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Constructing Governance Framework of a Green and Smart Port

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Abstract: Developing a green and smart port is a significant progress in the specific application of energy conservation and emission reduction as well as intelligent technologies in global ports and maritime shipping sectors. The paper aims to analyze the inherent relationships among different structural factors and proposes specific countermeasures and governance policies for green and smart port construction. It uses interpretive structural modeling analysis to divide the factors into different levels, and draws a model map of green and smart port construction structure. The research result contributes to providing a theoretical basis for governments to formulate a green and smart port policies and establishing effective method systems and technical means for the port industry and stakeholders to leverage intelligent port technologies for the port development.

Keywords: green port; smart port; interpretative structural modeling; port-shipping cooperation; governance framework; intelligent port technology

1. Introduction

A port is not only an important platform and node in the international maritime shipping network, but also plays a catalyst role in world economic and trade development [1,2]. Lee et al. argue that major Asian ports are fifth-generation ports [3,4]. The first three generations of ports generally emphasize port production and services. The fourth generation ports put more emphasis on the integration role of ports on the global supply chain and stress flexibility and information services of port-shipping alliances and port-port cooperation alliances. The fifth generation ports incorporate the service functions of all the first fourth-generation ports. Especially, the fifth generation ports adapt to the green and intelligent technology innovation trend, emphasizing that the port production and service must fit the concept of green environmental protection and high-tech technology. The first four generations of ports paid far too little attention to port technology innovation and environmental protection, failed to achieve green and low-carbon development, and neglected issues such as climate change and environmental pollution. Global climate warming is one of the huge challenges facing mankind, and people in all walks of life must endeavor to save energy and reduce emissions. Port pollution greatly affects the climate environment. Most of the pollution comes from port production and transport ships. Approximately 70% of the world's marine emissions occur in the coastal area of the port, whereas 60–90% occurs during the berthing period [5,6]. In the port handling process, there will be other kinds of pollution, such as dust and noise. Therefore, fifth-generation ports will focus on the application of the port intelligent technology and the realization of the sustainable green development on the basis of the integration of the former port logistics service function [4,7]. Compared with other industries, the port shipping industry produces a greater polluting impact on the environment. In addition, scientific and technological innovation is a powerful approach to increase port development competitiveness and protect port environments. In general, studying emerging intelligent operation technologies of ports and adhering to the green development trend of ports to build smart and green operation modes of ports are important directions for port development currently, which is of great significance to promote the sustainable development of ports and improve the overall operational efficiency of ports.

The development of modern ports should adapt to the trend of environmental protection, strengthen scientific and technological innovation in ports, and realize new models for green and intelligent development to deal with current crises and challenges in the port industry development. Green and intelligent designs are important trends and two major goals for the future development of ports. They have a close relationship. A green port is the macro-goal of port development, and aims to adapt port production and operation with environmental protection. Under the premise of green ports, smart ports strengthen technological innovation and application to apply new technologies in port production organizations, reduce environmental pollution, and achieve the goal of the sustainable development of green ports. Therefore, a green port and a smart port are systematic concepts of development and are not independent from each other. However, there is no systematic governance framework on how to build a green and smart port. The critical factors concerning the development of a green and smart port also fail to be identified clearly. To systematically and scientifically associate critical factors for green and smart ports into a system, we must perform a systematic analysis of these factors and then build up the governance framework for green and smart ports with the help of relevant models worked out. This is the main purpose of this study. This paper will use Interpretative Structural Modeling to study the critical factors and governance framework for the development of a green and smart port.

The rest of this paper is structured as follows. The literature review in Section 2 focuses on the current research effort on green and smart ports and analyzes shortcomings in these studies. Section 3 illustrates related concepts of development regarding green and smart ports and identifies the critical factors that influence their development. Section 4 presents the research methods used in this paper—the Interpretative Structural Modeling (ISM). Section 5 conducts empirical research, analyzes the critical factors of a green and smart port, and builds up a green and smart port governance framework. Section 6 states the conclusion of the whole paper.

2. Literature Review

Green and smart ports represent an important direction in port development in recent years. Generally speaking, there are many studies on green ports and relatively few references regarding smart ports. This paper organizes the literature from operation, science and technology, and policy perspectives. The following is a summary of relevant literature on green and smart ports.

Some studies proposed port optimization suggestions from the operation and production angle. Bergqvist et al. started from the green port tax to connect inland logistics with ports to enhance inland transportation effectiveness [7]. Lam et al. focused on the mathematical model and proposed that future research on ports and supply chains should focus on the optimization of global multimodal transport [8]. Esmemr et al. used a simulation model to determine the optimal quantity of port container handling equipment to improve the lean production capacity at Turkish ports [9].

Such studies are aimed at improving the efficiency of port operations. In addition, with regard to port ecological technologies, Peris et al. discussed the relationships between port and city development and, with Dover Port, Falmouth Harbor, and Truro Port as examples, analyzed the environmental protection work at various ports [10]. Myeong et al. established a green space planting model for port ecosystem to protect the port and coastal ecosystem [11]. Sawada et al. proposed an ecological development strategy for coastal areas, taking Osaka Bay area as an example [12]. Other studies on resource utilization show that reasonable control of resources can effectively improve the overall sustainability of ports [13–15].

Some other studies put forward suggestions on port policies. Chang et al. described the importance and design concept of the green evaluation system for ports [16,17]. Maritz et al. used the Analytic Hierarchy Process (AHP) to figure out guiding principles for running green ports [18,19]. Park used factor analysis to determine detailed port greenness factors and structures [20]. Karim evaluated the "greenness" of each port based on characteristics of the ports [21]. Yang believed that the government can roll out appropriate rules or provide incentives to encourage terminal operators to upgrade their handling equipment to reduce port operating costs and mitigate pollution [22]. Lam studied the effectiveness of green port policies and compared major ports in Asia and Europe such as Singapore, Shanghai, Antwerp, and Rotterdam [23].

