Topology Analysis of China's Port Shipping Network

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Abstract—**Based on China's port shipping statistical data from 2006 to 2010, the paper constructs China's port shipping network structure chart, and analyzes the degree distribution, average path length, network density and network clustering coefficient of the network. The results show that China's port shipping network has scale-free characteristic with short average path length, high network density, and its degree distribution follows a power law. Through the computer simulation, the higher correlation coefficient also shows that data fitting is satisfactory, which further validates that China's port shipping network is a scale-free network.**

Index Terms—**Complex network; shipping network; degree distribution; scale-free**

Ⅰ. INTRODUCTION

Transportation is a fundamental industry in national economy. Ports play significant roles in trade and business, and they are important hubs in water transport. On the one hand, the development of ports meets the need for economy and trade. On the other hand, it creates convenient conditions for the region, promotes the city's development, and improves the residents' living conditions. With the development of globalization, as the portal opening to the world, China's ports are playing increasingly important roles in trade improving and global economy competing. From 2006 to 2010, China ports' cargo throughput was 56, 64.10, 58.7, 76.57 and 89.32 billion tons respectively, which had an increase of 15.4%, 15.1%, 11.5%, 9% and 16.7% respectively over the same period of previous year. China Shipping cargo throughput shows an increasing trend, but it dropped in 2008, which was mainly because China's market was suffering economic crisis. Even so, the year-on-year growth rate has increased in different extent, which reflects China shipping scale is expanding gradually. After 60 years' development, the shipping network of China shipping industry has been initially formed.

Complex network is an emerging scientific discipline which relates to other disciplines [1-2]. Many empirical studies on network show that, a lot of natural networks and social networks, such as social network, information network, technology network and biological network [3], are neither regular network nor random network, but the network with some or all of the these properties like self-organizing, self-similarity, attractor, small-world phenomena and scale-free phenomena. As a powerful tool used to analyze complex system's topological structure and dynamic evolvement, complex network [4-7] is gradually becoming a hot area of research. In recent years, based on the small-world network theory and scale-free network theory, domestic and foreign scholars have already analyzed aviation network, and gained some achievements [8-9]. Guimer et al.[10] analyzed American aviation network, who indicated that the United States aviation network had a typical scale-free characteristic. Amaral [11] and Guimera [12] analyzed worldwide air transportation network, whose results showed that the network was a small-world network. Bagler [13]analyzed the air transportation network in India, and proved that the airport network is a complex weighted network, which has small-world properties. Sen [14] analyzed the Indian railway network, and proved that the railway network also is a "small-world" network. Using the complex network theories, Yaru Dang [15] analyzed China's air cargo network formed by the flow of goods between cities, and indicated that the core cities in the network were important and vulnerable. Hongguang Yao [16] analyzed the robustness of the China's aviation network. Feng Gao [17] analyzed the scale-free properties of aviation network. Xiangwei Mu [18] analyzed the topological structure of China's shipping network. Hui Zhang [19] studied the containerization in shipping network, and optimized the transportation routes. Wei Tian [20] analyzed the complexity of the world's shipping network, and proved that the international shipping network had small-world and scale-free properties. Through the above discussions, there are a lot of research results on the air transport network, while there are little analyses on shipping network, especially the shipping network based on ports.

Using the complex network theory, based on the China's port shipping statistical data from 2006 to 2010, the paper constructs China's port shipping network, and analyzes the network's topological structure and

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development tendency.

Ⅱ. COMPLEXITY ANALYSIS OF CHINA'S PORT NETWORK STRUCTURE

A. Data Selection

Shipping network is a network system that refers to ports and ship routes among cities. In this paper, ports whose throughput is more than 10 million tons per year are chosen to be vertices. If and only if there are real routes between two ports, we connect them. We choose the data as follows: (1) Not include the ports in Hong Kong, Macao, Taiwan or small ports (whose throughput is less than 10 million tons per year). (2) We count 64 ports in 2006, 66 ports in 2007, 67 ports in 2008, 77 ports in 2009 and 79 ports in 2010 to do the analysis. Figure 1 shows the main ports in China in 2010.

