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Research Article

Selecting the Strategic Port of "the Belt and Road" Based on the Global Network

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Under "the Belt and Road" initiative, China promoted cooperation between domestic enterprises and international ports vigorously, which brought back fruitful results, while the rational selection of strategic pivots ports and the optimization of the layout of the port network are important guarantees to a further promotion to the economic development of "the Belt and Road" ports and give full play to the driving and radiation role of strategic pivots ports. On the basis of constructing a network of 155 ports in the world, according to the number of ports crossed by the shortest path and betweenness centrality in the network, this paper uses K-Medoids clustering algorithm to train the strategic importance of ports and verifies the reliability of the analysis results. On this basis, the joint coverage analysis of strategically important ports is carried out, 17 ports are identified as strategic pivots ports of the global port network, and, finally, based on the two attributes of "the Belt and Road" and "Chinese enterprise participation" of strategic pivots ports, the leading role of strategic pivots ports in geographical location, path coverage, development potential, cooperation stability, and control is analyzed, and instructive suggestions are put forward.

1. Introduction

Since China launched "the Belt and Road" initiative in 2013, China's nonfinancial investment in "the Belt and Road" Agreement countries has exceeded US$100 billion by the end of 2019 (over the past seven years, China's total imports and exports of goods with countries along "the Belt and Road" have increased to $1.34 trillion[N]. Economic Daily, 2020-09-07), including 103 port cooperation projects involving 94 ports (the original reference is 101 projects involving 90 ports, and this article completes the data until August 2020) [1]. Not only are international ports the foundation and artery of international trade, but also the resulting network is an important platform to promote international industrial integration and optimize the allocation of international resources, and the world in the operation of more than 480 international ports, each port in geographical location, throughput capacity, cargo adaptability, and hinterland countries industrial economic conditions and bilateral trade relations with China and other countries have certain differences. Therefore, in the network of international ports, how to determine the strategic pivots of ports, effectively lay out the global port network, open up a new engine of port economic development, play the leading role of "the Belt and Road" initiative, and further promote the integration of China and "the Belt and Road" countries along the political and economic relations are of great significance.

From a global perspective, international politics and economics, as well as global governance and international rules, place new historical demands on "the Belt and Road" initiative's international cooperation in the areas of global debt and financing, green development, inclusive development, transparency and anticorruption, and third-party market cooperation [2]. "The Belt and Road" initiative is a major strategy for China to implement all-round opening up to the outside world and has built a new platform for mutually beneficial and win-win cooperation for deepening and expanding new sino-foreign cooperative relations, forming a multilevel and multiform pattern of cultural and economic exchanges, accelerating the economic transformation, and upgrading and developing the countries along the path in the new era [3]; based on economic exchanges, political mutual trust, people-to-people exchanges, and civilizational mutual learning, the common development of countries and regions along the path on the basis of "common business, coconstruction, and sharing" has been promoted, and the construction of a community of human destiny in the new era has been accelerated [4]. With the continuous promotion of "the Belt and Road," the current domestic affairs and contemporary international affairs have been integrated; in order to promote the reform of global economic governance, we must use the development-oriented and practical rationality to strengthen each other's theoretical thinking, combined with the practice of "development win-win" inclusive globalization operation logic, and put forward the "China Program" of global economic governance with inclusive development mechanism as the core concept [5].

From the perspective of national strategy, the essence of the "the Belt and Road" network economy is the logistics and communication network between countries, and its development focuses on the cognition and practice among countries, so the perspective of "the Belt and Road" is the spatial paradigm of network form, not geopolitical strategy [6]. On the one hand, "the Belt and Road" initiative not only is closely in line with China's national strategic objectives such as national rejuvenation but also achieves the diplomatic goals of "world peace and development" by deepening China's relations with its neighbors [7]; on the other hand, "the Belt and Road" initiative has promoted changes in economic structure [8, 9], trade patterns [10, 11], and green development [12] along the path, not only easing the tension caused by regional economic development differences but also promoting the development of global economic integration, and to a certain extent curbed terrorism in poor areas [13]. In addition, the industrial transfer of countries along the Belt and Road is mutually beneficial to the upgrading of bilateral or multilateral value chains, and symbiosis is an important transmission path to promote industrial transfer in countries along "the Belt and Road," including China [14].

The strategic pivots are the apes of a particular network that has greater influence and control over the entire network. In the network of countries along "the Belt and Road," strategic pivots countries not only have the basis and influence to promote strategic position, the radiation capability, common interests, level of bilateral relations, and so on [15] but also have special geographical status, economic demonstration role and key strategic values, and other basic functions [16], while in the strategic pivots city of space structure network [17, 18], the strategic pivots industry in complex structural networks [19] needs to be strategic enough to play a strong leading role. The pivots of maritime strategy have always been the hot direction of academic research, which is beneficial to realizing the layout of overseas port construction from a global perspective and to the investment construction of overseas port [20]; as a fixed supply point, rest point, and ship aircraft berth repair point overseas, the maritime strategic pivots are crucial to maintaining maritime transport security, promoting practical cooperation at sea, and realizing the strategy of maritime power [21], but the maritime strategic pivots are not only a strategic hub at sea but also a strategic channel, and strategic maritime areas are structurally and spatially different [22], which requires an overall optimization of the layout of the marine strategic network to lay the foundations of the marine security and economic strategy [23, 24].

From the abstract network point of view, the betweenness centrality of vertexes [25] and adaptive merest centrality [26] are the important basis for selecting the strategic pivots of the network, the port industry network covers a wide range, the situation is more complex, and the problems are endless [27], but the port industry is an important index to realize the development of the port; from the perspective of the global port system, the shipping network, and hub port space pattern, strategic pivots port is bound to be the main hub and important channel of the maritime shipping network system [28]; it has a great influence on the analysis, as collectivity, accessibility, and interconnectedness of coastal port networks in various countries [29]; from the spatial contact and regional difference panel data of the shipping network in the past 10 years, the global ocean shipping adversity coefficient has been gradually improved, the average path length of shipping has been gradually shortened, and the functional difference of transit connection is getting smaller and smaller [30], but the existing maritime distribution network has been shown to meet the rapid growth of cargo throughput [31], with higher requirements for line network and connectivity measurements, as well as for the efficiency of shipping and port operations [32]. The selection of strategic pivots such as other transportation networks [33], aviation logistics networks [34], and passenger flow networks also requires measuring the importance and influence of nodes [35].

The above research results have laid a good foundation, but the "the Belt and Road" initiative has not been put forward for a long time; the relevant experience data are relatively scarce, so its academic research is still in its infancy, the systematic research results are less, especially for the global port network strategic pivots selection, and optimization results are much rare. Under the "the Belt and Road" initiative, based on the fruitful results of domestic enterprises participating in international port investment, construction, and operation, how to find strategic pivots ports, optimize the layout of the port network, and promote the port economic development of countries along "the Belt and Road" is particularly important.

