

Article

An Integrated Entropy-COPRAS Framework for Ningbo-Zhoushan Port Logistics Development from the Perspective of Dual Circulation

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Abstract: To promote the construction of new development patterns of dual circulation and to accelerate the smooth flow of logistics channels, port logistics has become a new growth point for the logistics industry that accelerates the connection between domestic and foreign dual circulation. Ningbo-Zhoushan Port, as one of the main hub ports in China, is facing the key issue of how to clarify its current development status and future development direction. To scientifically measure and evaluate the status quo of the logistics development of Ningbo-Zhoushan Port, clarify the advantages and disadvantages of the development and construction of the Ningbo-Zhoushan Port logistics industry, based on the situation of new standards and new requirements for the logistics industry in the dual circulation pattern, this study firstly constructs a scientific and reasonable evaluation index system of port logistics from seven aspects, including port infrastructure, international logistics capacity, and smart logistics capacity. An integrated comprehensive evaluation method based on entropy and Complex Proportional Assessment (COPRAS) is then proposed, and a comprehensive evaluation and longitudinal comparative analysis of the logistics level of Ningbo-Zhoushan Port are carried out. The results show that the development of Ningbo-Zhoushan Port in recent years is in line with that of many other ports due to the benefit of green logistics capacity, but it is seriously limited by smart logistics capabilities, and in the future, it should choose to continue to exert efforts in international logistics capabilities, green logistics capabilities, and total logistics capabilities.

Keywords: dual circulation; port logistics; Ningbo-Zhoushan Port; entropy weight; COPRAS

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1. Research Background

Faced with the dilemma of the surge of international unfavorable factors and weak domestic consumer demand, the meeting of the Standing Committee of the Political Bureau of the Central Committee on 14 May 2020, proposed to deepen the supply-side structural reform, give full play to China's super-large-scale market advantages and domestic demand potential, and build a development pattern of domestic and international "dual circulation" mutual promotion. As a basic, strategic, leading industry, the logistics industry is an important support for the operation of the national economy. Among them, port logistics is the core hub for allocating urban resources, which provides an important driving force for urban economic development and is also an important part of national economic development. In this process, some coastal ports that can lead the domestic big circulation and connect the domestic and international "dual circulation" logistics hub nodes shoulder great responsibilities [1]. Although China's port logistics construction has gradually matured, the existing domestic research on the evaluation index of port logistics still stays on the basic index measurement, lacking a more advanced index system, and the evaluation results and development suggestions obtained are no longer applicable to today's "double-cycle" development trend.

Ningbo-Zhoushan Port is a rare deep-water port in the world [2]. As a key part of the Shanghai International Shipping Center, Ningbo-Zhoushan Port is not only an important transit base for iron ore and crude oil and a storage and transportation base for liquid chemicals, coal, and grain in China, but also a core carrier for serving the Yangtze River Economic Belt, building Zhoushan River-Sea Intermodal Service Center and the development of Zhejiang's marine economy. In the development and construction of the integration of "the belt and road initiative" and the Yangtze River Delta, it is considered as the "hardcore" backbone. Promoting the development and construction of Ningbo-Zhoushan Port is conducive to promoting the development of port-adjacent industries, promoting economic development, attracting capital inflows, and enhancing the competitiveness of the city. However, at present, the port logistics development of Ningbo-Zhoushan Port is not perfect, the service level of port logistics is low, the service cost is high, the collection and transportation system and logistics information service system are not ideal, and the innovation ability is relatively backward. Under the "double-circulation" pattern, all ports formulate corresponding strategic policies and actively promote the innovative development of port logistics. However, Ningbo-Zhoushan Port lacks a systematic port logistics development evaluation system, which leads to the failure of timely feedback on the port's real situation, the difficulty of effective supervision and evaluation of rules and regulations, and the blindness of its development.

To solve the aforementioned problems, this study re-selects the evaluation indicators that are in line with the progress of the times, scientifically measures and evaluates the logistics development status of Ningbo-Zhoushan Port from seven important aspects, and on the basis of which, an integrated Entropy-COPRAS framework is proposed to promote the efficient and green development of the port, and improve the formation of "dual circulation" pattern.

2. Literature Review

As the core hub for allocating urban resources, the port is an important node in the transportation network. With the integration of the world economy, its functions are constantly improved and its connotation is constantly broadened, and it is playing an increasingly important role in modern logistics. As a new term, "port logistics" has only been put forward frequently in recent years, and it has been paid more and more attention to the deepening of people's research on modern logistics. From the beginning of the 21st century, domestic and foreign scholars began to propose the quantitative analysis of port logistics, and now the theoretical research and practice of port logistics have gradually deepened and matured. Scholars have made diversified theoretical research on port logistics, which has not only achieved fruitful results in the supply chain [1] and green port efficiency [3], but also actively carried out research on port logistics analysis and forecast [4], regional port logistics [5], and port logistics optimization [6]. At the same time, the measurement of port logistics efficiency [7,8], the evaluation of the coordination degree and coordinated development of port logistics and the hinterland economy [9–11], the evaluation of green logistics development level in port [12], are gaining more and more attention.

