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Key factors for the success of smart ports during the post-pandemic era

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ABSTRACT

In view of the complexity of maritime transport and the lack of a unified indicator system to evaluate smart ports, this study analyzed the basic characteristics and service quality of smart ports in the post-pandemic era using the SERVQUAL service quality scale. This study further developed an expert questionnaire based on 25 evaluation indicators and evaluated the key indicators of smart port service quality and their causal relationships using the analytic hierarchy process (AHP) and decision making and trial evaluation laboratory (DEMATEL). The results of this study showed that the key smart port success factors are: (1) accurate and secure delivery of cargo; (2) accurate electronic document transfer; (3) rapid provision of port berths to shorten the turnover time of ships; (4) convenient and comprehensive logistics and customs procedures; (5) transparent information integration on a single platform; and (6) use of big data to arrange container transport. Causal relationships were found among the indicators, including the fact that "convenient and comprehensive logistics and customs procedures" was influenced by "accurate electronic document transfer," "transparent information integration on a single platform," and "use of big data to arrange container transport." The results of this study can help port operators and government agencies identify key success factors for smart ports. This will enable participants in the supply chain to take early measures to respond to the impact of emergencies in the post-pandemic era, thus improving port operations and customer satisfaction. This research provides a standard model of smart port service quality that can serve as a reference for building a competitive advantage and making sustainable management decisions.

1. Introduction

The outbreak of COVID-19 in 2020 has greatly affected global trade and economies everywhere by disrupting supply chains and leading to higher freight transportation costs. The global economic recovery is therefore facing new challenges. In the post-pandemic era, economic recovery is putting pressure on global supply chains by increasing the need for maritime traffic. While the continued growth of global trade in 2021 reflected strong market demand (Xu et al., 2021a), the continued quick growth in cargo volume has resulted in the stacking of containers at ports while carriers lack needed containers. An era of high shipping rates is thus approaching.

In the face of various changes and impacts, ports are finding it necessary to start the transformation to smart ports, and efficiency, reliability, and assurance are important indicators for the success of any port transformation. Switching from a conventional port to a smart port can improve efficiency and reliability, and is an ongoing trend (Jun et al., 2018). Smart ports are ports that apply emerging technologies such as the Internet of Things, big data, and cloud computing to port operations and management, thereby allowing the ports to fully automate and efficiently complete the loading and unloading of cargo and directing ships to and from the port (Ferretti and Schiavone, 2016). The 21st century has seen an ongoing trend toward greater automation of port cargo management. All these developments promise to transform the conventional transport industry into a high-tech service industry. When the Internet of Things is applied to the logistics field, including cargo transportation and warehousing management, costs are reduced and sales improve. It is expected that such technologies will generate USD1.9 trillion in economic value in the logistics and supply chain by 2025 (Macaulay et al., 2015).

High-quality maritime logistics services depend on port efficiency, which can be improved through cost controls and effective and sustainable operation and organization, and environmental protection is also an important consideration. High-quality maritime logistics should additionally consider reducing energy consumption to ensure services are safe and energy efficient (Amin et al., 2021). Because of the novelty

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of the smart port concept, many scholars are very interested in smart ports' potential, and are actively studying this concept. Since current research findings are still at a preliminary stage, however, this study organized and summarized some of the more innovative research on smart ports in Table 1.

In a post-pandemic era shaped by intense competition and uncertainty, it is crucial that port operators and relevant government agencies identify key success factors that will enable them to improve the quality and competitiveness of port services. The results of research on smart ports can therefore be used to guide sustainable management decisions and the enhancement of ports' competitive advantage. However, most existing studies have discussed smart ports from a technical perspective, and very few studies have taken a social science viewpoint (Smith, 2002). In light of the complexity of maritime transport, and the lack of a unified standards and evaluation indicators for assessing port service quality, this study sought to clarify the measurement of smart port service quality, establish a system of service quality indicators, and thereby provide guidance for the understanding and promotion of the smart port concept.

Saaty's the analytic hierarchy process (AHP) method (1980) can be used to gather the majority consensus views of experts and decision-makers, establish a hierarchical structure, and thus analyze the interactive relationships between the key factors determining smart port service quality. This method can further assess the relative importance of different service quality items using specific weight values. This study therefore used the AHP method to assess and analyze key determinants of smart port service quality. For its part, the decision making and trial evaluation laboratory (DEMATEL) technique can be used to establish and analyze the AHP hierarchical structure, and is an effective modeling method. Furthermore, this technique is often used to deal with multiple criteria assessment problems involving the mutual dependence of different criteria. Through the use of the DEMATEL technique, we can easily quantify the relationships of multiple criteria involved in complex questions, find the relations between key factors in a structural model, and thereby determine the causal relationships between these factors. This study used the AHP method in conjunction with a service quality scale (SERVQUAL) and the DEMATEL technique to assess the key indicators of smart port service quality in the post-pandemic era and determine their causal relationships.

To answer the questions arising from the research motives above, this article focused on the key factors in the service quality of smart ports and explored which determinants could enhance the competitiveness of smart ports. In this study, a systematic and hierarchical structure was used to organize 25 appropriate evaluation indicators and produce an expert questionnaire. Since there might be correlations among various important key factors, this study used DEMATEL to determine the existence of causal relationships among the key factors (Ding et al., 2019).

2. Literature reviews

2.1. Application of the AHP and DEMATEL methods to shipping and related fields

Because many criteria may influence service quality at a smart port, and these criteria may comprise key evaluation standards that can be used in decision-making concerning the smart port, how decision-makers can determine the criteria needed to assess smart port service quality is an important issue. The AHP method is extremely commonly applied to multi-criteria decision making (MCDM) problems at present, including assessment problems in such areas as sustainability, Internet of Things, e-commerce, supplier selection, international logistics, and risk factors (Ding et al., 2022). In particular, the AHP method has been used countless times in journal articles concerning the field of port management. Yeo and Song (2003) used the AHP method to assess the competitiveness of 10 ports in China and South Korea, and selected competitiveness indicators including freight traffic volume, port facilities, port location, and service standards. Ugboma et al. (2006) determined that port efficiency was the most important factors influencing shippers' port selection decisions using the AHP method. Yang et al. (2014) used the Delphi method to select 4 assessment aspects and 17 key factors, and then used the AHP method to determine the importance of various factors influencing container carriers' use of coastal shipping. Shin et al. (2018) investigated what the shipping and port logistics industry believes are necessary strategies for coping with development trends under the Fourth Industrial Revolution, and then used the AHP method to compare the importance of different strategies during four

Table 1
Research innovations in published articles.

Authors Innovative aspect	A	B	C	D	E	F	G	H	I	J	K	L	M
Green port			✓	✓			✓				✓		✓
Data security	✓	✓		✓				✓					
Information sharing	✓		✓	✓	✓			✓					
Organizational structure	✓		✓				✓	✓	✓	✓		✓	✓
Process planning			✓		✓	✓	✓	✓	✓		✓	✓	
Organizational strategy		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Management efficiency	✓			✓					✓	✓	✓	✓	✓
Automation		✓		✓	✓	✓				✓	✓	✓	✓
Big data	✓	✓	✓	✓	✓	✓			✓	✓		✓	✓
Natural environment			✓			✓	✓		✓		✓		✓
Timeliness				✓	✓					✓		✓	
Obstacles to port development					✓		✓	✓		✓	✓		
Crisis management						✓				✓	✓		
Effective information and communications	✓			✓								✓	
Team coordination		✓	✓	✓	✓			✓	✓				✓
Supply chains		✓		✓	✓	✓	✓				✓		
Theoretical support					✓		✓		✓			✓	✓
Employee qualifications	✓		✓					✓					
Digitization	✓	✓		✓	✓	✓				✓		✓	✓
Sustainable development			✓				✓				✓	✓	
Technology development	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓
Security monitoring	✓			✓	✓	✓				✓		✓	

A: Heilig and Voβ (2016); B: Shin et al. (2018); C: Chen et al. (2019).
D: Zhou et al. (2020)ʹ E. Sun (2021); F: Rodrigo González et al. (2020)
G: Yang et al. (2020); H: Jia and & Cui (2021); I: Guo et al. (2021).
J: Xiao et al. (2021); K: Alkheder et al. (2022); L: Min (2022); M: Yen et al. (2022).

stages. Zhou et al. (2020) used the AHP method to found 6 key factors enabling successful blockchain implementation in the maritime transport industry. Alkheder et al. (2022) used the AHP method to select from among three logistics areas suitable for establishment of a smart port under the Kuwait Ports Authority, and assess the various proposals. Yen et al. (2022) first made use of the DEA method to assess ports' operating performance; the study then determined that the three aspects of a smart port, and thereby shed light on how smart port aspects can affect operating performance.