2. The Setting and Processing of the Basic Data of the Port Network

Set the port network vertexes, edges, rights, and other basic data, and carry out the following steps to process them.

2.1. Port Sample Selection

2.1.1. Alternative Conditions Setting for Port Samples. In order to ensure that port sample data are covert, targeted, and important, alternative port sample selection ensures several principles: ensuring that countries along the main sea paths have port access to alternative samples, ensuring that alternative samples are accessed by the world's major maritime ports, basically ensuring that the Belt and Road Agreement countries have alternative samples for port access, and basically ensuring that ports have access to alternative samples for each maritime area.

To this end, the following alternative port samples are proposed: (1) ports in which Chinese enterprises are involved in investment, construction, and operation are all included in the alternative port sample; (2) the largest ports of the countries along "the Belt and Road" path are included in the sample of alternative ports; (3) when "the Belt and Road" countries span multiple maritime areas, ensure that each of the countries has at least one sample of alternative ports in each marine area; (4) the ports in the top 40 in world throughput in 2019 are used as samples of alternative ports.

2.1.2. Noise Reduction of Alternative Port Samples. In order to ensure the validity of the data and the time-ability of simulation verification, the alternative port samples were optimized for the noise reduction, excluding port samples that clearly did not meet the strategic pivots requirements, and the noise reduction conditions were as follows: (1) ports of island countries that did not enter the top 100 in 2019 were not considered as alternative samples; (2) there are no more than two alternative samples of a country's ports in the same sea area from the same continent.

2.1.3. Port Sample Results. After the selection and optimization of the port samples in the above two steps, 155 alternative port samples are obtained, as in Table 1.

The above alternative ports, including 79 countries that have signed "the Belt and Road" Agreement, as well as 64 ports in which China is involved in investment, construction, and operation, fully cover the major existing international sea paths and have a broad industry coverage base.

2.2. Set the Path between Ports. To set the path between ports is to set the rules for direct connections (direct connection: a straight line between ports) between ports. In order to simplify the calculation and ensure that the port connection is set in accordance with the rules of realistic sea paths, the rules for direct port connections are as follows: (1) All continents are nonnavigational. (2) All waters are navy accessible. (3) There is no transcontinental connection between ports, which is a valid path. (4) A direct connection within a neighboring port on the same continent crosses the continent in which it is located, and the direct connection is a valid path. (5) A direct connection within a port that does not conform to (3) and (4) transverses the continent and is invalid. (6) Ports cannot be connected to themselves.

Keep the valid path, cancel the invalid path, and get a connection between the vertexes that are not authorized to be identified by the port network diagram, that is, the path between the alternate ports.

2.3. Determine the Distance between Ports. The distance between ports is given to the corresponding effective path, that is, to the edge of the port network. Rules of empowerment are as follows: (1) The right to an effective path is the distance between ports (sea) (available directly at port.sol.com.cn, SeaRates.com, and McDistance shipping calculation tools. If there is a large difference in data between the three queries, the average method is used for optimization). (2) The right of the invalid path is recorded as $+\infty$.

The distance of the adjacent port is obtained through the official website and the shipping distance calculation tool (adjacent port distances are available through port.sol.com.cn, SeaRates.com, and McDistance shipping calculation tools), and the average of the three types of data serves as the final distance of the adjacent port. Since the network map of the adjacent port does not cover all ports, there is a certain difference between the shortest path value and the actual value of the nondirect port, but the error is small and the substantive influence on the choice of hub strategic pivots is limited.

The direct connection and distance between the alternative ports are determined, and, according to the characteristics of the two-way passage of sea paths, the port network is a nondirectional right network containing 155 vertices, which is recorded as $G(V, E, C)$, where V represents the vertexes of G, $V = \{v_1, v_2, \ldots, v_{155}\}$, E is the edge of G, and C is the right of direct connection. The distance between the alternative ports is represented by a matrix $G(C)$, which is the direct distance from port v_i to port v_j, "null" if the port-to-port is an invalid path, or 0 if the distance is 0, and the distance matrix $G(C)$ between the alternative ports is represented as

$$G(C) = \begin{bmatrix} c_{1-1} & c_{1-2} & \cdots & c_{1-155} \\ c_{2-1} & c_{2-2} & \cdots & c_{2-155} \\ \vdots & \vdots & \ddots & \vdots \\ c_{155-1} & c_{155-2} & \cdots & c_{155-155} \end{bmatrix} = \begin{bmatrix} 0 & 944.6 & \cdots & \text{null} \\ 944.6 & 0 & \cdots & \text{null} \\ \vdots & \vdots & \ddots & \vdots \\ \text{null} & \text{null} & \cdots & 0 \end{bmatrix}. \quad (1)$$

Table 1: List of alternative port samples.

Area	Alternative Ports
Asia (45)	Shanghai Port, Guangzhou Port, Hong Kong, Kaohsiung Port, Hanoi Port, Da Nang, Sihanoukville, Bangkok Port, Laem chabang, Kuantan Port, Melaka Gateway, Kuala Selangor, Penang Port, Singapore Port, Manila Port, Abu Dhabi Port, Gwadar Port, Yokohama Port, Chongjin Port, Busan, Dhaka Port, Chattogram Port, Kyaukpyu Port, Colombo Port, Hambantota Port, Mumbai Port, Chennai Port, Istanbul Port, Qishm, the Port of Chahbahar, Dammam Port, Jeddah, Doha Port, Salalah Port, Aden Port, Haifa Port, Jakarta-Kariburu, Jambi International Port, Tanjung Priok, Jerusalem Port, Batumi Port, Kuwait Port, Nicosia Port, Basrah Port, Lattakia Port
Africa (37)	Tunisia Port, Cherchell Port, Suez Port, Damietta Port, Por Said Port, Luanda Port, Bata Port, Lome Port, Masawa Port, Pointe Noire Port, Matadi Port, Djibouti Port, Boke Terminal, Conakry Port, Tema Port, Kribi Port, Abidjan Port, Mombasa Port, Tamataf Port, Dakar Port, Monrovia Port, Gentil Port, Cotonou Port, Tangier Port, Dakhla Port, Nouakchott Port, Beira Port, Maputo Port, Walvis Port, Lagos Tingcan Port, Sao Tome and Principe Port, Sudan Port, Dar es Saalam Port, Tripoli Port, Berbera Port, Cape Town Port, Durban Port
Europe (33)	Hamburg Hafen, London Port, Liverpool Port, Le Havre Port, Marseille Port, Lisbon Port, Hammerforst Port, Oslo Port, the Kingdom of Denmark, Stockholm Port, Helsinki Port, Gdańsk Port, Archangelsk Port, Vladivostok Port, Murmansk Port, Nakhodka Port, Sochi Port, Port of Rotterdam, Port of Amsterdam, Antwerp Port, Zebrukh Port, Valencia Port, the Port of Gibraltar, Bilbao Port, Piraeus Port Terminal, Wado Port, San Marino Port, Reykjavík Port, Rijeka Port, Durres Port, Constanta Port, Odessa Port, Varna Port
Oceania (7)	Darwin Port, Melbourne Port, Fremantle Port, Newcastle Port, Lae Port, Wellington Port, Suva Port
North America (22)	Manzanillo Port, Veracruz Port, New York Port, Port of Long Beach, Los Angeles, New Orleans Port, Vancouver Port, Churchill Port, Montreal Port, Havana port, Pilon port, Kingston harbor, Santo Domingo Port, Port-au-Prince, Guatemala Port, Puerto Barrios Port, Honduras Port, Managua Port, Cabesas Port, San Jose Port, Puerto Limon, Colon Port, Panama City Port
South America (11)	Cali port, Barranquilla Port, Guayaquil Port, Kayao Port, San Diego Port, Punta Arenas Port, La Guaira Port, Buenos Aires Port, Paranagua Port, Santos Port, St Louis Port

