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Abstract: “Port–hinterland synergy” means the development of port and hinterland should promote each other. The “dual circulation” development pattern indicates the requirement of exploring the domestic transportation demand and promoting the integration between ports and hinterlands. However, the current research on the synergy level between ports and hinterlands is not enough to meet the needs of constructing a “dual circulation” development pattern, and few studies have explored the influencing factors of port–hinterland synergy level directly, especially in the context of the new development pattern of “dual circulation”. After investigating the synergetic mechanism between ports and hinterlands, this study proposes to further consider the influence of fixed assets allocation and social commodity circulation on the synergy level under the “dual circulation” pattern. So, fixed asset investment and three different forms of commodity circulation activities are selected to represent the corresponding hinterland’s economic activities and added into the evaluation indices. To assess ports’ responsiveness to different kinds of transport demand, throughputs of each port are divided into those of domestic and foreign countries. Then this paper evaluates the level of port–hinterland synergy by the coupling synergy model, and the influence degree of these activities on the synergy level was studied with the partial least squares regression (PLS). The results show that there is heterogeneity in regional and port positioning in the port–hinterland synergy level, and that four selected economic activities’ improvement can enhance the port–hinterland synergy level. Among them, retail industry has the strongest positive effect, followed by tertiary industry, import and export trade, and fixed asset investment.

Keywords: coastal port; hinterland; coupling synergetic model; “dual circulation” development pattern; fixed asset allocation; social commerce circulation

1. Introduction

China is implementing an economic model of “dual circulation”. This model takes the domestic market as the main body and advocates promotion between the domestic market and the international market. Its goal is that China should give full play to its advantages: large market size, strong production capacity, and complete industrial system to tap into its domestic market demand and take the domestic market as the foothold of its development [1]. In 2021, “the 14th Five-Year Marine Economic Development Plan” issued by many provinces proposed that ports should actively integrate into the new national “dual circulation” development pattern. This plan intends that ports should further play a supporting role in hinterland industry, and explore the port service demand derived from domestic production activities to adapt to the transformation of the demand of the hinterlands’ economic development. The construction of fixed assets and social commodity circulation, the key elements to promote “domestic circulation” and
“foreign circulation”, are the important sources of port service demand [2]. Therefore, the above two kinds of economic activities should be considered in the evaluation of port–hinterland synergy level under the new development environment. So, it is necessary to evaluate the port–hinterland synergy level from a new perspective, and on this basis, study the impact of social fixed asset investment and social commodity circulation on the synergy level. By these means, we can provide some recommendations for the ports’ development and construction. This is an important part of pushing Chinese ports to respond to the needs of the new development pattern.

The synergy theory is an important tool and method to study systems science, and it reveals the common principle of change in the updating process of the system development [3]. It studies how each component of the system cooperates to produce the space structure, time structure, and function structure at the macro level. It agrees that the synergistic action of subsystems will form an overall macroscopic movement that is better than the sum of the parts’ movement, which will produce a synergy effect that is “1 + 1 > 2” [4]. The synergy theory, taking the system made up of two or more objects interrelating with each other as its subject, studies the process and the ability of accomplishing certain tasks by cooperating and coordinating with each other [5].

Referring to Liao’s discussion of “coordinated” and “development” [6], we argue that “port–hinterland synergy” means that the port system and the hinterland system are not disjointed in the development process. The port can meet the transportation demand from the hinterland, support the industrial development of the hinterland, and conform to the development trend of the hinterland. The hinterland makes full use of port resources through reasonable overall planning, resource allocation, and industrial layout. This evaluation of the synergetic relationship between port and hinterland is mainly aimed at the level of synergetic relationship between the port and hinterland economy.

2. Literature Review

2.1. Evaluation of Synergetic Degree

At present, the evaluation of synergy level in the academic field is mainly from two perspectives. One is to directly measure the synergy degree based on the coupling synergy model. Based on the definition and discussion of coordination, development, and coordinated development, Liao, C.B. deduced the calculation model of coordination degree and coordinated development degree respectively, and divided the coordinated development of environment and economy into three different levels from simple to detailed [6]. Zhan et al. evaluated the level of economic synergy between Beibu Gulf port and three cities of Guangxi by measuring the coupling coordination degree. The results show that the synergy between port logistics and the regional economy in Guangxi Beibu Gulf has continued to grow [7]. Liu et al. measured the port efficiency by using data envelopment analysis, and then incorporated it into a coupled synergy model to measure the level of synergy between major ports in the Yangtze River Delta region [8]. Meng et al. used the Cobb–Douglas function and deviation coefficients to decrease the deficiencies in the rationality of the economic assumptions in the traditional coupled synergy model. They used the optimized coupling synergy model to measure the level of port-production coupling in Wuhan port [9]. Lu et al. used a composite system coordination degree model to analyze the comprehensive competitiveness of nine major domestic ports and the synergetic mechanism of the ports and their hinterlands. Their job overcame the single perspective, dimension, and subject problems in existing port–hinterland studies. They believed that the ports’ comprehensive competitiveness should be derived from innovation and service, rather than infrastructure factors like before [10]. Cen et al. constructed a regional science and technology collaborative innovation evaluation index system based on system theory and synergy theory and used a coupling coordination model to empirically study the degree of coordinated development among systems. They concluded that the collaborative innovation performance of Shanghai,
Jiaxing, and Hangzhou all showed an upward trend and the overall degree of synergy was high [11]. Zhang et al. constructed a comprehensive evaluation of the port industry and urban economic development indicator system and measured the composite coordination degree of coordination between port industry and economic growth in Hebei Province [12]. A coupled synergy model combined with the entropy weight method or TOPSIS model has also been used to study the synergy level among economic, environmental, social and infrastructure subsystems of a city [13–15].