The above literature on green ports shows that at present there are few studies on smart ports. Bao held the view that smart ports should involve comprehensive technologies and modern management methods in port operation and management [24]. Siror discussed the design and operation of intelligent port models [25]. In essence, smart ports are designed to operate and manage modern ports with full use of intelligent technologies and means. The construction and sustainable development of a smart port should be based on the principles of cooperative cooperation, technological innovation, environmental protection, energy conservation, and the full use of information technology to realize intelligent and green port operation [26,27]. In view of this, green and intelligent ports are an organic whole system, and they are inseparable. The operation of green ports requires the support of the scientific and technical means of the smart ports, and the operation of the smart ports need to carry out the concept of green sustainable development. It can be seen that the two are closely related to each other. Both of them often exist in the form of simultaneous appearance. In short, concepts of green development and green technology permeate throughout the smart port operation process, so a green and smart port is a port development concept of organic unity.

To sum up, most studies stuck to one perspective in discussing green ports and smart ports. But, in fact, the factors influencing the construction of a green and smart port are diverse, and the influences of different factors are different and interrelated. Therefore, this paper integrates and classifies relevant factors, and uses a model to establish a green and smart port integration framework, which can systematically put forward proposals for the construction of a green and smart port to make up for the shortcomings in previous studies.

3. Developing Concepts and Critical Factors of Green and Smart Ports

As mentioned above, green and smart ports are inextricably integrated. Green ports and smart ports will be integrated in operation and development [26,27]. Green ports and smarts port are inseparable. A port should take the development of a green port as its key goal, and take the intelligent port development mode as its key technical means. The green development of the port is the main goal of the low energy consumption, low emission, and low pollution. The smart port development is based on the high-tech intelligent technology to improve the comprehensive efficiency and competitiveness of the port operation. The port's green development needs the support of port intelligence and technological innovation, and green development is also an important concept of the development of a smart port. Without the concept of green development, the sustainable development and smart mode of a port would be hardly realized. Generally speaking, green development is an important concept of smart port. At the same time, the technological innovation application of the smart port is the key means to achieve the goal of a green port. A green and smart port is an organic whole system (see Figure 1); the development of green and smart port integration will be an inevitable way to achieve sustainable development of the port in the future.

To build a more scientific and systematic governance framework for green and smart ports, this paper defines the development concept for green and smart ports and elaborates in six dimensions from the industry practice and academic research results, meaning greenness [28,29], agility [30,31], personalization [32–34], cooperation [35–37], intelligence [38,39], and liberalization [40,41] are the key elements for green and smart port development. The detailed introductions are shown in Table 1.

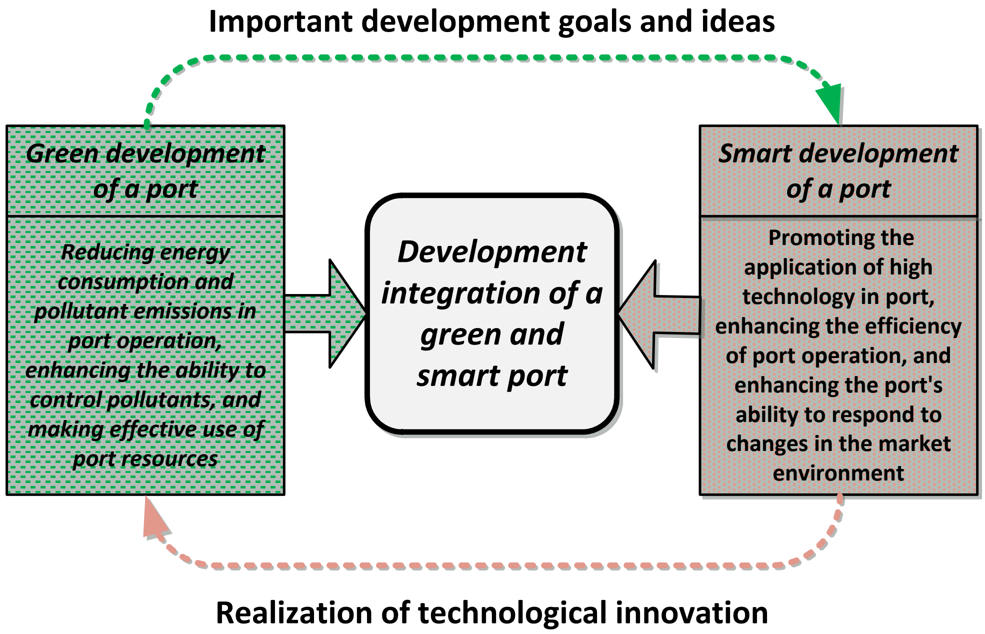

Figure 1. Concept map of a green and intelligent port integration.

Table 1. The development concept for green and smart ports.