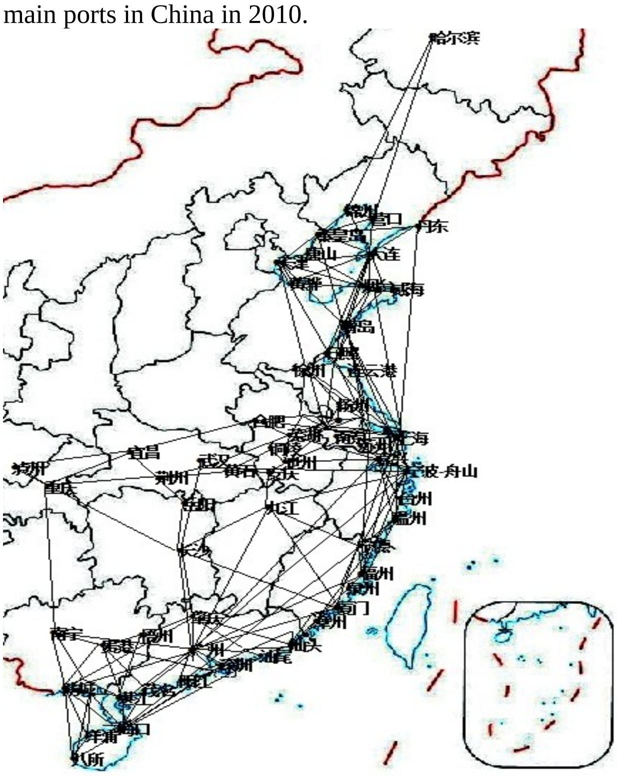

Fig. 1. Main ports (whose throughput is more than 10 million tons per year) and the ship routes in China in 2010

B. Complexity of China's Port Shipping Network Structure

In order to research the China's port network structure, we process the data from 2006 to 2010; draw the China's port network by UCINET (Figure.2a) to Figure.2 e)),where red vertices represent the top ten ports on throughput from 2006 to 2010 respectively.

