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A Study of Port Digital Transformation in Vietnam Using The Analytic Hierarchy Process (AHP)

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계층분석법(AHP)을 활용한 베트남 항만 디지털 전환에 관한 연구

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Abstract

Digital transformation is playing a key role at Vietnam's major seaports through process automation, optimized berth, yard, and equipment planning, increased real-time transparency, and reduced waiting times, costs, risks, and emissions. This process shifts value from expanding physical infrastructure to leveraging data and making synchronized decisions. This study uses the AHP methodology with a pairwise group-level comparison matrix to determine weights and rankings, based on a 2024 survey of 12 experts and over 92 workers at major ports, thereby clarifying the role and impact of factors in the digital transformation of seaports. Results indicate with the situation of Vietnam, People & Process dominates impact, followed by Technology & Data, with External Environment acting as an accelerator once foundations mature. Cai Mep–Thi Vai leads the sample, with Cat Lai, Hai Phong, Da Nang, and Quy Nhon following. Each table includes deeper interpretation and managerial implications, while worked examples demonstrate calculations and normalization.

Key words : Vietnam's port, Digital transformation, Human factor, External factors, Technology & data.

I. Introduction

Digital transformation in ports is a structural reconfiguration of how value is produced, not a minor technology upgrade. By substituting information for operational slack, it compresses variability, coordinates heterogeneous actors, and creates virtual capacity that

shortens queues and reduces exception costs while stabilizing service quality. Conversely, an hour saved at a critical node frees capacity, stabilizes schedules, and reduces fuel burn across multiple legs. The production function is reoptimized, improving unit economics, raising schedule reliability, and lowering systemic risk across maritime and hinterland networks. Economically, digitalization becomes a high option value substitute for heavy capital expenditure. Algorithmic planning, telemetry driven asset stewardship, and interoperable data exchange raise utilization, cut idle time, and eliminate rehandling, bending cost curves downward.

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This study analyzes the digital transformation process at major Vietnamese seaports using a structured multi-criteria evaluation method. Unlike previous studies that primarily focused on technology, this paper takes a more comprehensive approach by integrating human, process, external environment, and technological aspects into a unified analytical framework. The uniqueness of the study lies in its application of the Analytical Hierarchy Process (AHP) combined with empirical data collected from industry experts and stakeholders at the ports, thereby allowing for a deep assessment of the impact of factors driving digital transformation. Through a survey of five key seaports in Vietnam, the study aims to identify key success factors, clarify performance differences between ports, and propose strategic implications for promoting effective and sustainable digital transformation in the port sector.

The purpose of this study is to identify and prioritize the key criteria and sub-criteria influencing digital transformation readiness in Vietnamese seaports using the Analytical Hierarchy Process method. Based on these weighted evaluation criteria, the study further assesses and compares the digital transformation readiness levels of selected Vietnamese ports.

Ⅱ. Research Methods

1. Literature review

Operationally, ports are coordination engines under uncertainty, where information fidelity and timeliness set performance. Digital twins, Just in Time arrivals, and integrated planning across berths, cranes, yards, and gates reduce variance and stabilize vessel rotations, truck dispatching, and rail allocation. Small cuts in port call delay cascade into time and fuel savings on approach. International pilots under the IMO industry Global Industry Alliance (GIA) and the EU Sea Traffic Management (STM) Validation Project have documented significant improvements in predictability and fuel savings; simulations and pilots show large reductions in waiting time and approach phase fuel burn when JIT is adopted at scale (IMO GIA JIT, 2020–2022; STM Validation, 2018). Zhao(2010) found that ports with high levels of data interoperability experienced significant improvements in operational efficiency, including reduced dwell times, increased cargo velocity, and lower transportation costs. Landside, structured appointments, pre-arrival advice, automated gates, yard optimization, and algorithmic stowage and crane scheduling compress truck turn times, reduce rehandling, and sustain higher crane productivity, while predictive exception management preserves throughput. A study by Su(2026) revealed that ports with advanced IT infrastructure experienced substantial improvements in operational efficiency, including significant reductions in vessel turnaround times and a notable increase in overall cargo throughput

Safety, sustainability, and compliance gains reinforce these effects. Condition-based maintenance, reliability analytics, Maritime Single Window processes, and Port Community Systems reduce unplanned downtime, enable risk-based inspections, and smooth pre-arrival clearance, while shore power, voyage speed optimization, and verifiable emissions accounting through Monitoring, Reporting and Verification cut pollutants and fuel use. Research conducted by Munim and Dutta(2020) unequivocally underscores the critical role of a robust ICT infrastructure in facilitating the faster adoption of artificial intelligence (AI) and smart management systems within port operations. Delivery depends on interoperable data, rigorous governance, resilient cybersecurity, and workforce upskilling, guided by standards from the International Association of Marine Aids to Navigation and Lighthouse Authorities, the Digital Container Shipping Association, and the United Nations Centre for Trade Facilitation and Electronic Business.