Literature concerning the application of the DEMATEL technique to port management includes the use of DEMATEL by Duran et al. (2018) to identify causal relationships between port management technologies and risks, which yielded decision-making assessment criteria for port managers. Venkatesh et al. (2020) investigating obstacles to the integration of supply chains centered on ports from the perspective of emerging economies and various stakeholders, and determined whether obstacles would have a major impact. In using DEMATEL to evaluate the causal relationships between attributes, Yang et al. (2020) investigated the relationships between levels, established a multi-level structural model, and discussed the development of smart ports from the perspective of sustainability. Jia and Cui (2021) integrated grey system theory with DEMATEL in an investigation of the causal relationships between the obstacles encountered during the development of smart ports in China.

In summary, because of its advantages of ease of use, simple evaluation, practicality, and the ability to obtain the views of multiple experts and decision-makers, the AHP method can be used to simplify complex decision-making problems via use of a hierarchical structure. Continuous application and revision has served to refine and perfect AHP theory. Apart from AHP, this study also used DEMATEL to determine whether causal relationships existed between criteria, and to shed light on the complex interactions among different criteria.

2.2. Factors affecting the service quality of smart ports

This is a service quality-oriented era, and good service quality should not only include optimal product results, but also the best way to provide a service (Sasser et al., 1978). Parasuraman et al. (1985) defined service quality as "an attitude and the difference between consumers' expected services (ES) and their perceived services (PS)." Parasuraman et al. conducted a consumer behavior survey and proposed 10 factors determining service quality, namely tangibles, reliability, responsiveness, communication, credibility, safety, competence, courtesy, understanding customers, and accessibility, as the dimensions of the PZB (Parasuraman, Zeithaml, & Berry) model. After performing factor analysis of the results for five service industries, the researchers proposed five service quality dimensions, namely (1) tangibles, (2) reliability, (3) responsiveness, (4) assurance, and (5) empathy. The PZB model identifies the chief dimensions of service quality, proposes a scale for measuring service quality, and suggests possible causes of service quality problems. The well-known SERVQUAL service quality scale measures the five foregoing aspects of service quality.

The establishment and development of a smart port seeks to achieve the goal of intelligent, environmentally-friendly operations in their operation and management (Chen et al., 2019). Smart ports represent flexible, reconfigurable, responsive, and environmentally friendly port systems. In the West, the Port of Rotterdam and Port of Hamburg have all drafted smart port development plans in light of the potential benefits of this trend (Min, 2022). After smart port technologies improved traffic and cargo flow at the Port of Hamburg (Heilig et al., 2017), Germany initiated the 2021 Smart Port Logistics Plan for the Port of Hamburg, which included a conversion system and plans for ships and trucks. The Port of Rotterdam in the Netherlands opened its first automated terminal in 1993, which formed the kernel of a smart port. In 2015, Rotterdam maintained its leadership of the smart port industry by establishing an APM terminal (Port of Rotterdam official website, 2022). Many of the chief ports in Asia are developing fifth generation ports, which emphasize a port's production and services comply with environmental requirements and employ innovative, smart technologies (Chen et al., 2019). In China, there are many smart port promotion projects. In 2017, Guangzhou's Port of Mawan initiated a smart port plan, which involved the automation of conventional wharves, and began a 5G upgrading project. In 2018, the Port of Zhoushan in Ningbo successfully to enable the transmission of video and the remote operation and management of gantry cranes. This project has improved loading and unloading performance by 20%, cut personnel costs by more than one-half, and successfully demonstrated the use of 5G at a port in China for the first time (Sun, 2021). China's future port administration goal is to upgrade ports to smart ports, and the ports of Tianjin, Qingdao, and Yangshan in Shanghai have accelerated their smart port development plans. China is aware that the smart port concept can be applied even more broadly to the entire logistics sector through digitization and automation, which can achieve a high level of safe, unmanned operations (Shen, 2019).

Service quality is an important issue for operators who wish to maintain good relationships with customers and continue to develop their market. To maintain a competitive edge in today's fast-changing and competitive environment, it is important to identify an industry's key success factors. Every industry has its own characteristics, and the shipping industry is no exception. The factors that determine the success of a business vary depending on the business environment, specific operating attributes, strategic attributes, and the key competitive assets that are critical to the performance of the industry. When execution is effective in these areas, this can lead to successful competitive performance, enabling the organization to gain a sustainable competitive advantage (Aaker and Mascarenhas, 1984). This study has consequently adopted Parasuraman's five service quality aspects (tangibles, reliability, responsiveness, assurance, and empathy) as the main research items. The content of the five major aspects of smart port service quality is explained in the following section.

2.2.1. Tangibles

Smart ports are ports with a good working environment and modern, environmentally-friendly equipment that is used to improve productivity and enhance quality service (Bao, 2013; Heilig et al., 2017; Chen et al., 2019). Neatly-dressed employees can strengthen a port's brand image. If a smart port has a good working environment and modern equipment, the efficiency of its staff will be improved, and port facilities and staff services will complement each other to provide a better quality of service (Talley et al., 2014; Zhang, 2020; Min, 2022). In addition, if a smart port's service website provides comprehensive information and has a good visual design, can inform users of their current cargo status and sailing progress (Hofmann and Branding, 2019; Karaś, 2020; Ding et al., 2021). A smart port with an attractive environment can improve the quality of service to customers (Xiao et al., 2021).

2.2.2. Reliability

An important element of a smart port is an intelligent security management monitoring system that can monitor potential threats and avoid dangerous situations by analyzing ships' real-time operating data, and can thereby reduce the risk of accidents (Bao, 2013; Hofmann and Branding, 2019; Sanchez-Gonzalez et al., 2019). To ensure secure and accurate communication, a smart port should provide electronic data transmission and document sharing (Heilig et al., 2017; Ding et al., 2021; Xiao et al., 2021). A smart port can apply automated systems, such as big data computing, to improve port productivity and efficiency in arranging container deliveries (Tongzon, 2009; Talley et al., 2014; Zhang, 2020). A smart port should strive to improve the operating environment and traffic management. One example of such improvement is the use of sensors installed in and around the port, and enabling the port to achieve safer and more efficient traffic management and port operations (Smith, 2002; Min, 2022; Port of Rotterdam official website, 2022). Smart port operators should arrange their work schedules so that there are enough professional operators on standby. (Chen et al., 2019). In this way, if there is a problem with the port or the ships, the port will have sufficient manpower to solve it as quickly as possible, and avoid congestion (Marlow and Casaca, 2003).

2.2.3. Assurance

A smart port should aim to improve its operation and efficiency and achieve the smooth transfer of containers between ships and terminals by automating container information and enabling the rapid exchange of information (Bao, 2013; Chen et al., 2019; Port of Rotterdam official website, 2022). A smart port ensures the high quality, accurate, and secure delivery of cargo, while avoiding damage to or misplacement of cargo during port operations (Hofmann and Branding, 2019). A smart port will achieve the seamless connection of ports and cargo owners, shipping enterprises, and supervisory agencies through the establishment of an integrated network encompassing all service supply chain processes in the port and providing transparent information (Karaś, 2020; Zhang, 2020; Hsu et al., 2022). A smart port can provide convenient procedures, shorten the average customs clearance time, so that ships can call at the port and cargo can be unloaded on time (Talley et al., 2014). A smart port can be quickly adjusted to provide berths and shorten vessel turnaround times (Xiao et al., 2021).

2.2.4. Responsiveness

A smart port should actively respond to future trends by investing resources in the research and development of innovative technologies and applications (Bao, 2013; Chen et al., 2019; Karaś, 2020). The Port of Rotterdam's goal is to achieve a fully automated shipping network in the port by 2025. Ships entering the port will be able to automatically navigate the waterways without the assistance of a pilot (Port of Rotterdam official website, 2022). The maritime industry often needs to respond quickly to different situations. Because pandemic prevention policies are changing frequently in the post-pandemic era, smart ports should have the ability to deal with emergency situations (Masoudi, 2019). In maritime logistics, multimodal transport processes in ports need to coordinate the various players involved in the transport chain and optimize the movement of traffic and cargo, so as to reduce costs and increase efficiency (Lam and Gu, 2013; Heilig et al., 2017; Ding et al., 2021). Smart ports can speed up port logistics transfers through exchange of data, reduce cargo turnaround time, improve productivity, and meet the requirements of customers and ships (Min, 2022). A smart port should have all the necessary infrastructure and information technology, a skilled workforce, and automation to optimize the loading and unloading of cargo, facilitate knowledge development and sharing, increase the port's resilience and sustainability, and ensure safe and reliable operations (Hofmann and Branding, 2019; Sanchez-Gonzalez et al., 2019; Molavi et al., 2020). Employees in smart ports are engaged in many complex and interlocking tasks. They should be assigned work according to their specialties and coordinate, which can improve operating efficiency and quality (Pak and Majd, 2011; Zhang, 2020).