The second perspective is to indirectly evaluate the level of synergy by measuring the level of correlation between research objects. Yang et al. measured the level of synergy between ports and port industrial parks in six coastal cities in Liaoning province using the synergy relationship matrix and relative concentration index. The results showed that local port industrial parks show a prominent waste of resources and there is poor interaction between industrial parks and ports [16]. Lv et al. made an empirical analysis of the correlation between Chongqing’s port logistics and its regional economy by using the gray comprehensive correlation degree model. The results showed that there was a high correlation between the two. Meanwhile, the degree of coordination between them was analyzed by a multidimensional gray GM (1, N) model. It was concluded that port logistics and economic growth in Chongqing are overall coordinated [17]. Gao et al. studied the port–hinterland interaction between Ningbo and Ningbo port using the data envelopment analysis method and partial correlation analysis method, respectively. They concluded that the development of Ningbo port has a significant role in promoting the economy of Ningbo, particularly the secondary and tertiary industries [18]. Some scholars used a four-stage bootstrap DEA method to evaluate shipping efficiency considering the hinterland’s economic activities and a stochastic frontier analysis (SFA) or Tobit model to study the influencing factors of the efficiency [19–22]. Stanković et al. compared and monitored various aspects of sustainability with a multi-criteria decision-making framework and the preference ranking organization method for enrichment of evaluations [23]. Li et al. investigated the evolution of the container port system of the Pearl River Delta by dynamic shift-share analysis (DSSA). They analyzed the foreland and hinterland strategies of the ports, and argue for the need for more system-wide coordination and collaboration among ports, aiming to avoid wasteful competition [24].

It is found that the hinterland selected for the current evaluation of port–hinterland coordination degree is mostly the prefecture-level city or the single province where the port is located. However, with the upgrading of port scales and the enhancement of the close degree and scope of trade between regions, the hinterland scope radiated by the same port is no longer limited to the prefecture-level city or province where the port is located. Moreover, due to the competition and cooperation between ports in the same region, a hinterland may be served by multiple ports. Therefore, it is difficult to choose a single city or province as the research granularity to adapt to the current situation of a port’s development. In addition, existing evaluations on port development pay more attention to the total scale of port transportation. Now, China’s ports are facing transformation and upgrading under the new development pattern, and the demand for transportation cannot expand without limit. So, it is not appropriate to treat the total throughput only generally like before. Moreover, the existing research results only evaluate the degree of coupling synergy but do not further study the influencing factors and the degree of influence.

2.2. Hinterland Division

To resolve the problem of hinterland classification, some scholars have chosen to classify the hinterland by calculating the generalized cargo transportation cost [25], and some of them combined it with a probabilistic model [26,27] or categorized the hinterland by a neural network based on the assessment of transportation efficiency [28]. Some scholars have evaluated traffic accessibility based on ArcGIS spatial analysis technology.
and a modified gravity model, then used it as the basis for hinterland classification. A combination of geographic data, traditional statistical data [29], and emerging open data were also used to apply the field strength model for hinterland classification [30]. Michele Acciaro et al. studied the contestability of port hinterland, focusing on North Adriatic Ports (NAPs). They concluded that both efficiency- and non-efficiency-related factors affect NAPs [31]. Based on GIS, a spatial interaction model, in which the intermodal cost distance was computed by integrating the raster analysis method and network method, was developed to facilitate the examination of the spatial evolution process of the port group intermodal hinterland by Huang et al. [32]. Peng et al. constructed a discrete selection model based on random utility to divide the dominant hinterland, probabilistic hinterland, and major competitive hinterland of Chinese ports exporting to Europe via the Polar Silk Road [33]. José I. Castillo-Manzano et al. believed that a port’s location, size, and the presence of a logistics park will influence the dynamism of Spanish ports in capturing traffic in shared and disputed hinterlands using pool balanced dynamic models [34]. Ticiana Grecco ZanonMoura et al. used the Huff model to delimit the hinterland of ports considering repulsion and attraction factors [35]. In the context of statistical broad freight transportation costs, it is difficult to estimate accurately because of the many links in which transportation costs are incurred and many tariffs vary from place to place. It is also hard to process vector data due to the complex topology relationship in road networks and topographic relief.

For these reasons, this paper takes cities as units, uses open network data to represent distances, and the principle of “critical value” to classify hinterlands based on the hinterland field spread model, and establishes an evaluation model based on system dynamics to measure the level of port–city synergy by measuring the coupling synergy degree.

2.3. The Relationship between Port and Hinterland Economy

There is existing research including in-depth studies on the relationship between ports and hinterland economies. The research mainly focuses on the relationship between port throughput and hinterland economy and that between port infrastructure and hinterland economy. Song et al. estimate the output elasticity of port infrastructure through production function at the level of four port regions and the port province level. The results indicate port infrastructure investment positively influences the growth of GDP [36]. Wang et al. argue that the infrastructure related to maritime transport plays a key role in promoting the Chinese economy and international trade by the vector autoregressive and the vector error correction model [37]. By constructing a panel regression model, Jiang et al. found that GDP of a hinterland significantly prompts the growth of port throughput. In addition, hinterland population and secondary industry promote the growth of domestic trade throughput. Fixed asset investment significantly affects domestic trade throughput and foreign trade throughput [38]. Bottasso et al. suggest that an increase in the level of port throughput in a given region tends to increase GDP in that particular region by using a spatial panel econometric framework which controls for spatial fixed effects [39]. Using structural equation modeling, Deng et al. found that the growth in the amount and investment of port infrastructure helps to increase the throughput of ports. In addition, they believe that port throughput helps to increase local import and export volume, and the increase in import and export volume will eventually drive the tertiary industry and the size of the urban population [40]. Cong et al. found that there is a two-way Granger causality between foreign trade and throughput, and the growth of port throughput will lead to the development of regional secondary and tertiary industries. They also believe that secondary industry will promote the development of port throughput by constructing a second-generation panel method that considers cross-section dependence [41].
3. Construction of Port–Hinterland Synergetic Degree Indicator

In order to make the selected evaluation indicators not only describe the development level of various aspects of the hinterland and the port under the “dual circulation” development pattern, but also highlight the interaction characteristics with the port and the hinterland, this paper selects the indicators based on the analysis of the port–hinterland coordination mechanism and existing research. This helps us to calculate the level of port–hinterland synergy more appropriately.

3.1. Port–Hinterland Interaction Mechanism

By reviewing the relevant research results on port–hinterland synergy and referring to the research results of Si Z.C. [42] on the interaction mechanism of ports and hinterlands, we analyzed the interaction mechanism of ports and hinterlands by integrating factors that affect port development under the “dual circulation” development pattern, as shown in Figure 1.

![Figure 1. Port–hinterland economy development interaction mechanism.](image)

As the diagram shows, a hinterland’s transportation demand (+) → port throughput (+) → port’s operating income (+) → port’s development and construction investment (+) → professional level (+) → port’s loading and unloading and transportation capacity (+) → hinterland transportation demand (+). This means the port obtains income by meeting the transportation demand of the hinterland. This improves its hardware specialization and intelligence level and helps it adapt to the needs of the hinterland.

