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# Exploring The Relationship Between Smart Port Competitiveness And Factors Under Technology-Organization-Environment (T-O-E) Framework : A Structural Equation Modeling Approach

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**ABSTRACT**

The maritime industry's 4.0 revolution is advancing rapidly, requiring ports to continuously innovate and evolve. Ports must not only become smarter to improve efficiency, sustainability, and safety but also enhance interconnectivity with other ports. To stay competitive and boost productivity, ports must develop digital capabilities and evolve into "smart" ports. However, despite the increasing importance of smart ports, research in this area remains limited. This study used the Technology-Organization-Environment (T-O-E) framework to identify seven key factors and examine the interrelationships between policy support, port resources, technology compatibility and security, ICT integration, operational structures, and smart port competitiveness. A survey conducted among stakeholders in the port industry collected 320 responses, exploring the impact of ICT on port competitiveness. Data analysis was performed using structural equation modeling (SEM) through AMOS software. The findings reveal significant positive correlations between policy support, port resources, security, port operations, and ICT integration, confirming ICT integration's positive impact on smart port competitiveness. Additionally, ICT integration significantly enhances smart port competitiveness. This study enhances understanding of how ICT integration influences port development and competitiveness. The results provide actionable insights for governments, port practitioners, and policymakers to prioritize smart port upgrades and support national and regional development objectives.

***Keywords:*** Smart port, T-O-E, Factors, Competitiveness, SEM

## 1. Introduction

The "Belt and Road" initiative, also known as the Silk Road Economic Belt and the 21st Century Maritime Silk Road, is a global initiative proposed by the Chinese government in 2013. Its primary objectives are to promote global

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trade and economic cooperation, enhance regional stability and security, and foster the development of an open world economy. The 21st Century Maritime Silk Road consists of two main components. Firstly, it involves shipping to and from Chinese coastal ports traversing the South China Sea to reach the Indian Ocean, extending subsequently to Europe and Africa. Secondly, it encompasses shipping to and from Chinese coastal ports crossing the South China Sea to reach the South Pacific, ultimately extending to Oceania and Latin America.


**Figure 1:** The Belt and Road Initiative (BRI)

Since the inception of the "Belt and Road" initiative, Chinese ports have established connectivity routes with over 600 ports in more than 200 countries worldwide. Maritime services cover all the countries along the Maritime Silk Road. As of 2022, the trade volume between China and Belt and Road countries has increased from $1.04 trillion to $2.0 trillion, with an annual growth rate of 8%. Over 3,000 cooperation projects have been initiated, generating 420,000 employment opportunities and lifting four million people out of poverty. This initiative is the most extensive large-scale international cooperative platform in the contemporary world.

Major coastal ports in China, serving as vital nodes along the Maritime Silk Road, include Dalian, Tianjin, Qingdao, Shanghai, Ningbo, Shenzhen, and Beibu Gulf. These ports are strategically sized for the potential profit growth opportunities presented by the "Belt and Road" initiative. They are actively transitioning towards intelligent and sustainable operations, recognizing that competitive advantages are no longer confined to geographical location and improvements in port operational efficiency. To date, the global development of ports has generally traversed four phases and is presently advancing towards the transition into the fifth generation of port transformation. For Chinese coastal ports to sustain a robust competitive edge, proactive involvement in the construction of fifth-generation ports is imperative. This necessitates a continuous commitment to development in innovative domains such as informatization, intelligence, and automation.

Smart ports, aligning with the developmental trends of the era, have witnessed a continuously increasing focus on their competitiveness. Port enterprises have begun paying attention to the application of new technologies in smart ports. However, enhancing port competitiveness solely through the application of new technologies has proven to be challenging, necessitating further in-depth analysis and identification of the factors influencing smart port competitiveness on the foundation and development of traditional ports. In the scenario of multiple complex

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factors simultaneously affecting competitiveness, there arises a need to identify and quantify the specific impact of each influencing factor on the competitiveness of smart ports.

Therefore, to stimulate and strengthen smart port competitiveness, this research systematically reviewed existing studies and utilized empirical research to determine the key influencing factors and mechanisms affecting the competitiveness of smart ports. While China stands as a prominent maritime nation, it falls short of being a leading force in smart port technologies. Focusing on coastal ports, the majority are still in the early stages of construction and resource investment, lacking a complete realization of information, and internationalization.

The relevant research identified in the literature is summarized in the following list of current smart ports in China.

**Table 1: The Issues Faced by China's Smart Ports**

| Types of Issue | Specific description | Source |
|---|---|---|
| Information | • Smart ports lack a systematic and unified plan for information technology construction.<br>• Insufficient information sharing with stakeholders and other ports.<br>• Information security and data ownership in the construction and development of smart ports.<br>• Slow progress in the development of port ICT,<br>• uneven information technology development, and inadequate data sharing.<br>• Data isolation | (WangYufu, 2017; Zhang Jingwen, 2019)Li Hong, Wang Dacheng, & Liu Ting, 2020<br>(Wen Furong, Xie Jun, 2020)<br>(Liu Fen, Qian Lin, 2022<br>(Kang Minhua, 2023; Mengtong Dong, 2023) |
| Infrastructure | • Weak logistics infrastructure.<br>• A significant gap in equipment management levels.<br>• High costs of port terminal renovations. | (Gao Enpu, 2010; Zhang Jingwen, 2019)<br>Li Hong, Wang Dacheng, & Liu Ting, 2020<br>(Wen Furong, Xie Jun, 2020)<br>(Kang Minhua, 2023) |

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| Efficiency | • Low service and customs clearance efficiency.<br>• High tangible costs, and competition from ports located on rivers remote from the coast.<br>• Limitations in land availability.<br>• Low logistics efficiency.<br>• Inconsistent operational and service standards. | (He Hongcai, 2022; Li Hong, Wang Dacheng, & Liu Ting, 2020; Zhang Jingwen, 2019) (Kang Minhua, 2023) |
| Resources | • Limited deep-water shoreline resources.<br>• Geographical location.<br>• Limited direct shipping routes.<br>• Long transportation cycles.<br>• Lack of facilities for bidirectional cargo flows.<br>• Tight transport capacity. | (Fangyang, 2018) (Zhang Jingwen, 2019) (He Hongcai, 2022) |
| Competition | • Competition from other international container ports.<br>• Lagging in intermodal transportation capabilities. | (He Hongcai, 2022) |
| Talent | • Shortage of high-quality talent.<br>• Shortages in specialized international talent. | (Gao Enpu, 2010; He Hongcai, 2022) |
| Policy | • Insufficient government incentive measures.<br>• Policy barriers. | (Fangyang, 2018) |
| Technology | • Issues related to automated guided vehicles, intelligent containers, and port management systems.<br>• These issues encompass challenges associated with navigation methods, real-time monitoring, and insufficient interconnectivity. | (WangYufu, 2017; Yuan Yuxiang, Sui Zhenying, 2022) (Mengtong Dong, 2023) |
| Operation | • Lagging world standard management practices. | Li Hong, Wang Dacheng, & Liu Ting, |

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| | • The traditional management approach results in various functional departments holding their respective data, creating 'information 'islands'.<br>• Integrating data from different functional departments poses significant difficulties.<br>• Lack of synergy in the logistics chain<br>• inflexible service models.<br>• Insufficient service capabilities. | 2020<br>(Wen Furong, Xie Jun, 2020)<br>(Liu Fen, Qian Lin, 2022<br>(Kang Minhua, 2023) |

Given these restraints, the object of this study was to identify and understand the overall mechanism behind the application of ICT in China's smart ports and the competitiveness of those ports. Two research questions were stated to guide the study.