2.2.5. Empathy

Port staff can prioritize the customer's interests, provide customized, high-quality service to the customer (Ding et al., 2021). Every country with ports wants to transform them into green smart ports (Cicin-Sain and Belfiore, 2005; Bao, 2013; Chen et al., 2019). Since it is in line with the global demand for sustainable development, the application of environmentally-friendly renewable energy technologies at green ports is no longer an option, but is instead a necessity (Chiu et al., 2014; Maritz et al., 2014). A smart port can integrate information and can provide sea, road, and rail information in line with the arrival time of ships to improve the efficiency of port operations (Port of Hamburg official website, 2022). Smart port supply chains are better coordinated, reducing the time ships spend in port. A smart port can optimize port management and improve port operations by applying artificial intelligence to predict ship arrival times. (Tongzon, 2009; Xiao et al., 2021; Hsu et al., 2022). A smart port should prioritize the rights, interests, and requirements of its customers, to improve the quality of services and customers' perceptions of the port (Zhang, 2020).

In summary, based on relevant literature and suggestions from experts and scholars, this study has proposed an assessment framework for the service quality of smart ports in the post-pandemic era, as shown in Table 2.

3. Research method

The following section consists of a brief introduction to the AHP and DEMATEL methods (Ding et al., 2021).

3.1. The analytic hierarchy process

The AHP is a multi-criteria decision making (MCDM) method that combines qualitative and quantitative approaches (Saaty, 1980), and can be used to systematize and resolve complex problems. The AHP method can decompose complex problems into various aspects and factors, and the weight of each factor can be determined by integrating the opinions of experts. In this study, the AHP method was applied to obtain the relative weights of the key factors promoting the success of smart ports in the post-pandemic era. The steps used in the AHP method are shown below.

Step 1: Creation of a pairwise comparison matrix

We first established a pairwise comparison matrix of the relative importance of the key factors promoting the success of smart ports in the post-pandemic era, as evaluated on the basis of the evaluation scale shown in Table 2. The pairwise comparison matrix has the following form:

$$A = \begin{bmatrix} 1 & a12 & \cdots & a1n \\ 1/a12 & 1 & \cdots & a2n \\ \vdots & \vdots & \ddots & \vdots \\ 1/a1n & 1/a2n & \cdots & 1 \end{bmatrix} \tag{1}$$

where $a_{ij} = {}^{1}/_{a_{ji}}$, $a_{ij} > 0$, $\forall i, j$, $i, j = 1, 2, \ldots, n$, which represents the importance of factor i with respect to factor j. This pairwise comparison matrix is called a positive reciprocal matrix. If all the comparative measurement values comply with the law of transitivity, then $a_{ik} = a_{ij} \times a_{jk}$ holds for i, j, k, and A can be called a consistent matrix. However, an obvious condition for the consistency of matrix A is that $a_{ij} = w_i/w_j$; $i = 1, 2, \ldots, n$; and $j = 1, 2, \ldots, n$. In this equation, $w_1, w_2, \ldots, w_n$ indicates that Level i is subordinate to the weight of the n evaluation factors of a certain factor on level $i-1$.

Once a hierarchy has been established, pairwise comparisons between the elements on each level must be conducted on the basis of the criteria or objectives of the previous level. If there are multiple factors, multiple pairwise comparisons must be conducted. This study assessed the success factors of smart ports in the post-pandemic era on the basis of service quality. The impact of service quality on the success of a smart port was classified using dimensions and factors, and a pairwise comparison matrix was created using a scale of from 1 to 9 points.

Step 2: Calculation of eigenvalues and eigenvectors

Multiplying matrix A by the vector $w = (w_1, w_2, \ldots, w_n)^T$ created from the weights of the factors yields:

$$Aw = \begin{bmatrix} 1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & 1 & \cdots & w_2/w_n \\ \vdots & \vdots & 1 & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & 1 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = nw \tag{2}$$

As a_{ij} is a subjective assessment given by decision-makers when

Table 2
Assessment of the quality-of-service impacts in the smart port.

Aspect	Descriptions of aspect	Criterion	References
Tangibles	Direct and indirect services provided by a smart port, including equipment, premises, and manpower	A_1: Good environment and modern equipment A_2: Well-dressed staff A_3: Cooperation between equipment and staff services A_4: A website with full information and a good visual design A_5: An attractive environment in the port	Parasuraman et al. (1985); Bao (2013); Talley et al. (2014); Heilig et al. (2017); Hofmann and Branding (2019); Chen et al. (2019); Karaś (2020); Zhang (2020); Xiao et al. (2021); Ding et al. (2021); Min (2022)
Reliability	Services provided as promised by the smart port	B_1: An intelligent security management monitoring system that monitors potential threats B_2: Accurate electronic document transfer B_3: Use of big data to arrange container transport B_4: Ship traffic management and control of port operations B_5: Professional operators on standby at all times	Parasuraman et al. (1985); Smith (2002); Marlow and Casaca (2003); Tongzon (2009); Bao (2013); Heilig et al. (2017); Talley et al. (2014); Chen et al. (2019); Hofmann and Branding (2019); Sanchez-Gonzalez et al. (2019); Zhang (2020); Xiao et al. (2021); Ding et al. (2021); Port of Rotterdam official website (2022); Min (2022).
Assurance	Professional and trustworthy cargo handling capabilities by the smart port	C_1: Container informatization and automated transfers C_2: Accurate and secure delivery of cargo C_3: Transparent information integration on a single platform C_4: Convenient and comprehensive logistics and customs procedures C_5: Rapid provision of port berths to shorten ship turnover times	Parasuraman et al. (1985); Marlow and Casaca (2003); Bao (2013); Talley et al. (2014); Hofmann and Branding (2019); Chen et al. (2019); Zhang (2020); Karaś (2020); Xiao et al. (2021); Ding et al. (2021); Port of Rotterdam official website (2022); Hsu et al. (2022).
Responsiveness	A smart port's ability to respond rapidly to customers' needs	D_1: Active response to technological innovations and new applications D_2: Ability to deal with emergency situations D_3: Optimized transfer speed in the port D_4: Smart efficient management for loading and unloading optimization D_5: Coordinated staff and effective teamwork	Parasuraman et al. (1985); Marlow and Casaca (2003); Pak and Majd (2011); Lam and Gu (2013); Bao (2013); Heilig et al. (2017); Chen et al. (2019); Hofmann and Branding (2019); Sanchez-Gonzalez et al. (2019); Karaś (2020); Molavi et al. (2020); Zhang (2020); Ding et al. (2021); Port of Hamburg official website (2022); Port of Rotterdam official website (2022); Min (2022).
Empathy	The smart port is able to meet the special needs of its customers	E_1: Customized services meeting individual needs E_2: A green port in line with global sustainable development trends E_3: A cargo query system that integrates information from different sources E_4: Required services provided in accordance with ships' arrival times E_5: Emphasis on customers' rights and interests	Parasuraman et al. (1985); Cicin Sain and Belfiore (2005); Tongzon (2009); Bao (2013); Maritz et al. (2014); Chiu et al. (2014); Chen et al. (2019); Zhang (2020); Ding et al. (2021); Xiao et al. (2021); Port of Hamburg official website (2022); Hsu. et al. (2022).

conducting a pairwise comparison of the importance of the evaluation elements, it will be different from the true w_i/w_j value to a certain extent, and $Aw = nw$ will not be valid. Saaty consequently suggested replacing n with the maximum eigenvalue (λ_{max}) of the relative matrix A, i.e., $Aw = \lambda_{max}$.

Step 3: Checking for consistency

Once the eigenvalue and eigenvector are calculated, the maximum eigenvalue (λ max) can be calculated. The consistency ratio (C.R.) and the consistency index (C.I.) are checked for consistency using the maximum eigenvalue, and the relative weights of the evaluation criteria are finally obtained. Saaty suggested that the consistency ratio should be less than or equal to 0.1 to ensure consistency.

3.2. DEMATEL technique

The DEMATEL technique is used to evaluate the causal relationships among key determinants of smart ports. The steps used in the DEMATEL technique (Ding et al., 2019) are described briefly as follows.