Digital transformation in port logistics is increasingly seen as a core element for improving operational efficiency and competitiveness, with integrated management and digital systems playing a central role in optimizing port logistics performance (Sirajuddin, 2025). Studies also indicate that process improvements, particularly through "smart gates" models, help improve operational efficiency and reduce cargo handling time at ports (Basulo-Ribeiro, 2024). At the industry level, digital transformation in maritime transport is driving structural changes, from automation to big data analytics, to improve the supply chain (Zeeshan, 2023). Simultaneously, logistics capacity is significantly improved as ports adopt digital technologies appropriate to their local context (Iman, 2022). Key success factors include technological infrastructure, institutional framework, and logistics operational efficiency (Yang and Hsieh, 2024; Alavi-Borazjani, 2025).

2. Methodology: AHP

The Analytic Hierarchy Process (AHP) is one of the original multi-criteria decision-making methods developed by Professor Thomas L. Saaty. The Analytic

Hierarchy Process (AHP) is a multi-criteria decision-making method that involves the basic structural criteria of multiple options into a hierarchy, including the relative values of all criteria, comparing the choices for each specific criterion and determining the average importance of alternatives. That way, an establishment is created to make appropriate decisions. This method is used to solve different situations in which the goal is to make decisions. Areas such as government management, economics, health, education (Ivan Pogarcic and Vlatka Davidovic, 2008)

In AHP, priorities between alternatives are determined by pair comparison. In a paired comparison, decision makers examine two alternatives by considering a criterion and indicating a preference. These comparisons are made using the priority scale, assigning numerical values to different priority levels (Taha, 2003).

According to Rezaei, ae al., 2013, while the decision-makers need to determine the goal and alternative solution to attain it, experts have a duty to evaluate the alternative solutions based on criteria. At the end of this step, components of each criterion are structured. After this section, the weights for different criteria are found by pairwise comparison matrices. Based on the level of supporting to the goal, from the first level to lowest level of contribution, criteria in the same level will be compared.

In the survey collection

$$a = (a_1 * a_2 * a_3 * \ldots * a_i * \ldots * a_n)^{(1/n)} \quad \text{................} (1)$$

a is the sum of values for comparison pairs,

a1 is the single evaluation of comparable couples,

n is the number of evaluations

The number of comparisons depends on the number of items being evaluated in <Table 1>.

<Table 1> Number of comparisons depends on number of things

Number of things	1	2	3	4	5	6	7	n
Number of comparisons	0	1	3	6	10	15	21	$\frac{n(n-1)}{2}$

Source: Saaty, T. L. (1977)

Elements in the matrix such as aij represent the importance of Criteria 1 relative to criterion 2 whereas they satisfy the following constraints: aij * aji =1

Comparison matrix

$$A = aij = \begin{array}{c|ccccc} & A1 & A2 & A3 & \cdots & An \\ A1 & 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ A2 & a_{21} & 1 & a_{23} & \cdots & a_{2n} \\ A3 & a_{31} & a_{32} & 1 & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ An & a_{n1} & a_{n2} & a_{n3} & \cdots & 1 \end{array} \quad \cdots\cdots\cdots (2)$$

In the case that

aij > 1, Criterion I is considered more important than J

aij < 1, Criterion j is considered more important than i

aij = 1, Criterion i and j have similar importance

The Decision maker needs to evaluate the criteria in terms of their relative importance. According to Saaty T.L (1977), the relative importance between two criteria is from 1 to 9 as the <Table 2> below.

- Calculate Priority vector (x)
- Calculate adjusted weight
- Calculate Consistency index (CI)

<Table 2> The relative importance between two criteria

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is favored very strongly over another: its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

Source: Saaty, T. L. (1977)

CI = (λ max − n) / (n−1)

λ max is Eigenvalue

n is the number of criteria

- Calculate Consistency Ratio (CR)

CR= Consistency index (CI)/ Random Index (RI)

Consistency Ratio = CR ≤ 0.1 is considered reasonable.

For the Consistency Ratio (CR= CI/RI)), with the Random Index (RI) corresponding to the matrix size is also required in <Table 3>.