During the research of port logistics, Feng et al. [13] took Shandong coastal ports (Qingdao, Rizhao, Yantai, Weihai, Weifang, and Jining ports) as research objects, established an evaluation index system and evaluation model of logistics transportation efficiency on the basis of the analytic hierarchy process (AHP), evaluated their logistics transportation efficiency, and put forward suggestions for improvement. Gao et al. [14] used fuzzy-AHP and ELECTRE III to evaluate the port competitiveness according to the total weights obtained based on six key criteria (port size, port location, hinterland economy, port costs, operations management, and growth potential), thus obtaining reasonable and effective evaluation results. Zhong et al. [15] selected five evaluation indexes and used the grey target model to measure the port's economic efficiency. This method is simple in the calculation, and can effectively overcome the problem which is that the previous

research cannot accurately evaluate the port efficiency with small samples and multiple indexes. In addition, some scholars also used the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method, comprehensive weighting method, principal component analysis (PCA), and the data envelopment analysis (DEA) model for theoretical research [16].

In today's mature development of port logistics construction, most of the existing domestic and foreign studies on port logistics evaluation indexes still focus on infrastructure construction and basic throughput, and the methods used are basically the traditional evaluation methods. It should be noted that China's port construction has entered a high-quality development stage, and the "double-circulation" situation is becoming more and more fierce. Under such a domestic environment, although there are some researches on intelligent logistics and international logistics in the industry, these more advanced indicators have never been used to measure the port logistics capability, and the new comprehensive evaluation system is lacking. The Complex Proportional Assessment (COPRAS) method proposed by Zavadskas et al. [17], as an effective multi-attribute decision-making method, does not need to convert and unify attribute categories during use, can comprehensively consider the importance and validity of attributes, and is easy to operate and calculate. It has been widely used in various project selection and performance evaluations at present. For example, to overcome the shortage of water resources and the increasing water demand by using inter-basin water transfer schemes, eight inter-basin water transfer schemes from the Grand Karon Basin to the central plateau of Iran are prioritized by the COPRAS method [18], which is beneficial for decision makers to evaluate inter-basin water transfer projects under uncertain conditions; Alkan et al. [19] used the COPRAS method to evaluate and rank renewable energy in 26 regions of Turkey, which provided a theoretical reference for development institutions and investors. Hezer et al. [20] studied the security level of 100 regions around the world under the impact of the COVID-19 virus, and ranked them by using COPRAS and VIKOR methods, respectively.

The main aim of this study is to construct a set of scientific and reasonable index systems of port logistics development that is more in line with the requirements of the "double-cycle" era, take the logistics situation of Ningbo-Zhoushan Port from 2014 to 2020 as an individual plan, and make a longitudinal analysis and evaluation of its logistics situation by using the new proposed Entropy-COPRAS evaluation framework. Compared with TOPSIS, DEA, and other methods, COPRAS is suitable for the research of larger samples in the case that individual data may be missing, which is more in line with the research idea and purpose of this paper. In the evaluation process, the utility of indicators can be comprehensively considered, which makes the evaluation results more reasonable. The entropy weight method mainly determines the weight through the difference of index information, which can avoid the interference of human factors in the process of solving the weight, and has strong objectivity. Thus, the proposed Entropy-COPRAS method can make the evaluation results more realistic and facilitate the objective and reasonable analysis of the Ningbo-Zhoushan port logistics level. This will help us to better define the self-positioning of regional port logistics in the new era, and intuitively reflect the problems in the development of regional port logistics, to get targeted countermeasures and suggestions.

3. Evaluation Index System of Port Logistics Based on "Dual Circulation" Pattern

3.1. Principles of Selecting Index

Formulating a set of operable and effective comprehensive evaluation index systems is the basis for evaluating port logistics from the perspective of "dual circulation". According to existing researches of port logistics evaluation [21–26], this paper will be as close to the following principles as possible during the selection of evaluation indexes to construct a comprehensive evaluation system:

(1) Scientific principle. The scientific principle means that the selection of evaluation indexes should conform to the requirements of "dual circulation" for port logistics and

the socio-economic law of port logistics development when constructing a comprehensive evaluation system. The requirement is that the classification of indexes is accurate and comprehensive, the definition of indexes is concise and clear, and each stage of data processing must have a realistic basis of science and strong supporting theory.

(2) Principle of comprehensiveness. The selected port logistics indexes should include not only basic indexes such as port infrastructure, logistics capacity, and the economy of the city where the port is located, but also innovative indexes such as production logistics capacity, international logistics capacity, and intelligent logistics capacity that can reflect the future development direction of port logistics based on the “dual circulation” pattern. The system should comprehensively reflect the development of port logistics from the “dual circulation” perspective.

(3) Principle of operability. When designing the index system, it is necessary to consider whether the index selection is comprehensive or not, as well as the operability of the index, such as whether the index data can be collected, what method to collect, etc. We shall try to select the index with strong operability and representativeness.

3.2. Analysis of the Composition of the Index System

Combined with the new requirements of the development pattern of “constructing a large domestic circulation as the main body, and the mutual promotion of international and domestic ‘dual circulation’” to port logistics, this paper takes port logistics infrastructure, logistics capacity, the economy of the city where the port is located, production logistics capacity, international logistics capacity, green logistics capacity, and intelligent logistics capacity as the seven subsystems of the index system to construct the evaluation index system of port logistics from the perspective of “dual circulation”.

(1) Port logistics infrastructure

Port infrastructure refers to the facilities that must be provided to complete the most basic functions of the port, generally including port channel, breakwater, anchorage, wharf, berth, port traffic and supporting facilities, etc. Considering the related logistics, representativeness and operability of the indexes, the total number of wharf berths and berths above 10,000 tons are selected to measure the infrastructure of the port.