RQ1 To identify and classify factors affecting the competitiveness of smart ports.

RQ2 To explore the relationship between smart port competitiveness and factors under the T-O-E Framework.

These questions demonstrate our goal which was to identify the key factors driving the competitiveness and development of China's smart ports and analyze the causal relationship between these factors. Beibu Gulf Port was chosen for our empirical study to provide theoretical and management enlightenment to identify the factors underlying the smart port model transformation of that port. A structural equation model (SEM) was developed to achieve these objectives and to examine the relationship between smart port competitiveness and smart port development factors under the ICT and T-O-E frameworks. SEM was used to verify the conceptual model and evaluate the relationship between factors through the path analysis of the competitiveness of smart ports in the T-O-E framework by ICT.

The contribution of this research has two aspects. First, this study affirms the powerful explanatory power of T-O-E for understanding ICT integration and smart port competitiveness. The extension of T-O-E emerges by supplementing some key factors (including port operations, and port resources) to enrich the analysis of factors affecting the competitiveness of smart ports. Secondly, this study will guide port managers, practitioners, and policy makers to promote port ICT integration through significant key factors such as strengthening policy support and port operations. Therefore, the key factors in the Beibu Gulf Port will be described, and solutions for the development of other traditional Chinese ports to upgrade to smart ports will be identified.

## 2. Theoretical Background

The T-O-E framework as proposed by (Tornatzky & Fleischer, 1990), offers a comprehensive analytical framework for studying the adoption of technological innovation. This framework considers the three aspects of technology, organization, and environment, which significantly influence the internal adoption and implementation of

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technological innovation within enterprises. Through contextual analysis of technology application, the T-O-E framework categorizes these influencing factors into the three main classes of technological characteristics, organizational features, and environmental conditions, together with the market environment. (Lin & Lin, 2008) emphasize the complementary nature of the T-O-E framework to the Diffusion of Innovation (DOI) theory, while enhancing its applicability in explaining internal innovation diffusion within enterprises. The T-O-E model by (Valio Dominguez Gonzalez & Fernando Martins, 2014) highlights technological, environmental, and organizational factors. However, organizational aspects may be selectively overlooked in specific studies.

In the realm of information technology adoption theories, the T-O-E framework finds widespread application. (Fujihara et al., 2022) reviewed theories related to information technology adoption, emphasizing the significance of the Theory of Planned Behavior (TPB), Technology Acceptance Model (TAM), Innovation Diffusion Theory (IDT), Unified Theory of Acceptance and Use of Technology (UTAUT), and T-O-E, in explaining user intentions and behavior in technology adoption. Researchers, utilizing the T-O-E framework, as seen in the study by (H. Tang et al., 2022), have scrutinized the multifactorial influences of the Internet on digital innovation in enterprises, while (Nguyen et al., 2022) integrates the Technology Acceptance Model (TAM) and T-O-E framework, conducting a systematic review of factors influencing digital innovation. (Park et al., 2022) advocated combining the Innovation Diffusion Theory with the T-O-E framework and established a model to identify factors affecting the adoption intention of autonomous ships in the shipping industry, revealing that top management support, financial flexibility, and competitive intensity significantly influence the willingness to adopt autonomous ships.

In summary, these studies highlight the versatility and applicability of the T-O-E framework in understanding and analyzing the adoption of technological innovations across various organizational contexts and industries.

In this literature review, we observed that the factors influencing smart ports can be categorized into the T-O-E dimensions in the technological, organizational, and environmental contexts. Table 2 provides an overview of the factors reported in published studies on the evaluation indicators for smart ports. Drawing upon the literature review of the smart port evaluation index system, the revised system includes six primary indicators, Twelve secondary indicators, and thirty-eight tertiary indicators. The principal aim of the proposed index system is to assess and guide the informatization and intelligent development of ports in China. Its objective is to promote the extensive utilization of emerging information technologies in ports, elevate the overall innovation capacity of ports, and enhance port competitiveness.

**Table 2: Framework of the evaluation index system of smart port**

| Category | Primary Indicator | Secondary Indicator | Tertiary Indicator |
|---|---|---|---|
| • Environment | • Policy Support | • Institutional and Regulatory Safeguards<br>• Economic Incentives | • National-Level Policies<br>• Supportive Services Provided by Local Administrative Departments |



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| | | • Proactive Leadership | • Financial Funding Support<br>• Level of Leadership Emphasis |
| | • Port Resources | • Tangible Resources<br>• Soft Environment | • Berth Quantity<br>• Quay Length<br>• Yard Area<br>• Navigational Channel Standard Dept<br>• Hinterland Conditions<br>• Internal Stakeholder Perception<br>• External Stakeholder Perception<br>• Vision and Planning<br>• Smart Port Soft Environment |
| • Technology | • Compatibility | • Smart Port Technology Applications | • IoT<br>• Cloud Computing/Storage Technology<br>• Mobile Internet Technology<br>• Big Data<br>• AI<br>• System Simulation Technology<br>• Intelligent Diagnostics Technology<br>• Automatic Identification and Control Technology |
| | • Security | • Communication Equipment<br>• Security Assurance | • Broadband Network<br>• Wireless Network<br>• Sensor Network<br>• Wireless Communication<br>• Data Center<br>• Monitoring and Dispatch Center |

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| • Organization | • Port Operation | • Smart Port Production<br>• Management and Services | • Basic Information Platform<br>• Network Information Security<br>• Security Department<br>• Intelligent Port Operations<br>• Intelligent Port Management<br>• Intelligent Port Services |
| | • Organizational Structure | • Organizational Scale<br>• Technical Competence of Smart Port Personnel | • Staff Size<br>• Degree of Decision-Making Centralization<br>• Educational Level<br>• Technical Level<br>• Training Level |

In summary, the literature review highlights that an excessive number of indicators can impede accurate problem investigation, necessitating careful selection to ensure their relevance and effectiveness in research. Overall, these studies offer diverse perspectives and methodologies for evaluating port competitiveness, providing profound insights into industry development and trends toward digitalization. Given the current rapid development of smart port construction and the persistent lack of a unified smart port standard system, we have leveraged the research foundation on the developmental trajectory of smart port construction. By combining domestic and international research outcomes of evaluation indicator systems of ICT development, the key influencing factors of smart port competitiveness suitable for China's national conditions have been established.

## 3. Conceptual Model and Hypotheses Formulation

### *3.1 Relationship Between Policy Support and ICT*

The developmental level of a country's economy and scientific environment positively influences companies' adoption of ICT innovation, as well as the quantity of knowledge and ICT infrastructure within that country. (Jordá Borrell et al., 2018a) argue that government policies supporting the availability of ICT and the existence of tailored laws and regulations are crucial for fostering a favorable economic environment for companies.

On the other hand, (Bibri & Krogstie, 2019) suggest that, alongside formulating policies to promote ICT, it is essential to establish high-density, high-quality research and innovation institutions to generate cutting-edge ICT knowledge. Similarly, some argue that government procurement of advanced technology products stimulates the

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development of the technological investment structure (Castelnovo & Dal Molin, 2021). All these factors, coupled with high-quality management schools, instil confidence in companies and enhance the performance of adopted ICT innovations.