<Table 3> Random Consistency Index

N	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

Source: Saaty, T. L. (1977)

3. Main and sub factors

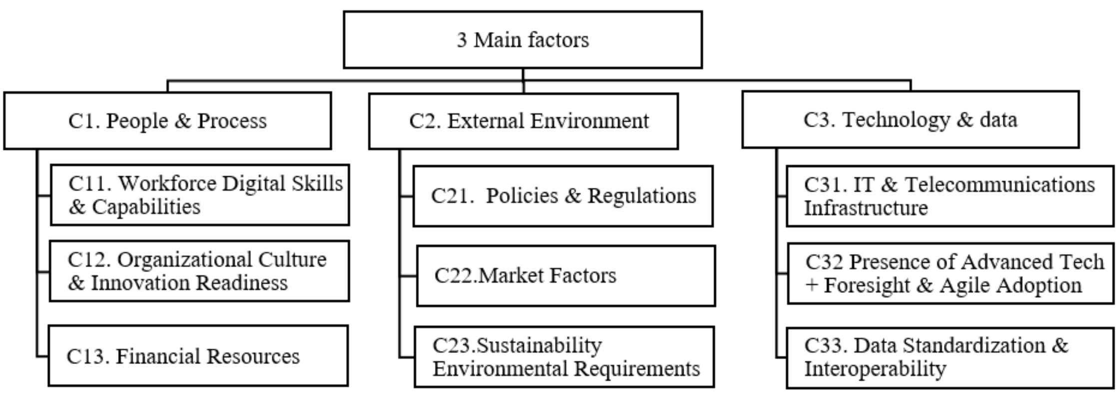
Port digital transformation is propelled by a combination of technological, organizational, and environmental factors; specifically, recent systematic reviews identify core drivers in technological infrastructure, organizational capabilities, and policy-environmental pressures (Belmoukari, 2023; Yaya, 2024).

Technologically, robust digital infrastructures such as the Port Community System (PCS), Internet of Things IoT, cloud computing, and shared data platforms together with interoperability standards and cybersecurity, forms the foundation for secure stakeholder data sharing and operational optimization (Yau, 2020; Belmoukari, 2023).

On the environmental-policy front, sustainability requirements and green governance frameworks steer investments toward clean technologies, automation, and emissions management (Yaya, 2024)

Factors affecting the digital transformation of seaports are divided into three main groups of factors: People & Process, External Environment, Technology & data, and sub-factors based on popular theories in seaport digital transformation research, previously published research results, combined with professional comments collected from experts in the field of seaports and the current situation of seaports in Vietnam. The People & Process group is separated because no matter how advanced technology is, the results of digital transformation still depend on leadership vision, strategy, organizational structure, internal processes and human resources capacity - factors that determine the ability to deploy and operate effectively. Meanwhile, the External Environment group reflects objective pressures and conditions such as state policies, customer requirements and market competition, environmental regulations and green port trends; these are factors beyond the control of the port but play an important role in orienting the level and speed of digital transformation. The Technology group is indispensable because the digital transformation of the port depends heavily on technical capabilities such as the level of system modernity, compatibility, information security level and the level of readiness to apply new technology.

The allocation of sub-factors into each group helps clarify the source of impact from technological capabilities, internal organizational strength to external pressure creating a logical, comprehensive and practical analysis structure for seaport operations. With this structure in [Fig. 1],



[Fig. 1] Main and sub factors to evaluate digital transformation the port can accurately assess the current situation, identify risks, prioritize resources and build a digital transformation strategy in a synchronous and effective manner.

1) C11. Workforce Digital Skills & Capabilities

Digital transformation at seaports is people-centric, as technology creates value when skilled staff, a culture of innovation, and disciplined change management operate as an integrated system. If one pillar is weak, the benefits from the others will be eroded; investments turn pilot projects into scale benefits in safety, throughput, and customer service. Building a competent workforce with digital skills, data literacy, and cybersecurity hygiene enables executives and frontline workers to interpret accurate insights, make quick decisions, and execute processes consistently, minimizing errors and accelerating adoption. To achieve this, port employees need structured, role-based training, micro-learning, mentoring and hands-on practice with simulators and VR in an environment that encourages experimentation. Brunila(2021) points out that the skills gap and lack of a human resource development strategy are among the major obstacles slowing the implementation of digital technologies in ports.

2) C12. Organizational Culture & Innovation Readiness

A culture of innovation readiness is essential. According to Sooprayen(2024), it will drive adoption by rewarding learning, research, and thoughtful risk-taking under clear leadership and oversight. Clearly communicating the vision and benefits of digitalization to employees helps reduce resistance, attract talent, and turn ideas into pilots, which can then be turned into successful outcomes and scaled.

3) C13. Financial Resources & Investment Capacity

Digital transformation in ports depends on sustained, well-governed investment, not merely the existence of a budget. Capital must be strategically allocated (Chen, 2025) across software such as Terminal Operating Systems, analytics platforms, and cybersecurity tools; hardware and operational technology such as Internet of Things sensors, automation equipment, and computing infrastructure; robust cybersecurity safeguards; and comprehensive workforce training. Because access to capital strongly correlates with successful digital transformation, especially for smaller ports with budget constraints, prioritize projects with clear return on investment and short-term benefits while building platforms that enable long-term scale.