Hinterland’s transportation demand (+) → port throughput (+) → scale of harbor industry (+) → output value of secondary industry (+) → volume of import and export, throughput of domestic trade good (+) → scale of foreign trade goods, total retail sales of consumer goods (+) → hinterland transportation demand (+). Continuous interaction between the port and the hinterland drives the development of the local harbor industry. Goods manufactured by the local port industry are transferred to other links of the supply chain. This promotes the opening of the region and the internal flow of resources.

3.2. Indices of Port–Hinterland Coupling Synergetic Degree

Because some indicators are difficult to quantify, or the data are not publicly available, we selected the variables in Table 1 as evaluation indicators according to the port–hinterland synergy mechanism and previous studies [5–8,10]. According to the port–hinterland synergy mechanism, a hinterland’s economic activities such as secondary industry, tertiary industry, import and export trade, fixed asset investment, and port
industry development are all involved in the synergy between port and hinterland. Therefore, indicators related to the above activities are included in the index system. At the same time, basic hardware facilities and four kinds of throughput of the port are taken as indicators to evaluate the port transportation capacity and scale. We use the data of the China Port Yearbook, China Traffic Yearbook, open data of ports, and statistical yearbooks from relevant provinces and cities from 2011 to 2020.

**Table 1.** Indicators of synergy degree between port and hinterland economy.

| System Layer          | Level-1 Indicators | Level-2 Indicators                                                                 | Meaning                  | Attribute |
|-----------------------|--------------------|-----------------------------------------------------------------------------------|--------------------------|-----------|
| Port Construction     | Berth length       | Port’s handling capacity                                                           | +                        |           |
| Capacity              | Berth number       |                                                                                    | +                        |           |
|                       | Number of berths   | Number of berths for ships over 10,000 tons                                         | +                        |           |
|                       |                    | Domestic cargo throughput                                                          | Domestics trade          | +         |
|                       |                    | Domestic trade container throughput                                                |                          |           |
| Level of Port         |                    | Foreign trade cargo throughput                                                      | Foreign trade            | +         |
| Development           |                    | Foreign trade container throughput                                                 |                          | +         |
| Port                  |                    | GDP                                                                                | GDP of hinterland        | +         |
| Transportation Scale  |                    | Investment in fixed assets                                                         | Fixed-asset investment   | +         |
|                       |                    | The output value of tertiary industry                                               |                          |           |
|                       |                    | The total volume of import and export trade                                         | Three forms of social    | +         |
|                       |                    | Total retail sales of consumer goods                                               | commodity circulation    |           |
|                       |                    | The population of permanent urban residents                                        | Level of urbanization of | +         |
|                       |                    |                                                                                   | hinterland               |           |

**4. Construction of Port–Hinterland Synergetic Degree Model**

**4.1. Hinterland Division Based on Field Strength Model**

Considering the flexibility and reliability of the field strength model and online map in spatial pattern characterization, we selected the hinterland division method based on the field strength model proposed by Liu et al. [30]. This method uses internet map services to measure time distance and the energy level index to evaluate port development level.

**4.1.1. Port Energy Level Index**

Regional energy level refers to the degree of development of a region and the degree of influence on the surrounding areas. The port’s radiating scope and intensity can be described by the port energy level. By using principal component analysis on the port indicators in Table 1, we calculated the energy level index of the port with the principal component score, and finally, it was non-negative normalized as follows.

\[
Z_i' = \frac{100}{(1 + e^{-z_i})}
\]  

(1)
4.1.2. Time Distance Measurement Based on Baidu Map

To overcome the difficulties in the process of obtaining vector-based data and generalized transportation costs, this study adopted the Baidu navigation map to obtain the time from the port to reach the hinterland. We take the map to locate a port as the starting point, the hinterland city as the endpoint, and the shortest distance to represent the time reachability.

4.1.3. Field Strength Model

The field strength can express the radiation effect of a port on its surrounding cities. The field energy can express the superposition of the field strength of the city by the port. The higher the field energy of a city is, the more the city is influenced by the port and the stronger the port–hinterland connection, and vice versa. The field strength and field energy are calculated as:

\[
F_{ij} = \frac{Z_i'}{D_{ij}} F_j = \sum_{i=1}^{n} \frac{Z_i'}{D_{ij}}
\]

(2)

where \(F_{ij}\) indicates the field strength of port \(i\) to hinterland city \(j\), \(F_j\) the field energy of multiple ports to the same hinterland city \(j\), \(Z_i'\) the energy level index of port \(i\), and \(D_{ij}\) the distance from port \(i\) to city \(j\) based on the Baidu map. It uses time distance instead of space distance, and \(a\) is the distance friction coefficient. Since the port scope of this paper is Chinese coastal ports, which is closest to the national scale, \(a\) is taken as 1.0 as the standard value [30].

Since a city may be in the radius of more than one port, it becomes a competitive hinterland served by more than one port. In this paper, we define the city where the port is located as its direct hinterland. Then we use the “critical value principle” to identify the hinterland of the port: if the port field strength value of a city is higher than the critical value, it will be a hinterland of the port. The average value is chosen as the critical value.

4.2. Coupling and Synergetic Degree Calculation Model

4.2.1. System Order Degree

In synergetic theory, the efficiency function is used to calculate the contribution degree of order of the subsystem. The positive efficiency indicator means that the larger the index data, the greater the contribution degree to the subsystem. In contrast, the negative efficiency index means that the greater the value of the index, the less its contribution to the subsystem. The calculation formula of the efficacy function is as follows:

\[
X_{ij} = \begin{cases} 
\frac{x_{ij} - \beta_{ij}}{\alpha_{ij} - \beta_{ij}}, & x_{ij} \text{is a positive efficiency indicator} \\
\frac{\alpha_{ij} - x_{ij}}{\alpha_{ij} - \beta_{ij}}, & x_{ij} \text{is a negative efficiency indicator} 
\end{cases}
\]

(3)

where the efficacy value of \(x_{ij}\) \((i = 1, 2, ..., n; j = 1, 2, ..., p; n \) is the number of samples, \(p \) is the number of indicators) is \(X_{ij}\) and its value is between 0 and 1. An efficacy value closer to 0 means that the indicator’s contribution to the system is smaller, and vice versa, meaning that the indicator’s contribution to the system is larger. \(\alpha_{ij}\) and \(\beta_{ij}\) are the upper and lower limits of each indicator, respectively. In the calculation, to avoid the efficacy values of 0 and 1, the upper limit value \(\alpha_{ij}\) is expanded by 1% and the lower limit value \(\beta_{ij}\) is reduced by 1%.