Step 1: Define key determinants and establish a quantitative scale for each determinant

The scales commonly used to measure different levels of influence between factors typically include "No influence" (0), "Low influence" (1), "Moderate influence" (2), "High influence" (3), and "Very high influence" (4).

Step 2: Establishment of a direct-relation matrix

A direct-relation matrix can be created by integrating the results of all respondents. Let Y be the integrated pairwise comparison of the magnitudes of influence between n factors by m respondents, and the direct-relation matrix of the assessment results can then be expressed as:

$$Y = [y_{ij}]_{n\times n}$$

where

$$y_{ij} = \sum_{t=1}^{m} a_{ij}^{t} \Big/ m, \forall i \neq j,$$

$$y_{ii} = 0, \forall i = j \tag{3}$$

Here a_{ij}^t represents the results of the t th respondent's assessment of the magnitude of the influence of the i th factor on the j th factor.

Step 3: Normalizing the direct-relation matrix

The normalized direct-relation matrix of the direct-relation matrix is represented as Y. Then:

$$X = \lambda \times Y,$$

where

$$\lambda = 1 \Big/ \max\left\{ \max_i \left\{ \sum_{j=1}^{n} y_{ij} \right\}, \max_j \left\{ \sum_{i=1}^{n} y_{ij} \right\} \right\} \tag{4}$$

Step 4: Deriving the total relation matrix

The total relation matrix is represented as T. Then:

$$T = [t_{ij}]_{n\times n} = \lim_{k\to\infty} \left(X + X^2 + \cdots + X^k\right) = X(I - X)^{-1} \tag{5}$$

Here I is the unit matrix.

Step 5: Calculating the sums of the rows and the sums of the columns

Definition:

$$D_i = \sum_{j=1}^{n} t_{ij}, i = 1, 2, \ldots, n, \tag{6}$$

$$R_j = \sum_{i=1}^{n} t_{ij}, j = 1, 2, \ldots, n. \tag{7}$$

D_i represents the sum of the magnitudes of the influences of factor C_i as a cause on other factors, while R_j represents the sum of the magnitudes of the influences of other factors on factor C_j as an effect.

Step 6: Finding the prominence and relation

Calculate the respective $D + R$ value and the $D - R$ value of each factor based on the D value and the R value obtained in Step 5 for each factor.

Step 7: Drawing the cause-effect diagram

Use the $D + R$ and $D - R$ values of all factors to plot the distribution of each factor on a two-dimensional coordinate system, and use the appropriate threshold values to plot the causality between factors and perform interaction analysis.

3.3. Combining AHP and DEMATEL

The AHP method can be used to decompose a complex problem into a system of aspects and factors. However, since AHP assumes that all aspects and sub-criteria are independent of each other (i.e., AHP only explores the direct relationships between aspects and sub-criteria), the results may not be consistent with reality. This study therefore used the DEMATEL technique to analyze whether there were causal relationships among the criteria. DEMATEL can not only analyze the causal relationships between criteria but also facilitate understanding of the complex interactions between criteria, and can therefore compensate for the limitations of AHP.

Although DEMATEL relationships can be used to evaluate the importance of criteria among the key factors of smart port service quality, DEMATEL does not have a consistency test step. However, when the weights obtained by AHP are all less than 0.1 after the consistency testing step, this means that the judgments of the decision-makers concerning the five aspects and the different levels are consistent. This study consequently used the AHP method to measure the key determinant factors of smart port service quality in the post-epidemic era, and then used DEMATEL to evaluate the causal relationships among these key factors. The specific analytical process was as shown as Fig. 1.

4. Empirical results

4.1. AHP results

The questionnaire used in this study sought to assess the relative importance and ranking order of the key factors affecting the success of a smart port in the post-pandemic era. The questionnaire of the AHP survey in this article is an expert questionnaire. The questionnaire contained 5 assessment dimensions and 25 assessment standards, which formed a hierarchical structure. A pairwise comparison matrix was used to compare the influencing levels and assessment indicators, which were assigned values on a scale of 1–9 points. The pairwise comparison of the weights of each assessment criterion was then performed using a 1–9 point scale. Because pairwise comparison is one of the most effective methods of obtaining consensus judgments. After establishing a pairwise comparison matrix and calculating the eigenvalue and eigenvector, the largest eigenvalue was used for consistency testing, and the relative weight of each assessment criterion could be obtained.

After recovery of the questionnaires, Expert Choice 11 software was used to perform data processing and calculations. The effective sample was obtained on the basis of a CR value $\leqq 0.1$, and the ranking order of the effective sample determined in accordance with weighting. To check whether the thinking of the respondents at different times was consistent when they performed pairwise comparisons, Saaty believed that the consistency index (C.I.) should ideally be $\leqq$ 0.1. After calculations involving the CI and random index (R.I.) values, the consistency ratio (C. R.) was found to be $\leqq$ 0.1, which met consistency testing requirements. The weights of the indicators on each level were then calculated on the basis of the foregoing results, and the weight values were used to determine the key factors promoting good smart port service quality in the post-pandemic era.

The AHP expert questionnaire in this study was designed on the basis of the five evaluation aspects and 25 service quality factors shown in Table 2. The questionnaire was first pre-tested and revised by experts to ensure the scale had good content validity. The AHP questionnaire consisted of three sections, among which the first section obtained basic information about the respondent, including the respondent's job title, years of experience in maritime transport, and company department. The second section contained an explanation of the examples, aspects, and criteria in the questionnaire. The third section asked the respondents to evaluate the relative importance of the criteria for the key success factors. Experts completed the survey questionnaire in the presence of the researchers. A total of ten questionnaires were distributed, and all ten questionnaires were returned and were valid. Table 3 contains basic information concerning the respondents who completed valid questionnaires. Males accounted for roughly 60% of respondents and females for roughly 40%. Participants aged over the age of 41 accounted for roughly 90%. With regard to the level of education, approximately 40% of respondents had an undergraduate degree, while those holding master's degrees respectively accounted for around 50%. The respondents consisted of managers and shipping agents working at the head office or branch offices of shipping companies located at the Port of Kaohsiung in Taiwan. In terms of professional background, roughly 30% each were respectively involved in carrier and shipping agents, while logistic companies accounted for roughly 40% of the respondents. All respondents had at least 15 years of experience in the shipping industry, and most of them were management personnel with

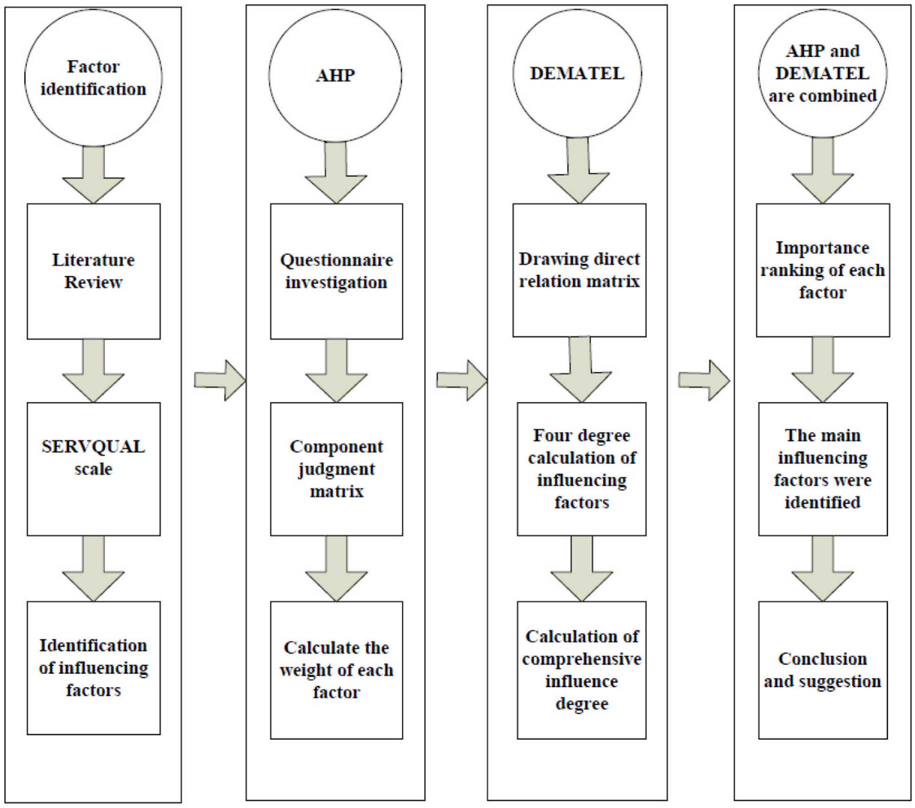

Fig. 1. Analysis of key factors of smart port service quality based on AHP-DEMATEL.