	Dimension	Descriptions	Source
Green and Smart Port	Greenness	Industrial and production modes with high technology content, low resource consumption, and less environmental pollution	[28,29]
	Agility	Working methods guided by a quick and efficient methodology subject to constant reforms	[24,31]
	Personalization	New production models that are able to meet unique market requirements in the new market environment	[32–34]
	Cooperation	Strengthened international cooperation, enhanced port-city integration and increased cooperation with inland ports	[35–37]
	Intelligence	More modern intelligent technologies integrated into port working environments to improve port operation levels	[38,39]
	Liberalization	Relaxed government regulation to give full play to the role of market mechanism to facilitate trade	[40,41]

This paper considers 20 critical factors influencing the development of a green and smart port, referring to a comprehensive literature review as shown in Table 1. The greenness concept covers four factors: energy-saving and emission-reducing capability, pollution treatment capability, effective utilization of resources and environmental protection concept, and policy system. Agility covers three factors: agile production capability, comprehensive logistic capability, and refined operation capability. Personalization includes port-differentiated service levels, personalized service levels for customers, and emergency and rapid response capabilities. Cooperation includes international port-shipping cooperation, port-city integration, and cooperation between subsidiary and parent ports. Intelligence refers to intelligent production infrastructure and operation, intelligent administration, intelligent facility security, and innovative R&D and technology applications. Liberalization includes the liberalization of economic and trade policies, the facilitation of logistics and customs clearance, and the openness of investment and financing.

4. Research Methodology

Interpretative Structural Modeling (ISM) was initially used as a method for analyzing problems related to complex socioeconomic systems [42]. ISM is a widely used analytical method in modern systems engineering, and it is also a kind of structural modeling technology. It decomposes the complex system into several subsystem elements, uses people's practical experience and knowledge as well as the help of computer, and finally, forms a multilevel hierarchical structure model. As a systematic analysis tool, it is characterized by breaking up a complex system into several subsystems and finding out the interrelationships among various elements to form a structure graph and a structure matrix [43]. This model can transform the idea of important modules into intuitive system with good structural relationship, especially for the analysis of system structure with many variables and complex relationships. Through corresponding matrix calculation and conversion, fuzzy and complicated systems are clarified and streamlined. A hierarchical structure model can be set up at the same time to facilitate systematic analysis to serve a powerful explanatory function. Concrete steps for building a governance framework for a green and smart port can be shown in Figure 2.

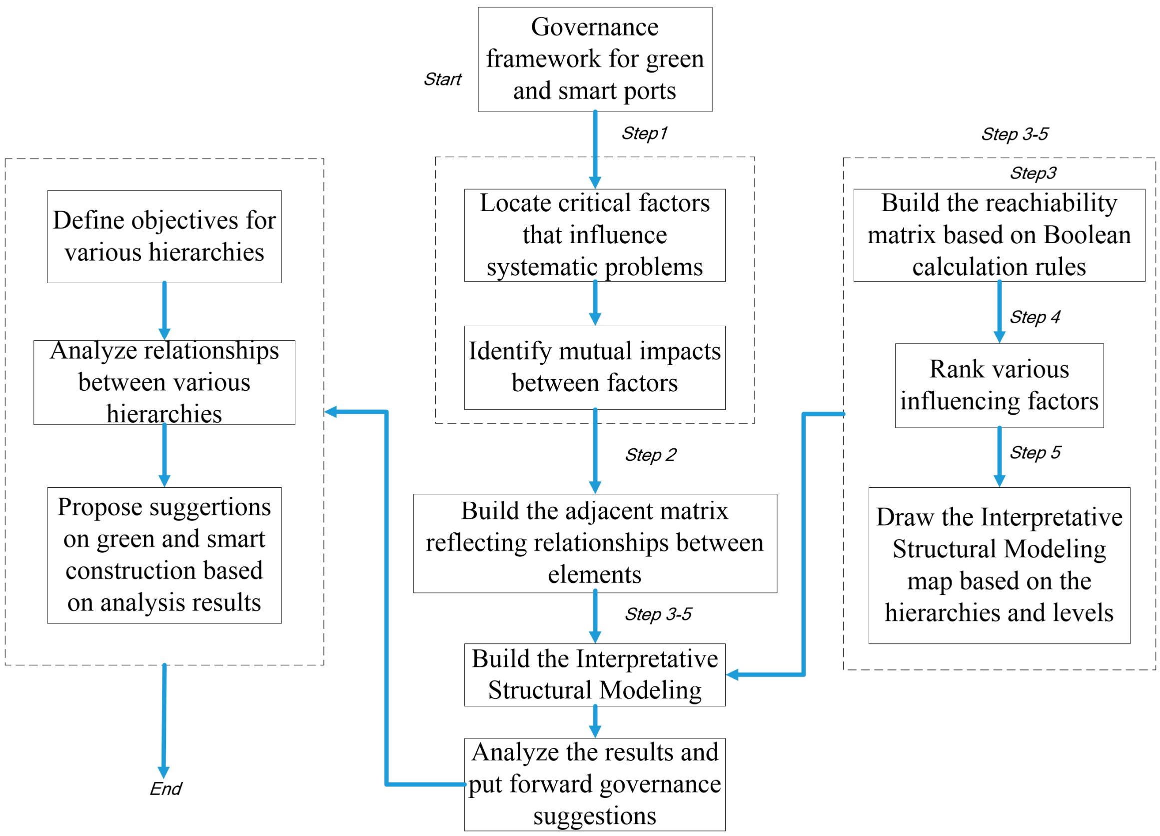

Figure 2. Steps to build a governance framework for a green and smart port.