See the Table Port Distance and the Table Port Shortest Path Value (the Distance data between ports can be searched or downloaded from the Table Port Distance and the Table Port Shortest Path Value in the following link: https://doi.org/10.4121/14298851) for specific data.

3. The Choice of Strategic Pivots of the Port Network Based on the Number of Ports Crossed by the Shortest Path

The port and path are abstracted into the port network model, the shortest path between the two ports is solved, the shortest path is calculated through the port, the strategic importance of the port is judged as superior or not, and the strategic pivots of the port network are finally selected.

3.1. Building a Model about the Number of Ports Crossed by the Shortest Path. Using the Floyd algorithm, the shortest path between two ports in the port network diagram is solved (there may be several shortest paths between the two ports, but this is not the case here, and the results simulated by Python are used as the only final result. The results of the shortest path solution can be searched or downloaded from the Table Port Shortest Path in the following link: https://doi.org/10.4121/14298851). Ports are connected only to each other, not directly to each other, and the shortest path between ports may include, in addition to the port from port to port, the passage through intermediate ports, which together with the port from the beginning constitute the shortest path from port to port. To solve the number of ports crossed by the shortest path, it needs to be solved in three steps.

3.1.1. Determine Whether a Port Is Crossed by a Shortest Path. Determine whether the shortest path from port v_i to port v_j crossed port v_k or not, and remember z_{kij}. If $z_{kij} = 1$, it indicates that the shortest path from port v_i to port v_j crossed port v_k. If $z_{kij} = 0$, it indicates that the shortest path crossed port v_k. The judgment vector for the shortest path between port v_i and port v_j can then be expressed as $[z_{kij}]$, where $i \neq j, k = 1, 2, \cdots, 155$.

3.1.2. Solving a Collection of the Shortest Path between Ports. Based on port v_i to port v_j judgment vector, a collection A_{ij} of ports crossed by the shortest path between the two ports are expressed as follows:

$$A_{ij} = \left\{ v_k | z_{kij} = 1 \right\}, \quad \forall k, i \neq j. \tag{2}$$

The collection of the shortest paths between all ports can be represented by a matrix as follows:

$$A = \begin{bmatrix} A_{1-1} & A_{1-2} & \cdots & A_{1-155} \\ A_{2-1} & A_{2-2} & \cdots & A_{2-155} \\ \vdots & \vdots & \ddots & \vdots \\ A_{155-1} & A_{155-2} & \cdots & A_{155-155} \end{bmatrix} = \begin{bmatrix} \varnothing & A_{1-2} & \cdots & A_{1-155} \\ A_{2-1} & \varnothing & \cdots & A_{2-155} \\ \vdots & \vdots & \ddots & \vdots \\ A_{155-1} & A_{155-2} & \cdots & \varnothing \end{bmatrix}. \quad (3)$$

3.1.3. Solving the Number of Ports Crossed by the Shortest Path. Order X_k is the total number of the shortest paths between two ports in the port network through the k port; then there is

$$X_k = \sum_{i=1}^{155} \sum_{j=1}^{155} z_{kij}, \quad j \neq i, k = 1, 2, 3, \cdots, 155. \quad (4)$$

3.2. Presentation and Analysis of Simulation Results

3.2.1. Simulation Data Analysis of the Number of Ports Crossed by the Shortest Path. Based on the model in the above section, the number of crosses between ports is solved and the results are sorted from more to less, as in Table 2.

In Table 2, the total number of all ports crossed by the shortest path is 176,897, of which the top 17 ports, with a total of 88,949 times, accounted for 10.97% of the total number of all ports crossed by the shortest path of 50.32%; the top 23 ports, with a total of 107,177 times, accounted for 14.84% of the total number of all ports crossed by the shortest path of 60.63%; the top 31 ports, with a total of 124,614 times, accounted for 20% of the total number of all ports crossed by the shortest path of 70.49%; the top 41 ports, with a total of 141,902 times, accounted for 26.45% of the total number of all ports crossed by the shortest path of 80.26%.

The simulation results show that the quantity concentration of the shortest path crossing each port is high, which meets the requirements of port network strategic pivots selection, and also show that the algorithm is effective for port network strategic pivots selection.

3.2.2. Analysis of the Distribution of the Number of Ports Crossed by the Shortest Path. In order to present the simulation results more intuitively, the number of the shortest path crosses of each port is presented on the map in the form of heat attempt, and the degree of heat of the port being crossed by the shortest path is represented by thick red to light blue, and the thermal distribution results of the port are shown in Figure 1.

To better demonstrate the effect of the port thermal distribution, take only the first 41 ports, the sum of the number of ports crossed by the shortest path is more than 80% of the total number of ports crossed by the shortest path as shown in the thermodynamic diagram in Figure 2.

As can be seen from the above two thermodynamic diagrams, most of the ports that are through are located in the channel between the major oceans, such as the Strait of Malacca between the Pacific Ocean and the Indian Ocean, the African coastline between the Indian Ocean and the Atlantic Ocean, the Red Sea Strait between the Indian Ocean and the Mediterranean Sea, the Strait of Gibraltar between the Mediterranean Sea and the Atlantic Ocean, the English Channel between the Atlantic Ocean and the North Sea, and the Panama Canal connecting the Atlantic Ocean and the Pacific Ocean.

The actual situation of the port thermodynamic diagram distribution and the main international shipping paths is consistent, which shows that the basic data such as port samples, direct edge processing, and port distance data are reasonable and effective and also shows that the algorithm is feasible and effective to select the strategic pivots of the port network.

3.3. Analysis of the Strategic Importance of the Port.

The strategic pivots of the port network are to select some ports as strategic pivots in the port network, so as to pry the development of the whole port network and promote the common economic development of the port hinterland countries and neighboring countries.