However, despite the advantages of information and communication technology, there is considerable variation in the amount of investment that different countries, sectors, and companies dedicate to these technologies. Evidence suggests that not all companies in each country are eager to adopt ICT-based solutions (Alam & Noor, 2009). For instance, cloud computing is a cutting-edge technology, yet there are still unresolved issues (such as lack of regulation, high risks, and costs), and companies' understanding of this technology remains limited (Ilyihamije, 2019).

H1. Policy support has a positive impact on ICT.

*3.2 Relationship Between Port Resources and ICT*

(Fangyang, 2018) explores the competitiveness of the Beibu Gulf Port in Guangxi from the perspectives of resource theory and institutional environment. Resources are categorized into tangible and intangible, with infrastructure considered as the tangible resource of the port. Linear shipping connectivity and operational efficiency are regarded as intangible resources. An empirical analysis model is constructed to examine the impact of port resources and policy environment on port competitiveness. The hypothesis is proved: The port facility conditions; connectivity conditions and operational efficiency of Beibu Gulf Port are positively correlated with port competitiveness.

(Mugobi & Mlozi, 2020) aimed to assess ICT determinants of World Heritage Sites' Performance in Tanzania with a mediation variable of ICT usage. ICT support infrastructure had a statistically positive, significant relationship with ICT usage in WHSs.

H2. Port resources have a positive impact on ICT.

*3.3 Relationship Between Compatibility and ICT*

The consensus within the academic community both domestically and internationally asserts that technological innovation serves as a fundamental source for acquiring sustained competitive advantage for enterprises. Research and development (R&D) investments and technological mergers and acquisitions are widely recognized as the most crucial means to achieve technological innovation within companies (Li Yajie, 2019). The Internet of Things (IoT) technology is acknowledged for its capacity to enhance information transparency and management efficiency, transform traditional industries, promote the in-depth integration of informatization and industrialization, construct new competitive advantages, and further stimulate awareness and levels of innovation.

The more a new technological innovation is perceived to align with the current value systems and procedures of potential adopters, the more likely it is to be adopted (Baker, 2012). Therefore, if autonomous vessels are highly compatible with the management and operation of traditional vessels, their adoption is likely to increase. (Ishahak, 2020) confirmed that compatibility positively influences the intention to adopt autonomous vessels.

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Hamburg Port, as one of Europe's largest ports, is managed by the Hamburg Port Authority (HPA), a public institution with approximately 1800 employees. The HPA is responsible for maintaining and developing port infrastructure, emphasizing efficiency, safety, and economic viability. Activities encompass shipping control, operations, and maintenance based on information technology, as well as the expansion of various port-related facilities, roads, and real estate. The initiated Smart Port initiative aims to reduce energy consumption and emissions, implement predictive maintenance schemes for port-related infrastructure, and enhance traffic and parking management.

H3. Compatibility has a positive impact on ICT.

*3.4 Relationship Between Security and ICT*

(Jordá Borrell et al., 2018b)The scientific literature has devoted considerable effort to analyzing the mechanisms that influence the adoption of ICTI by enterprises. A large proportion of these studies have focused on factors related to the organization and the technology adopted, highlighting the cost, reliability and safety of adoption or the lack of skills to implement the technology. (Kok-Lim Alvin Yau et al., 2020)Connecting crucial network physical systems with digital technology introduces substantial risks. The application of artificial intelligence (AI) has the potential to profoundly transform various aspects of security, which has become increasingly intricate. However, the use of AI may give rise to security vulnerabilities, as attackers can manipulate acquired knowledge. Therefore, it is imperative to design and implement appropriate rules to address these challenges. (Onwuegbuchunam et al., 2021)Identifying a significant relationship between port security systems, port security incidents, and port performance, the findings indicate that implementing appropriate security measures can significantly reduce port security incidents and enhance port performance.

The relationship between security assurance and ICT of Lincangban Deepwater Port is explored through the hypotheses: Security assurance has a positive impact on the long-term development of Lincangban Deepwater Port.

H4 Security has a positive impact on ICT.

*3.5 Relationship Between Port Operation and ICT*

The effective exchange of information between and within a port and its community members is critical to effectively facilitate the physical movement of cargo in and out of a port. Indeed, ICT has emerged to become a key catalyst in port management and development. The increasing digitalization is not only driven by efficiency gains (e.g., reducing cargo transit time and port congestion), but also by safety, security, and environmental concerns (Cavalli et al., 2021).

(Jiang et al., 2023) An advanced level of integrated IT infrastructure is positively associated with the capability of a port to integrate business processes internally and externally with port users. Although the information platform in enhancing port operational capability (including financial flows, information flows and physical flows) was not well addressed in prior research, our finding indicates that there is a clear positive impact of PCIS on port community operational capability.

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Proposing that the integration of internal and external information has a positive impact on port performance, and that port operational capabilities exert a positive influence on port performance. Propose a Hypothesis: Operations have a positive influence on the long-term development of Lincangban Deepwater Port.

H5. The port operation has a positive impact on ICT.

*3.6 Relationship Between Organizational Structure and ICT*

(Garcia-Morales et al., 2007) conducted a study utilizing four variables: company size, total revenue, business sectors, and number of employees. In summary, the research demonstrated the fact that ICT induces changes in corporate organizational structures. The conclusion drawn was that ICT not only affects all elements of organizational structure but also fundamentally transforms these elements. Miller suggested a relationship between the types of structures adopted by organizations and their use of ICT. It is widely believed that Information and Communication Technology can serve as an enabling mechanism for organizational design change. Existing literature commonly predicts that due to changes in information technology, organizational structures will tend to flatten.

(Spanos et al., 2002) described the flattening of managerial hierarchies and a reduction in information intermediaries. According to his viewpoint, middle-level managers' roles as information overseers will become obsolete, as ICT allows top-level managers to communicate the required information without the need for middle-level management. Decision-making processes will involve fewer organizational levels, as information communication technology facilitates easier access to information.

(Koraca, 2021) Make hypotheses and draw them ICT will have a significant impact on organizational structure. ICT will have a significant impact on firm performance. Organizational structure will have a significant impact on firm performance.

Furthermore, the relationship between organizational structure and ICT integration is discussed, drawing on (Koraca, 2021) perspective that information integration within and between organizational functions is a crucial facilitating factor for enhancing organizational competitiveness and performance. Environmental factors have a positive impact on the long-term development of (Nakchatree & Prabnasak, 2023) Lincangban Deepwater Port. The main results indicate that ICT adoption is significantly influenced by the globalization level of each country, and the country's ICT capability accessibility is affected indirectly due to its important mediating role in influencing other factors. The total sum of indirect impacts among the factors in the model is greater than the direct impact.

H6. Organizational structure has a positive impact on ICT.

*3.7 Relationship Between ICT and Smart Port Competitiveness*

Implementation of a port-centered ICT system in the port supply chain allows the port to acquire information about its service providers and customers, thereby enhancing the capabilities of information and process integration, ultimately influencing port performance (Tseng & Liao, 2015). (Zhang et al., 2016) indicated that information coordination and sharing across the entire supply chain can enhance the performance of supply chain

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partners. In manufacturing, both internal and external information system integration can optimize inventory levels and customer service, with positive impacts on cost and quality performance. (Hasnain & Pasha, 2022) emphasized the importance of information integration between intra-organizational functions and inter-organizational functions.