(2) Logistics capability

Port logistics refers to the central port city making use of its own port advantages, relying on the advanced software and hardware environment, strengthening its radiation ability to the logistics activities around the port, highlighting the advantages of port collection, inventory, and distribution, and developing a comprehensive port service system with the characteristics of covering all links of the logistics industry chain, based on the port-adjacent industry and supported by information technology, with the goal of optimizing the integration of port resources. According to the existing comprehensive evaluation system of port logistics, this paper selects the cargo throughput (100 million tons) and container throughput (10,000 TEU) to represent the logistics capacity of the port.

(3) Economy of port city

The economic situation of the port city affects all aspects of the port, and the development of the urban logistics industry is also closely related to port logistics. Therefore, the economic development of the port city is an important index to evaluate the port logistics. Based on the summary of the existing evaluation index system, this paper selects fiscal revenue (CNY 100 million), the added value of primary industry (CNY 100 million), added value of secondary industry (CNY 100 million), per capita GDP (yuan), freight volume (10,000 tons), and railway freight volume (10,000 tons) to measure the economy of the city where the port is located.

(4) Production logistics capacity

Production logistics refers to the logistics activities in the production process. Generally, it means that after raw materials and purchased parts are put into production, they are delivered to each processing point and storage point through the distributed materials. In the form of work-in-process, they flow from one production unit (warehouse) to another

and are processed and stored according to the specified process. With the help of certain transportation devices, they circulate at a certain point and then flow out from a certain point, which always reflects the flow process of the physical form of materials. The productive berth refers to the place where the freighter carrying the means of production stops. In this paper, productive berths (10,000 tons or more) are selected to measure the port's production and logistics capacity.

(5) International logistics capacity

International logistics, also known as global logistics, refers to an international commodity transaction or exchange activity in which the production and consumption are carried out independently in two or more countries, in order to overcome the space and time distance between production and consumption and to physically move the materials, so as to achieve the ultimate goal of international commodity transactions. In this paper, the throughput of foreign trade goods (100 million tons) and the volume of international transit containers (10,000 TEU) are selected to measure the international logistics capability of ports.

(6) Green logistics capacity

Green logistics is the process of reducing the impact of logistics on the environment by making full use of logistics resources, adopting advanced logistics technology, and rationally planning and implementing logistics activities such as transportation, storage, loading and unloading, handling, packaging, distribution, processing, distribution, and information processing. According to some existing research and news reports, this paper selects coal throughput (10,000 tons), ore throughput (10,000 tons), and sea-rail intermodal container volume (10,000 TUE) to measure the port's green logistics capability. It should be noted that coal throughput (ten thousand tons) and ore throughput (ten thousand tons) may seem to have nothing to do with green logistics, but in fact, when analyzing the entire domestic logistics chain, it is very important to change "bulk transportation" to "container transportation" in key places, and ports are such places. The main advantage of "bulk transportation" to "container transportation" is that the use of fully enclosed transportation results in less pollution to the environment, less affected by transportation loss, and effective use of empty containers for return journey, etc. It is undeniable that the efficiency improvement brought by "bulk transportation" to "container transportation" is related to the green construction of a complete domestic logistics chain, and the overall efficiency improvement will promote the green construction of the port part. The annual export volume of coal and ore in our country has reached a certain level, which will not increase or drop sharply in a short time. Therefore, as a key point where "bulk transportation" is changed from "container transportation" to "container transportation" in logistics chain, the port green logistics capacity can be measured by these two indicators to a certain extent.

(7) Intelligent logistics capacity

Intelligent logistics refers to improving the ability of analysis and decision-making and intelligent execution of logistics systems through intelligent technologies and means such as intelligent hardware, the Internet of Things, big data, and improving the intelligence and automation level of the whole logistics system. On 7 June 2017, the Ministry of Transport issued the "Notice on Publishing the List of Smart Port Demonstration Projects and Related Matters", which indicates that all work on China's smart port demonstration projects has officially entered the implementation stage. As important content and the most direct embodiment of smart port, smart logistics is the strategic direction and key area of China's port development during the 13th Five-Year Plan period and in the future. However, at present, when measuring the port's intelligent logistics capability, there is still a problem that most indexes are not representative enough, and there is also a lack of complete evaluation system research in the field. However, considering the scientific nature of the data, this paper still chooses two operable indicators: R&D expenditure (10,000 yuan) and the number of winning projects (items) for the "China Port Association Science and Technology Award" to measure the intelligent logistics capability of ports.

The detailed evaluation index of port logistics is listed in Table 1.

Table 1. Evaluation Index System of Port Logistics.

First-Level Index	Second-Level Index	Unit	References
Port infrastructure construction (X_1)	Total number of berths (C_{11})	Individual	Mo et al. [21]
	Berths above 10,000 tons (C_{12})	Individual	Feng et al. [13]
Logistics capability (X_2)	Cargo throughput (C_{21})	Tons	Mo et al. [21]
	Container throughput (C_{22})	Wanteu	Qing et al. [27]
Economy of port city (X_3)	State revenue (C_{31})	One hundred million yuan	Mo et al. [21] Wang et al. [22] Yang et al. [28]
	Added value of primary industry (C_{32})	One hundred million yuan	
	Added value of secondary industry (C_{33})	One hundred million yuan	
	Per capita GDP (C_{34})	Yuan Dynasty (1206–1368)	
	Volume of goods transported (C_{35})	Ten thousand tons	
	Railway freight volume (C_{36})	Ten thousand tons	
Production logistics capacity (X_4)	Productive berth (C_{41})	individual	Mo et al. [21]
	Productive berths with a tonnage of over 10,000 tons (C_{42})	individual	Jiang et al. [23]
International logistics capability (X_5)	Foreign trade throughput (C_{51})	Tons	Mo et al. [21]
	International transit volume (C_{52})	Wanteu	Jiang et al. [23]
Green logistics capability (X_6)	Coal throughput (C_{61})	Ten thousand tons	Hu et al. [24] Hua et al. [12]
	Ore throughput (C_{62})	Ten thousand tons	
	Container volume of sea-rail combined transport (C_{63})	Wanteu	
Smart logistics capability (X_7)	R&D expenditure (C_{71})	Ten thousand yuan	Hua et al. [12]
	Number of winning projects of the Science and Technology Award of China	Item	Meng et al. [26]
	Port Association (C_{72})		Yang et al. [28]