First, find out the critical factors that influence systematic problems. We use Sn to stand for the n-th factor that influences systematic problems and determine the direct (adjacent) influences between factors, and use X, V, A, and O to represent different influence relationships.

$$\begin{cases} \text{X indicates that the factors in the row and the column influence each other,} \\ \text{V indicates that the factors in the row influences the factor in the column,} \\ \text{A indicates that the factors in the column influences the factor in the row,} \\ \text{O indicates that the factors in the row and column do not influence each other.} \end{cases}$$

Second, establish an adjacency matrix, A, to reflect the relationships among various elements. Element a_{ij} in A can be converted using the above influence relationship. The conversion method is as follows.

$$\begin{cases} a_{ij} \text{ corresponds to X, then } a_{ij} = a_{ji} = 1, \\ a_{ij} \text{ corresponds to V, then } a_{ij} = 1,\ a_{ji} = 0, \\ a_{ij} \text{ corresponds to A, then } a_{ij} = 0,\ a_{ji} = 1, \\ a_{ij} \text{ corresponds to O, then } a_{ij} = a_{ji} = 0. \end{cases}$$

Third, establish a reachability matrix. Reachability matrix refers to the degree to which each node in a directed graph described with a matrix can reach via a pathway of a certain length. The specific calculation method: according to the Boolean calculation rules, we suppose $A_1 = A + I$. If $A_1 \neq A_2 \neq \ldots \neq A_{r-1} = A_r$ ($r \neq n - 1$, and n is the order of a matrix) and $A_n = (A + I)_n$, so the reachability matrix $R = A_{r-1} = (A + I)_{r-1}$.

Fourth, rank the factors. We can apply the reachability matrix R to work out the following set of elements S_i, $P(S_i) = \{S_j \mid m_{ij} = 1\}$, $Q(S_i) = \{S_j \mid m_{ji} = 1\}$, $P(S_i) \cap Q(S_i) = T(S_i)$. Specifically, $P(S_i)$ is called a reachable set, that is, the set of all the elements that can be reached from Element S_i. $Q(S_i)$ is called the leading set, that is, the set of all elements that can reach Si in the reachability matrix. $T(S_i)$ is known as the collective set, the intersection of the reachable set, and the leading set. Through calculation, when the numbers of factors contained in the reachable set $P(S_i)$ and the collective set $T(S_i)$ are the same, the uppermost level of unit is obtained. Then we can delete the rows and columns where elements in the collective set are located from the original reachability matrix R to find the next level of unit. Continue the ranking and finally we can distribute factors into a hierarchical structure.

Fifth, draw the Interpretative Structural Modeling map. According to the results, we use the nodes at each level as factors on the same hierarchical structure level and use the same box for the same level.

5. Test Results and Discussion

5.1. Test Results

We then apply the ISM to the 20 critical factors in Table 2 affecting the development of a green and smart port. First, following the procedure described in the first step, we use X, V, A, and O to represent different influence relationships. The detailed results are shown in Table 3.

Table 2. Description of critical influencing factors.

Dimension	Serial No.	Critical Influencing Factors	Descriptions	Source
Greenness	S_1	Energy-saving and emission-reducing capability	Port's capability in saving energy and controlling pollutant discharges	[10–12]
	S_2	Pollution treatment capability	Responsiveness and degree of a port in treating pollutants	[20–22]
	S_3	Efficient utilization of resources	Whether a port has the capability to utilize resources effectively to reduce resource waste	[13–15]
	S_4	Environmental protection concept and policy system	Knowledge and practices of port management personnel and policy-makers in green concepts	[22,23]
Agility	S_5	Agile production capability	Port's capability in fully utilizing the limited resources and quickly responding to orders	[44]
	S_6	Comprehensive logistic capability	Levels of a port's comprehensive logistic services and supply chains	[7,8]
	S_7	Refined operation capability	Whether a port adopts refined operation modes and has JIT capabilities	[45]
Personalization	S_8	Port-differentiated service levels	Levels of a port's services that are different from those at other ports	[34,46]
	S_9	Personalized service levels for customers	Levels of personalized services provided by the port to customers	[32,47]
	S_{10}	Emergency and quick response capabilities	Port's response capabilities to multiple emergencies and adjustability to changes	[48,49]
Cooperation	S_{11}	International port-shipping cooperation	Degree and model of international port-shipping cooperation	[35,50]
	S_{12}	Port-city integration	Port-city cooperation	[48–50]
	S_{13}	Cooperation between subsidiary and parent ports	Cooperation between subsidiary and parent ports (international dry ports, feeder ports and inland port areas)	[37]
	S_{14}	Intelligent production infrastructure and operation	Intelligence degree of port infrastructure operation and production	[51,52]
Intelligence	S_{15}	Intelligent administration	Intelligence degree of port administration	[53]
	S_{16}	Intelligent facility security	Intelligence degree of port facility security	[54,55]
	S_{17}	Innovative R&D and technology application	Port's technical innovation R&D capability and degree of application	[55]
Liberalization	S_{18}	Liberalization of trade and economic policies	Port's liberalization degree in domestic and foreign trade	[56]
	S_{19}	Facilitation of logistics and customs clearance	Port's coordination with the Customs and quarantine departments and degree of cargo transportation facilitation	[8,57]
	S_{20}	Openness of investment and financing	Openness of a port in market investment and financing	[58,59]

Table 3. Mutual influences of various factors.

Influencing Factors	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}	S_{18}	S_{19}	S_{20}
S_1		O	A	A	O	O	O	V	V	O	A	A	A	A	A	O	A	O	O	O
S_2			O	A	O	O	O	V	V	A	A	A	A	A	A	O	A	O	O	O
S_3				A	O	O	A	O	O	O	A	A	A	A	A	O	A	O	O	O
S_4					O	O	O	O	O	O	A	A	A	V	V	V	X	O	O	O
S_5						O	O	V	V	V	A	A	A	X	O	O	A	O	O	O
S_6							O	V	V	V	A	A	A	A	A	O	A	A	O	O
S_7								V	V	O	A	A	A	A	A	O	A	O	O	O
S_8									O	A	A	A	A	A	A	A	A	A	A	A
S_9										A	A	A	A	A	A	A	A	A	A	A
S_{10}											A	A	A	O	A	O	O	O	O	O
S_{11}												X	X	V	V	V	V	X	V	X
S_{12}													X	V	V	V	V	V	V	X
S_{13}														V	V	V	V	V	V	X
S_{14}															O	O	A	O	O	O
S_{15}																V	A	O	O	O
S_{16}																	A	O	O	O
S_{17}																		O	O	O
S_{18}																			V	V
S_{19}																				O
S_{20}																				

Then we build the adjacency matrix based on the second step, as shown in Table 4.