Table 3
Profiles of the group experts.

Basic information	Distribution	Number of experts	Percentage
Gender	Male	6	60%
	Female	4	40%
	Total	10	100%
Age	31–40	1	10%
	41–50	6	60%
	51–60	3	30%
	Total	10	100%
Education	Bachelor	4	40%
	Master	5	50%
	PhD	1	10%
	Total	10	100%
Professional background	Carrier	3	30%
	Shipping agent	3	30%
	Logistic company	4	40%
	Total	10	100%
Experience	16–20 years	4	40%
	21–25 years	6	60%
	Total	10	100%
Position	Director	4	40%
	Senior Manager	4	40%
	Supervisor	2	20%
	Total	10	100%

more than 20 years of experience. Robbins (1994) suggested that the number of experts required to solve a group decision-making problem should be five to seven. The valid responses of AHP experts in this study should therefore be representative to a certain extent.

After analyzing the valid returned questionnaires and taking the expert opinions into account, this study used the AHP method to gauge the relative weights of the evaluation aspects and factors, which were as shown in Table 4.

1. According to the results calculated, the weights of aspects of service quality are as follows: (1) the weight of “tangibles” is 0.165, (2) the weight of “reliability” is 0.305, (3) the weight of “assurance” is 0.310, (4) the weight of “responsiveness” is 0.128, and (5) the weight of “empathy” is 0.093. Among them, “assurance” is the most important, while “empathy” is the least important. A C.I. of $0.01 < 0.1$ indicates that it passes the consistency test, and a C.R. of $0.007 < 0.1$ indicates that the matrix consistency is satisfactory.
2. Since there are 3–6 key success factors in most industries, if a company wants to be successful, it must do particularly well in these key factors in order to move toward the right target. In this study, the priority of the overall evaluation in the second layer is shown in Table 4. Meanwhile, the analysis on the priority of the overall evaluation of the six factors is shown in the table as follows: (1) the integrated weight of "accurate and secure delivery of cargo (C_2)" is 0.103, (2) the integrated weight of "accurate electronic document transfer (B_2)" is 0.101, (3) the integrated weight of "rapid provision of port berths to shorten ship turnover times (C_5)" is 0.083, (4) the integrated weight of "convenient and comprehensive logistics and customs procedures (C_4)" is 0.067, and (5) the integrated weight of " transparent information integration on a single platform (C_3)" is 0.060. (6) the integrated weight of " Use of big data to arrange container transport (B_3)" is 0.059. Hence, according to this study, the most important strategies are the 6 factors in the aspects of “reliability” and “assurance”.

4.2. Discussions of the AHP results

The following discussion focuses on the six key factors in the aspects of "reliability" and "assurance" that were found to be the chief determinants of smart port service quality.

Table 4
Weighting table of all measurement factors.

Aspect	Weight	Criterion	Integrated weight
Tangibles	0.165 (3)	A_1: Good environment and modern equipment	0.055 (7)
		A_2: Well-dressed staff	0.006 (25)
		A_3: Cooperation between equipment and staff services	0.030 (15)
		A_4: A website with complete information and a good visual design	0.014(23)
		A_5: An attractive environment in the port	0.008 (24)
Reliability	0.305 (2)	B_1: An intelligent security management monitoring system that monitors potential threats	0.053 (9)
		B_2: Accurate electronic document transfer	0.101 (2)
		B_3: Use of big data to arrange container transport	0.059 (6)
		B_4: Ship traffic management and control of port operations	0.053(8)
		B_5: Professional operators on standby at all times	0.026(17)
Assurance	0.310 (1)	C_1: Container informatization and automated transfers	0.039 (11)
		C_2: Accurate and secure delivery of cargo	0.103 (1)
		C_3: Transparent information integration on a single platform	0.059 (5)
		C_4: Convenient and comprehensive logistics and customs procedures	0.067(4)
		C_5: Rapid provision of port berths to shorten ship turnover times	0.083 (3)
Responsiveness	0.128 (4)	D_1: Active response to technological innovations and new applications	0.017(20)
		D_2: Ability to deal with emergency situations	0.042 (10)
		D_3: Optimized transfer speed in the port	0.031(14)
		D_4: Smart efficient management for loading and unloading optimization	0.031(12)
		D_5: Coordinated staff and effective teamwork	0.016 (21)
Empathy	0.093 (5)	E_1: Customized services meeting individual needs	0.015 (22)
		E_2: A green port in line with global sustainable development trends	0.017 (19)
		E_3: A cargo query system that integrates information from different sources	0.031 (13)
		E_4: Required services provided in accordance with ships' arrival times	0.028(16)
		E_5: Emphasis on customers' rights and interests	0.017 (18)

4.2.1. Reliability

- ***Accurate electronic document transfer (B_2)***

Smart ports should provide participants and users with secure, accurate, and fast document transfer, conversion, and sharing service via electronic methods. Accurate electronic document transfer can integrate the exchange of information between participants, and can save time through simplification of the paperwork needed for international logistics and international trade procedures. This is consistent with the past findings that the speed and accuracy of documentary procedures are one of the key factors that consignors consider most important when evaluating shipping operators (Ding et al., 2021). Global supply chains have been under stress during the post-pandemic era, and the shipping companies playing important roles in supply chains have also been heavily impacted. Among the currently ongoing global supply chain problems are shortages of containers, insufficient cargo space, port congestion, high shipping fees, and transportation chain imbalances. As a result, in order to cope with surging container traffic, many conventional ports have embarked on a transformation into high-efficiency smart ports. The adoption of new technologies, such as blockchain, by smart ports can save shipping companies large amounts of manpower and document transmission overhead compared with conventional models. Electronic document exchange can establish trust and ensure effective information security (Hsu et al., 2022).

- ***Use of big data to arrange container transport (B_3)***

In the event of a strike by dockworkers or an epidemic that results in port congestion or crew shortages, the cargo owner may be required to pay additional charges such as port congestion charges and delay charges. A smart port can use big data applications to provide users with immediate, convenient knowledge of the current location and status of containers, facilitate complex delivery services, and keep supply chain participants informed of the status of containers. In the field of maritime logistics, multimodal transportation procedures in ports require coordination of a network of the various participants active in the transport chain in order to optimize traffic and cargo movements (Berg and Hauer, 2015).

In recent years, the transportation policies of smart port systems have been redesigned to improve traffic safety, management efficiency, and service performance through developing and integrating information technologies, such as the Internet of Things, cloud computing, big data analysis, and artificial intelligence (MOTC, 2020). This study therefore suggests that if smart ports can ensure the security and reliability of electronic document transfer and provide big data applications to arrange real-time container scheduling, such high-quality service will enable participants to obtain current shipping space and container information at all times. This service will also make it more convenient for participants to dispatch and schedule the allocation of transportation vehicles at any time. These benefits will be invaluable in light of the uncertainty of supply chain logistics delays and changes in the post-epidemic era, and will increase satisfaction with the port. They will also enable supply chain participants to respond to relevant impacts in advance in order to minimize losses when unfavorable port conditions occur.

4.2.2. Assurance aspect

- ***Accurate and secure delivery of cargo (C_2)***

The most important attribute of a carrier is the ability to provide consignors with cargo security and shipping space guarantees during peak seasons or periods of peak demand (Fanamet al., 2019). The key capabilities of a smart port that can improve service quality for participants are ensuring the security and accuracy of cargo delivery, conducting loading and unloading procedures quickly and accurately without causing damage or loss of cargo, and delivering cargo accurately to its destination.

The findings of this study indicate that in the post-epidemic era, at a time when the demand for maritime transport has increased dramatically and given rise to shortages of both shipping space and containers, smart ports can provide the most suitable, secure, and speedy means for the stevedoring and transportation industry to unload cargo from ships to land-based carriers and deliver them to their destination as securely as possible. A smart port can ensure the high-quality, accurate, and secure delivery of cargo, while avoiding damage to or misplacement of cargo during port operations (Hofmann and Branding, 2019; Ding et al., 2021). Regardless of what innovative technologies are employed, the core key values of a smart port must be the accuracy of the destination and the assurance of cargo security. Only by providing assurance of secure and accurate deliveries can a port earn the trust of the participants and enhance the quality of services.