According to the model solution principle of the shortest path of the network, the more times a network has been crossed by the shortest path, the closer the connection between the network and the other network outlets, the greater the role of the network, and the greater its strategic importance. Therefore, according to the number of ports crossed by the shortest path of each port in the port network, it is the standard to judge the strategic importance of the port, that is, whether the port is selected as the strategic pivot.

3.3.1. Building an Analysis Model of the Strategic Importance of the Port. According to the grouping rules with similar number of ports crossed by shortest path, the K central point cluster analysis model is constructed, and the port training is divided into three groups with specific ideas:

(1) The array $(X = \{x_i | x_1, x_2, \cdots, x_{155}\})$ of the shortest path crossing each port is used as the object of machine learning and training, and x_i corresponds to the number of the shortest paths crossing ports v_i.

(2) Three values are found in the array with the number of centers (y_j); according to the principle of the minimum difference between the values in the array and the number of centers, all the values in the number of values in the array are divided into three groups; each value is assigned to the group with the smallest difference from the number of centers; that is, all the values in the group have the closest number of crosses by the shortest path, the values x_i are assigned to group j then marked x_{ij}, and $x_{ij} = x_i$ are not assigned to group j; then $x_{ij} = 0$.

Table 2: The number of ports crossed by the shortest path (ports with values equal to 0 are not listed in the table; they can be searched or downloaded from the following link: https://doi.org/10.4121/14298851).

Rank	The port code	Name of Port	The number of ports crossed by the shortest path
1	v70	Piraeus Port Terminal	8032
2	v35	Aden Port	7738
3	v83	Por Said Port	7440
4	v80	Cherchell Port	7186
5	v81	Suez Port	6992
6	v79	Tunisia Port	6636
7	v32	Jeddah	6602
8	v26	Mumbai Port	4842
9	v24	Colombo Port	4768
10	v68	The Port of Gibraltar	4064
11	v14	Singapore Port	4038
12	v102	Tangier Port	3872
13	v98	Dakar Port	3498
14	v144	Panama City Port	3338
15	v13	Penang Port	3322
15	v91	Boke Terminal	3322
17	v143	Colon Port	3242
18	v92	Conakry Port	3150
19	v11	Melaka Gateway	3148
20	v12	Kuala Selangor	3108
21	v99	Monrovia Port	3062
22	v130	Montreal Port	3038
23	v95	Abidjan Port	2716
24	v3	Hong Kong	2608
25	v134	Santo Domingo Port	2556
26	v49	Le Havre Port	2127
27	v125	New York Port	2112
28	v17	Gwadar Port	2058
29	v109	Sao Tome and Principe Port	2050
30	v103	Dakhla Port	1968
31	v104	Nouakchott Port	1950
32	v100	Gentil Port	1890
33	v88	Pointe Noire Port	1848
34	v89	Matadi Port	1792
35	v107	Walvis Port	1790
36	v113	Berbera Port	1754
37	v84	Luanda Port	1736
38	v34	Salalah Port	1712
39	v114	Cape Town Port	1634
40	v118	Fremantle Port	1568
41	v96	Mombasa Port	1554
42	v141	San Jose Port	1514
43	v28	Istanbul Port	1490
44	v66	Zebrukh Port	1485
45	v30	The Port of Chahbahar	1480
46	v111	Dar es Saalam Port	1374
47	v29	Qishm	1198
48	v135	Port-au-Prince	1184
49	v133	Kingston Harbor	1082
50	v115	Durban Port	1046
51	v105	Beira Port	1008
52	v63	Port of Rotterdam	940
53	v106	Maputo Port	912
54	v54	The Kingdom of Denmark	906
55	v20	Busan	890
56	v145	Cali Port	804
57	v4	Kaohsiung Port	760
58	v71	Wado Port	740
59	v117	Melbourne Port	688

Table 2: Continued.

Rank	The port code	Name of Port	The number of ports crossed by the shortest path
60	v64	Port of Amsterdam	672
61	v131	Havana Port	646
62	v139	Managua Port	640
63	v18	Yokohama Port	632
64	v93	Tema Port	624
65	v53	Oslo Port	588
66	v46	Hamburg Hafen	560
67	v147	Guayaquil Port	552
68	v6	Da Nang	452
69	v86	Lome Port	422
70	v136	Guatemala Port	416
71	v37	Jakarta-Kariburu	372
72	v39	Tanjung Priok	364
73	v15	Manila Port	350
74	v132	Pilon Port	328
75	v60	Murmansk Port	324
75	v138	Honduras Port	324
77	v59	Vladivostok Port	312
78	v52	Hammerforst Port	308
79	v148	Kayao Port	306
80	v5	Hanoi Port	302
80	v33	Doha Port	302
80	v75	Durres Port	302
83	v78	Varna Port	300
84	v47	London Port	296
85	v73	Reykjavík Port	294
86	v9	Laem Chabang	280
87	v142	Puerto Limon	268
88	v119	Newcastle Port	240
89	v140	Cabesas Port	234
90	v10	Kuantan Port	230
91	v48	Liverpool Port	224
92	v23	Kyaukpyu Port	216
92	v101	Cotonou Port	216
94	v150	Punta Arenas Port	208
95	v2	Guangzhou Port	202
96	v123	Manzanillo Port	194
97	v43	Nicosia Port	172
98	v110	Sudan Port	170
98	v149	San Diego Port	170
100	v50	Marseille Port	154
101	v72	San Marino Port	152
102	v22	Chattogram Port	148
103	v67	Valencia Port	146
103	v112	Tripoli Port	146
105	v82	Damietta Port	132
105	v87	Massawa Port	132
107	v85	Bata Port	124
108	v116	Darwin Port	82
109	v8	Bangkok Port	66
110	v120	Lae Port	50
111	v7	Sihanoukville	8
111	v108	Lagos Tingcan Port	8
113	v62	Sochi Port	4
113	v94	Kribi Port	4
115	v31	Dammam Port	2
115	v40	Jerusalem Port	2
115	v42	Kuwait Port	2
115	v45	Lattakia Port	2
115	v76	Constanta Port	2
115	v137	Puerto Barrios Port	2

Figure 1: The thermodynamic diagram about the number of ports crossed by the shortest path.