4. An Integrated Entropy-COPRAS Framework for the Port Logistics Development

4.1. The Weights of Index System

In this paper, from the perspective of vertical development, the weights of nineteen indexes in seven subsystems of port logistics are determined by the entropy method. The evaluation information of the entropy weight method mostly comes from the original data of the evaluated object, which can reflect the development course of the port in the last seven years to the greatest extent and is comparable in time, so it is an objective comprehensive evaluation method. The main steps are described as follows.

Step 1. It is assumed that various indexes in the year are to be evaluated. The collection of different annual monomer is $A = \{A_1, A_2, \dots, A_m\}$, and the index $C = \{C_1, C_2, \dots, C_n\}$ with the quantity n is used to evaluate the port logistics status every year. As the measurement units, economic significance and manifestation of each index are different in the measurement index system, these indexes cannot be compared directly, and they must be standardized first. The collection of positive indexes is recorded as J_1 , and the collection of negative indexes is recorded as J_2 . The standardized formula is given as:

$$x_{ij} = I_{ij} / \sum_{i=1}^m I_{ij}, \quad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n. \quad (1)$$

where I_{ij} is the evaluation value of index C_j in year i , x_{ij} is the standardized result. Therefore,

the standardized decision matrix $\bar{X} = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ x_{21} & \cdots & x_{2n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix}$ is obtained.

Step 2. Calculate the entropy e_j of index C_j in year i :

$$e_j = -k \sum_{i=1}^n x_{ij} \ln x_{ij} \quad (2)$$

Step 3. Calculate the difference coefficient g_j of index C_j :

$$g_j = 1 - e_j \quad (3)$$

Step 4. Normalize g_j and calculate the weight w_j of index C_j in year i :

$$w_j = g_j / \sum_{j=1}^n g_j \quad (4)$$

Obviously, $0 \leq w_j \leq 1$ and $\sum_{j=1}^n w_j = 1$.

4.2. Evaluation Process of COPRAS Method

After obtaining the index weight, we use the COPRAS method to transform the evaluation of each index into the overall characteristics of the reaction index. The main steps are as follows:

Step 1. Calculate the weighted standardized decision matrix $\hat{X}$ based on the standardized decision matrix.

$$\hat{X} = \begin{pmatrix} \hat{x}_{11} & \cdots & \hat{x}_{1n} \\ \vdots & \ddots & \vdots \\ \hat{x}_{m1} & \cdots & \hat{x}_{mn} \end{pmatrix} \quad (5)$$

where the weighted standardized assessment is:

$$\hat{x}_{ij} = w_j \times x_{ij} \quad (6)$$

Step 2. Calculate the comprehensive benefit value of the set A_i composed of each annual monomer by using the following formula for the positive index of each year:

$$p_i^a = \sum_{j=1}^n \hat{x}_{+ij}, \quad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n. \quad (7)$$

where, $\hat{x}_{+ij} = \begin{cases} \hat{x}_{ij}, & \text{if } C_j \in J_1 \\ 0, & \text{if } C_j \in J_2 \end{cases}$. Obviously, p_i^a should be as large as possible.

For the reverse index of each year, the following formula is used to calculate its comprehensive cost value:

$$p_i^b = \sum_{j=1}^n \hat{x}_{-ij}, \quad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n. \quad (8)$$

where, $\hat{x}_{-ij} = \begin{cases} 0, & \text{if } C_j \in J_1 \\ \hat{x}_{ij}, & \text{if } C_j \in J_2 \end{cases}$. Obviously, p_i^b should be as small as possible.

Step 3. Calculate the comprehensive evaluation value of each annual monomer set A_i , by using the following formula:

$$Q_i = p_i^a + \frac{p_{\min}^b \times \sum_{i=1}^m p_i^b}{p_i^b \times \sum_{i=1}^m \frac{p_{\min}^b}{p_i^b}} = p_i^a + \frac{\sum_{i=1}^m p_i^b}{p_i^b \times \sum_{i=1}^m \frac{1}{p_i^b}}, \quad i = 1, 2, \dots, m \quad (9)$$

where $p_{\min}^b = \min\{p_i^b\}$. Obviously, the larger the value of Q_i , the better the annual monomer set A_i .

Step 4. Define the utility degree of each annual monomer set A_i as the ratio between the comprehensive evaluation value of the annual monomer itself and the maximum comprehensive evaluation value:

$$U_i = \frac{Q_i}{Q_{\max}} \times 100\%, \quad i = 1, 2, \dots, m \quad (10)$$

where $Q_{\max} = \max\{Q_i\}$.