● ***Transparent information integration on a single platform (C_3)***

From the perspective of service science, the supply chain links in a smart port area must be able to provide prompt and responsive information service, so that shipping supply chain participants can communicate in real-time and the operating units can make correct decisions based on the latest information. The extensive use of information and communication technologies is therefore necessary to provide real-time access to information in smart port areas (Botti et al., 2017). By providing convenient information services, such as expedited customs clearance and the notification of inbound entry and berthing arrangements, a smart port can ensure that ships can call at the port and cargo can be unloaded on time (Talley et al., 2014). A smart port should provide information on customs efficiency, customs clearance, inland transportation, and the real-time status of transshipment ports to customers in a timely manner (Yang and Chang, 2019). The most effective way for a smart port to provide these services is through the establishment of a single platform to integrate information concerning various participants and provide transparent responses to queries.

● ***Convenient and comprehensive logistics and customs procedures (C_4)***

Up-to-date smart ports handle not only the loading and unloading of cargo but also information flow, operational planning, and logistic linkage needed for ship entry, loading and unloading, cargo storage and transportation, customs clearance, and notification. This has made port management and provision of services even more challenging. The greatest delays at a port and places where complex cooperation is needed in the port community consist in the procedures from the pilot station to the berth and then transportation to the inland hinterland. But while technology is at the core of a smart port, it alone cannot bring all the necessary changes. For instance, even though container terminals are investing heavily in measures to improve truck turnaround time, trucks still have to wait 2 h for customs inspection after arrival at the port.

According to the Transportation Policy White Paper (MOTC, 2020), data format and service supply standards should be planned and formulated according to the following: an integrated transportation information exchange platform should be established, and transportation data service infrastructure should be improved. Smart ports should promote and develop foundational and supportive application services by leveraging big data analysis under related laws and regulations. This study's results suggest that smart ports should provide standard logistics clearance procedures that are convenient, fast, and comprehensive, so that logistics participants have standards to follow. A smart port should serve as an intermediary between maritime and land-based logistics and should coordinate the cooperation of all participants. A smart port should actively communicate and coordinate with customs, commodity inspections, animal and plant quarantine, health quarantine, and other departments to optimize policies, facilitate logistics and clearance, and improve operational efficiency (Chen et al., 2019).

● ***Rapid provision of port berths to shorten ship turnover times (C_5)***

As the ship sizes and cargo volumes handled by smart ports have increased in order to improve efficiency, reduce costs, save energy, and reduce carbon emissions, terminal equipment has also become increasingly large and automated as a means of improving ship and cargo handling capacity. In order to improve the operational efficiency and competitiveness of port terminals, if relevant operations such as loading and unloading of inbound ships can be completed in the shortest possible time, the turnaround time of ships can be shortened by providing port berths as quickly as possible. The key factors that shipping operators look for in smart port services are reliability, high service quality, reduced costs, and optimized turnaround time. In the highly uncertain post-epidemic era, if a port is unable to effectively control disease transmission or control and coordinate the loading and unloading of containers, personnel management, and other related logistics and transportation issues, this may force ships to berth in the port area for more days than expected, thus increasing the operating costs of shipping operators and reducing operational efficiency (Xu et al., 2021b).

In conclusion, we believe that smart ports should closely coordinate matters related to loading and unloading, so that such relevant operations as loading, unloading, and replenishment arrangements can be completed in the shortest possible time. This can help reduce the number of berthing days in the port area and the operating costs borne by shipping firms, while providing more efficient service. Smart ports must therefore cooperate closely with partners and customers to meet the requirement for low costs, high quality, accurate arrival, and greater flexibility, so as to cope with a rapidly changing operating environment.

Ports provide feeder transportation services within the supply chain industry. Vessels and vehicles typically transport cargoes between ports and the inland, situating ports as a prominent node along the supply chain. In practice, port corporations collaborate with Customs Administration under the Ministry of Finance (MOF) to effectively apply the big data of vessels, cargoes, vehicles, and persons through several value-added services. These services depend on data exchange and information integration between their information platforms and convenient customs clearance to integrate all "cargo flow" information for port management. Smart port development improves the efficiency of customs clearance services and the synergy of the operation and management of Taiwan's international commercial ports. In addition, a more efficient operating environment will be provided for stakeholders in the maritime industry through the development of smart port systems (TIPC, 2020a).

4.3. DEMATEL results

After the six key factors with the greatest influence on smart port service quality were evaluated using the AHP method, as described in Section 4.1, the DEMATEL technique was used to design and implement an expert questionnaire to evaluate the interactions and causal relationships of the six key factors. The DEMATEL investigation also involved an expert questionnaire, which was distributed in the same way as the questionnaire described in Section 4.1 and was completed by relevant stakeholders (middle and senior managers and the heads of shipping departments). The valid response rate of the DEMATEL survey was considered representative to a certain extent (Robbins, 1994), and the DEMATEL investigation yielded the empirical results shown in

Table 5
Results of DEMATEL analysis.

Key determinants	D	R	$D+R$	D-R	Quadrant
C_2: Accurate and secure delivery of cargo	4.8217	5.2203	10.0420	−0.3986	III
C_5: Rapid provision of port berths to shorten ship turnover times	4.1048	5.1325	9.2372	−1.0277	III
B_2: Accurate electronic document transfer	6.0221	4.9676	10.9897	1.0545	I
C_4: Convenient and comprehensive logistics and customs procedures	5.6044	5.7200	11.3244	−0.1156	IV
C_3: Transparent information integration on a single platform	5.2153	4.8151	10.0305	0.4002	II
B_3: Use of big data to arrange container transport	5.0199	4.9327	9.9525	0.0872	II

Note: The threshold value (10.2627) is set as the average value of $D+R$.

Table 5 and Fig. 2.

1. A smart port was found to have three causal factors, namely "accurate electronic document transfer (B_2)," "transparent information integration on a single platform (C_3)," and "use of big data to arrange container transport (B_3)." Since $D\text{-}R > 0$, these causal factors had greater influence on other factors.
   (1) The service quality factor "accurate electronic document transfer (B_2)" was in the first quadrant, which implied that B_2 is a core factor in smart port service quality.
   (2) The other two key factors, "transparent information integration on a single platform (C_3)" and "use of big data to arrange container transport (B_3)" were in the second quadrant. The independence of these two factors was very low. They were also included in the causal group, however, because they could influence other factors.
2. The other three determinants of smart port service quality, "accurate and secure delivery of cargo (C_2)," "rapid provision of port berths to shorten ship turnover times (C_5)," and "convenient and comprehensive logistics and customs procedures (C_4)," were classified in the influenced group. In other words, $D\text{-}R < 0$, meaning these three key factors were more influenced by other factors.
   (1) The smart port service quality factors "accurate and secure delivery of cargo (C_2)" and "rapid provision of port berths to shorten ship turnover times (C_5)" were in the third quadrant. The independence of these factors was very high. These factors were assigned to the independent group, indicating they received relatively little influence from other factors.
   (2) The smart port service quality factor "convenient and comprehensive logistics and customs procedures (C_4)" was in the fourth quadrant. This factor was influenced by the core determinant "accurate electronic document transfer (B_2)."
3. The core key factors "accurate electronic document transfer (B_2)" and "convenient and comprehensive logistics and customs procedures (C_4)" influenced each other and also influenced the other four factors, namely "transparent information integration on a single platform (C_3)," "use of big data to arrange container transport (B_3)," "accurate and secure delivery of cargo (C_2)," and "rapid provision of port berths to shorten ship turnover times (C_5)."
4. Two key factors in smart port service quality, "accurate and secure delivery of cargo (C_2)" and "convenient and comprehensive logistics and customs procedures (C_4)," had an interaction with each other. As an independent key factor, the "rapid provision of port berths to shorten ship turnover times (C_5)" had no influence on any other factor.
5. The factor "convenient and comprehensive logistics and customs procedures (C_4)" influenced "accurate and secure delivery of cargo (C_2)," "rapid provision of port berths to shorten ship turnover times (C_5)," "accurate electronic document transfer (B_2)," and "transparent information integration on a single platform (C_3)," but had no influence on the factor "use of big data to arrange container transport (B_3)."
6. The factors "transparent information integration on a single platform (C_3)" and "convenient and comprehensive logistics and customs procedures (C_4)" had an interaction with each other, but had no influence on other factors.
7. The factor "use of big data to arrange container transport (B_3)" had an influence on "rapid provision of port berths to shorten ship turnover times (C_5)" and "convenient and comprehensive logistics and customs procedures (C_4)," but had no influence on other factors.