The subsystem’s order is a weighted summation of the orderliness of each indicator sequential parameter component, and the mathematical expression is as follows:
\[ X_i = \sum_{j=1}^{n} w_{ij}X_{ij} \sum_{j=1}^{n} w_{ij} = 1 \] (4)

where \( X_i \) is the orderliness of each subsystem, \( w_{ij}X_{ij} \) the order of the ordinal parametric components, and \( w_{ij} \) the weight. To avoid the subjectivity of the assignment, we use the entropy weighting method to get the weight of each indicator.

The system is divided into the port subsystem and the hinterland economic subsystem, and the indicators of the port subsystem are defined as \( x_1, x_2, \ldots, x_n \), the indicator weight is \( a_i \), the indicators of the hinterland economic subsystem are \( y_1, y_2, \ldots, y_m \), and the indicator weight is \( b_i \), so the two are integrated as:

\[ P(x) = \sum_{i=1}^{n} a_ix_i \] (5)
\[ Q(y) = \sum_{i=1}^{m} b_iy_i \] (6)

4.2.2. Synergy Degree Model

A coupling synergy model between the two subsystems of the port and its hinterland can be expressed as:

\[ Y_t = \sqrt{C \cdot F} \] (7)
\[ C = 2 \cdot \sqrt{(P(x) \cdot Q(y)) / (P(x) + Q(y))^2} \] (8)
\[ F = \alpha P(x) + \beta Q(y) \] (9)

where \( Y_t \) indicates the coupling synergy degree between the two subsystems: port subsystem and hinterland economic subsystem. Its value is between 0 and 1. The more it tends to 1, the higher the level of synergy between the two subsystems. In contrast, a value nearer 0 means the less synergy relationship between the two systems, and the development of them is disorderly. \( P(x) \) indicates the changing trend of the coordination fitness of the port system. \( Q(y) \) denotes the changing trend of the coordination fitness of the hinterland system. \( C \) denotes the coordination degree of the port and economic development level of hinterland. \( F \) is the comprehensive evaluation index of the two subsystems, which reflects the overall benefit or level of environment and economy, \( \alpha \) and \( \beta \) are the weights to be determined. Referring to Liao’s research results, this paper proposes that hinterland economic development and port development are equally important, so the values of \( \alpha \) and \( \beta \) are the same, which are set as 0.5 [4].

4.3. Regression Model Based on PLS

Partial least squares regression (PLS) adopts the method of recombining the information in the sample instead of eliminating variables. When extracting components, it considers the linear relationship between the cause and independent variables and selects the principal component with the best explanation effect of the most cause and independent variables to eliminate noise interference. So, it can weaken the multicollinearity interference and make the model more stable. So PLS is also known as the second-generation regression method.

In the PLS regression process, \( n \) indicates explanatory variables, \( k \) samples, \( X = [X_1, X_2, X_3, \ldots, X_n] \) \( k \times n \) independent variable matrix, and \( Y \) dependent variable matrix. When
extracting the first principal component T1, PLS extracts the variation information of the data as comprehensively as possible, and its correlation with Y should be as large as possible. If the regression effect of extraction reaches the preset requirements after the first round, the regression will be completed. Otherwise, the remaining information content will be extracted from the second principal component T2 and the regression will be repeated until the preset regression accuracy is met.

4.4. Selection of Research Objects

To evaluate the coordination level of Chinese coastal ports and their hinterland, we take five major coastal port groups and their service scopes as the research objects defined in the “13th Five-Year Plan for The Development of National Marine Economy” issued in 2017. Table 2 shows the situation.

Table 2. Coastal ports and their main hinterland.

| Region          | Ports                                      | Hinterland                                                                 |
|-----------------|--------------------------------------------|----------------------------------------------------------------------------|
| Liaoning Province | Dalian Port, Yingkou Port,                | Three northeastern provinces and eastern Inner Mongolia                     |
| Beijing-Tianjin-Hebei Province | Tianjin Port, Qinhuangdao Port, Tangshan Port, Huanghai Port | Beijing and Tianjin, north China and some areas extending westward |
| Shandong Province | Qingdao Port, Yantai Port, Rizhao Port, and Weihai Port | The Shandong Peninsula and its westward extension of some areas |
| Yangtze River Delta | Shanghai Port, Ningbo-Zhoushan Port, Lianyungang Port | Yangtze River Delta and regions along the Yangtze River |
| Fujian Province | Xiamen Port, Fuzhou Port                  | Fujian province, Jiangxi, and other inland provinces                     |
| Pearl River Delta | Shenzhen Port, Guangzhou Port, Xiamen Port, Fuzhou Port | South China, some southwest provinces and cities |
| Southwest China | Qinzhou Port, Fangcheng Port, Haikou Port | Main coastal areas in southwest China                                      |

5. Results and Discussions

5.1. The Results of Port–Hinterland Coupling Synergy Degree

We obtained descriptive statistics in calculating results of the port–hinterland coupling synergy degree. Table 3 shows the results. The descriptive statistics show that the level of port–hinterland synergy varies greatly among ports. The results of the K-S test show that the calculated results are abnormal.