Previous research suggests that, under favorable conditions of information quality, customer integration has a positive impact on operational performance (Kok-Lim Alvin Yau et al., 2020) found that increasing collaboration and communication between manufacturers and supply chain partners can reduce transaction costs and enhance business performance. Combining these insights, the study posits that both internal and external information integration have a positive impact on port performance.

(Bakari Omari Bakari & Subriadi, 2020) designed a model in this study, with the Information System (IS) usage structure as the independent variable, performance as the dependent variable, and service quality dimensions (RES, OUT, PRO, MAN, ISR) as mediating variables. Using Partial Least Squares Structural Equation Modeling (PLS-SEM), the empirical model established that information systems are a crucial factor influencing the performance of container terminals. Interestingly, except for management, service quality dimensions do not directly support the performance of container terminals. The usage of information systems has a statistically significant direct impact on all dimensions of perceived service quality and terminal performance., (Jiang et al., 2023) explored how the information integration provided by the recently developed Port Community Information and Communication Technology Systems (PCIS) affects port performance. The study, conducted at Qingdao Port, the seventh-largest comprehensive port globally, employed Partial Least Squares Structural Equation Modeling (PLS-SEM) analysis. The model focused on testing the mechanisms of information integration among port community members—internal and external information integration—and their direct and indirect impacts on port performance.

H7. ICT has a positive impact on smart port competitiveness.

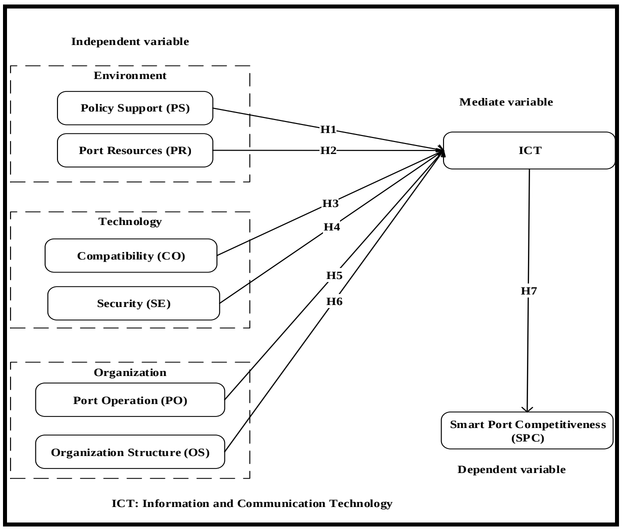


**Figure 2:** Conceptual model

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## 4. MATERIALS AND METHODS

### *4.1 Sample and Procedure*

In this study, Beibu Gulf Port stakeholders are analyzed into three groups. The first group is the key stakeholder: the owner, that is, the Beibu Gulf Port Group itself Mainly responsible for port operation management; the second group is the primary stakeholder: the user, that is, Consumers, mainly divided into cargo owners and shipping companies: The third group is secondary stakeholders: government departments, local governments, professional associations, universities, research institutions, such as Guangxi Port and Shipping Development Center, Guangxi Maritime Safety Administration, port customs, Guangxi Beibu Gulf Port Authority, China Port Association, and the Beibu Gulf University Port Research Institute.

Questionnaires were distributed and collected through the "Credamo" survey platform. Therefore, the study site is cross-regional, covering enterprises and institutions related to the smart port in the Beibu Gulf of China. Management personnel and related professionals in China's Beibu Gulf port.

Due to the complex and large number of port stakeholders, it is difficult to estimate the number of groups. As the number of observed variables increases and all pairwise correlations among variables are considered, the required sample size must be proportionally increased to ensure confidence in the computed correlations. The greater the number of observed covariances, the more estimates are required, leading to the adoption of empirical rules based on the participant-to-variable ratio—commonly suggested to be 10:1(J. S. Tanaka, 1987).

From another perspective, under the assumption of close fit in structural equation modeling (MacCallum et al., 1996), the sample sizes required to achieve acceptable power levels for models with 6, 9, and 15 variables are 294, 147, and 73, respectively. While these values generally fall within the range of typical prevention research, it must be noted that more complex models demand larger sample sizes (Lakens, 2022).In this context, the present study involves 8 latent variables and 28 observed variables, necessitating a minimum sample size of 280 to meet the established requirements.

Therefore, the sample size used in this study was 320, which met the minimum requirement of 280 sample size. In the actual research, 355 samples were retrieved for data collection. The researchers contacted the target sample population and shared the purpose of the study. After obtaining consent to participate in the survey, send the survey link via email. During the survey period from October to December 2024, 320 valid answers were retained for data analysis based on discarding incorrect or incomplete answers.

Both pilot study and formal data are collected using the online questionnaire platform "Credamo" as presented in Table 3.

**Table 3:** Descriptive statistics of demographic data

| Variable | Categories | Freque | Percentage (%) |
|---|---|---|---|
| Key stakeholder | Beibu Gulf Port Group | 105 | 32.8 |

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| Primary stakeholder (The user) | Cargo owners and logistics | 58 | 40.0 |
| | Shipping companies | 37 | |
| | Investment institutions | 14 | |
| | Technology companies. | 20 | |
| Secondary stakeholders | Government and | 31 | 27.2 |
| | Academic and research | 28 | |
| | Communities around the | 27 | |
| The total | | 320 | 100 |

Table 4 shows the demographic characteristics of the respondents. Among them, 44.1% were males. Most respondents (96.9%) were under the age of 50. Postgraduate education accounted for 23.8%, undergraduate education accounted for 66.9%, and high school or junior college education accounted for 9.4%. In total, 40.3% of respondents were managers, compared to 27.2% for low-level employees, and 32.5% for senior employees. 63.7% have more than 5 years of working life. 35.6% of the respondents had more than 15 years of work experience. Among the enterprises participating in the survey, state-owned enterprises and enterprises and public institutions accounted for 42.2%, private enterprises accounted for 45.6, and enterprises established more than 20 years (33.4%) accounted for the most, followed by enterprises established 5 to 10 years accounted for 21.6%. Small and medium-sized companies with 20 to 299 employees (40.6%) led the way, followed

by large companies with 300 to 999 employees (24.1 %).