4.4. Management implications

This study used the AHP method to assess the key factors affecting smart port service quality, and then used the DEMATEL technique to assess the causal relationships between the six key factors with the greatest influence on service quality. The DEMATEL technique, which is used to determine the mutual relationships between different criteria, has been used frequently to assess the relationships between a port's benefits, opportunities, costs, and risks (Uçdu and Kılıç 2022). In theory, an underlying assumption of the AHP method is that all assessment factors are mutually independent. If some assessment factors are correlated, the analytic network process (ANP) should be used to determine factor weights. Since, in theory, ANP should be used to determine the causal relationships of the six key factors, why did this study use the DEMATEL technique instead of using the ANP method from the start? The following are the main reasons for this:

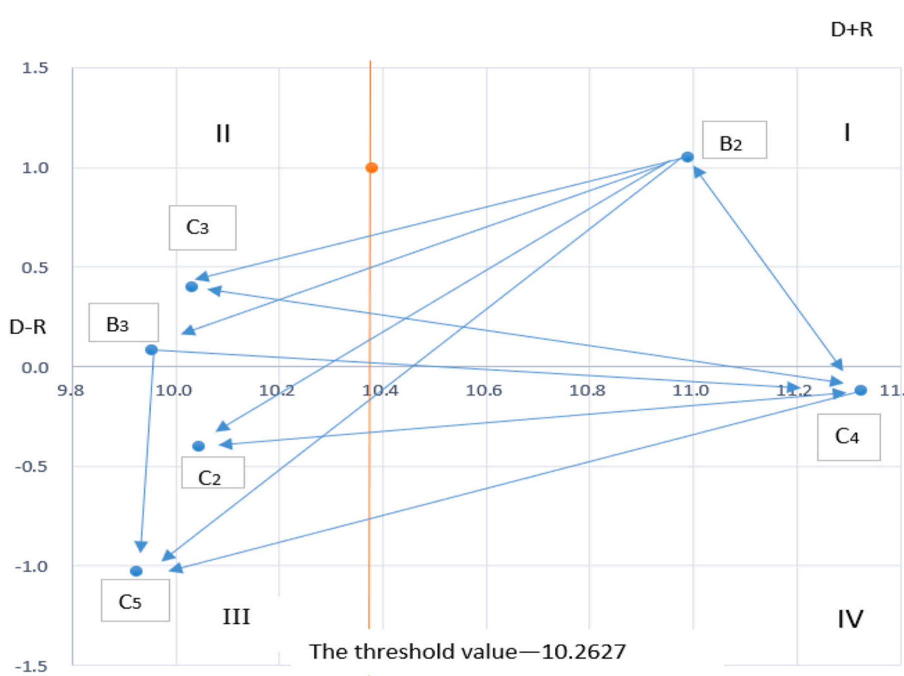

Fig. 2. Cause-effect diagram of key determinants of smart port service quality.

1. If ANP was used to determine the weights of the key factors, it would be necessary to use DEMATEL or some other methodology to verify that the assessment factors are mutually dependent. However, if a DEMATEL expert questionnaire was used directly, and the port stakeholders were asked to assess the 25 key factors affecting smart port service quality using a relationship matrix, apart from the considerable expense and time required, effective assessment results would be difficult to obtain. This is because when the assessment factors on a DEMATEL expert questionnaire are too numerous, the port stakeholders' lack of full understanding of the questionnaire content would result in poor questionnaire effectiveness and few valid questionnaires. In addition, it would be especially difficult to employ ANP to further determine the weights of the key factors when using data from poor-quality DEMATEL expert questionnaires. In particular, when the five aspects and the 25 assessment criteria under them are mutually dependent, the respondents would find it difficult to determine the weights of individual factors on an ANP questionnaire, and the design of such a complicated ANP questionnaire would increase the respondents' confusion, leading to unsatisfactory results.
2. Although the AHP method assumes the independent of individual aspects and criteria, and only probes the direct relationships between aspects and criteria, indirect relationships may in fact exist between aspects and criteria. DEMATEL can therefore not only analyze the causal relationships between criteria, but can also shed light on the complex interactions between criteria, and can therefore compensate for the limitations of the AHP method (Ding et al., 2019). Motivated by time and cost considerations, this study first used the AHP method to determine the key factors affecting smart port service quality, and then used the DEMATEL technique to determine the causal relationships between those key factors.

In summary, this study designed an expert questionnaire survey based on AHP and the DEMATEL technique to evaluate the relationships and causality of the six key factors affecting smart port service quality.

As shown in Table 5, the three causal factors were "accurate electronic document transfer (B_2)," "transparent information integration on a single platform (C_3)," and "use of big data to arrange container transport (B_3)." This result indicated that smart ports should consider these factors as the primary service quality items to be improved in the process of developing smart ports, and should increase the favorable impact of other aspects by strengthening the influence of the aspects in the causal group. In addition, "accurate and secure delivery of cargo (C_2)," "rapid provision of port berths to shorten ship turnover times (C_5)" and "convenient and comprehensive logistics and customs procedures (C_4)" had negative values, implying that they received considerable influence from aspects belonging to the effect group. The degree to which the three aspects were influenced was greater than that of their own influence. Smart port operators should therefore take advantage of these three aspects in the long-term development of their smart ports, as they can help decision-makers carry out strategic planning with limited resources. Furthermore, this study provides some management insights and implications as follows concerning the key factors in the four quadrants.

4.4.1. Management implications for factors in the first and second quadrants

(1) Factors possessing core influence

Factors in the first quadrant are the core influencing factors and should be prioritized, and the investment of management resources should focus on indicators in this quadrant. The first-quadrant factor "accurate electronic document transfer (B_2)" is a key factor affecting service quality, and has high centrality and causality. Compared with factors in other quadrants, factors in this quadrant occupy a relatively important position. Since the improvement of factors in the first quadrant can indirectly improve the risk factors in the fourth quadrant, factors in the first quadrant should be the highest priority for improvement when resources are limited.

(2) Factors with the driving characteristic

Factors in the second quadrant are those with driving influence. The indicators in this quadrant are factors in the causal category, and consist of "transparent information integration on a single platform (C_3)" and "use of big data to arrange container transport (B_3)." Factors in this quadrant are risk factors with low centrality but high causality. Since the improvement of these causal factors can also indirectly improve the key factors in the fourth quadrant, they should be considered to have the second highest priority for improvement.

4.4.2. Management implications of factors in the third and fourth quadrants

(1) Factors with independent factor characteristics

Only risk factors with both low centrality and low causality fall in the third quadrant. The factors in this quadrant are in the effect category and have low interaction with other factors. From a management perspective, it is sufficient to merely control factors in this quadrant, and they are ranked as a third priority when it comes to the investment of management resources. Factors characterized as independent factors consist of "accurate and secure delivery of cargo (C_2)" and "rapid provision of port berths to shorten ship turnover times (C_5)," which are both in the third quadrant.

(2) Factors with influenced factor characteristics

Factors in the fourth quadrant consist of influenced factors. The one factor in this quadrant, "convenient and comprehensive logistics and customs procedures (C_4)" has a negative value, is a key factor with high centrality but low causality. Risk factors in this quadrant are important, but they have limited influence on other factors. Factors in this quadrant are in the effect category. Although such factors are in need of management, they cannot be directly improved in management practice. Key service quality factors in this quadrant can be improved through the improvement of the key factors in the first and second quadrants. Improvement of other key service quality factors can help optimize the service quality of customs clearance procedures in a smart port.

Therefore, the study results apply this management implication in practice. Specifically, "accurate electronic document transfer (B_2) " should be listed as the first factor for improvement. Regarding the digitization trend of the maritime industry, this study proposed proper utilization of the existing domestic information technologies to develop and simplify the maritime operation procedure, improve the efficiency of port information systems, and promote smart port development (MOTC, 2020). The Maritime Port Bureau and Taiwan International Ports Corporation are in the planning stages of applying blockchain technologies to simplify maritime operation procedures. When emerging technologies, such as blockchain, are applied to smart port systems, the maritime industry will considerably cut labor costs and correspondence time associated with traditional operating models. Electronic exchange and transmission can build trust and fully protect information security. Smart ports should provide participants and users with the document transmission and sharing process. Providing safe and efficient service quality associated with smart port development can simplify transnational logistics and international trade processes. This process integrates the information exchange between participants and saves time.

"Transparent information integration on a single platform (C_3) " and " use of big data to arrange container transport (B_3) " should be listed as the second key factor for improvement. This study suggests smart port development from a service science perspective, which includes the following application: to enable participants along the supply chain of smart ports to communicate with each other in real-time; this will enable operation units to effectively make correct decisions according to the latest information and communication technologies. Therefore, smart ports must provide a single platform to integrate the information of participants and to provide transparent information inquiry. The multimodal transportation procedure of ports must coordinate all participants in the transportation chain and optimize transportation and cargo flows. This will allow participants in the supply chain to keep abreast of container conditions at any given time. Smart ports can apply big data arrangements to facilitate multimodal transportation supply services to all participants along the supply chain.