Table 4. Adjacency matrix A.

Influencing Factors	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}	S_{18}	S_{19}	S_{20}
S_1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
S_2	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
S_3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_4	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0
S_5	0	0	0	0	0	0	0	1	1	1	0	0	0	1	0	0	0	0	0	0
S_6	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
S_7	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
S_8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{10}	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
S_{11}	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
S_{12}	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
S_{13}	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
S_{14}	1	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
S_{15}	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
S_{16}	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
S_{17}	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	0	0	0	0
S_{18}	0	0	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	1	1
S_{19}	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
S_{20}	0	0	0	0	0	0	0	1	1	0	1	1	1	0	0	0	0	0	0	0

According to Boolean calculation rules, we can work out A_2, A_3, ... , An and, finally, that $A_3 = A_4$. So the reachability matrix is $R = A_3 = (A + I)_3$, as shown in Table 5.

Table 5. Reachability matrix R.

Influencing Factors	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}	S_{18}	S_{19}	S_{20}
S_1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
S_2	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
S_3	1	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
S_4	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	0	0	0
S_5	1	1	1	0	1	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0
S_6	0	1	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0
S_7	1	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
S_8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
S_9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
S_{10}	0	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
S_{11}	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
S_{12}	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
S_{13}	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
S_{14}	1	1	1	0	1	1	1	1	1	1	0	0	0	1	0	0	0	0	0	0
S_{15}	1	1	1	0	0	1	1	1	1	1	0	0	0	0	1	1	0	0	0	0
S_{16}	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0
S_{17}	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	0	0	0
S_{18}	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
S_{19}	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0
S_{20}	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

The calculation results are shown in Tables 6–12.

Table 6. First level of reachability set, leading set, and their intersection.

	$P(S_i)$	$Q(S_i)$	$T(S_i)$
S_1	1,8,9	1,3,4,5,7,11–15,17,18,20	1
S_2	2,8,9	2,4,5,6,10–15,17,18,20	2
S_3	1,3,8,9	3,4,5,7,11–15,17,18,20	3
S_4	1–10,14–17	4,11,12,13,17,18,20	4,17
S_5	1,2,3,5–10,14	4,5,11,12,13,14,17,18,20	5,14
S_6	2,6,8,9,10	4,5,6,11–15,17,18,20	6
S_7	1,3,7,8,9	4,5,7,11–15,17,18,20	7
S_8	8	1–8,10–20	8
S_9	9	1–7,9–20	9
S_{10}	2,8,9,10	4,5,6,10–15,17,18,20	10
S_{11}	1–20	11,12,13,18,20	11,12,13,18,20
S_{12}	1–20	11,12,13,18,20	11,12,13,18,20
S_{13}	1–20	11,12,13,18,20	11,12,13,18,20
S_{14}	1,2,3,5–10,14	4,5,11,12,13,14,17,18,20	5,14
S_{15}	1,2,3,6–10,15,16	4,11,12,13,15,17,18,20	15
S_{16}	8,9,16	4,11,12,13,15–18,20	16
S_{17}	1–10,14–17	4,11,12,13,17,18,20	4,17
S_{18}	1–20	11,12,13,18,20	11,12,13,18,20
S_{19}	8,9,19	11,12,13,18,19,20	19
S_{20}	1–20	11,12,13,18,20	11,12,13,18,20

From Table 6, we can work out that the first-level nodes are S_8 and S_9.

Table 7. Second level of reachability set, leading set, and their intersection.

	$P(S_i)$	$Q(S_i)$	$T(S_i)$
S_1	1	1,3,4,5,7,11–15,17,18,20	1
S_2	2	2,4,5,6,10–15,17,18,20	2
S_3	1,3	3,4,5,7,11–15,17,18,20	3
S_4	1–7,10,14–17	4,11,12,13,17,18,20	4,17
S_5	1,2,3,5,6,7,10,14	4,5,11,12,13,14,17,18,20	5,14
S_6	2,6,10	4,5,6,11–15,17,18,20	6
S_7	1,3,7	4,5,7,11–15,17,18,20	7
S_{10}	2,10	4,5,6,10–15,17,18,20	10
S_{11}	1–7,10–20	11,12,13,18,20	11,12,13,18,20
S_{12}	1–7,10–20	11,12,13,18,20	11,12,13,18,20
S_{13}	1–7,10–20	11,12,13,18,20	11,12,13,18,20
S_{14}	1,2,3,5,6,7,10,14	4,5,11,12,13,14,17,18,20	5,14
S_{15}	1,2,3,6,7,10,15,16	4,11,12,13,15,17,18,20	15
S_{16}	16	4,11,12,13,15–18,20	16
S_{17}	1–7,10,14–17	4,11,12,13,17,18,20	4,17
S_{18}	1–7,10–20	11,12,13,18,20	11,12,13,18,20
S_{19}	19	11,12,13,18,19,20	19
S_{20}	1–7,10–20	11,12,13,18,20	11,12,13,18,20

From Table 7, we can work out that the second-level nodes are S_1, S_2, S_{16}, and S_{19}.

Table 8. Third level of reachability set, leading set, and their intersection.