**Table 4.** Respondents' descriptive statistics

| | | Frequency | Percenta |
|---|---|---|---|
| Gender | Male | 141 | 44.1% |
| | Female | 179 | 55.9% |
| Age | Below 30 | 120 | 37.5% |
| | 31-40 | 157 | 49.1% |
| | 41-50 | 33 | 10.3% |
| | 51-60 | 10 | 3.1% |
| Educational Background | High school and | 7 | 2.2% |
| | Diploma/College | 23 | 7.2% |
| | Bachelor | 214 | 66.9% |
| | Master | 64 | 20.0% |
| | Ph.D | 12 | 3.8% |
| Job Title/Position | Junior Staff | 87 | 27.2% |
| | Senior Staff | 104 | 32.5% |
| | Junior manager | 88 | 27.5% |
| | Senior manager | 41 | 12.8% |

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| | | | |
|---|---|---|---|
| Woking Period | Less than 5 years | 116 | 36.3% |
| | 5-10 years | 50 | 15.6% |
| | 11-15 years | 40 | 12.5% |
| | 16-20 years | 84 | 26.3% |
| | Over 20 years | 30 | 9.3% |
| Type of your organization | State-owned enterprise | 65 | 20.3% |
| | Private enterprise | 146 | 45.6% |
| | Government office | 70 | 21.9% |
| | Others | 29 | 9.1% |
| Years in Operation | Less than 5 years | 27 | 8.4% |
| | 5-10 years | 69 | 21.6% |
| | 11-15 years | 62 | 19.4% |
| | 16-20 years | 55 | 17.2% |
| | Over 20 years | 107 | 33.4% |
| Total number of employees in your organization | Less than 20 | 35 | 10.9% |
| | 20-299 | 130 | 40.6% |
| | 300-999 | 77 | 24.1% |
| | 1000-2999 | 43 | 13.4% |
| | Over 3000 | 33 | 10.3% |

*4.2. Instrument Development*

The questionnaire-based survey was divided into two sections. The first section described the respondents' demographic characteristics. The second section presented the Variable measurement items. With the assistance of experts' advice, the statements were modified to make them contextually relevant. The questionnaire was developed using a 5-point Likert scale (1 for extreme disagreement and 5 for extreme agreement). The items and their sources are shown in Table 5.

**Table 4:** The preliminary formation of Smart port questionnaire

| Factors | Tags | Question | Referenc e |
|---|---|---|---|
| Policy Support (PS) | PS1 | The government provides legal and regulatory support for the application of ICT in smart ports. | (AlBar & Hoque, 2019) |
| | PS2 | Government incentives drive the use of ICT in smart ports. | |
| | PS3 | Government managers provide strong leadership and involvement in this process. | |
| Port | PR1 | The port we are using has excellent | (Yeo et |

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| | | | |
|---|---|---|---|
| Resources (PR) | | infrastructure, such as berths, cargo yards, warehouses, distribution centers, and hinterland connectivity networks. | al., 2015) (Mugobi & Mlozi, 2020) |
| | PR2 | The equipment and facilities used in the port are intelligent. | |
| | PR3 | Container terminals always have the necessary equipment and facilities to meet customer demands. | |
| | PR4 | The port has outstanding transportation channels. | |
| Compatibility (CO) | CO1 | The ICTI is in line with our organization's working style. | Oliveira et al. (2014)(Mugobi & Mlozi, 2020) |
| | CO2 | The ICTI is entirely compatible with our current organizational operations. | |
| | CO3 | The use of ICTI is compatible with our organization's corporate culture and value system. | |
| | CO4 | ICTI will be compatible with the existing hardware and software in our organization. | |
| Security (SE) | SE1 | There are adequate security measures in the port. | Onwuegbuchunam et al., 2021) |
| | SE2 | The port/terminal complies with the International Ship and Port Facility Security (ISPS) Code. | |
| | SE3 | Measures have been taken to ensure compliance with the ISPS Code. | |
| | SE4 | Security measures in the port contribute to improving port performance. | |
| | SE5 | Issues related to port security incidents, including information leakage, cargo theft/pilferage, stowaways, armed robbery, attacks on port vessels, and smuggling. | |
| Port Operation (PO) | PO1 | The operational aspect of a smart port focuses on the efficient flow of goods and personnel through the port. This includes cargo handling, vessel traffic management, | (Nakchatree & Prabnasak, 2023) |

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| | | | |
|---|---|---|---|
| | | and multimodal transportation. | (Wang et al., 2016) (Farhanghi et al., 2012), |
| | PO2 | The environmental aspect of a smart port emphasizes minimizing the port's impact on the environment. This includes reducing carbon emissions, noise pollution, and waste generation. | |
| | PO3 | Smart ports utilize advanced technologies such as sensors, video surveillance, and drones to enhance safety and security measures. | |
| Organizational Structure (OS) | OS1 | Compared to relevant industries, our organization's overall capital is high. | |
| | OS2 | Compared to relevant industries, our organization's overall revenue is high. | |
| | OS3 | Compared to relevant industries, our organization has a high number of employees. | |
| | OS4 | Information and communication technology will have a significant impact on the organizational structure. | |
| ICT | ICT1 | We have a strong intention to integrate ICT technology into our organization. | (Woo et al., 2013) and (AlBar & Hoque, 2019) (Mugobi & Mlozi, 2020) |
| | ICT2 | We intend to understand how to integrate ICT technology into our organization. | |
| | ICT3 | We plan to integrate ICT technology into operational management. | |
| | ICT4 | The ICTI in our organization enhances efficiency. | |
| | ICT5 | The ICTI in our organization leads to an improvement in quality. | |
| | | | |
| | ICT6 | The ICTI in our organization can enhance productivity. | |
| Smart Port Competitiveness (SPC) | SPC1 | Compared with the port competitors I am familiar with the degree of intelligence of the products or services of my company is | (Li et al., 2022; Liu & Jiang, |

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| | | | |
|---|---|---|---|
| | | significantly different from that of my familiar competitors. | 2016) |
| | SPC2 | Compared with the port competitors I am familiar with my company's products or services have unique selling points | |
| | SPC3 | The products or services operated by our port enterprises have obvious local characteristics. | |

### *4.3 Content validity*

The questionnaires used in this research were to check inter-reliability by index of concordance = IOC. To verify the connection between the questions and the research objectives. Also, the consistency between each question and each of the research purposes must be evaluated (Tuntavanitch, 2018). Experts conducted a criterion-based evaluation by scoring +1,0 or -1. When +1 indicates that the question is compatible with the objective, 0 indicates that the question is unclear, and -1 indicates that the question is not associated with the objective, (Srisatidnarakul, 2012), Items with scores greater than or equal to 0.5 were deemed appropriate; those with scores less than 0.5 were deemed unacceptable and had to be updated based on expert recommendations. The questions that choose to use should have a value ranging from 0.50 (IOC≥ 0.50), Srisatidnarakul (2012)

In this study, five experts from different educational institutions and port-related enterprises testified to the questionnaire IOC. Guang Dong University of Finance and Economics, Guangzhou, Guangdong, China. Guangxi University of Finance and Economics, Nanning, Guangxi, China. Qinzhou Port Sheng Port Terminal Co., LTD. Zhong Gu Logistics Flow Guangxi Fangcheng port office. Guangxi Guiwu Intelligent Technology Co., Ltd.

All experts critically gave valuable feedback on some of the questions and the summary of the score evaluation is attached to Appendix F. All items were rated higher than 0.50 on the IOC index, indicating they were acceptably congruent with objective set.

## 5. RESULTS

### *5.1 Measurement Model*

This study evaluated construct reliability through standardized loading and CA and evaluated construct reliability through convergence validity and discriminant validity. The reliability of the construction is estimated by standardized load. Load estimates must be greater than 0.6 The results show that the load estimates of all projects exceed the acceptable values(Hair et al., 2012). In addition, CA is used to test the internal consistency of the structure, where CA values are appropriate (greater than 0.7) (see Table 6). In addition, composite reliability (CR) and mean variance extraction (AVE) are used to measure the convergence of the structure. The recommended values for CR and AVE are 0.7 and 0.5, respectively (Black & Babin, 2019). As shown in Table 5, both CR and AVE values exceed the threshold, indicating convergence of effectiveness.