5. Evaluation and Analysis of Ningbo-Zhoushan Port Logistics Development Level

5.1. Evaluation Results of Ningbo-Zhoushan Port Logistics Level

In this subsection, the proposed integrated Entropy-COPRAS method is used to measure the logistics development level of Ningbo-Zhoushan port from 2014 to 2020, so as to clarify the development trend and path of the Ningbo-Zhoushan port logistics industry, and thus provide targeted countermeasures and suggestions for its new development. According to the designed evaluation index system of port logistics, most of the index data are derived from China Port Yearbook, Ningbo Statistical Yearbook, and Zhoushan Statistical Yearbook. In addition, this paper uses the isolated method to interpolate and extrapolate the existing data to fill in a small number of missing data. Considering that the original data of each index are different in measurement units and economic significance, the original data of each index of Ningbo-Zhoushan Port shall be standardized.

Firstly, the original data of indexes are standardized into a same type according to Equation (1), and then the standardized decision matrix X is constructed.

Secondly, according to Equations (2)–(4), the entropy and difference coefficient of each index of Ningbo-Zhoushan port logistics can be calculated, and the weights of each index can be obtained. The results are shown in Table 2.

Table 2. Index weight of port logistics in Ningbo-Zhoushan Port.

w_1	0.001	w_8	0.026	w_{15}	0.024
w_2	0.010	w_9	0.053	w_{16}	0.072
w_3	0.014	w_{10}	0.009	w_{17}	0.480
w_4	0.022	w_{11}	0.001	w_{18}	0.055
w_5	0.028	w_{12}	0.010	w_{19}	0.135
w_6	0.005	w_{13}	0.010		
w_7	0.029	w_{14}	0.019		

Then, based on the standardized decision matrix, the COPRAS method is used to measure the standardized data according to Equation (5), and the utility degree of each subsystem evaluation index of Ningbo-Zhoushan port logistics is calculated according to Equations (7)–(10), respectively. The evaluation result of each subsystem evaluation index of Ningbo-Zhoushan port logistics is shown in Table 3.

Table 3. Evaluation results of each subsystem of port logistics in Ningbo-Zhoushan Port.

	2014	2015	2016	2017	2018	2019	2020
X_1	0.769	0.804	0.834	0.875	0.910	0.970	1
X_2	0.703	0.733	0.764	0.858	0.920	0.957	1
X_3	0.634	0.669	0.717	0.818	0.906	0.971	1
X_4	0.769	0.804	0.834	0.874	0.910	0.970	1
X_5	0.732	0.766	0.793	0.883	0.939	0.977	1
X_6	0.208	0.216	0.362	0.456	0.634	0.818	1
X_7	1	0.591	0.836	0.612	0.549	0.726	0.663

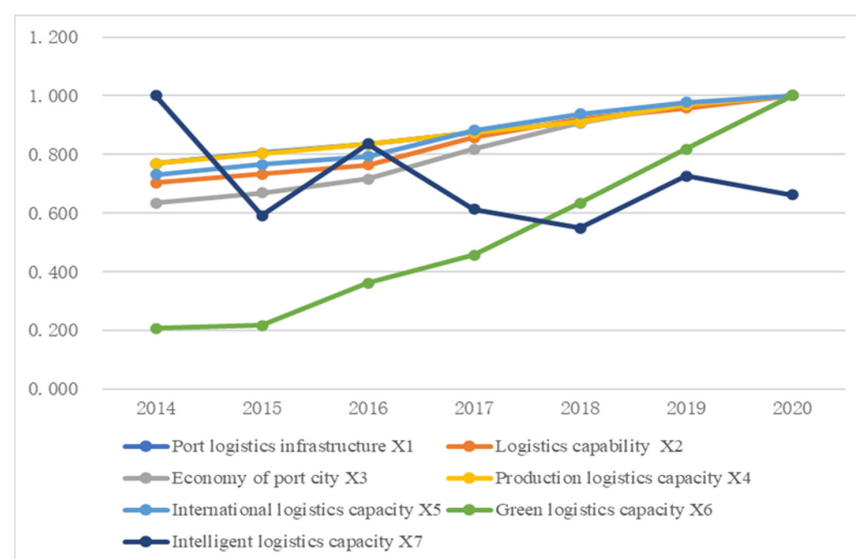
Similarly, on the basis of Equations (7)–(10), the comprehensive benefit value, comprehensive cost value, comprehensive evaluation value, and utility degree corresponding to each index value of port logistics of Ningbo-Zhoushan Port in each year are calculated, and the comprehensive evaluation of different years is sorted according to the obtained utility degree. The results are shown in Table 4.

5.2. Analysis of Evaluation Results of Each Subsystem Index

According to the utility obtained in Table 3, we make the development trend chart of Ningbo-Zhoushan Port Logistics from 2014 to 2020, shown in Figure 1.

Table 4. Ningbo-Zhoushan Port Logistics Evaluation Results.