In practice, hardware investment in stevedoring automation has been part of smart transportation policy planning in recent years. Furthermore, software development has also been improved. These developments have allowed all participants of the transportation chain, including terminals, carriers, cargo owners, and customs, to have complete access to information technology for planning purposes. Smart port action plans including the smart land transportation system and the smart monitoring of management systems are essential to effective port operations. The Taiwan International Ports Corporation has strengthened its port single window service platform and optimized the information service system accordingly. As such, the Taiwan International Ports Corporation has promoted the development of smart ports and improved port operational efficiency and safety (MOTC, 2020). Their initiatives highlight the importance of real-time information made available by smart port systems and coincide with the key factors proposed in this study for improvement.

5. Conclusions and suggestions

5.1. Conclusions

The proposed indicators in this study were obtained using the AHP method to filter the most suitable indicators based on their weights. A total of five aspects of service quality were determined through research when establishing the key indicators of smart port service quality. The completion of a weighting table of all factors then enabled the six most important key factors of smart port service quality to be found. The DEMATEL technique further was used to design and implement an expert questionnaire evaluating the relationships and causality of the six key factors of smart port service quality. The procedures used in this study are summarized as follows:

1. A literature review and interviews with expert scholars were conducted to determine the final 25 most appropriate measurement factors.
2. The AHP method was used to determine that the six factors with the highest weights were: (1) accurate and secure delivery of cargo; (2) accurate electronic document transfer; (3) rapid provision of port berths to shorten the turnover time of ships; (4) convenient and comprehensive logistics and customs procedures; (5) transparent information integration on a single platform; and (6) use of big data to arrange container transport.
3. Causal relationships between the foregoing six influencing factors were obtained using the DEMATEL technique. The key core factor that was influenced was "convenient and comprehensive logistics and customs procedures," which was influenced by the factors "accurate electronic document transfer," "transparent information integration on a single platforms," and "use of big data to arrange container transport." The six key factors can provide a basis for improvement of smart port service quality in the post-epidemic era, construction of standard service models, and development of key success factors. This study's findings can therefore provide a reference for decisions concerning building a competitive advantage and ensuring sustainable port operations. This study's results provide valuable insight into smart port development. Our findings can help maritime stakeholders identify the key reconstruction mechanisms and success factors of smart port systems that lead to integrating service quality and its key success factors. The results can be applied in the port policy management practices of various countries to explore future service models by providing a reference for establishing a competitive advantage and ensuring sustainable operations. These findings can provide port operators, carriers, governments, and other stakeholders with specific policy implications based on best practices in smart port development that can lead to implementing and promoting efficient smart port systems.

5.2. Suggestions

The fact that the reliability and assurance of smart port service quality was assigned the greatest importance indicated that consignors attach great importance to whether the services of smart ports can provide the promised service quality and meet delivery requirements. Consigners also emphasize professionalism in the subsequent cargo logistics provided by smart ports, and whether the ports offer trustworthy cargo handling services. It is consequently recommended that the aspects of reliability and assurance serve as the chief indicators for the operation and management of a smart port.

Based on the above recommendations and the relevant results of this study, this study proposed the following business directions and strategies for improvement of the service quality of a smart port.

1. With the advance of digitalization and Industry 4.0, more and more ports are planning the transformation to smart ports. Smart ports can help reduce customers' time costs, make better use of equipment and labor, and improve operational efficiency by achieving faster, more convenient, and more secure information exchange among participants, who include port operators, cargo owners, and shipping operators (Min, 2022). The results of this study suggest that if a smart port can ensure the security and reliability of electronic document transfer and provide real-time container scheduling with big data computing, query services will allow participants to learn about the current status of cargo space and container information at any time. Port services can also facilitate scheduling of land transportation, which will increase the satisfaction with the port in the context of the uncertainty caused by supply chain logistics delays and changes in the post-epidemic era. The effective transmission of information can enable supply chain participants to avoid risks in the face of unfavorable port conditions, and can allow both customers and shipping companies can respond to impacts in advance and take measures to manage risks and minimize damages.
2. Smart ports should closely coordinate loading- and unloading-related matters, so that relevant operations such as loading, unloading, and replenishment can be completed in the shortest possible time, which will help reduce the number of berthing days in the port area, reduce the operating costs borne by the shipping industry, and provide efficient services (Fancello et al., 2011). When there is an accident during port entry and exit or loading and unloading, or when the uncertainty increases significantly, smart ports should solve their problems, meet user needs, and propose the best possible solution as soon as possible. In response to the cruise market's recovery in demand due to the mitigation of the epidemic, smart ports also provide a clear review procedure for addressing berth conflicts, sail schedule changes, and large cruise assignments. Furthermore, a sailing schedule forecast information website system has replaced the traditional paper declaration mechanism. This has simplified the application and review interfaces and addressed the problem of unclear berth assignment information, as reported by carriers. The cruise sail schedule forecast system will significantly

improve operational efficiency when it is implemented in the future. Smart port construction will be further implemented through the promotion of this system (TIPC, 2020b). Smart ports must cooperate closely with partners and customers to meet the requirement for low cost, high-quality service, accurate arrival times, and greater flexibility, so as to cope with a rapidly changing environment. By doing so, smart ports can increase shipping operators' satisfaction with and loyalty to smart ports, as well as the frequency of cooperation.

3. Smart port operators must have good professional communication ability in order to help shipping industry participants successfully fulfill their commitments. In the current post-epidemic era, when the demand for maritime transport increases greatly, smart ports can provide the services of the most suitable, secure, and fastest firms in the loading and unloading and transportation industries to unload cargo from ships to land carriers and deliver it to the destination in the most secure way. Regardless of the level of innovative technology and automation use, the core values of a smart port are the accuracy of the destination and the assurance of cargo security. Only by providing assurance can a port earn the trust of participants and truly enhance the quality of its services. Vessels have grown larger in recent years. With the rise of increasing cruise passenger crowds, complicated customs clearance tasks must be completed within a limited timeframe. Smart ports apply the display application of their smart management systems to provide better service quality. They can also launch port emergency response mechanisms according to required passenger flow control in the post-pandemic era. Smart port development should include epidemic prevention, such as promoting the use of an electronic pass for accessing international commercial ports and replacing paper certificates with electronic RFID certificates that can be electronically sensed. This can ensure that port border management is executed effectively in preventing the spread of illness during a pandemic. A better service experience can be provided to passengers through passenger flow management, which is contingent upon smart port development (TIPC, 2021). Smart ports should also provide standardized logistics clearance procedures that are convenient, fast, and comprehensive, and should give relevant logistics participants clear standards to follow. Whether a port serves as an effective intermediary between maritime and land logistics, ensures the cooperation of all participants, and provides secure, stable, and flexible services will be key factors for shipping operators in selecting a port of call.

The global supply chain has been placed under significant pressure in the post-pandemic era. The maritime industry, which plays a vital role in the supply chain, has also been hit heavily by pandemic-related circumstances. Therefore, traditional ports are being transformed into efficient, digitalized smart port systems to improve the information service system and port operational efficiency and safety. While unexpected delays and changes in supply chain logistics are creating uncertainties, early measures can be taken in response to the impact of such emergencies. Smart port systems can be characterized by their capacity to encourage participant engagement in the supply chain to minimize damage and improve port operations and customer satisfaction. In "Trans-SMART Plan, Transform Sustainable, Modern and Advanced ports with Revolutionary Technology," the Taiwan International Ports Corporation continuously promotes the transformation and upgrade of its ports by centering on four core developments; namely, operation safety, operational efficiency, service quality, and sustainable development. The TIPC is applying big data analysis, artificial intelligence, and unmanned vehicles to increase the speed of smart transformation of Taiwanese ports (TIPC, 2021). This study's limitation surrounds the notion that expert judgment may involve confusion and ambiguity. In light of this limitation, research on smart port development should be conducted in a more complete and sustainable manner. For example, other core factor aspects can be included in subsequent studies. Methods such as Fuzzy-Total Interpretive Structural Modeling (FTISM) or Fuzzy-Best-Worst Method (FBWM) can be applied to analyze related criteria to produce more detailed results.

The main contribution of this study was the establishment of a basic conceptual framework consisting of key factors guiding the progressive development of smart port software and hardware equipment at ports that wish to improve their service quality. This framework can help smart ports evaluate cost reduction measures in these uncertain times and create profit opportunities through revenue-generating operations in the post-epidemic era. In the future, smart ports should optimize their service quality by addressing the above three recommendations, which can help smart ports enhance their value and resources, strengthen their service quality, and boost their core competitiveness.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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