4) C21. Legal Policies & Regulations

Digital transformation in ports is supported by the Vietnamese government with a clear and flexible legal and regulatory framework that builds trust, fosters innovation and manages risk. De Oliveira(2021) proved that state-issued policies/legal frameworks and governance structures significantly influence port efficiency and development. Policies include standardized and interoperable data exchange, strong data security and privacy protections, adequate cybersecurity requirements for critical infrastructure, and clear rules for emerging, advanced technologies such as artificial intelligence, blockchain, and autonomous systems. These rules should also clarify the parties' liability obligations, audit and incident reporting, as well as certification and procurement standards, so that technology suppliers and operators, and port leaders, have a clear understanding of expectations.

5) C22. Market Factors

Ports operate in a rapidly evolving global market where competitive pressures are a powerful catalyst and driver for innovation and digital transformation. Brunila(2021) point out that small or under-resourced ports are easily left behind if they do not apply digitalization Thus, competition will create a strong motivation for ports to invest in digital transformation in order not to be inferior to competitors. Highly successful ports are constantly analyzing, researching, learning from competitors, clearly identifying customer needs, and then using digital technology to differentiate themselves in efficiency, reliability, cost, and sustainability. This pressure drives investment in solutions such as artificial intelligence, blockchain, automation, and real-time visibility, along with process improvements and better services.

6) C23. Sustainability & Environmental Requirements

Sustainability and environmental requirements have become strategic drivers for port modernization, pushing ports to move beyond compliance and adopt proactive “Green Port” measures (Su(2024)). Digital technologies-Internet of Things sensors, real-time analytics, cloud-based digital twins, artificial intelligence, and blockchain enable precise monitoring of emissions and energy use, which helps optimize vessel and equipment traffic, reduce equipment and vessel fuel consumption, and build an accurate, transparent, and responsible supply chain.

7) C31. IT & Telecommunications Infrastructure

Belmoukari(2023) proves that Digitalization of operational processes depends not only on software or application platforms, but also on network connectivity, data storage, security and information transmission capabilities.

Modern ports depend on a resilient, secure, and scalable information technology and telecommunications backbone that connects every asset and workflow. High bandwidth fiber optic networks, wireless local area networks, and private fifth generation mobile networks together with well architected data centers or cloud platforms power terminal operating systems, real time tracking, and analytics.

8) C32. Presence of Advanced Tech + Foresight & Agile Adoption

Sustaining the benefits of cutting-edge technologies at seaports requires technological foresight and the ability to apply them flexibly. Conduct systematic ongoing reviews of emerging technologies, launch focused pilot projects, collaborate with academia and startups, and disseminate proven applications and best practices. The goal of this element is not to buy tools but to learn continuously, experiment, and provide multi-functional services, adapt quickly, and manage risks. Inkinen(2021) analyzed port development can follow different “technology curves” depending on the level of technology adoption and the strategy of the operator showing that having a strategic vision is very important in the digital transformation of seaports.

9) C33. Data Standardization & Interoperability

Data standardization and interoperability unlock the value of information in digitally enabled ports. Sarabia(2020) highlights the limitations of current systems including different formats leading to untimely data exchange and presents technical solutions to achieve interoperability, ensure data sovereignty, traceability and secure sharing. When stakeholders adopt common data formats, shared vocabularies, and open exchange protocols, data becomes consistent, accurate, and accessible across systems, enabling real-time visibility, faster decisions, and coordinated operations.

4. Ports In Vietnam

The selection of the five ports—Cai Mep-Thi Vai, Cat Lai, Hai Phong, Da Nang, and Quy Nhon—was based on their strategic importance within Vietnam's maritime and logistics network, as well as their differing levels of digital transformation readiness and operational characteristics. Cai Mep-Thi Vai and Cat Lai were selected because they are among Vietnam's largest and most internationally connected container ports, possessing advanced technological infrastructure and high cargo throughput.

Hai Phong was included due to its role as the primary maritime gateway in Northern Vietnam and its ongoing smart port development initiatives. Meanwhile, Da Nang and Quy Nhon represent emerging central-region ports with growing strategic importance in regional logistics and trade connectivity. The inclusion of ports from Northern, Central, and Southern Vietnam ensures geographical representation and enables comparative analysis across different development conditions, technological capacities, and management approaches. This diversity enhances the reliability and comprehensiveness of the study's assessment framework

Basic information about the 5 selected ports is shown in <Table 4>.