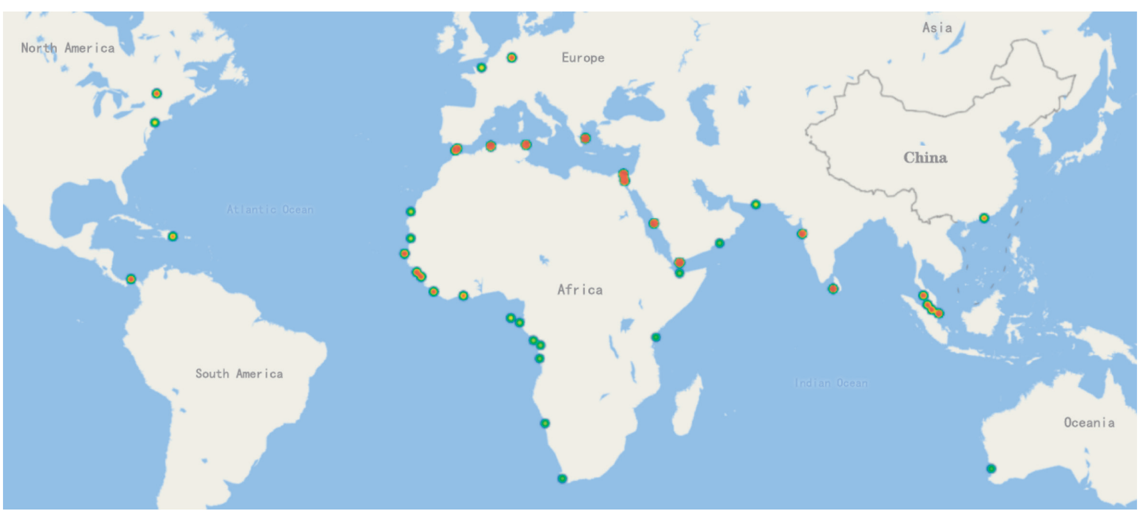

Figure 2: The thermodynamic diagram about rank in the top 41 of the number of ports crossed by the shortest path.

(3) Group to solve the distance between all the values of this group and the number of centers of this group, and group cumulatively adding up to Y_1, Y_2, and Y_3:

$$Y_j = \sum_{i=1}^{155} x_{ij}, \quad j = 1, 2, 3. \tag{5}$$

(4) Add the differences between the groups and add them up; get $Z = \sum_{j=1}^{3} Y_j$.

(5) At the end of the training, when the sum Z value is the minimum value ($Z_{\min}$), the resulting grouping is the final grouping of strategic importance of the port; on this basis, according to the average size of the number of each group of ports crossed by the shortest path, the three types of ports are divided into the strategic importance "superior" group, "general" group, and "inferior" group.

3.3.2. Superior Analysis and Verification of the Port Strategic Importance. According to the above grouping ideas, build an unsealed learning model; the solution results show that when $Z_{\min} = 58186$, the three centers are 6992, 2050, and 296; the strategic importance of the "superior" group has 9 ports, "general" group has 39 ports, and "inferior" group has 107 ports; the specific data can be seen in Table 3.

Table 3: The results of the training grouping of the number of ports crossed by the shortest path (ports in the "inferior" group are not listed; specific and available data can be searched or downloaded from the Table Port Betweenness Centrality in the following link: https://doi.org/10.4121/14298851).

Strategic importance	The list of ports
"Superior" group (9)	Piraeus Port Terminal, Aden Port, Por Said Port, Cherchell Port, Suez Port, Tunisia Port, Jeddah, Mumbai Port, Colombo Port
"General" group (39)	The Port of Gibraltar, Singapore Port, Tangier Port, Dakar Port, Panama City Port, Yokohama port, Boke Terminal, Colon Port, Conakry Port, Melaka Gateway, Kuala Selangor, Monrovia Port, Montreal Port, Abidjan Port, Hong Kong, Santo Domingo Port, Le Havre Port, New York Port, Gwadar Port, Sao Tome and Principe Port, Dakhla Port, Nouakchott Port, Gentil Port, Pointe Noire Port, Matadi Port, Walvis Port, Berbera Port, Luanda Port, Salalah Port, Cape Town Port, Fremantle Port, Mombasa Port, San Jose Port, Istanbul Port, Zebrukh Port, the Port of Chahbahar, Dar es Saalam Port, Qishm, Port-au-Prince

Table 4: Kruskal–Wallis test grouping results.

Variable	Constituencies	Average	Standard deviation	The number of samples	Kruskal–Wallis inspection	
					The card square value	P value
The number of ports crossed by the shortest path	The first group (superior)	6692.89	1168.27	9	21.49^{***}	$P \leq 0.01$
	The second group (general)	2342.31	847.77	39		
	The second group (general)	2342.31	847.77	39	85.16^{***}	$P \leq 0.01$
	The third group (inferior)	235.10	289.84	107		

For the above training results, the grouping results were analyzed by Kruskal–Wallis test, as in Table 4.

The test results show that the variance test value is less than 0.01%, which is significant and shows that the results of strategic importance are reliable and effective.

4. Strategic Pivots Selection Based on Betweenness Centrality of the Port Network

Betweenness centrality is one of the measures of network vertexes to network graph centrality. For the whole port network, the greater the value of the betweenness centrality of the port is, the greater the influence and control of the port on the entire port network are, the stronger its strategic importance is, and the more the port should be preferred as the strategic pivots port of the entire network.

4.1. Building a Strategically Important Model of Port Network. According to the principle of betweenness centrality model, the number $Q_{ij(k)}$ of port v_k through the shortest path between port v_i and port v_j in the whole network, and the ratio of the total number Q_{ij} of shortest paths between port v_i and port v_j, the sum of the ratios throughout the network is as follows:

$$BC_k = \sum_{i \neq j \neq k \in N} \frac{Q_{ij(k)}}{Q_{ij}}. \tag{6}$$

That is the betweenness centrality of the port.

4.2. Presentation and Analysis of Simulation Results. To be comparable, the underlying data and settings in this section are the same as in the previous section.

4.2.1. Analysis of Betweenness Centrality Values. According to the betweenness centrality model, the betweenness centrality of each port is solved and the results are sorted, as in Table 5.

In the table above, the sum of the betweenness centralities of all ports is 118306, of which, for the top 14 ports, the sum of their betweenness centralities is 60091.60, and 9.03% of the port number accounts for 50.79% of the betweenness centrality sum; for the top 19 ports, the sum of their betweenness centralities is 71457.63, and 12.26% of the port number accounts for 60.4% of the betweenness centrality sum; for the top 26 ports, the sum of their betweenness centralities is 84108.40, and 16.77% of the port number accounts for 71.09% of the betweenness centrality sum; for the top 34 ports, the sum of their betweenness centralities is 95163.40, and 21.94% of the port number accounts for 80.44% of the betweenness centrality sum. The simulation results show that the centralization of the port is high, and, from the point of view of the concentration of the betweenness centrality, the simulation results meet the requirements of the port strategy pivots selection, and they also show that it is effective in judging the strategic importance of the port in the whole network based on the betweenness centrality.

Table 5: The betweenness centrality for each port.