	$P(S_i)$	$Q(S_i)$	$T(S_i)$
S_3	3	3,4,5,7,11–15,17,18,20	3
S_4	3–7,10,14,15,17	4,11,12,13,17,18,20	4,17
S_5	3,5,6,7,10,14	4,5,11,12,13,14,17,18,20	5,14
S_6	6,10	4,5,6,11–15,17,18,20	6
S_7	3,7	4,5,7,11–15,17,18,20	7
S_{10}	10	4,5,6,10–15,17,18,20	10
S_{11}	3–7,10–15,17,18,20	11,12,13,18,20	11,12,13,18,20
S_{12}	3–7,10–15,17,18,20	11,12,13,18,20	11,12,13,18,20
S_{13}	3–7,10–15,17,18,20	11,12,13,18,20	11,12,13,18,20
S_{14}	3,5,6,7,10,14	4,5,11,12,13,14,17,18,20	5,14
S_{15}	3,6,7,10,15	4,11,12,13,15,17,18,20	15
S_{17}	3–7,10,14,15,17	4,11,12,13,17,18,20	4,17
S_{18}	3–7,10–15,17,18,20	11,12,13,18,20	11,12,13,18,20
S_{20}	3–7,10–15,17,18,20	11,12,13,18,20	11,12,13,18,20

From Table 8, we can work out that the third-level nodes are S_3 and S_{10}.

Table 9. Fourth level of reachability set, leading set, and their intersection.

	$P(S_i)$	$Q(S_i)$	$T(S_i)$
S_4	4–7,14,15,17	4,11,12,13,17,18,20	4,17
S_5	5,6,7,14	4,5,11,12,13,14,17,18,20	5,14
S_6	6	4,5,6,11–15,17,18,20	6
S_7	7	4,5,7,11–15,17,18,20	7
S_{11}	4–7,11–15,17,18,20	11,12,13,18,20	11,12,13,18,20
S_{12}	4–7,11–15,17,18,20	11,12,13,18,20	11,12,13,18,20
S_{13}	4–7,11–15,17,18,20	11,12,13,18,20	11,12,13,18,20
S_{14}	5,6,7,14	4,5,11,12,13,14,17,18,20	5,14
S_{15}	6,7,15	4,11,12,13,15,17,18,20	15
S_{17}	4–7,14,15,17	4,11,12,13,17,18,20	4,17
S_{18}	4–7,11–15,17,18,20	11,12,13,18,20	11,12,13,18,20
S_{20}	4–7,11–15,17,18,20	11,12,13,18,20	11,12,13,18,20

From Table 9, we can work out that the fourth-level nodes are S_6 and S_7.

Table 10. Fifth level of reachability set, leading set, and their intersection.

	$P(S_i)$	$Q(S_i)$	$T(S_i)$
S_4	4,5,14,15,17	4,11,12,13,17,18,20	4,17
S_5	5,14	4,5,11,12,13,14,17,18,20	5,14
S_{11}	4,5,11–15,17,18,20	11,12,13,18,20	11,12,13,18,20
S_{12}	4,5,11–15,17,18,20	11,12,13,18,20	11,12,13,18,20
S_{13}	4,5,11–15,17,18,20	11,12,13,18,20	11,12,13,18,20
S_{14}	5,14	4,5,11,12,13,14,17,18,20	5,14
S_{15}	15	4,11,12,13,15,17,18,20	15
S_{17}	4,5,14,15,17	4,11,12,13,17,18,20	4,17
S_{18}	4,5,11–15,17,18,20	11,12,13,18,20	11,12,13,18,20
S_{20}	4,5,11–15,17,18,20	11,12,13,18,20	11,12,13,18,20

From Table 10, we can work out that the fifth-level nodes are S_5, S_{14}, and S_{15}.

Table 11. Sixth level of reachability set, leading set, and their intersection.

	$P(S_i)$	$Q(S_i)$	$T(S_i)$
S_4	4,17	4,11,12,13,17,18,20	4,17
S_{11}	4,11–13,17,18,20	11,12,13,18,20	11,12,13,18,20
S_{12}	4,11–13,17,18,20	11,12,13,18,20	11,12,13,18,20
S_{13}	4,11–13,17,18,20	11,12,13,18,20	11,12,13,18,20
S_{17}	4,17	4,11,12,13,17,18,20	4,17
S_{18}	4,11–13,17,18,20	11,12,13,18,20	11,12,13,18,20
S_{20}	4,11–13,17,18,20	11,12,13,18,20	11,12,13,18,20

From Table 11, we can work out that the sixth-level nodes are S_4 and S_{17}.

Table 12. Seventh level of reachability set, leading set, and their intersection.

	$P(S_i)$	$Q(S_i)$	$T(S_i)$
S_{11}	11,12,13,18,20	11,12,13,18,20	11,12,13,18,20
S_{12}	11,12,13,18,20	11,12,13,18,20	11,12,13,18,20
S_{13}	11,12,13,18,20	11,12,13,18,20	11,12,13,18,20
S_{18}	11,12,13,18,20	11,12,13,18,20	11,12,13,18,20
S_{20}	11,12,13,18,20	11,12,13,18,20	11,12,13,18,20

From Table 12, we can work out that the seventh-level nodes are S_{11}, S_{12}, S_{13}, S_{18}, and S_{20}. Finally, we can draw the ISM map according to the fifth step, as shown in Figure 3.