Table 3. Description statistics results of port–hinterland coupling synergy degree.

| Port–Hinterland Coupling Synergy Degree | Min.   | Max.   | SE     | K-S Test statistic |
|----------------------------------------|--------|--------|--------|--------------------|
|                                        | 0.050  | 0.920  | 0.215  | 0.150, p value = 5.742 × 10^-9 |

5.1.1. Clustering Analysis of Port–Hinterland Coupling Synergy Degree

To cluster the variables and avoid subjectivity caused by manual classification criteria, we use the hierarchical cluster method to classify the ports according to the data shown in Table 4. Figure 2 and Table 5 show the results. In Figure 2, the colors of each port represent the classification result of their coordination levels, which are green, blue, yellow and pink from high to low.
Table 4. Measurement results of coupling synergy degree of major coastal ports in China.

| Port                  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  | 2019  | 2020  |
|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Dalian Port           | 0.55  | 0.56  | 0.61  | 0.60  | 0.58  | 0.55  | 0.56  | 0.56  | 0.54  | 0.41  |
| Yingkou Port          | 0.42  | 0.45  | 0.49  | 0.48  | 0.46  | 0.48  | 0.47  | 0.45  | 0.40  | 0.32  |
| Dandong Port          | 0.13  | 0.12  | 0.14  | 0.14  | 0.14  | 0.13  | 0.12  | 0.10  | 0.09  | 0.05  |
| Jinzhou Port          | 0.16  | 0.17  | 0.16  | 0.17  | 0.15  | 0.14  | 0.14  | 0.13  | 0.16  | 0.11  |
| Qinhuangdao Port      | 0.18  | 0.14  | 0.16  | 0.16  | 0.16  | 0.16  | 0.16  | 0.16  | 0.16  | 0.13  |
| Tangshan Port         | 0.33  | 0.38  | 0.4   | 0.47  | 0.47  | 0.49  | 0.53  | 0.48  | 0.51  | 0.42  |
| Huanghua Port         | 0.17  | 0.22  | 0.19  | 0.20  | 0.20  | 0.21  | 0.21  | 0.22  | 0.21  | 0.18  |
| Tianjin Port          | 0.72  | 0.74  | 0.77  | 0.75  | 0.75  | 0.74  | 0.70  | 0.70  | 0.69  | 0.56  |
| Qingdao Port          | 0.57  | 0.62  | 0.64  | 0.62  | 0.62  | 0.60  | 0.63  | 0.59  | 0.59  | 0.54  |
| Yantai Port           | 0.29  | 0.32  | 0.32  | 0.31  | 0.32  | 0.37  | 0.38  | 0.42  | 0.37  | 0.28  |
| Rizhao Port           | 0.33  | 0.35  | 0.35  | 0.39  | 0.38  | 0.42  | 0.35  | 0.41  | 0.40  | 0.28  |
| Weihai Port           | 0.15  | 0.20  | 0.16  | 0.16  | 0.15  | 0.16  | 0.16  | 0.19  | 0.17  | 0.17  |
| Shanghai Port         | 0.87  | 0.87  | 0.90  | 0.92  | 0.91  | 0.91  | 0.91  | 0.90  | 0.89  | 0.78  |
| Lianyungang Port      | 0.28  | 0.30  | 0.31  | 0.32  | 0.32  | 0.33  | 0.31  | 0.30  | 0.30  | 0.26  |
| Ningbo-Zhoushan Port  | 0.73  | 0.76  | 0.77  | 0.77  | 0.78  | 0.79  | 0.81  | 0.81  | 0.82  | 0.69  |
| Taizhou Port          | 0.19  | 0.19  | 0.20  | 0.20  | 0.20  | 0.23  | 0.23  | 0.21  | 0.21  | 0.17  |
| Wenzhou Port          | 0.23  | 0.22  | 0.24  | 0.24  | 0.22  | 0.24  | 0.22  | 0.25  | 0.25  | 0.37  |
| Jiaxing Port          | 0.15  | 0.17  | 0.17  | 0.17  | 0.18  | 0.18  | 0.18  | 0.21  | 0.22  | 0.19  |
| Fuzhou Port           | 0.3   | 0.33  | 0.34  | 0.35  | 0.35  | 0.35  | 0.35  | 0.37  | 0.37  | 0.31  |
| Xiamen Port           | 0.36  | 0.37  | 0.39  | 0.39  | 0.40  | 0.40  | 0.40  | 0.40  | 0.40  | 0.34  |
| Quanzhou Port         | 0.23  | 0.23  | 0.26  | 0.26  | 0.26  | 0.26  | 0.26  | 0.27  | 0.27  | 0.21  |
| Guangzhou Port        | 0.63  | 0.66  | 0.70  | 0.70  | 0.70  | 0.64  | 0.66  | 0.71  | 0.69  | 0.57  |
| Zhanjiang Port        | 0.22  | 0.22  | 0.23  | 0.23  | 0.24  | 0.25  | 0.24  | 0.24  | 0.23  | 0.19  |
| Shantou Port          | 0.18  | 0.16  | 0.20  | 0.20  | 0.19  | 0.20  | 0.18  | 0.19  | 0.19  | 0.22  |
| Shenzhen Port         | 0.60  | 0.61  | 0.61  | 0.60  | 0.62  | 0.60  | 0.63  | 0.59  | 0.59  | 0.39  |
| Beihai Port           | 0.05  | 0.06  | 0.06  | 0.06  | 0.08  | 0.09  | 0.09  | 0.09  | 0.09  | 0.11  |
| Fangchenggang Port   | 0.25  | 0.28  | 0.27  | 0.28  | 0.28  | 0.28  | 0.29  | 0.27  | 0.27  | 0.23  |
| Qinzhou Port          | 0.22  | 0.25  | 0.25  | 0.26  | 0.27  | 0.28  | 0.27  | 0.29  | 0.31  | 0.27  |

This indicates that ports are divided into four categories of high level, medium-high level, general level, and low-level coordination, by their coupling coordination degree. It also shows that some ports with a high port–hinterland coordination level are mostly hub ports in the port group, such as Qingdao Port, Tianjin Port, and Dalian Port. Some of them have obvious trade hub port attributes, such as Guangzhou Port, Shenzhen Port, and Shanghai Port. However, ports such as Dandong Port and Beihai Port with a low level of port–hinterland coordination are mostly feeder ports in the port group. Their cargo handling scale, hinterland radiation capacity, and facilities are weaker than those of hub ports. This indicates that there is heterogeneity in port positioning on the level of port–hinterland coordination.

However, among the hub ports, there is a big gap between Shanghai Port, Tianjin Port, Guangzhou Port, and other ports with a high-level synergy or medium-high Level Synergy. The hinterland within the radius of Shanghai Port includes Jiangsu province, Zhejiang province and Shanghai city itself whose economic size and manufacturing scale are better than those of Guangdong province, radiated by Guangzhou Port, and even better than the Beijing-Tianjin-Hebei region, radiated by Tianjin Port. Aside from the differences in port positioning, Shanghai Port, Tianjin Port, and Shenzhen Port are all located in developed areas in China. The mature industrial manufacturing industry and highly developed tertiary industry in these regions have generated a large number of port transportation needs. In contrast, coastal ports located in southwest or northeast China, such as Beihai Port, Jinzhou Port, and Dandong Port, have a low level of port–hinterland synergy. This indicates that there is regional heterogeneity in the coordination level of the port–hinterland.
Figure 2. Hierarchical cluster result of port–hinterland synergy level.