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**Table 5:** Reliability of constructions and their measuring items

| Variables | Std.Loading | Unstd. | S.E. | t-value | P | SMC | 1-SMC | CR | AVE |
|---|---|---|---|---|---|---|---|---|---|
| PS1 | 0.924 | 1 | | | | 0.854 | 0.146 | 0.969 | 0.912 |
| PS2 | 0.977 | 1.144 | 0.031 | 37.146 | *** | 0.955 | 0.045 | | |
| PS3 | 0.963 | 1.108 | 0.032 | 35.144 | *** | 0.927 | 0.073 | | |
| PR1 | 0.87 | 1 | | | | 0.757 | 0.243 | 0.939 | 0.795 |
| PR2 | 0.888 | 1.097 | 0.049 | 22.345 | *** | 0.789 | 0.211 | | |
| PR3 | 0.914 | 1.217 | 0.051 | 23.735 | *** | 0.835 | 0.165 | | |
| PR4 | 0.894 | 1.127 | 0.05 | 22.644 | *** | 0.799 | 0.201 | | |
| ICT1 | 0.917 | 1 | | | | 0.841 | 0.159 | 0.954 | 0.874 |
| ICT2 | 0.922 | 1.005 | 0.035 | 28.834 | *** | 0.850 | 0.150 | | |
| ICT3 | 0.965 | 1.047 | 0.031 | 33.621 | *** | 0.931 | 0.069 | | |
| SPC1 | 0.936 | 1 | | | | 0.876 | 0.124 | 0.967 | 0.908 |
| SPC2 | 0.967 | 1.096 | 0.029 | 37.525 | *** | 0.935 | 0.065 | | |
| SPC3 | 0.956 | 1.062 | 0.03 | 35.769 | *** | 0.914 | 0.086 | | |
| CO1 | 0.906 | 1 | | | | 0.821 | 0.179 | 0.945 | 0.81 |
| CO2 | 0.869 | 1.063 | 0.045 | 23.468 | *** | 0.755 | 0.245 | | |
| CO3 | 0.885 | 0.915 | 0.037 | 24.582 | *** | 0.783 | 0.217 | | |
| CO4 | 0.939 | 0.982 | 0.034 | 28.808 | *** | 0.882 | 0.118 | | |
| SE1 | 0.859 | 1 | | | | 0.738 | 0.262 | 0.907 | 0.71 |
| SE2 | 0.813 | 0.821 | 0.045 | 18.165 | *** | 0.661 | 0.339 | | |
| SE3 | 0.842 | 0.845 | 0.044 | 19.307 | *** | 0.709 | 0.291 | | |

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| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SE4 | 0.855 | 0.863 | 0.044 | 19.806 | *** | 0.731 | 0.269 | | |
| PO1 | 0.924 | 1 | | | | 0.854 | 0.146 | | |
| PO2 | 0.960 | 1.023 | 0.03 | 33.797 | *** | 0.922 | 0.078 | 0.96 | 0.888 |
| PO3 | 0.942 | 0.977 | 0.031 | 31.647 | *** | 0.887 | 0.113 | | |
| OS1 | 0.864 | 1 | | | | 0.746 | 0.254 | | |
| OS2 | 0.922 | 1.334 | 0.056 | 23.84 | *** | 0.850 | 0.150 | 0.941 | 0.799 |
| OS3 | 0.903 | 1.182 | 0.052 | 22.802 | *** | 0.815 | 0.185 | | |
| OS4 | 0.886 | 1.019 | 0.046 | 21.948 | *** | 0.785 | 0.215 | | |

Next, the discriminant validity was measured by considering the square root of AVE and the correlation between structures(Bagozzi & Yi, 2012) . The results confirm significant discriminative validity, as the square root of AVE is higher than the inter-structural correlation (As shown in Table 7).

**Table 6: Discriminate validity**

| Variable | AVE | OS | PO | SE | CO | PR | PS | ICT | SPC |
|---|---|---|---|---|---|---|---|---|---|
| OS | 0.799 | **0.894** | | | | | | | |
| PO | 0.888 | 0.703 | **0.942** | | | | | | |
| SE | 0.710 | 0.77 | 0.809 | **0.843** | | | | | |
| CO | 0.810 | 0.844 | 0.725 | 0.793 | **0.900** | | | | |
| PR | 0.795 | 0.758 | 0.694 | 0.758 | 0.852 | **0.892** | | | |
| PS | 0.912 | 0.754 | 0.804 | 0.823 | 0.768 | 0.75 | **0.955** | | |
| ICT | 0.874 | 0.773 | 0.811 | 0.833 | 0.788 | 0.774 | 0.864 | **0.935** | |
| SPC | 0.908 | 0.617 | 0.647 | 0.665 | 0.629 | 0.618 | 0.69 | 0.798 | **0.953** |

*5.2 Model Fitness*

The model fitness was measured by CMIN/df (ratio of the minimum difference and the degree of freedom), CFI (comparative fitting index), TLI (Tucker Lewis index), NFI (normalized fitting index), IFI (incremental fitting index), RFI (relative fitting index) and RMSEA (approximate root-mean-square error). (Hair et al., 2012) proposed that CMIN/df and RMSEA must be less than 3 and 0.08 respectively, while CFI, TLI, NFI, IFI and RFI must be greater than 0.9. The results show that all indexes are satisfactory (As shown in Table 8), indicating that the model has a good fit.

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**Table 7:** Model's fitness

| Indices | Recommended Criteria | Default Model |
|---|---|---|
| CMIN/df | 1-3 Excellent. 3-5 Good | 1.725 |
| CFI | ≥0.9 Excellent.>0.8 Good | 0.961 |
| TLI | ≥0.9 Excellent.>0.8 Good | 0.955 |
| IFI | ≥0.9 Excellent.>0.8 Good | 0.961 |
| NFI | ≥0.9 Excellent.>0.8 Good | 0.935 |
| RFI | ≥0.9 Excellent.>0.8 Good | 0.925 |
| RMSEA | <0.05 Excellent. <0.08 Good | 0.067 |

*5.3 Structural Model*

Among the seven hypotheses proposed in the theoretical model, two hypotheses (H3 and H6) were not supported (as shown in Table 9 and Figure 3). Based on the theoretical model constructed earlier, research hypotheses were formulated and subsequently tested using sample data. The specific findings of the hypothesis testing are presented in Table 5. Five hypothesis paths were supported, while two hypothesis paths were not validated. The detailed results are as follows:

**Table 8:** Path hypothesis testing

| Hypothesis | Variables | | | Estimate | S.E. | C.R. | p-Value | Finding |
|---|---|---|---|---|---|---|---|---|
| H1 | ICT | <--- | PS | 0.413 | 0.066 | 6.209 | *** | Supported |
| H2 | ICT | <--- | PR | 0.131 | 0.064 | 2.038 | * | Supported |
| H3 | ICT | <--- | CO | 0.029 | 0.067 | 0.426 | .670 | Unsupported |
| H4 | ICT | <--- | SE | 0.144 | 0.059 | 2.429 | * | Supported |
| H5 | ICT | <--- | PO | 0.195 | 0.058 | 3.367 | *** | Supported |
| H6 | ICT | <--- | OS | 0.096 | 0.056 | 1.714 | .087 | Unsupported |
| H7 | SPC | <--- | ICT | 0.865 | 0.047 | 18.274 | *** | Supported |

Note: *** p-value < 0.001, ** p-value < 0.01, * p-value < 0.05, n/s not significant.