	Comprehensive Benefit Value	Comprehensive Cost Value	Comprehensive Evaluation Value	Utility Degree	Sort
2014	0.084	0.014	0.097	44.01%	6
2015	0.075	0.019	0.084	38.13%	7
2016	0.098	0.009	0.118	53.39%	5
2017	0.114	0.013	0.128	57.80%	4
2018	0.143	0.014	0.156	70.64%	3
2019	0.181	0.014	0.194	87.71%	2
2020	0.209	0.014	0.221	100.00%	1

**Figure 1.** Utility degree of port logistics of Ningbo-Zhoushan Port from 2014 to 2020.

It can be seen from the changes in the utility degree of Ningbo-Zhoushan Port's logistics evaluation indexes from 2014 to 2020, the development level of the five indexes of Ningbo-Zhoushan Port's infrastructure, logistics capacity, city economy where the port is located, production logistics capacity and international logistics capacity are equivalent, with the average utility degree reaching more than 80%. Correspondingly, the levels of green logistics capability and intelligent logistics capability vary greatly, but the average utility is not high. This shows that from 2014 to 2020, Ningbo-Zhoushan Port's port logistics industry has achieved great success in port infrastructure construction, logistics capacity, the economy of the city where the port is located, production logistics capacity, and international logistics capacity, and it is still progressing with a weak growth trend. The construction of port logistics infrastructure and production logistics capacity is the material basis for the vigorous development of the port logistics industry. Ningbo-Zhoushan Port's emphasis on logistics infrastructure construction, logistics capacity, and production logistics capacity has provided a strong guarantee for the rapid development of the port logistics industry in recent years. The international logistics capability reflects the competitiveness of the port logistics industry in overseas markets, and at the same time, it responds to the new development pattern of "dual circulation" and promotes the international and domestic dual circulation policy. Secondly, the vigorous development of Ningbo-Zhoushan Port's port logistics industry is inextricably linked with the improvement of Ningbo's economic level. However, the low level of green logistics capability and intelligent logistics capability indicates that the process of vigorously promoting low-carbon development, reinforcing the construction of ecological civilization, promoting the greening and recycling of the logistics industry, and combining high-tech with the logistics industry to raise the

intelligence and automation level of the whole logistics system is slow, which is more difficult than other aspects.

From the growth rate, the five indexes of port infrastructure, logistics capacity, the economy of the city where the port is located, production logistics capacity, and international logistics capacity are all showing an increasing trend year by year, and the development paths are consistent. It can be seen that the logistics industry of Ningbo-Zhoushan Port has a good development prospect and shows a steady growth trend. However, due to some achievements in these aspects, there is not much room for improvement. Among them, after 2016, the economic growth rate of the city where the port is located has increased compared with previous years, because the merger of Ningbo Port and Zhoushan Port was completed in 2015, which further promoted the integration of Ningbo-Zhoushan Port, and the port economy has been rapidly improved, thus promoting the rapid economic development of Ningbo. At the same time, compared with previous years, Ningbo-Zhoushan Port's international logistics capability has also improved significantly. The reason is that in recent years, Ningbo-Zhoushan Port has paid attention to expanding the international market of the port logistics industry, striving to build a world-class strong port and an international shipping logistics hub. Especially after the new development pattern of "dual circulation" was put forward, in the process of promoting dual circulation at home and abroad, expanding the international market became an indispensable condition for the further development of the port logistics industry under the new pattern of "dual circulation". However, the development level of intelligent logistics capability fluctuated greatly from 2014 to 2020, except for 2015–2016 and 2018–2019, which showed a downward trend. According to the collected data analysis, the R&D expenditure of Ningbo-Zhoushan Port's logistics industry has increased year by year, but the number of "China Port Association Science and Technology Award" winning projects has not increased year by year, and even dropped from 11 in 2014 to 5 in 2020, thus affecting the development of intelligent logistics capabilities. Therefore, to promote the combination of the high-tech and port logistics industry, and push forward the digital and intelligent development of the port logistics industry requires not only the investment of technical research and development, but also the progress of scientific and technological capability and technology. Moreover, with the country's vigorous implementation of the "innovation for all" policy, the competitive pressure among ports increases, and the progress of technological innovation tends to fall into the bottleneck period. Therefore, the development level of intelligent logistics capability will show such a fluctuation range. The development level of green logistics capability in 2014–2020 is also increasing year by year, and the growth rate is faster than other indexes. This shows that in recent years, Ningbo-Zhoushan Port has responded to the national policy, vigorously promoted the greening and recycling of the logistics industry, and achieved remarkable results.

5.3. Analysis of Comprehensive Evaluation Results of Logistics Level

According to the utility obtained in Table 4, we make the overall development trend chart of Ningbo-Zhoushan Port Logistics from 2014 to 2020, as shown in Figure 2.

From the vertical perspective, the development level of the port logistics industry in Ningbo-Zhoushan Port decreased from 2014 to 2015. From the perspective of subsystem indicators, the reason is that the development of intelligent logistics capability slowed down, which indicated that the decline of it would affect the overall development speed of the port logistics industry. Except for 2014–2015, the port logistics level of Ningbo-Zhoushan Port has improved at a certain speed, especially after 2017, which shows that the port logistics industry of Ningbo-Zhoushan Port has a good development prospect, a large development space, and a more intuitive and remarkable development results. Among them, the growth rate of Ningbo-Zhoushan Port's port logistics level is larger than that of five subsystems such as port infrastructure, which is equivalent to the growing trend of green logistics capability. It can be seen that the improvement of green logistics capability has a strong promoting effect on Ningbo-Zhoushan Port. To sum up, under the "dual

circulation” development pattern, maintaining the development of port infrastructure, logistics capacity, the economy of the city where the port is located, production logistics capacity and international logistics capacity, and increasing investment in smart logistics and green logistics can promote the high-quality development of Ningbo-Zhoushan port logistics industry.