The port code	Port	Betweenness centrality
v118	Fremantle Port	6431.97
v35	Aden Port	5826.28
v14	Singapore Port	5088.82
v144	Panama City Port	4863.39
v125	New York Port	4716.63
v114	Cape Town Port	4706.16
v143	Colon Port	4501.09
v3	Hong Kong	4325.15
v104	Nouakchott Port	3762.52
v154	Santos Port	3721.93
v70	Piraeus Port Terminal	3403.56
v80	Cherchell Port	3346.09
v83	Por Said Port	2850.96
v32	Jeddah	2547.05
v81	Suez Port	2532.32
v134	Santo Domingo Port	2371.64
v68	The Port of Gibraltar	2170.51
v107	Walvis Port	2156.25
v26	Mumbai Port	2135.30
v17	Gwadar Port	2059
v109	Sao Tome and Principe Port	1956.94
v24	Colombo Port	1862.11
v102	Tangier Port	1858.771
v130	Montreal Port	1839.79
v71	Wado Port	1558.43
v37	Jakarta-Kariburu	1515.73
v28	Istanbul Port	1492
v79	Tunisia Port	1479.56
v150	Punta Arenas Port	1458.78
v140	Cabesas Port	1427.31
v132	Pilon port	1356.69
v47	London Port	1351.42
v18	Yokohama Port	1254.07
v39	Tanjung Priok	1235.17
v16	Abu Dhabi Port	1085.33
v54	The Kingdom of Denmark	1083.86
v99	Monrovia Port	1076.67
v1	Shanghai Port	1074.54
v34	Salalah Port	1073.07
v115	Durban Port	1047.97
v135	Port-au-Prince	836.05
v131	Havana Port	782.24
v155	St Louis Port	757.51
v152	Buenos Aires Port	674.36
v49	Le Havre Port	570.08
v48	Liverpool Port	554.59
v66	Zebrukh Port	530.32
v153	Paranagua Port	515.64
v29	Qishm	506
v113	Berbera Port	432.03
v116	Darwin Port	414.89
v98	Dakar Port	405.60
v33	Doha Port	400.67
v30	The Port of Chahbahar	394.67
v59	Vladivostok Port	381.27
v117	Melbourne Port	375.67
v141	San Jose Port	370.95
v60	Murmansk Port	369.73
v145	Cali Port	359.73
v12	Kuala Selangor	347.00

Table 5: Continued.

The port code	Port	Betweenness centrality
v2	Guangzhou Port	320.10
v149	San Diego Port	318.28
v75	Durres Port	299.52
v97	Tamataf Port	295.74
v88	Pointe Noire Port	272.74
v96	Mombasa Port	255.33
v111	Dar es Saalam Port	253.41
v106	Maputo Port	216.67
v20	Busan	212.17
v119	Newcastle Port	210.52
v84	Luanda Port	201.06
v13	Penang Port	193.72
v147	Guayaquil Port	173.53
v8	Bangkok Port	172.66
v53	Oslo Port	170.08
v103	Dakhla Port	161.42
v133	Kingston Harbor	151.63
v148	Kayao Port	151.39
v4	Kaohsiung Port	147.902
v95	Abidjan Port	137.31
v112	Tripoli Port	136.92
v151	La Guaira Port	134.38
v91	Boke Terminal	133.99
v11	Melaka Gateway	129.34
v92	Conakry Port	117.8
v90	Djibouti Port	111.56
v82	Damietta Port	102.8
v15	Manila Port	100.04
v87	Masawa Port	91.45
v5	Hanoi Port	89.57
v6	Da Nang	87.97
v62	Sochi Port	77
v64	Port of Amsterdam	75.59
v41	Batumi Port	75
v77	Odessa Port	75
v78	Varna Port	75
v128	Vancouver Port	72.38
v43	Nicosia Port	64.60
v72	San Marino Port	61.73
v138	Honduras Port	58.97
v121	Wellington Port	55.77
v7	Sihanoukville	49.75
v10	Kuantan Port	49.75
v67	Valencia Port	46.27
v50	Marseille Port	44.04
v46	Hamburg Hafen	38.64
v129	Churchill Port	34.24
v110	Sudan Port	33.85
v146	Barranquilla Port	29.047
v142	Puerto limon	28.57
v73	Reykjavík Port	23.04
v127	New Orleans Port	22.08
v100	Gentil Port	11.41
v124	Veracruz Port	7.36
v137	Puerto Barrios Port	7.36
v63	Port of Rotterdam	5.33
v120	Lae Port	3.83
v122	Suva Port	3.83
v105	Beira Port	3.67
v9	Laem Chabang	3

Table 5: Continued.

The port code	Port	Betweenness centrality
v42	Kuwait Port	3
v89	Matadi Port	2.75
v93	Tema Port	2.67
v52	Hammerforst Port	2.57
v38	Jambi International Port	2.33
v22	Chattogram Port	2
v27	Chennai Port	2
v76	Constanta Port	2
v85	Bata Port	1.83
v123	Manzanillo Port	1.79
v139	Managua Port	1.79
v126	Port of Long Beach, Los Angeles	1.186
v23	Kyaukpyu Port	1
v40	Jerusalem Port	1
v45	Lattakia Port	1
v86	Lome Port	1
v94	Kribi Port	1
v101	Cotonou Port	1
v108	Lagos Tingcan Port	1
v136	Guatemala Port	0.79
v31	Dammam Port	0.67
v44	Basrah Port	0.67
v19	Chongjin Port	0

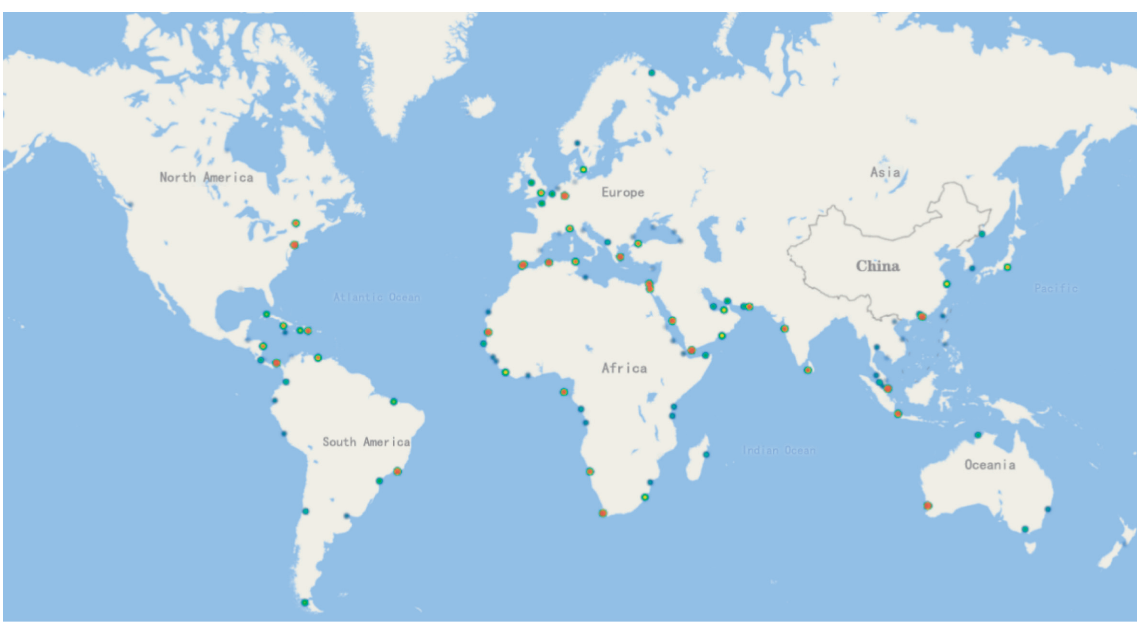

Figure 3: The thermodynamic diagram about the betweenness centrality of each port.