Ⅲ. Research Results

The research was conducted in two phases. The first phase involved a comprehensive survey in 2024, including interviews with 12 reputable port experts working at the Vietnam Maritime University, FPT University, and Ho Chi Minh City University of Transport to establish and refine the AHP framework, including the selection of primary and secondary criteria. This preliminary process helped ensure the suitability and applicability of the assessment model within the context of Vietnamese ports. The second phase, a six months survey (from June to December 2024) conducted using both online and in-person methods, was carried out to collect pairwise comparative data for the AHP analysis. The survey included experts, managers, and entry-level staff from ports and logistics companies.

Their responses were used to determine the relative importance weights of the assessment criteria. The collected assessments were aggregated into a group decision matrix using geometric mean, a method widely applied in AHP studies to combine expert opinions while maintaining reciprocal consistency.

The AHP questionnaire was designed based on a hierarchical structure including research objectives, primary criteria, and sub-criteria. The highest objective was to assess the digital transformation readiness of Vietnamese seaports. The second level included primary criteria such as People & Processes, Technology & Data, and External Environment. Each primary criterion was further subdivided into sub-criteria to reflect the details of each aspect of the assessment. The questionnaire used a pairwise comparison method, where respondents rated the relative importance of two criteria at the same level of analysis. To ensure the reliability and consistency of the results, consistency tests, including the Consistency Index (CI) and the Consistency Ratio (CR), were performed on the pairwise comparison matrices. Answers with unacceptable levels of consistency were reviewed or removed from the final analysis. This process enhanced

<Table 4> Ports in Vietnam

Port	Location & Role	Main Cargo Types	Connectivity	Digitalization & Modernization
Saigon-Cat Lai Port (A1)	Cat Lai Port — Vietnam's busiest container port and the main logistics gateway of Southern Vietnam	Containers, domestic transshipment, import/export cargo	Connects Ho Chi Minh City, Mekong Delta, and Cambodia	TOOS, OCR, AI-assisted operations, E-Port, vehicle scheduling systems
Quy Nhon Port (A2)	Quy Nhon Port — Strategic regional port for Central Vietnam and the Central Highlands	Bulk cargo, general cargo, containers, agricultural exports	Connected to the East-West Economic Corridor and National Route 19	Ongoing modernization and channel expansion projects
Hai Phong Port (A3)	Hai Phong Port — Largest maritime gateway in Northern Vietnam	Containers, bulk cargo, industrial goods, general cargo	Connected to Hanoi, northern industrial zones, China trade corridor	Smart port initiatives, cybersecurity investment, modern terminal systems
Cai Mep-Thi Vai Port (A4)	Cai Mep-Thi Vai Port — Vietnam's leading deep-sea international gateway	International containers, transshipment cargo, bulk cargo	Direct shipping routes to Europe and North America	E-Port, eDO, semi-automation, smart terminal technologies
Da Nang Port (A5)	Da Nang Port — Central Vietnam's cargo and cruise gateway	Containers, general cargo, tourism and cruise passengers	Key node of the East-West Economic Corridor linking Laos, Thailand, and Myanmar	Recent infrastructure upgrades and terminal modernization

the robustness and reliability of the final AHP weights and ranking results.

1. Main factors

Based on the aggregation of expert judgments collected from specialists, managers, and practitioners in the maritime and logistics sectors, a pairwise comparison matrix titled "Evaluate the Importance of Three Main Factors" was developed. The matrix was used to assess the relative importance of the three primary factors influencing digital transformation readiness in Vietnamese seaports: Human & Process (C1), Technology & Data (C2), and External Environment (C3), which can be present in <Table 5>.

<Table 5> Using AHP to evaluate the importance of 3 Main Factors

	C1	C2	C3	Weight
C1	1.00	1.54	1.38	0.42
C2	0.65	1.00	0.86	0.27
C3	0.72	1.16	1.00	0.31
Total	2.37	3.70	3.24	1.00

CI = 0.0007
CR = 0.0011< 0.1 (acceptable)

In Table 5, each pair of criteria was compared with one another using the pairwise comparison method of the Analytic Hierarchy Process (AHP). specifically, the numerical values in the matrix reflect the relative importance between two criteria based on survey participants.Through this pairwise comparison process, all criteria were evaluated step by step against each other to determine their relative priorities and final weights. The resulting weights represent the normalized importance of each criterion in the overall assessment framework. Furthermore, the consistency of these comparisons was verified using the Consistency Index (CI) and Consistency Ratio (CR), where CR values below 0.1 indicate acceptable consistency and reliability