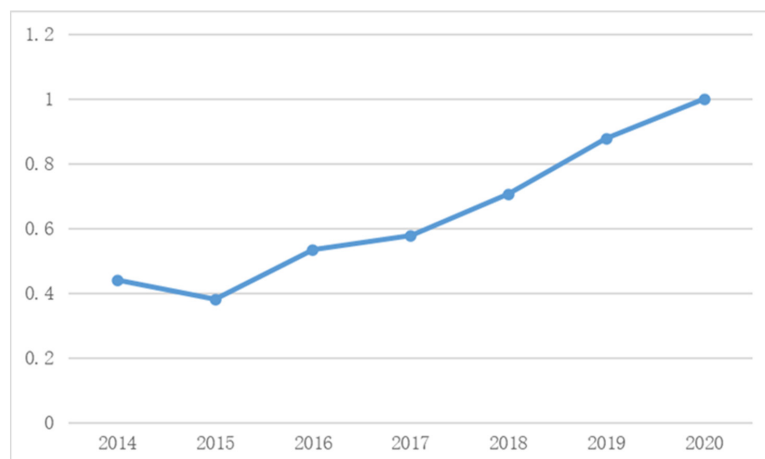


Figure 2. Development Trend of Ningbo-Zhoushan Port Logistics from 2014 to 2020.

5.4. Comparative Analysis with Major Domestic Ports

In this paper, the development level of the logistics industry of the four major ports in China, i.e., Shenzhen Port (Y_1), Shanghai Port (Y_2), Dalian Port (Y_3), and Ningbo-Zhoushan Port (Y_4), is analyzed and compared over the past seven years. On this basis, the horizontal comparison among ports is made, the logistics development level of major domestic ports is analyzed, and the development status of Ningbo-Zhoushan Port is explored.

The collected raw data of various indexes of Shenzhen Port, Shanghai Port, Dalian Port, and Ningbo-Zhoushan Port are processed, and the comprehensive benefit value, comprehensive cost value, comprehensive evaluation value, and utility degree corresponding to each port's logistics index value are obtained every year. Then the index values of each port are sorted according to the obtained utility degree, and the results are shown in Table 5. The utility degree of port logistics evaluation index in different years of each port is shown in Table 6 and Figure 3.

Table 5. Comprehensive evaluation results of port logistics in each port.

Port	Comprehensive Benefit Value	Comprehensive Cost Value	Comprehensive Evaluation Value	Utility Degree	Sort
Y_1	0.097	0.009	0.186	63.52%	4
Y_2	0.278	0.049	0.294	100.00%	1
Y_3	0.214	0.012	0.276	94.00%	2
Y_4	0.237	0.105	0.244	83.09%	3

Table 6. Utility degree of port logistics evaluation index in different years of each port.

Year	Y_1	Y_2	Y_3	Y_4
2014	1.000	0.865	0.913	0.816
2015	1.000	0.774	0.798	0.607
2016	1.000	0.956	0.890	0.916
2017	0.708	0.958	1.000	0.883
2018	0.606	1.000	0.920	0.839
2019	0.537	1.000	0.848	0.854
2020	0.467	1.000	0.768	0.790

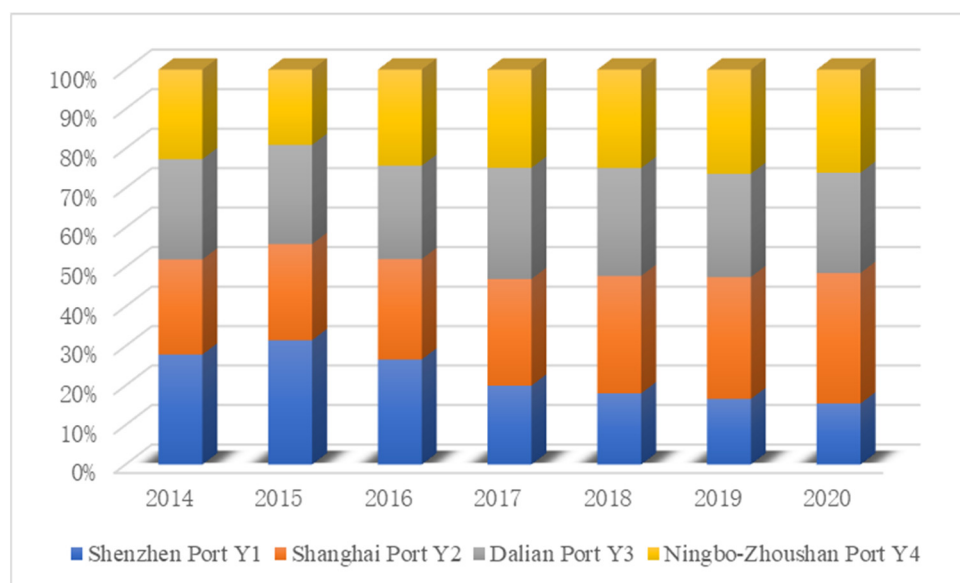


Figure 3. Utility degree of port logistics evaluation index in different years of each port.