4.2.2. Analysis of Betweenness Centrality Distribution Map. In order to present the simulation results more intuitively, the betweenness centrality of each port is presented on the map in the form of heat-trying, and the degree of the betweenness centrality of the port is represented by thick red to light blue, and the distribution results of the port thermal force are shown in Figure 3.

In order to better demonstrate the distribution effect of port betweenness centrality heat, only the top 34 are shown, and the sum of betweenness centralities exceeds 80% of the port heating, as shown in Figure 4.

From the above two thermal distribution charts, it can be seen that most of the ports with large betweenness centrality values are distributed in the channels between the major oceans; it can be seen that the distribution of port betweenness centrality heat is consistent with the actual situation of the major international shipping paths, indicating that the basic data such as port samples, direct edge

FIGURE 4: The thermodynamic diagram about rank in the top 34 ports in the betweenness centrality.

TABLE 6: Group results by interstitial central numerical training (ports in the "inferior" group are not listed; specific and available data can be searched or downloaded from the Table Port Betweenness Centrality in the following link: https://doi.org/10.4121/14298851).

Strategic importance	The list of ports
"Superior" group (12)	Fremantle Port, Aden Port, Singapore Port, Panama City Port, New York Port, Cape Town Port, Colon Port, Hong Kong, Nouakchott Port, Santos Port, Piraeus Port Terminal, Cherchell Port
"General" group (30)	Por Said Port, Jeddah, Suez Port, Santo Domingo Port, the Port of Gibraltar, Walvis Port, Mumbai Port, Gwadar Port, Sao Tome and Principe Port, Colombo Port, Tangier Port, Montreal Port, Wado Port, Jakarta-Kariburu, Istanbul Port, Tunisia Port, Punta Arenas Port, Cabesas Port, Pilon Port, London Port, Yokohama Port, Tanjung Priok, Abu Dhabi Port, the Kingdom of Denmark, Monrovia Port, Shanghai Port, Salalah Port, Durban Port, Port-au-Prince, Havana Port

TABLE 7: Kruskal–Wallis test grouping results.

Variable	Constituencies	Average	Standard deviation	The number of samples	Kruskal–Wallis inspection	
					The card square value	P value
The number of ports crossed by the shortest path	The first group (superior)	4557.80	940.66	12	25.12^{***}	$P \leq 0.01$
	The second group (general)	1617.65	54.12	30		
	The second group (general)	1617.65	54.12	30	70.63^{***}	$P \leq 0.01$
	The third group (inferior)	133.48	171.87	113		

processing, and port distance data are reasonable and effective and that the algorithm is feasible and effective to carry out strategic pivots analysis of the port network.

4.3. Superior Analysis and Verification of the Port Strategic Importance. According to the model solution principle of betweenness centrality, the greater the betweenness centrality value of a dot in the network, which indicates closer connection between the dot and other networks in the network, the greater the influence, the greater the role played on the network, and the greater the strategic importance.

According to the third part of the clustering algorithm, the training results show that when the three sets of data difference $Z_{\min} = 35688.46$, the three centers are 4706.16, 1479.56, and 61.73; the strategic importance of the

Table 8: A joint coverage matrix of strategically important "superior" ports.

		The number of ports crossed by the shortest path		
		Superior	General	Inferior
Betweenness centrality	Superior	Piraeus Port Terminal, Aden Port, Cherchell Port	Hong Kong, Singapore Port, Nouakchott Port, Cape Town Port, Fremantle Port, New York Port, Colon Port, Panama City Port	Santos Port
	General	Por Said Port, Suez Port, Tunisia Port, Jeddah, Mumbai Port, Colombo Port		
	Inferior			

Table 9: A double attribute category table for strategic pivot ports.

		Whether Chinese companies participate in attributes	
		Yes	No
"The Belt and Road" country properties	Yes	Hong Kong, Colombo Port, Piraeus Port Terminal, Cherchell Port, Suez Port, Por Said Port, Nouakchott Port, Colon Port	Aden Port, Singapore Port, Tunisia Port, Jeddah, Cape Town Port, Panama City Port
	No	Zero	Fremantle Port, New York Port, Mumbai Port

"superior" group has 12 ports, "general" group has 30 ports, and "inferior" group has 113 ports, as in Table 6.

For the above training results, the grouping results were analyzed by Kruskal–Wallis test, as in Table 7.

According to the above test results, the average variance of the three sets of data is less than 0.01%.

5. Conclusions

The number of ports is crossed by the shortest path and betweenness centrality of the two simulations of the port in the network as "superior," "general," and "inferior" groups; the grouping results test is valid, but the results of the grouping are the same, so it is necessary to further the above two simulation results of joint coverage analysis and finally determine the strategic pivots port.

Both sets of simulation results are "general" or "inferior" ports of strategic importance; we think that should not be selected as the strategic pivots of the port network; therefore, the two sets of simulation results, only for at least one set of simulation results, show the strategic importance of "superior" ports, a joint coverage analysis. Among them, for the strategic importance of the "superior" group, the number of ports crossed by the shortest path in the "superior" group is 9 ports, the betweenness centrality dimension "superior" group of 12 ports; the specific results can be seen in Table 8.

Based on the data in the table above, only the ports in the upper left triangle matrix are strategically important "superior" ports, so the four sets of ports are analyzed.

(1) The strategic importance of both simulation results is that there are three "superior" ports. Geographically, the three ports are located in the channel from the Indian Ocean, through the Red Sea, the Mediterranean Sea and into the Atlantic Ocean, with the Aden Port and the Cherchell Port as the ports at the mouth of the channel, while the Piraeus Port is at the Centre of the Mediterranean Sea and is the main transit point between the ports of European and North African countries. The three ports are located in the busiest shipping lanes in the world, so it is realistic and reasonable that the three ports should be chosen as strategic pivots ports.