In the environmental context, policy support ($\beta = 0.413$, $p < 0.001$) and port resources ($\beta = 0.131$, $p < 0.05$) have a positive impact on ICT integration, thereby supporting H1 and H2.

In the technological context, security ($\beta = 0.144$, $p < 0.05$) positively influences ICT integration in smart ports, thus supporting H4. However, compatibility ($\beta = 0.029$, $p > 0.05$) does not significantly contribute to ICT integration in smart ports, and thus, H3 is not supported.

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In the organizational context, port operations (β = 0.195, p < 0.001) positively influence ICT integration in smart ports, while organizational structure (β = 0.096, p > 0.05) has no significant effect. Therefore, H6 is not supported.

Finally, the results indicate that ICT integration (β = 0.865, p < 0.001) positively impacts the competitiveness of smart ports, thereby supporting H7.

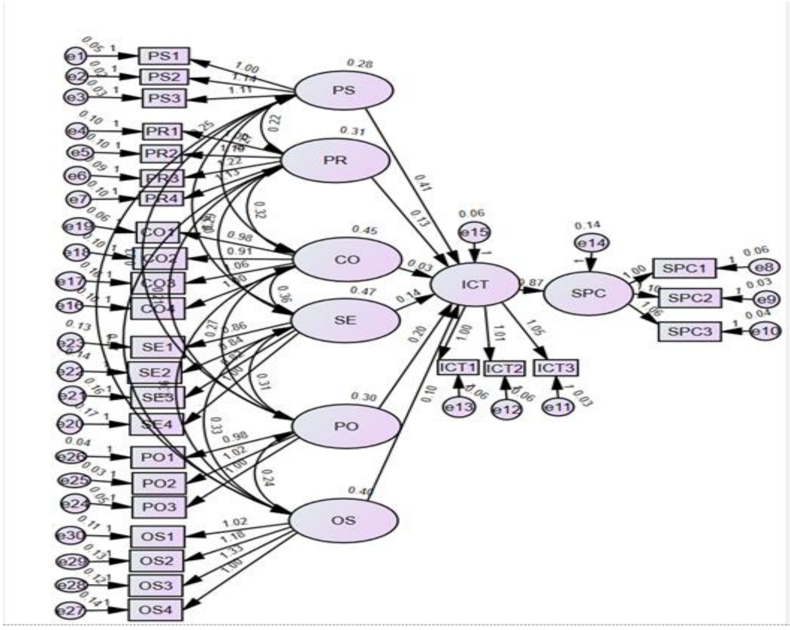


**Figure 3:** Path coefficient for the structural model

## 6. Discussion and Research Implications

Based on the T-O-E framework, this study uncovers evidence on how six influencing factors support the integration of ICT in the context of digital transformation in smart ports. Additionally, it verifies the positive impact of ICT integration on the competitiveness of smart ports.

### *6.1 Discussion on the Environmental Dimension*

Firstly, environmental factors determine the opportunities for ICT integration, including policy support and port resources. The study reveals that policy support exerts a positive influence on ICT integration, aligning with earlier research. For instance, (Cepolina & Ghiara, 2013) highlighted that ports in different countries have varying tools and capabilities to face global competition, emphasizing that shared support tools in port authority strategies can be identified as ICT infrastructure. Development strategies and policy support from port authorities can significantly promote ICT infrastructure development. This indicates that policy support serves as a strong driving force for ICT integration. Over the past decade, the Chinese government has demonstrated a keen interest in fostering the development of port information systems and technologies to facilitate trade and transportation. When enterprises perceive policy support as a mechanism for creating a favorable environment for ICT integration and upgrading port intelligence in digital transformation, they are more inclined to integrate ICT into their business processes. Among the environmental factors, policy support stands out as the most significant predictor.

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As articulated in the study by (Vairetti et al., 2019), port ICT integration is closely linked to policy support, encompassing political will, leadership, and institutional frameworks. However, political will alone is insufficient to drive the technological development of ports. Instead, institutional leadership is essential for fostering commitment and reinforcing the process of managerial transformation. The implementation of ICT integration strategies in ports is influenced by the leadership of institutions, as leadership and strategy advance in tandem. A close relationship exists between policy support and ICT integration, indicating that government encouragement plays a critical role in advancing ICT integration within enterprises. This aligns with recent studies (Lee & Shen, 2020; Petry, 2023), which confirm that government support; through the formulation of policies, and financial and non-financial assistance, is necessary, thereby strengthening enterprise decision-making in promoting ICT integration.

Secondly, port resources also have a positive impact on ICT integration. Scholars ((Nakchatree & Prabnasak, 2023) have identified the port resource environment as a critical factor in the development of smart ports. Specifically, four factors, environment, security, and energy—are recognized as key success factors for achieving port intelligence.

Moreover, the integration of port resources such as coastlines, terminals, yards, and waterways facilitate the consolidation of shipping, trade, and information-related elements. It also promotes the integration of key hub facilities, including distribution and transshipment centers as well as logistics and storage stations, thereby fostering the development of river-sea and river-land intermodal transport. If port resource integration is perceived as a driver for enhancing port competitiveness, enterprises are more likely to strengthen the integration of ICT in smart ports (Jianchao Ke & Siyu Pan, 2021).

In conclusion, the analysis further demonstrates that government policies and various port resources, such as geographical location and infrastructure, significantly influence the leading organizations in ports regarding ICT integration (Coronado Mondragon et al., 2017). This study identifies policy support and port resources within the environmental dimension as critical factors influencing the integration of ICT in smart ports, both exerting a positive impact.

### *6.2 Discussion on the Technological Dimension*

Firstly, among the technological factors, security is the strongest factor influencing ICT integration in smart ports, followed by compatibility. Intelligent security services ensure the availability, confidentiality, integrity, and traceability of data, information, and systems in the presence of malicious entities, thereby optimizing the security of smart ports, enhancing ICT performance, and safeguarding network and data security. Additionally, automated smart port infrastructure and advanced shipping technologies may introduce new cybersecurity risks within the smart port ecosystem. It is widely recognized that integrating critical cyber-physical systems with digital technologies in cyberspace poses significant risks, as the complexity of automated systems demands more stringent security measures (Atif et al., 2019; Haykin, 2019).

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Secondly, during the transformation from traditional ports to smart ports, ICT integration must particularly focus on compatibility. However, it has been verified that the relationship between compatibility and ICT integration does not seem to be supported. This aligns with the findings of Roberts and Wilson who suggested that mechanical tasks or "routine elements" can be greatly supported using ICT, while activities requiring human cognitive processes, interpretation, creativity, and reflection are the most challenging to align with ICT. The research process of ICT also represents a constraint, rather than just an opportunity(Roberts & Wilson, n.d.). (Karahanna et al., 2006) decomposed the concept of compatibility into four distinct and separable constructs: compatibility with preferred ways of working, compatibility with existing work practices, compatibility with prior experiences, and compatibility with values. The developed compatibility measures exhibit acceptable psychometric properties, supporting the existence of these four different constructs.

Therefore, from a technological perspective, security is a key factor in the integration of communication technologies in smart ports, as compatibility is influenced by multiple dimensions such as device compatibility, operational compatibility, and compatibility with values. Achieving simultaneous compatibility across all these dimensions is challenging for the integration of communication technologies in smart ports. As a result, this paper concludes that the positive impact of compatibility on ICT integration is not significant.