Table 5. Classification results of port–hinterland synergy level.

| Types                  | Ports                                                                 |
|------------------------|----------------------------------------------------------------------|
| High-Level Synergy     | Shanghai Port                                                        |
| Medium-high Level Synergy | Ningbo-Zhoushan Port, Guangzhou Port, Tianjin Port, Shenzhen Port, Qingdao Port, Dalian Port |
| General Level Synergy  | Xiamen Port, Rizhao Port, Fuzhou port, Yantai Port, Tangshan Port, Yingkou Port |
| Low-Level Synergy      | Lianyungang Port, Wenzhou Port, Beihai Port, Zhanjiang Port, Qinhuangdao Port, Fangchenggang Port, Quanzhou Port, Dandong Port, Qinhuangdao Port, Jinzhou Port, Jiaxing Port, Weihai Port, Shantou Port, Taizhou Port, Huanghua Port |

5.1.2. The Fluctuation of Port–Hinterland Coupling Coordination Degree

To study the changing port–hinterland synergy level of each port, Figure 3 shows the line charts of this index of ports with different synergy levels. It shows that, in 2020, the port–hinterland coupling synergy degree of most ports declined. Qinhuangdao Port, Huanghua Port, and Jiaxing Port saw the least decline (0.03) and Shenzhen Port the most (0.20). Such fluctuations were mainly affected by the decline in the level of hinterland development in that year. In terms of the overall trend, during 2011–2019, the port–hinterland coordination level of 13 ports among 28 major coastal ports increased, while that of 10 ports was stable, and that of 5 ports increased first and then decreased. Among the ports with an improved synergistic level, Tangshan Port has the largest increase, reaching 0.18. The synergistic level of Dalian Port, Yingkou Port, and Dandong Port showed a decrease of 0.05, 0.09, and 0.05 respectively. Tianjin Port and Qingdao Port experienced a decrease of 0.08 and 0.05, respectively, in 2013–2019.
5.1.3. Index Weight Analysis

Figures 4 and 5 show the changes in the weight of each evaluation index of the development level of the port and hinterland subsystem from 2011 to 2020, respectively. It is found that the weights of each index remained stable from 2011 to 2019. In the port subsystem, indices reflecting the scale of port infrastructure, hardware, length and the number of berths, and the number of berths above 10,000 ton, stay at a low level. This means that after the early large-scale development of new berths, integration of old docks, and other measures, China’s main coastal ports’ transport capacity has met the demands of the carriage of goods. In other words, today, if ports simply pursue the scale of infrastructure, they will be unable to achieve the goals of China’s ports transformation strategy in developing from “big ports” to “strong ports”.

Among the indicators reflecting the volume of handled cargo, the weight of container throughput was nearly two times that of dry bulk cargo throughput. The weight of foreign trade container throughput was the highest and gradually expanded in ten years, finally reaching 32%. At the same time, the weight of domestic trade container throughput was compressed, and the gap between the two gradually widened. In terms of bulk cargo throughput, the weight of domestic cargo throughput rose slowly, and the gap with that of foreign trade cargo throughput gradually narrowed. This shows the characteristics of China’s export-oriented economy and the dependence of bulk foreign trade goods on water transport. With the development of China’s transportation industry, the cooperation of various transportation modes and the interaction between ports and inland areas are closer than ever before. More domestic trade goods were transported by sea.

Figure 3. Line charts of port–hinterland coupling synergistic degree of major coastal ports in China.
In the hinterland subsystem, the weight of import and export volume was always the highest, and the output value of the tertiary industry’s weight rose slowly in the fluctuation, but there was still a gap between the two. Such weight difference shows that foreign trade activity is stronger than the tertiary industry in promoting hinterland development. In addition, with the outbreak of COVID-19 in 2020, the previous stable situation of the weight of the hinterland subsystem was broken. The weight of total retail sales of consumer goods and the permanent urban population rose sharply, while the weight of other indicators showed varying degrees of decline.

**Figure 4.** Changes of weights of port subsystem indices.

**Figure 5.** Changes of weights of hinterland subsystem indices.
5.1.4. Development Level of Port and Hinterland Subsystem

This paper measured the development level of each port and its hinterland respectively and presents the mean development level of the two subsystems of each port according to the port group to which they belong. Table 6 shows the results.

| Port                  | Port Subsystem | Hinterland Subsystem |
|-----------------------|----------------|----------------------|
| Dalian Port           | 0.277          | 0.349                |
| Yingkou Port          | 0.164          | 0.241                |
| Dandong Port          | 0.043          | 0.005                |
| Jinzhou Port          | 0.032          | 0.017                |
| Qinhuangdao Port      | 0.078          | 0.01                 |
| Tangshan Port         | 0.220          | 0.202                |
| Huanghua Port         | 0.061          | 0.028                |
| Tianjin Port          | 0.365          | 0.736                |
| Qingdao Port          | 0.359          | 0.378                |
| Yantai Port           | 0.161          | 0.091                |
| Rizhao Port           | 0.162          | 0.117                |
| Weihai Port           | 0.039          | 0.024                |
| Shanghai Port         | 0.750          | 0.845                |
| Lianyungang Port      | 0.135          | 0.064                |
| Ningbo-Zhoushan Port  | 0.666          | 0.547                |
| Taizhou Port          | 0.053          | 0.035                |
| Wenzhou Port          | 0.067          | 0.074                |
| Jiaxing Port          | 0.054          | 0.026                |
| Fuzhou Port           | 0.127          | 0.112                |
| Xiamen Port           | 0.206          | 0.110                |
| Quanzhou Port         | 0.074          | 0.052                |
| Guangzhou Port        | 0.430          | 0.476                |
| Zhanjiang Port        | 0.101          | 0.033                |
| Shantou Port          | 0.040          | 0.042                |
| Shenzhen Port         | 0.353          | 0.351                |
| Beihai Port           | 0.018          | 0.001                |
| Fangchenggang Port    | 0.074          | 0.077                |
| Qinzhou Port          | 0.077          | 0.074                |

This shows that the development level of ports and hinterland subsystems of port groups located in different regions of China varies greatly. Considering the hub ports of Jiangsu, Zhejiang, and Shanghai Port groups, Shanghai Port and Ningbo-Zhoushan Port, the development degree of their hinterlands and the ports themselves was higher than that of the hub ports in other port groups. The development level of the two subsystems of feeder ports in different port groups was generally low. In the same port group, the development level of the two subsystems between trunk ports and branch ports was significantly different. Dalian Port, Tianjin Port, Qingdao Port, Shanghai Port, Ningbo-Zhoushan Port, Xiamen Port, Guangzhou Port, and Shenzhen Port all had significantly higher levels than feeder ports in their port group in terms of their own development level and hinterland subsystem development level.