First, the 42% weighting for factor C1 - People and Processes confirms that the human factor is the most important foundation. In the context of digital transformation, the human factor and processes play a key role. Training human resources with digital skills, building an organizational culture ready to innovate and standardizing business processes are the decisive factors for the success of the digital transformation process. Without a high-quality workforce and an efficient working process, the application of advanced technology will not bring the expected results. Vietnam has the advantage of a young population, with about 70% of the total 98 million people under 35 years old. However, this advantage in terms of labor resources cannot be converted into digital capacity without proper investment in skills and process development guidance. According to recent national statistics, approximately 60% of workers lack basic digital skills, and only 15% have advanced digital capabilities - the core element to apply technology in the context of Industry 4.0. In the context of Vietnam, the paradox is that the port workforce, despite being both insufficient in number and lacking in skills, has a decisive influence on the digital transformation process. The high weighting (0.40) indicates that this is a key factor, while the low competency level reflects a shortage of skills and high-quality personnel, especially in technical and operational positions. This weakness makes human resources a "bottleneck," slowing down the entire transformation process. Therefore, prioritizing human resource training, standardizing processes and improving organizational capacity becomes a prerequisite in every digital transformation strategy of seaports.

Next, the 31% weight for C3 - Technology and Data shows that technology plays an important role but is not the leading decisive factor as many people mistakenly believe. Vietnam has invested heavily in digital infrastructure including fiber optic networks, data centers, 5G deployment as well as cloud computing service development. However, reality shows that many technology projects are ineffective due to the lack of high-quality human resources and appropriate operating processes. According to Theotokas's (2024) study on human resource management in the digitalization of the maritime industry, many IT projects at seaports and maritime enterprises fail or fall short of expectations due to a lack of digitally skilled personnel, lack of training programs, and inappropriate internal implementation processes.

Finally, the 27% weight given to C2 - External Environment reflects the role of contextual factors such as policies, economic integration, international technology trends, or requirements from the global supply chain. Although these factors create important dynamics and set mandatory requirements for Vietnamese enterprises, they are not decisive in terms of competitiveness between organizations. All enterprises are similarly affected by the external environment; therefore, the ability to differentiate lies in the internal capabilities of each enterprise - including the quality of human resources, the level of process standardization, and the ability to effectively deploy technology. Therefore, environmental factors are an indirect group of impacts, shaping the changing context but not creating sustainable competitive advantages.

In general, the C1 - C3 - C2 weighing confirms that sustainable digital transformation does not start with technology, but with people, processes, then technology and the external environment.

2. Evaluation Sub-Criteria

Based on the Analytical Hierarchy Process (AHP), a quantitative tool used for evaluation, sub-criteria were developed and applied similarly to the process described above. Specifically, each sub-criterion corresponding to the five ports mentioned was subjected to pairwise comparison, weighting, and score aggregation to reflect the importance and performance of each port in each evaluation aspect. The results obtained from this process are presented in detail below in <Table 6>, showing the clear differences between the ports according to each criterion.

<Table 6> People & Process (C1) Sub-criteria Weights

	C11	C12	C13	Weight
C11	1.00	1.42	1.34	0.40
C12	0.70	1.00	0.64	0.25
C13	0.75	1.56	1.00	0.34
Total	2.45	3.98	2.98	1.00

CI = 0.0088
CR = 0.015 < 0.1 (acceptable)

<Table 6> presents the relative importance of each sub-criterion within the People & Process dimension (including Workforce Digital Skills & Capabilities (C11), Organizational Culture & Innovation Readiness (C12), Financial Resources (C13) , as determined through the AHP analysis.

The high weight of C11 (0.40) indicates that human resources and digital skills are the most important factors influencing digital transformation at Vietnamese seaports. Investment in technologies such as port operating systems, IoT monitoring platforms, automation systems, data analytics, and e-customs can only be effective when workers can operate, adapting, and innovating with these technologies. As Vietnamese ports transition from traditional manual operations to a digital environment, the shortage of digitally skilled workers has become a major challenge. Many workers have extensive operational experience but are still unfamiliar with digital systems, increasing the risk of inefficiency, cybersecurity vulnerabilities, and delays in cargo handling.

C12 (0.25) emphasizes the supportive role of organizational culture in driving digital transformation. Although weighted lower than C11, organizational culture strongly influences the speed and effectiveness of innovation adoption. Many Vietnamese ports still operate under traditional and hierarchical management structures, prioritizing stability and strict adherence to procedures. Such conservatism can reduce organizational flexibility and hinder experimentation with new technologies. Employees and managers are often hesitant to digitalize due to concerns related to changes in workflows and job responsibilities.

For C13 – Financial Resources (0.34), the results show that financial capacity remains a significant factor facilitating digital transformation, although less influential than human resources. In the context of Vietnamese seaports, the main obstacles often relate not only to limited investment capital but also to governance capacity, technology standardization, and implementation efficiency. Ports need sustainable investment strategies that support cybersecurity protection, network segmentation for operational technology systems, standardized APIs, and improved data management across the port community.

With regard to the next dimension, <Table 7> illustrates the relative significance of each sub-criterion within the External Environment dimension including: Policies & Regulations (C21), Market Factors (C22), Sustainability Environmental Requirements (C23), based on the results of the AHP analysis.