### *6.3 Discussion on the Organizational Dimension*

Firstly, preliminary research on organizational factors confirms the effectiveness of port operations in guiding ICT integration. However, few studies have analyzed ICT integration from the perspective of port operations. This paper examines three dimensions: the operational aspect of smart ports, which emphasizes the efficient flow of goods through the port; the environmental aspect, which focuses on minimizing the port's environmental impact; and the security aspect, which highlights the use of advanced technologies such as sensors, video surveillance, and drones to enhance safety measures. The analysis demonstrates a significant relationship between port operations and ICT integration. Regarding the flow of goods, cargo management entails data exchange to optimize the utilization of vessels and port facilities (e.g., terminals and yards). As complexity grows exponentially—from a single destination for bulk cargo on a specialized ship to thousands of containers with thousands of origins and destinations per vessel—traditional management methods are unable to address the challenges posed by these volumes. This results in low utilization rates of available vessels and port facilities, such as terminals and yards. Additionally, the reliance on outdated paper-based solutions for information/documents related to authorization processes represents a significant constraint at higher levels. In the context of financial transactions, containers are subject to the complexities of cross-border financial dealings, including differing banking regulations and the risks associated with payment release processes.

Therefore, the practical challenges in port operations can be effectively addressed through the potential offered by ICT. By integrating communication processes and enabling the sharing of information and documents among decision-makers, collaboration becomes feasible.

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Addressing administrative and financial issues in port operations often proves more time-consuming than the actual movement of goods(Chandra & Van Hillegersberg, 2022; Russo & Musolino, 2021). The physical flow, information flow, and financial flow in port collaboration are interdependent, posing numerous coordination challenges for the parties involved. Emerging ICT technologies play a decisive role in reducing the time associated with administrative and financial tasks, enabling decision-makers from various interactions to share information and optimize solutions to these challenges.

This study also observed organizational structure through dimensions such as organizational size, revenue, service quality, and organizational culture. The findings indicate that the hypothesis of a positive influence of organizational structure on ICT integration is not supported. This also confirms that traditional organizational structures are not conducive to cross-departmental knowledge sharing and transformation. Conventional organizational frameworks should reduce hierarchical layers and eliminate departmental silos to facilitate communication and collaboration among employees(Lai, 2013). When the decision-making process is concentrated at the top levels, the organization is centralized. When managers oversee many employees, the hierarchical structure tends to flatten. In highly specialized organizations, employees perform only a small subset of activities and tasks specified in their job descriptions. Additionally, organizational culture can be described as a shared set of values, beliefs, understandings, and norms among employees. However, some scholars, such as (Spanos et al., 2002) have identified a relationship between the type of organizational structure and its use of ICT. It is widely recognized that ICT can serve as an enabling mechanism for organizational design changes. Existing literature generally predicts that organizational charts will become increasingly flat due to changes brought about by information technology. For example, Farhanghi described the flattening of management hierarchies, arguing that the role of middle management as information supervisors will become obsolete, as ICT enables senior management to directly communicate the necessary information without intermediary layers (Farhanghi et al., 2012). This suggests that decision-making processes will involve fewer organizational layers. However, these predictions do not align with the empirical findings of this study.

In analyzing the reasons, this paper hypothesizes that most Chinese ports are state-owned enterprises characterized by a unique centralization in their organizational structure. Significant informational silos exist between ports, which pose barriers to ICT integration.

### *6.4 Discussion on the Impact of ICT Integration on the Competitiveness of Smart Ports*

The findings reveal that policy support, port resources, security, and port operations significantly enhance ICT integration, boosting smart port competitiveness. This aligns with prior studies (Bakari Omari Bakari & Subriadi, 2020; Fangyang, 2018; Jiang et al., 2023; Mugobi & Mlozi, 2020; Onwuegbuchunam et al., 2021) that identify these factors as key enablers. However, the hypothesized positive impact of compatibility and organizational size on ICT integration was not supported. This aligns with Roberts and Wilson, who noted ICT's effectiveness in routine tasks but challenges in aligning with activities requiring human cognition, creativity, and reflection. Compatibility also involves integrating work experience and values, which can be complex, as highlighted by(Farhanghi et al., 2012; Karahanna et al., 2006). The impact of organizational structure on ICT integration was also found to be

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insignificant. While previous studies(Ishahak, 2020; Koraca, 2021; Nakchatree & Prabnasak, 2023) noted its role in port efficiency, this influence is likely constrained by regional and managerial differences. For instance, the centralized management of China's Beibu Gulf Port by the Beibu Gulf Port Group reflects structural uniqueness that may limit ICT integration. In summary, while factors like policy support, port resources, and security strongly drive ICT integration, the influence of compatibility and organizational structure is limited. These findings underscore the complexity of technological and managerial contexts in smart ports, suggesting directions for further research.

On the other hand, ICT integration has significantly enhanced the competitiveness of smart ports. The findings reveal that ICT integration significantly stimulates the competitiveness of smart ports. Traditionally, geographic location, infrastructure, and services have been the primary pillars supporting a port's ability to compete and collaborate with other ports. In recent years, a new pillar has emerged: ICT, which has become a key driver of port competitiveness.

In the past, port managers focused on adopting modernized equipment to enhance competitiveness due to the lack of differentiation among ports. However, equipment-based competitive advantages are easily imitated and difficult to sustain. Unlike equipment, knowledge is not as easily replicable. Consequently, knowledge-based competitive advantages are more likely to achieve sustainability compared to equipment-based advantages (Lai, 2013).

Furthermore, an analysis of global port systems and efficiency changes indicates that improvements in global port efficiency primarily stem from three sources: advancements in container terminal management and operations (TEC), adjustments in scale efficiency (SEC), and technological progress (TP) (Cheon et al., 2010). These findings further validate the critical influence of ICT and its integration, demonstrating that ICT integration plays a significant role in enhancing the competitiveness of smart ports.

## 7. CONCLUSIONS AND PROMISING SCOPE

This study examined the relationship between ICT integration and the competitiveness of smart ports within the context of the T-O-E framework. The contribution of this paper lies in analyzing the technological, organizational, and environmental dimensions that facilitate or hinder ICT integration. Grounded in the robust theoretical and psychometric foundation of the T-O-E framework, this study introduces novel constructs such as resource-oriented and technology-oriented perspectives into the research model. The proposed model investigates the positive impact of external factors like policy support and port resources on ICT integration, emphasizes security considerations in the technological dimension, and highlights the continuous improvement of port operations within the organizational dimension. These factors are identified as key drivers of ICT integration in smart ports and intrinsic motivators for enhancing their competitiveness.

Like other studies, this work has certain limitations. First, the direct impact of key factors on the competitiveness of smart ports, as well as the mediating effect of ICT on these key factors, has not yet been thoroughly studied. In order to improve the generality of the results, it is suggested that future research should

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explore multiple directions. Second, to extend this research, future studies could extend the analysis of both internal and external ICT integration, which would better explain ICT integration or incorporation into other models, such as TAM, DOI, or UTAUT. Third, while this study strives to provide a holistic understanding within the context of smart port enterprises, future research could focus on specific sectors. In this regard, promising avenues for research remain open.

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