5.2. Regression Results Based on PLS

5.2.1. Selection of Variables and Model Construction

To figure out the factors influencing the port–hinterland synergy level, we took the port–hinterland coupling synergy degree as the dependent variable and identified eight independent variables. The fixed assets investment $x_5$, import and export trade volume $x_6$, the output value of the tertiary industry $x_7$, total retail sales of consumer goods $x_8$, ...
and the demand for port service from fixed asset investment and different types of social commodity circulation. Domestic trade bulk cargo throughput $x_1$, foreign trade bulk cargo throughput $x_2$, domestic trade container throughput $x_3$, and foreign trade container throughput $x_4$ represent the actual response effect of the port to the hinterland demand. We constructed the following PLS regression model:

$$\ln y = \alpha_1 \ln x_1 + \alpha_2 \ln x_2 + \alpha_3 \ln x_3 + \alpha_4 \ln x_4 + \alpha_5 \ln x_5 + \alpha_6 \ln x_6 + \alpha_7 \ln x_7 + \alpha_8 \ln x_8 + \varepsilon$$

where $\varepsilon$ is the residual of regression model, and $\alpha_1, \alpha_2, \ldots, \alpha_8$, respectively, represent the corresponding coefficients. The data are taken as a natural logarithm form to eliminate the heteroscedastic phenomenon, and the dependent variable in the form of natural logarithms passed the K-S test (statistic = 0.075, $p$ value = 0.081).

5.2.2. Regression Results

Before PLS regression, it is necessary to determine the number of selected principal components according to the results of cross-validity testing. In Table 7, $Q^2$ is less than the critical value. The explanatory contribution rate of component 1 to the independent variable is 66.5%, and that to the dependent variable is 93.8%. Therefore, choosing one component is enough to achieve good regression accuracy. The following analysis was conducted based on one component.

**Table 7. Cross-validation test results and variable interpretation ratio table.**

| Component | Qh2  | Critical Value | RX2  | RY2  |
|-----------|------|----------------|------|------|
| 1         | 0.931| 0.0975         | 0.665| 0.938|
| 2         | -0.036| 0.0975       | 0.090| 0.007|

After determining the number of principal components, we found that there is an obvious linear relationship between dependent variables and independent variables with the help of the Figure 6, and the goodness of fit(R2) reached 0.938. So, it was reasonable to establish a regression model with PLS, and the fitting effect was good.

According to the extracted principal components, the regression equation was obtained:

$$\ln y = 0.117 \ln x_1 + 0.155 \ln x_2 + 0.065 \ln x_3 + 0.120 \ln x_4 + 0.171 \ln x_5 + 0.165 \ln x_6 + 0.179 \ln x_7 + 0.177 \ln x_8 - 1.945$$

(10)

where $\ln x_i$ ($i = 1, 2, \ldots, 8$) is the standardized variable.
The VIP value reflects the explanatory ability of each variable in the dependent variable information. Figure 7 shows that the VIP value of domestic trade container throughput(x3) was 0.44, that of other variables exceeded 0.5, and five of the variables had VIP values greater than 1, indicating that indicators adopted in this model have strong explanatory abilities for the dependent variable, and the selection of indicators was reasonable.

![Figure 7. VIP values.](image)

The coefficient table (Table 8) shows the coefficients of each variable in the regression equation. Because the partial least squares method is different from the general least squares method, the variance of its regression coefficients cannot be accurately estimated without bias. Therefore, Miller proposed the Quenouille–Tukey jackknife method to estimate the variance of regression coefficients. The jack.test function of R software was used to test the significance of regression coefficients [43]. The test results show that the coefficients of all variables are significant.

| Variable | Coefficient |
|----------|-------------|
| ln \(x_5\) | 0.171 *** |
| ln \(x_6\) | 0.165 *** |
| ln \(x_7\) | 0.179 *** |
| ln \(x_8\) | 0.177 *** |
| ln \(x_1\) | 0.117 *** |
| ln \(x_2\) | 0.155 *** |
| ln \(x_3\) | 0.065 *** |
| ln \(x_4\) | 0.120 *** |
| \(R^2\) | 0.938 |

Note: *** refers that the coefficients of all variables are highest significant.

PLS regression results show that each independent variable had a significant positive impact on the development of the port–hinterland synergy level. It indicates that the improvement of the hinterlands’ economic level and that of the ports’ ability to meet the cargo transport demand of the hinterlands are conducive to the improvement of the synergy level. Among variables, tertiary industry had the greatest influence, followed by the output value of total retail sales of consumer goods, and the investment of fixed assets. Among variables concerning throughput, domestic dry bulk cargo throughput and container throughput had less impact than foreign trade bulk cargo and container throughput.
5.2.3. Impact of Different Types of Demand on the Level of Port–Hinterland Synergy

1. Variable Selection

We took various throughputs of ports as control variables and used PLS regression to study the impact of fixed asset investment, total retail sales of consumer goods, import and export volume, and the output value of tertiary industry on the level of port–hinterland synergy. So, we can further clarify the impact of economic activities concerning fixed asset investment and different types of social commodity circulation on the port–hinterland synergy degree.