<Table 7> External Environment(C2)

	C21	C22	C23	Weight
C21	1.00	1.67	2.34	0.48
C22	0.60	1.00	2.45	0.35
C23	0.43	0.41	1.00	0.17
Total	2.03	3.08	5.79	1.00

CI = 0.019
CR = 0.032< 0.1 (acceptable)

The research results indicate that the external environment plays a crucial role in shaping the operational efficiency and digital transformation readiness of Vietnamese seaports. Among the three sub-criteria, Policies and Regulations (0.48) received the highest weight, showing that institutional support and management efficiency are the most influential external factors. A transparent legal framework, efficient licensing procedures, stable tariff policies, and clear regulations on foreign investment are essential to minimize uncertainty and encourage long-term infrastructure investment.

Market Factor (0.35) represents the second most important external factor, reflecting the increasing competition among Vietnamese seaports and regional maritime gateways. Ports that can offer lower logistics costs, higher productivity, reliable inland connections, and consistent service quality are more likely to attract carriers and cargo volumes. Competitive pressure encourages ports to continuously improve operational performance, enhance logistics integration, and adopt digital technology instead of relying on one-time infrastructure upgrades. This finding also reflects the increasing importance of supply chain efficiency and customer-oriented port services in the regional logistics market.

Sustainability (0.17) received the lowest weight among the external environmental factors, indicating that Vietnam's port industry still prioritizes growth and operational efficiency over environmental goals. However, sustainability is becoming increasingly important due to global pressure for green logistics, stricter environmental regulations, and international decarbonization initiatives. Environmental assessments, emissions regulations, green port standards, and energy-saving practices are gradually shaping long-term competitiveness and access to international cargo flows. While sustainable investment remains challenging due to financial and technological constraints, the development of green logistics and environmentally friendly port systems is expected to become a more influential factor in the near future.

Finally, <Table 8> presents the relative importance of each sub-criterion within the Technology and Data dimension including IT & Telecommunications Infrastructure (C31), Presence of Advanced Tech + Foresight & Agile Adoption (C32), Data Standardization & Interoperability (C33)

With an overwhelming weight of C31 (0.43), infrastructure is the first and most important

<Table 8> Technology and data (C3) Sub-criteria Weights

	C31	C32	C33	Weight
C31	1.00	1.80	1.30	0.43
C32	0.56	1.00	0.72	0.24
C33	0.77	1.39	1.00	0.33
Total	2.33	4.19	3.02	1.00

CI = 0.00032
CR = 0.0004< 0.1 (acceptable)

battleground. In port operations, IT infrastructure means flexible dual-path fiber, SD-WAN across all sites, and robust wireless across gates, yards, and wharfs, where device movement and latency must be predictable. Many terminals in Vietnam already have good core connectivity and basic redundancy but still suffer from "dead zones" in yards, blind spots, single points of failure in access circuits, and limited disaster recovery.

Data Standardization & Interoperability (C33) ranks second in importance, with a weight of 0.33. Data Standardization and Interoperability in the port system will ensure that different systems can "talk" to each other and share information quickly and easily, especially in difficult situations. This is important in the logistics industry, where information must be exchanged regularly and continuously between various stakeholders, including ports, shipping lines, logistics companies and customs authorities. The application of international and regional standards helps increase transparency and efficiency of the supply chain. Without standardization, system integration and data mining will be difficult and expensive.

C32: Presence of Advanced Technology + Agile Vision & Adoption has the lowest weight (0.24), but this does not mean that this factor is not important, but only because it depends on the infrastructure as well as the ability to standardize data interactions. The application of advanced technologies such as artificial intelligence (AI), Internet of Things (IoT) and blockchain can help improve operational efficiency and reduce costs for seaports. For example, AI systems can accurately predict the time and destination of cargo ships, helping ports handle cargo more efficiently. However, for these advanced technologies to work effectively, a solid IT infrastructure and standardized data are essential.

3. Port Ranking

Based on the Analytical Hierarchy Process (AHP), a quantitative tool used for evaluation, sub-criteria were developed and applied similarly to the process described above. Specifically, each sub-criterion corresponding to the five ports mentioned was subjected to pairwise comparison, weighting, and score aggregation to reflect the importance and performance of each port in each evaluation aspect. The results obtained from this process are presented in detail below (<Table 9>), showing the clear differences between the ports according to each criterion.

<Table 9> Port Scores by Criterion and Overall

	C1	C2	C3	Final weight
A1	0.306	0.32	0.21	0.279
A2	0.097	0.09	0.13	0.106
A3	0.179	0.25	0.16	0.196
A4	0.318	0.24	0.37	0.309
A5	0.1	0.1	0.13	0.110

Based on the results obtained from the AHP method, the five ports were ranked from 1 to 5 as shown in <Table 10>.