5.2. Discussions and Suggestions for Constructing Green and Smart Ports

With the established ISM map, we divided the 20 critical factors influencing the development of the green and smart ports into seven levels in bottom-to-top order. The seven levels are further divided into four hierarchies. The first hierarchy is the strategic objective hierarchy, including the first level. The second hierarchy is the technical capability hierarchy, including the second and third levels. The third hierarchy is the production and operation hierarchy, including the fourth and fifth levels. The fourth hierarchy is the policy support and technical innovation hierarchy, including the sixth and seventh levels. The relationships between the four hierarchies are discussed as follows.

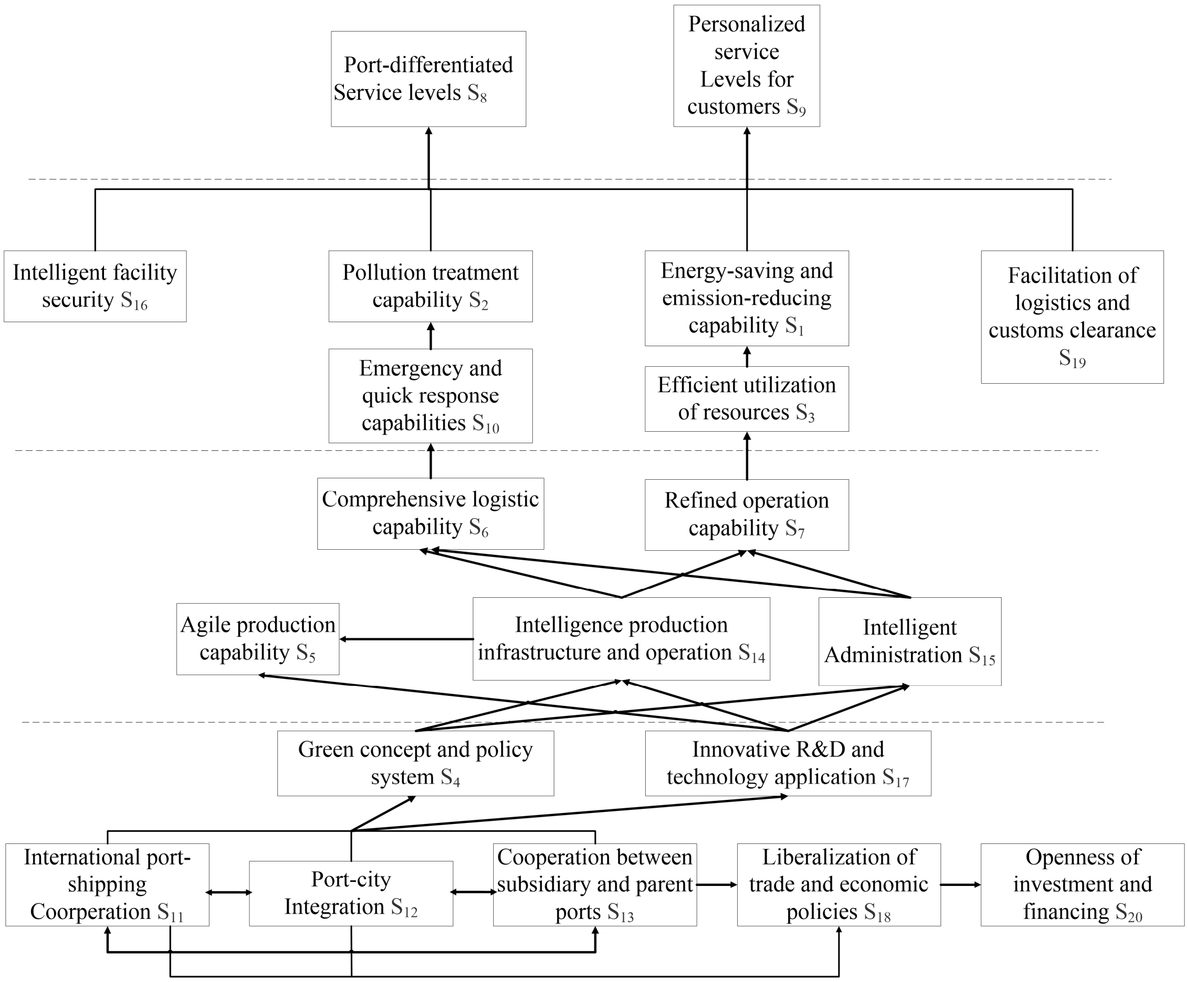

Figure 3. Governance framework of critical influencing factors for green and smart ports.

5.2.1. Analysis of the Relationship between Factors at the First and the Second Hierarchies

The first hierarchy contains port-differentiated service levels, S_8, and personalized service levels for customers, S_9, both of which fall into two distinct aspects of personalization. The port-differentiated service level stands for the capability of port services that are different from those at other ports, while personalized service levels for customers refer to the capability of providing services targeting different customers, both of which are at the core competitiveness of ports. The second hierarchy contains energy-saving and emission-reducing capability S_1, pollution treatment capability S_2, efficient utilization of resources S_3, emergency and quick response capabilities S_{10}, intelligent facility security S_{16}, and logistics clearance ability S_{19}. The first three are greenness factors and their implementation helps achieve the greenness goals of ports. Although the emergency and quick response ability of personalization S_{10} is not at the first level, it is still an inevitable requirement for port development. The second hierarchy directly affects the fulfillment of the first hierarchy. In the second hierarchy, emergency and quick response capabilities S_{10} and efficient utilization of resources S_3 at the third level, respectively, affect the emission treatment capability S_2 and the energy-saving and emission-reducing capability S_1. The stronger the response capability to environmental accidents, the quicker and more proper the pollution control. Meanwhile, efficient utilization of resources can also boost energy conservation and emission reduction to a large extent.