As can be seen from Table 5, compared with Shenzhen Port, Shanghai Port, and Dalian Port, Ningbo-Zhoushan Port's port logistics industry has not achieved remarkable development results, and the utility of comprehensive evaluation is 83.09%, which is only higher than Shenzhen Port. However, it can be seen from Figure 3, among the four ports, only Ningbo-Zhoushan Port and Shanghai Port's comprehensive evaluation utility ratio shows an increasing trend year by year. That is to say, compared with other ports, Ningbo-Zhoushan Port and Shanghai Port's port logistics industry can maintain a better development trend. On the whole, although the development level of Ningbo-Zhoushan Port's port logistics industry is not the best, its future development trend is good, and it has more room for development. Therefore, taking Ningbo-Zhoushan Port as the research object of this paper has stronger practical significance. At the same time, combined with the collected port logistics data and the evaluation results in Table 5, it can be seen that the comprehensive benefit value of Ningbo-Zhoushan Port's port logistics index is second only to Shanghai Port, and the benefit performance is good, but the comprehensive cost value ranks first among the four ports, which indicates that the treatment of Ningbo-Zhoushan Port's port logistics in the reverse index is not in place. For example, the coal throughput of Ningbo-Zhoushan Port is much higher than that of other ports. Similarly, for some positive indicators, Ningbo-Zhoushan Port is still weak and needs to be improved. For example, the added value, fiscal revenue, and R&D expenditure of the secondary industry are not as good as those of Shanghai Port and Shenzhen Port. On the whole, compared with other ports, Ningbo-Zhoushan Port's development achievements are not significant, and its green logistics capability and intelligent logistics capability have not been greatly improved. At the same time, the economic development of Ningbo, the hinterland of the port, is also relatively slow.

6. Conclusions

6.1. Main Contributions

Port logistics is an important part of modern logistics. Due to the vigorous promotion of governments at all levels, the active exploration of port enterprises and the entry of foreign multinational logistics enterprises, the development of domestic port logistics is full of vitality. However, development is difficult and there are still many problems. In this case, it is of great theoretical and practical significance to comprehensively and systematically study and evaluate the development state of Ningbo-Zhoushan port logistics from a new perspective of "dual circulation" development pattern. This paper makes an in-depth study on the development of Ningbo-Zhoushan port logistics under the new development

pattern of “dual circulation” from both theoretical and empirical aspects. The main research contributions are as follows:

(1) Construct the analytical framework of port logistics development under the “dual circulation” development pattern. On the basis of clearly defining the concept of port logistics and the background of “double-circulation” development, this paper combined the development of port logistics with the pattern of “double-circulation” and discussed the development trend and direction of port logistics under the development pattern of “double-circulation”, which provided a broader perspective for theoretical analysis and practical exploration of port logistics evaluation in the new era and new environment.

(2) Under the guidance of fully embodying the principles of economy, technology, timeliness, and sustainable development of port logistics system, this paper tentatively discussed the evaluation index factors of port logistics under the “double-circulation” development pattern, and then subdivided the major factors into twenty indexes. Following the principle of establishing port logistics evaluation index, the comprehensive evaluation index system of port logistics under the background of “dual circulation” was established, and the applicability of the evaluation index system of port logistics was analyzed and explained. It lays a certain foundation for further evaluation of port logistics under the background of “dual circulation”.

(3) A mathematical Entropy-COPRAS evaluation framework was tentatively constructed by using qualitative analysis and quantitative analysis, wherein the weights of multiple indicators were determined by the entropy method, and the comprehensive evaluation of port logistics was achieved by the COPRAS approach. Then, the logistics level of Ningbo-Zhoushan Port and Ningbo-Zhoushan Port and other ports was empirically studied and analyzed. The evaluation results are in good agreement with the actual development of these ports. It provides some guidance and theoretical support for better solving the practice of port logistics evaluation under the background of “dual circulation”, and further enriches the existing theoretical system of port logistics evaluation.

6.2. Main Research Conclusions

According to the qualitative analysis and quantitative analysis, and the logistics level of Ningbo-Zhoushan Port and Ningbo-Zhoushan Port and other ports, the evaluation results are in good agreement with the actual development of these ports. It provides some guidance and theoretical support for better solving the practice of port logistics evaluation under the background of “dual circulation”, and further enriches the existing theoretical system of port logistics evaluation.

Specifically, the empirical research results show that the development of Ningbo-Zhoushan Port in recent years meets the requirements of “dual circulation”, but it still needs to keep forging ahead and seeking new ideas, and actively responding to the new call for development. It should focus on the construction of international logistics, green logistics, intelligent logistics, production logistics, etc., and make continuous efforts in international logistics capacity, green logistics capacity, total logistics capacity, etc., to realize the construction of a new port logistics system and adapt the port development to the new logistics demand of “dual circulation”.

Based on the analysis of the development status of Ningbo-Zhoushan Port, the following suggestions are given.

(1) In terms of international logistics, it is necessary to further optimize the supply system, improve the construction of port management division of labor system, enhance the comprehensive service awareness of ports, vigorously develop multimodal transport based on ports, and provide various modes of transportation such as sea, road, railway, and inland river, promote the effective connection of different modes, reinforce the bonded function of parks, and set up special channels for customs supervision between terminals to improve the international transportation capacity of ports.

(2) In terms of smart logistics, major ports need to enhance their independent innovation capability, grasp the essence of smart logistics, accurately understand the connotation

of smart logistics, accelerate the informatization construction of port logistics, and make infrastructure scientific and technological. It also shall improve the construction of port information networks, integrate the existing transportation, warehousing, and other logistics infrastructure, revitalize existing assets, expand functions, improve services, and better meet the needs of port logistics development. On this basis, strengthen the integrated services of the logistics value chain, do a good job in the efficient collaborative operation of the logistics service chain, realize intelligent operation based on the data drive, and finally build an open, shared, and interconnected port ecosystem.

(3) Increase investment in green logistics, apply the new concept of low-carbon development and green economy to port construction, reduce pollution and strengthen governance through technological transformation and technological innovation, strengthen resource recycling and ecological protection, improve energy efficiency, and vigorously build a resource-saving, environment-friendly, and quality-efficient port.

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