions and external actors within the port community ecosystem. This pillar addresses the connective tissue that links infrastructure investment to coordinated system-level performance.

Empirical evidence points to persistent data fragmentation in Vietnam's port and logistics sector. Although port operations depend on continuous information exchange among ports, customs authorities, shipping lines, and logistics service providers, survey results indicate that 97.8% of firms rely primarily on spreadsheet-based data management. In contrast, Port Community Systems such as that implemented in Valencia enable coordinated data exchange among more than one thousand stakeholders. The International Maritime Organization's mandate on Maritime Single Windows from 2024 further underscores interoperability as a governance requirement rather than an optional technical enhancement. The absence of comparable mechanisms in Vietnam sustains digital silos and limits coordination efficiency [40].

VPDI addresses this gap through Pillar II indicators (II.1–II.3), focusing on data standardization, internal interoperability, and external ecosystem connectivity. Observation in applied settings may involve examining data formats, reviewing system interfaces, and verifying the existence of automated data links with Customs and key logistics partners.

3.3. Intelligent operations

Intelligent operations refer to the use of real-time data, digital systems, and analytical tools to support planning, coordination, and adaptive decision-making. This pillar distinguishes integrated operational intelligence from isolated or experimental automation.

Evidence from advanced port systems shows that digital twin applications and automation have delivered significant productivity gains, including increases of over 30% in large-scale terminals. In Vietnam, coordinated berth integration at Cái Mép extended quay length to 1,200 meters and raised productivity by an estimated 30–40%. However, such cases remain exceptions. Most Vietnamese ports deploy advanced technologies only in isolated pilots, while high capital costs, limited cargo volumes, and fragmented organizational structures restrict the consolidation of operational data into systematic planning and decision-support processes.

These dynamics are captured in Pillar III indicators (III.1–III.3), which address advanced TOS functionality (distinguishing between basic cargo tracking and automated functions such as yard planning or berth allocation), real-time monitoring, and predictive analytics. Practical assessment may focus on whether terminal systems support automated planning functions and whether operational dashboards are actively used to inform tactical and strategic decisions.

3.4. Cybersecurity and data safety

Cybersecurity and data safety encompass the capacity of port systems to manage cyber risks, protect critical data, and maintain operational continuity as digital connectivity expands.

Global evidence indicates that cyberattacks targeting operational technology systems have increased dramatically since 2017, with incidents propagating more rapidly in automated networks than physical failures. The 2017 ransomware attack on Maersk, which required the reinstallation of thousands of servers and generated losses estimated at USD 200 million, illustrates the scale of potential disruption. In Vietnam, 46.6% of logistics firms identify cybersecurity as a primary barrier to digital transformation, highlighting the operational salience of cyber risk management [41]. While assessed as a distinct pillar within VPDI, cybersecurity effectively functions as a protective layer ensuring the integrity of infrastructure (Pillar I) and data flows (Pillar II).

Within VPDI, Pillar IV indicators (IV.1–IV.3) address network segmentation, data protection, and incident response readiness. These aspects may be examined through reviews of security policies, inspection of IT/OT network architectures, and verification of tested response and recovery procedures.

3.5. Organizational Capacity and Policy

Organizational and policy capacity captures the institutional, human, and governance conditions that shape the sustainability of digital transformation. This pillar reflects the premise that technology investment alone rarely alters operating practices without corresponding organizational readiness.

Survey evidence identifies leadership commitment and workforce capability as the most influential internal drivers of digital transformation, reported by 70% and 68.3% of firms, respectively. Yet human capital constraints remain pronounced: only 5–7% of the logistics workforce has received formal digital training, and training expenditure across port-related networks remains below 1.1% of total payroll. Fragmented institutional responsibilities and limited public funding further weaken project governance, reducing the likelihood that technological investments translate into systemic change.

VPDI incorporates these constraints through Pillar V indicators (V.1–V.3), focusing on digital human capital readiness, leadership commitment, and governance agility. In applied contexts, these indicators may be examined using organizational surveys, prioritizing evidence-based verification (e.g., system logs, audit trails) over self-reporting to mitigate bias, and analysis of training and investment records.

4. CONCLUSIONS

The Vietnam Port Digitalization Index (VPDI) was created to address the lack of a suitable assessment framework for the current port system governance and data conditions. International digital maturity models often rely on assumptions about an integrated data environment and stable coordination, conditions that are not yet observable in most domestic ports. Therefore, the

explanatory value of purely technological benchmarks remains limited in this context.

Digital maturity is redefined here through a structure comprising five competency areas and fifteen indicators. In this logic, organizational capacity and policy readiness operate as indispensable components alongside infrastructure. The fragmented data environment and weak coordination mechanisms currently limit the operational impact of digital investment. Therefore, simply applying technology is insufficient evidence of transformation.

This study presents the VPDI as a conceptual assessment framework rather than a complete measurement scale. The objective of this study is limited to supporting strategic planning for the period 2025-2030. Quantitative research for VPDI will be undertaken in the future by the author when sufficient data and evaluation capacity requirements are met. VPDI does not seek to replace existing international indices, but to complement them by addressing readiness asymmetries in emerging port systems.

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