(2) The number of ports crossed by the shortest path simulation is grouped as "superior" and the betweenness centrality simulation is grouped into "general" with six ports. Four of these ports are located in the Channel from the Indian Ocean, through the Red Sea, the Mediterranean Sea and into the Atlantic Ocean, while the Mumbai Port and the Colombo Port are located at the Pacific to Indian Ocean exits and are the main shipping lanes connecting the Pacific and the Indian Oceans; from this point of view, the six ports selected as strategic pivot ports are realistic and reasonable.

(3) The number of ports crossed by the shortest path simulation is grouped into "general," and the betweenness centrality simulation is grouped into "superior" with eight ports. Among them, the Hong Kong and the Singapore Port are located at the entrance of the Pacific to Indian Ocean path, the ports of Nouakchott and Cape Town are located on the southern path between the Indian Ocean and the Atlantic Ocean, and the Colombo Port and the Panama City Port are the two ports connecting the Pacific Ocean and the Atlantic Ocean, while the ports of New York Port and the Fremantle Port are the main points of entry for the North American continent and the Australian mainland. These ports are located on major international paths, so it is realistic and reasonable that they should be chosen as strategic pivot ports.

(4) The number of ports crossed by the shortest path simulation is grouped as "inferior," and the port

with the betweenness centrality simulation grouped as "superior" is only the Santos Port. The Santos Port is an important port in Brazil; from the simulation process, it can be seen that Santos, in the grouping results of the large error, because the route Santos has strong substitutability, and there are more ports on the east coast of the Atlantic than the west coast of the Atlantic; therefore, the Santos Port is divided into the number of ports crossed by the shortest path dimension "down" group. For this reason, the Santos Port should not be chosen as a strategic pivots port.

In summary, 17 of the 18 ports with "superior" strategic importance above, with the exception of the Santos Port, have been identified as strategic pivot points of the global port network.

6. Suggestions and Discussions

6.1. "The Belt and Road" Strategic Pivots Port Analysis and Instructive Suggestions. "The Belt and Road" initiative is a new engine for promoting international capacity cooperation and a strong guarantee for win-win cooperation among the agreed countries. "Belt and Road," the economic industry across Asia, Europe, and Africa, covers 60% of the world's population, including 30% of the global economy; there is a huge potential for development. If the "Belt and Road" Agreement is signed in the hinterland of the port, it will certainly get a great deal of assistance in infrastructure and will play a more important role in the economic and trade exchanges between the countries of the agreement.

Chinese enterprises are involved in investment, construction, and operation of ports; whether from the commercial logic or from a technical point of view, the future cooperation will greatly improve control and stability. Although there are sovereign barriers between countries, the commercial rules of the world economy run through the beginning and the end of economic development.

In view of the 17 ports where the above strategic pivot points are "superior," if China wants to develop the strategic layout of its port network in the world, it needs to consider the economic development potential of the port network from China's perspective, as well as the controllability and stability of future cooperation. Therefore, the two attributes of "One Belt and One Road" and "whether Chinese enterprises participate" of these strategic pivot ports are analyzed by analogy analysis. Based on these two attributes, strategic pivot ports are grouped into four categories, as in Table 9.

According to the properties of strategic pivots ports, they are analyzed separately and enlightening suggestions are made:

(1) There are eight strategic pivot ports with the participation of Chinese enterprises and hinterland countries that have signed "the Belt and Road" Agreement. From the geographical location of the international shipping paths, two ports are the main ports of the Indo-Pacific sea path (the Indo-Pacific sea path is a sea path connecting India and the Pacific Ocean), four ports are the main ports connecting the Indian Ocean and the Atlantic Ocean north path, a port connects the Atlantic Ocean and the Pacific Ocean, and one of these ports is an important port from Africa radiation to North America, South America, and Europe; from this point of view, these eight ports are located on the main international shipping paths, and comprehensive coverage of several major maritime paths connects several major sea areas. The hinterland countries in which the port is located have signed "the Belt and Road" Agreement, with low political risks and great potential for economic development, and the role of the port in the future economic development process will become more and more important. The port has Chinese enterprises involved in investment, construction, and operation; in the future cooperation of the port, Chinese enterprises will have a strong voice. Therefore, it will play a vital role to give priority to the development of these eight strategic pivot ports and take these eight ports as the core hubs of "the Belt and Road" port network to radiate and lead the economic development of the countries along "the Belt and Roa."

(2) The port hinterland countries have signed "the Belt and Road" Agreement but there are six strategic pivot ports in which Chinese enterprises are not involved in investment and construction operations. Geographically, it is the Indo-Pacific sea path, the Indo-Atlantic North Sea path, the Indo-Atlantic South Sea path (the Indo-Atlantic North Sea path is a sea path connecting India and the Atlantic Ocean, via the Red Sea and the Mediterranean Sea, and the Indo- Atlantic South sea path is a sea path connecting India and the Atlantic Ocean, through the Mozambique Strait and through South Africa), the Indian-South Sea path refers to the sea path connecting India and the Atlantic Ocean, through the Red Sea, the Mediterranean Sea, the main port of the Atlantic and Pacific Panama paths. The hinterland countries in which these ports are located have signed "the Belt and Road" Agreement, which has a good basis for political and economic cooperation, and need to vigorously promote cooperation between Chinese enterprises and these ports at the commercial or technical level, which is not only conducive to enhancing the stability of "the Belt and Road" port network but also conducive to promoting the participation of these countries in "the Belt and Road" other industrial energy and other aspects of cooperation.

(3) There are three ports where neither attribute is available. Geographically, these ports are not the main sea paths of the port but are important medium-transformation ports. New York Port is the main transshipment port on the west coast of the Atlantic Ocean, Fremantle Port is an important transshipment port to the Australian mainland in

other waters, and Mumbai Port is an important transshipment port on the east coast of the Indian Ocean. Therefore, it is necessary to strengthen cooperation with the commercial level of these ports, reduce the transit costs of maritime transport, and enhance the competitiveness of "the Belt and Road" port network.

6.2. Discussion of Other Association Studies. This paper abstracts the global port and path into a nondirected power network and considers the shortest path between ports, the shortest path through the port, the betweenness centrality of the port network and other factors, from whether the strategic importance of the port is superior to judge and choose whether it should be identified as the strategic pivot of the global port network; the strategic layout of the global port network to promote "the Belt and Road" along the port economic development has a strong reference significance. However, the influence factors do not take into account the cost of actual shipping, port throughput capacity, and trade volume between countries and other factors; therefore, in practice, the impact factors for further in-depth study can also be increased.

Data Availability

The data used to support the findings of this study have been deposited in the 4TU.Research Data (SCIENCE· ENGINEERING· DSIGN) repository (https://doi.org/10.4121/14298851).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

The materials in the text files are raw data which are used to derive the data in the tables in the manuscript. (*Supplementary Materials*)

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