5.2.2. Analysis of the Relationship between Factors at the Second and the Third Hierarchies

Agile production capability S_5, comprehensive logistic capability S_6, and refined operation capability S_7 belong to the agility category. They jointly serve as the basic means of port operations. Intelligent port production infrastructure, operation S_{14}, and intelligent administration S_{15} belong to the intelligence category. They provide hardware and technical support for port development. In this sense, the third hierarchy constitutes a basic approach to realize the second hierarchy. Specifically, intelligent port production infrastructure and operation S_{14} can effectively promote the roles of agile production capability S_5, comprehensive logistic capability S_6, and refined operation capability S_7, while intelligent administration is also an effective guarantee of exerting agile capabilities.

5.2.3. Analysis of the Relationship between Factors at the Third and the Fourth Hierarchies

Level 6 factors in the fourth hierarchy include the environmental protection concept and policy system S_4 and the innovative R&D and technology application S_{17}, both of which are core ideas of green and smart port development and are required for ports to develop core competitiveness. The two influence each other. The popularization of green ideas and implementation of relevant policies will promote R&D and the application of new concepts and technologies, while innovative ideas will, in turn, promote the greening progress. The international port-shipping cooperation S_{11}, the port-city integration S_{12}, and cooperation between subsidiary and parent ports S_{13} at the seventh level belong to the cooperation category. The three promote each other and represent an inevitable trend of port development. The liberalization of trade and economic policies S_{18} and the openness of investment and financing S_{20} fall into the liberalization category. Liberalized policies can open up investment and financing markets and promote international cooperation. The fourth hierarchy is related to ideological, strategic, and policy elements. As the third hierarchy evolves, it will inevitably require the support of ideas, underlying strategies and the soft environment of policies. They are also deep-seated factors that affect port development.

5.2.4. Suggestions on the Development of Green and Smart Ports

Based on the analysis, the paper puts forward countermeasures and suggestions in three aspects: port operation strategies, technical means, and approaches of implementation. First of all, in terms of business strategy, this paper proposes to enhance international port-shipping and port-port cooperation, vigorously promotes the new development mode of subsidiary and parent port consortia, and nurtures the relevant talents. The paper advises the vigorous publicizing and promoting of green philosophy to elevate greening to a new height and enhance social responsibility. It also suggests that competent authorities should actively formulate relevant policies to guide the greening process and attach importance to innovative R&D and technological application. At the same time, dedicated innovative R&D departments should be set up through cooperation and, drawing on advanced experience from peers to boost mutual promotion between technological application and innovative R&D, expand the liberalization of economic and trade policies and open up investment and financing markets to promote market liberalization and international development. Second, in terms of technical means, we should put more stress on port Internet of Things (IoT) and set up relevant departments to study this technology. It is advisable to start with pilot projects such as large ports and inland dry ports and focus on solving key technical barriers involved in port IoT construction to achieve gradual promotion of best practices and the improvement of management patterns so that the traditional management mode can transform toward a modern and intelligent one. Meanwhile, it is also imperative to cultivate learning-oriented and innovative talents with compound skills and organically combine the information technology with management means to facilitate the fulfillment of the information goal. We should learn from large ports in the world to update certain port infrastructures and improve port production operations, logistics, and other basic capabilities. Third, in terms of approaches of implementation, we should place emphasis on environmental protection and sustainable development and increase greening investment such as energy conservation and emission reduction, pollution treatment and the efficient utilization of resources to gradually elevate our greening capabilities. Management personnel should pay close attention to changes in the environment and market and formulate detailed plans and objectives, as well as follow-up measures to build up capabilities in quick and emergency responses. Intelligent security systems should be introduced and infrastructure should be regularly maintained to increase operational efficiency. Moreover, competent authorities should actively communicate and coordinate with customs, as well as commodity inspection, animal and plant quarantine, and health quarantine departments to optimize policies and facilitate logistics and customs clearance.

6. Conclusions

Development of a green and smart port represents an inevitable trend for future ports. Mutually integrated development of the two contributes to enhancing port competitiveness as well as to accommodating issues of sustainability in tandem with artificial intelligence, and big data environment. Therefore, it is worthwhile to study and analyze the critical factors driving the development of a green and smart port. The contribution of this study is threefold. First, it creates an initiative for the governance framework of a green and smart port. Second, it provides a practical tool for the factor analysis of a green and smart port. Third, the achievements of this study can provide a decision-making basis and information reference for international organizations, relevant governments or policy-makers to formulate reasonable and effective governance strategies for green and smart port development.

Based on the analysis of the related concepts of green and smart ports, this paper reviewed relevant literature and experts' suggestions to extract the factors influencing the development of green and smart ports and set up a reasonable governance framework for green and smart ports using the ISM, in an attempt to make suggestions on building green and smart ports from port operation strategies, technical means, and approaches of implementation of three aspects. First of all, in terms of operational strategy, we should attach greater importance to cooperation and development, strengthen cooperation between ports and shipping departments, and jointly promote the concept of green and smart port development. Secondly, in terms of technical means, we should accelerate the application of high-tech, new technology, focus on solving the key core technical problems involved in the development of green and smart ports, and combine intelligent technology innovation with port operation management to realize the intelligentization and green environmental protection of port production and development. Third, in terms of ways of realization, the concept of sustainable development should be strengthened. We should formulate detailed green and smart port planning targets and specific operational plan measures to improve the capability of rapid response and emergency, optimize port logistics policy, and improve the convenience of port logistics operation. Further research into the development of green and smart ports is in the planning stage to explore in-depth the content and theories regarding ports, expand the research scope, improve the rationality of the indicator system, and rectify deficiencies in order to summarize more accurate and effective suggestions on green and smart port construction.

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