<Table 10> Port Ranking (Overall)

Port	Rank
Cai Mep-Thi Vai (A4)	1
Cat Lai (A1)	2
Hai Phong (A3)	3
Da Nang (A5)	4
Quy Nhon (A2)	5

According to the table, Cai Mep-Thi Vai Port (A4) has the highest weight (0.309) and ranked 1st, followed by Cat Lai Port (A1) (0.279) in 2nd. Hai Phong Port (A3) is ranked 3rd with a weight of 0.196 and the remaining two ports Da Nang (A5) and Quy Nhon (A2) have low weights with 0.110 and 0.106 respectively. This result reflects a clear difference in capacity and readiness for digital transformation.

C1. People & Processes. Cai Mep-Thi Vai has the highest score (0.3108), followed by Cat Lai with 0.306. These two ports have modern management teams, apply international standard operating systems and train specialized digital human resources. In addition, Cai Mep-Thi Vai is oriented to become a digital super port, requiring streamlined operations and multimodal connections. In contrast, Quy Nhon (0.097) and Da Nang (0.10) are still limited in process synchronization and lack of specialized IT human resources.

C2. External environment. This is a factor reflecting the connection with the global supply chain, connecting infrastructure, and support policies. Cat Lai leads (0.32) with the location near the center of Ho Chi Minh City, international trade gateway and extensive logistics service network. Meanwhile, Cai Mep-Thi Vai (0.24) stands out for its regional strategy and trans-Pacific shipping routes (22/25 routes to the US depart from here). Hai Phong also scores 0.25 because of its direct connection to international shipping routes and strategic location in the North.

C3. Technology & Data. Cai Mep-Thi Vai scored 0.37, excelling in its application of Big Data, IoT, and automated port management system. Cat Lai (0.21) has deployed container management software and the E-Port system, but its scale and integration are not as good as Cai Mep-Thi Vai. Hai Phong (0.16) is still in the process of perfecting digital solutions and is affected by process and infrastructure barriers, so it is not rated too highly. Da Nang and Quy Nhon (0.13) currently still lack centralized data systems and online analytics capabilities.

Cai Mep-Thi Vai ranked first and scored highly in all three criteria, especially C1 and C3, along with a favorable external environment. Cat Lai followed closely in second place with advantages in international trade and cooperation with many large shipping lines but was weaker than Cai Mep-Thi Vai in terms of technology. Hai Phong ranked third, strong in location and external environment, but technology was not yet synchronized. Da Nang and Quy Nhon ranked last in all three criteria, mainly due to technology infrastructure and human resources not meeting modern digital transformation standards.

Ⅳ. Conclusion

The purpose of this research is to assess and rank the digital transformation readiness of major seaports in Vietnam using the Analytical Hierarchy Process (AHP) methodology. The study aims to identify key factors influencing port digital transformation, including people and processes, the external environment, and technology and data infrastructure.

The findings indicate that Human & Process is the most influential factor in the digital transformation readiness of Vietnamese seaports, emphasizing the importance of human resources, governance, and organizational adaptability over technology alone. Technology & Data rank second, highlighting the role of digital infrastructure, automation, and data standardization in improving port competitiveness. External Environment ranks third, reflecting the influence of regulations, market pressures, and sustainability requirements. In terms of readiness, Cai Mep–Thi Vai ranks first, followed by Cat Lai, Hai Phong, Da Nang, and Quy Nhon.

The research provide several strategic implications for Vietnamese policymakers and port operators. First, seaports should prioritize investment in integrated digital infrastructure, including Port Community Systems, Internet of Things applications, artificial intelligence-based management systems, and automation technologies, to improve operational efficiency and competitiveness, particularly at Hai Phong, Da Nang, and Quy Nhon ports. Second, ports should strengthen digital workforce training, change management, and innovation-oriented organizational cultures to support sustainable digital transformation. Finally, the government should enhance regulatory frameworks, promote data-sharing standards, and provide financial support for smart port and green logistics development to improve the competitiveness of Vietnam's maritime sector.

This study has several limitations that need to be acknowledged. Firstly, the number of ports surveyed is limited, which may reduce the ability to generalize the findings to the entire Vietnamese maritime industry. Secondly, the AHP methodology relies heavily on expert opinions, so the results may be influenced by the experience, perceptions, and preferences of the respondents. Furthermore, subjective bias may occur during pairwise comparisons despite the application of consistency tests such as CI and CR to improve reliability.

Therefore, future research should expand the dataset by including more domestic and international ports to improve comparative analysis and external validity, as well as incorporating time-series data to better capture changes in digital transformation readiness over time.

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