2. Regression Results

3. After $x_1$, $x_2$, $x_3$, and $x_4$ were set as control variables, Table 9 shows the coefficients and $R^2$ of the four regression equations. The correlation coefficients of each independent variable in the four equations are significant.

| Variable | Coefficient |
|----------|-------------|
| $\ln x_5$ | 0.326 *** |
| $\ln x_6$ | 0.319 *** |
| $\ln x_7$ | 0.332 *** |
| $\ln x_8$ | 0.333 *** |
| $\ln x_1$ | 0.223 *** |
| $\ln x_2$ | 0.226 *** |
| $\ln x_3$ | 0.217 *** |
| $\ln x_4$ | 0.221 *** |
| $\ln x_5$ | 0.296 *** |
| $\ln x_6$ | 0.300 *** |
| $\ln x_7$ | 0.288 *** |
| $\ln x_8$ | 0.293 *** |
| $\ln x_1$ | 0.124 *** |
| $\ln x_2$ | 0.126 *** |
| $\ln x_3$ | 0.121 *** |
| $\ln x_4$ | 0.123 *** |
| $\ln x_5$ | 0.228 *** |
| $\ln x_6$ | 0.231 *** |
| $\ln x_7$ | 0.222 *** |
| $\ln x_8$ | 0.226 *** |
| $R^2$ | 0.869 |
|          | 0.861 |
|          | 0.873 |
|          | 0.879 |

Table 9. Impacts of different types of economic activities on the port–hinterland synergy level.

Note: *** refers that the coefficients of all variables are highest significant.

As Table 9 shows, the impact of fixed asset investment on the level of coordination was slightly less than that of the total retail sales of consumer goods and tertiary industry, and the promotion effect by import and export trade had the least impact. First, considering that coal, ore, cement, and other bulk raw materials are the main goods of China’s coastal ports at present, these goods are necessary materials and direct demand for the construction of local fixed assets. However, in the hinterland subsystem, the weight of fixed asset investment was lower than that of the tertiary industry, and it has declined year by year. Therefore, among the four variables, its impact on the port–hinterland synergy level was less prominent than that of tertiary industry, which is in line with common sense.

Second, the total of retail sales of consumer goods represents the development level of retail industry. Its influence on the synergy level was similar to that of tertiary industry, or even slightly higher than that of tertiary industry. This shows that the development of the retail industry, as part of tertiary industry, will promote the level of port–hinterland synergy. Such a promoting effect will not only promote the development of tertiary industry to improve the level of collaboration, but also spill over to other industries.

Third, import and export trade had a significant impact on the level of port–hinterland synergy. On one hand, this shows that the transportation demand derived from China’s large-scale import and export trade creates opportunities for port development. On the other hand, under the condition of transnational long-distance transportation, the economy of waterway transportation is better than that of other transportation. This is an advantage of port enterprises in competition with other types of transportation.
From the overall source of demand, the impact of domestic fixed asset construction and tertiary industry development on the level of port–hinterland synergy was higher than that of import and export trade, which is mainly from abroad. It can be seen that although the throughput of domestic goods and containers has little impact on the level of port development, the weight of output value of tertiary industry in the hinterland subsystem is rising slightly. At the same time, the weight of fixed assets investment gradually decreased. This shows that there is room for exploring domestic demand, and the ports are facing a change of emphasis on coordination with hinterlands.

Considering the coefficients of the four regression equations with control variables, the coefficients of each control variable are all positive and significant. This shows that improving the response capacity of ports to hinterland demand plays a positive role in promoting the synergetic effect of ports and cities.

6. Conclusions and Recommendations

According to the data of major coastal ports and their hinterlands in China from 2011 to 2020, we measured the synergy degree of coastal ports and their hinterlands by constructing a port–hinterland coupling synergy model. Then, we established a model to explore the relationship between different types of hinterland economic activities as well as port service capacity and port–hinterland synergy level. The research draws the following conclusions: (1) there is heterogeneity in port positioning and location of the main coastal ports in China. The heterogeneity shows that, at the level of synergy, trunk ports and developed areas are more synergistic than hub ports and underdeveloped areas; (2) from 2011 to 2019, more than 75% of China’s major coastal ports maintained a stable level or improved their port–hinterland coordination level, but in 2020, the level of most ports declined. (3) The improvement of the scale of port infrastructure, the volume responding to the demand of the hinterland, and the hinterland’s demand for port services all have a positive impact on the level of port city coordination. (4) The improvement of regional fixed asset investment, import and export trade, tertiary industry and retail industry’s demand for port services all play a role in improving the level of port–hinterland synergy, among which tertiary industry plays the most prominent role. (5) In terms of the source of transportation demand, the promotion effect of the hinterlands’ domestic demand on the level of port–hinterland synergy is better than that of its import and export activities.

According to the above conclusions, we put forward the following three recommendations:

(1) Governments should attach importance to overall port planning and differentiated development.

At present, the synergy degree of trunk ports in a port group is higher than that of branch ports. There is a disparity among different regions in their port–hinterland synergy level. Therefore, governments should promote the balanced development of local ports. Ports in the same region should prioritize comprehensive planning, clarify the industrial division and function positioning of different ports, and promote the specialized construction and differentiated development of ports. In the planning process, policies and resources should also be avoided that tilt too much towards hub ports. In addition, feeder ports should seek suitable development routes and tap potential transportation demand according to their shoreline route resources and industrial characteristics.

(2) Hinterlands should focus on promoting the development of the local tertiary industry to improve the synergies between ports and hinterlands, particularly the retail industry.

As the largest independent variable in the regression coefficient, the output value of the tertiary industry has the highest weight in the evaluation of hinterland economic development. Retail industry, a part of tertiary industry, has significant positive influence on the synergy level. It accounts for more than half of the impact of tertiary industry on the synergy level. Furthermore, its weight in the evaluation of hinterland develop-
ment level has been increasing year by year. This reflects that both the consumption demand and the consumption ability of Chinese residents are improving. At the same time, the depth of the integration of Chinese ports into the regional economy needs to be expanded. Therefore, ports should seek cooperation with retail enterprises and service enterprises, give full play to the advantages of water transportation in medium and long-distance transportation, and help enterprises dredge the existing supply chain, reduce costs and increase efficiency. Local governments can speed up the planning and construction of free trade zones and guide foreign trade retail enterprises with strong demand for shipping to settle in.

(3) Ports should strengthen the promotion of container transportation of foreign trade goods.

First, the impact of foreign trade cargo throughput on the level of port–hinterland synergy is second only to that of fixed asset investment and the output value of tertiary industry. Second, in the evaluation of port development level, the weight of foreign trade container throughput is the largest and shows an increase. Therefore, ports should give full play to the advantages of container transport: such as lower transport losses, light packaging, and convenient multimodal transport, and actively guide high value-added foreign trade goods to adopt container transport. By these means, ports can improve their operational efficiency, reduce the difficulties of regional cargo transport, and improve the level of port–hinterland coordination.

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