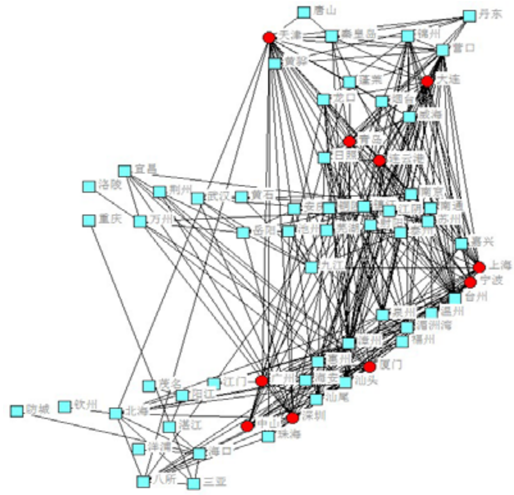

Fig. 2a).Average response time per number of sites in 2006

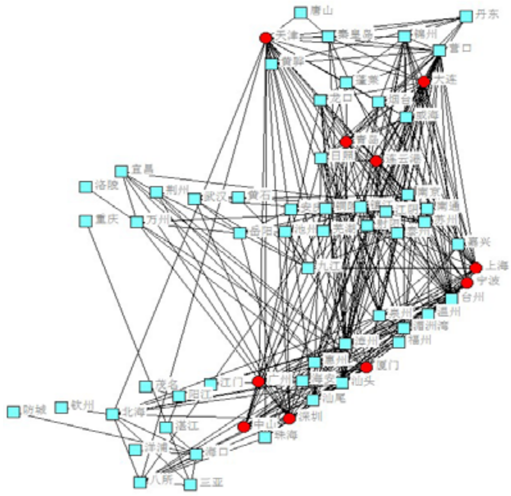

Fig. 2b).Average response time per number of sites in2007

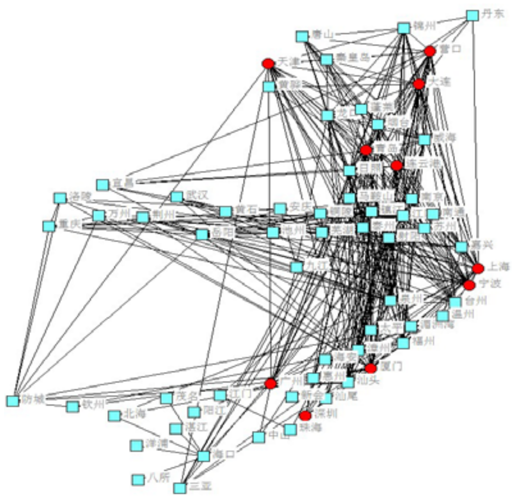

Fig. 2c).Average response time per number of sites in 2008

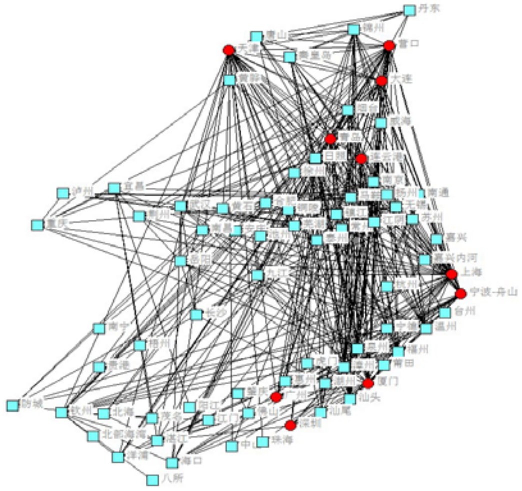

Fig. 2d).Average response time per number of sites of 2009

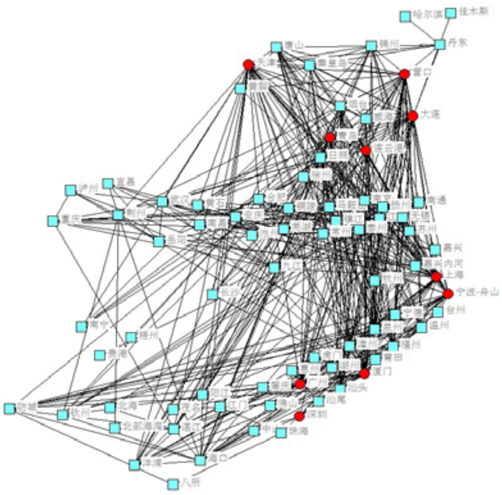

Fig. 2e).Average response time per number of sites in 2010

From the pictures above, we can see that the number of big ports whose throughput is more than 10 million tons per year was constantly increasing from 2006 to 2010. The number of internal ship routes had an increase from 576 routes in 2006 to 878 routes in 2010, which indicated China's rapid development of port cargo industry. However, the ports in coastal area developed much rapider than those in inland area. Meanwhile, it is clear that the network graphs carry "scale-free" property viewed from the figure 2. The degree of vertices has uneven distribution features; most vertices have small degree while just very little vertices have big degree. Seen from the figure 2, we can get that the core ports in China's port network are Shanghai, Ningbo-Zhoushan, Guangzhou, Xiamen, Shenzhen, Tianjin, Qingdao, Yingkou, 8 ports in coastal area, and Suzhou port in inland area. The red vertices represent the top ten ports in China; those ports always play important roles in China's port cargo industry. They have close connection with other ports, and their scale is becoming larger and larger. They are important core hubs in the port network.

III. TOPOLOGY ANALYSIS OF CHINA'S PORT SHIPPING NETWORK

In complex network theory, the measurements related to topology analysis mainly are degree of nodes, average degree of vertices, average distance, network density, clustering coefficient, betweenness centrality and so on. Based on the data in "Statistical Yearbook of China's port" from 2007 to 2011, we structure the port shipping network. In which, relational matrix is defined as $\left(e_{ij}\right)$. e_{ij} represent the relationship between port i and port j, if and only if there are directly freight transport, $e_{ij} = 1$, otherwise $e_{ij} = 0$. According to the network we defined, the paper computes the network's topology eigenvalues by UCINET software, which are shown in table 1.

TABLE1.
THE TOPOLOGY EIGENVALUES OF CHINA'S PORT SHIPPING NETWORK

Years	Ports' number	Degree	Average degree	Average distance	Network density	Clustering coefficient	Average betweenness centrality
2006	64	576	8.597	2.831	0.9002	0.499	13.728
2007	66	598	9.061	2.724	0.8956	0.465	12.831
2008	67	701	10.463	2.564	0.9124	0.600	15.594
2009	77	712	10.546	2.490	0.9137	0.541	13.797
2010	79	878	11.114	2.300	0.9193	0.455	14.485

In the China's port shipping network, the bigger the degree of a vertex, the more important the port. Bigger degree means better service ability on shipping. For example, the ports in Shanghai, Shenzhen, Guangzhou, Qingdao and Tianjin have bigger degree, which shows these ports have more freight relationship with other ports, and they are in the core position in the port shipping network.

The node degree is an important statistical characteristic of the complex network. Let k_i be the node degree, namely the number of other nodes connected to the node. Each node i is assigned from the degree distribution $p(k)$, which describes the macro statistical characteristics of the network with $p(k) = n_k / N$, whereas n_k is the number of vertices whose degree is k and the sum of vertices is N. In complex network, let $C_B(v) = \sum_{s,t \in V} \frac{\sigma(i, j|v)}{\sigma(i, j)}$ be the betweenness centrality, whereas $\sigma(i, j)$ is the sum of shortest paths between the nodes i and j, and $\sigma(i, j|v)$ is the total number of shortest paths via the node v.So, the degree of the total vertices has the trend of increase year by year, which shows that the scale of the network has been becoming bigger and bigger. The average degree of the network increased from 8.597 in 2006 to 11.114 in 2010, which indicated that every port had ship routes with other 9 ports on average in 2006, while in 2010, the number increased to 12 on average.

Another important characteristic parameter, which can be called the clustering coefficient, is used to measure the level of group of a complex network. It describes the probability of a new pair of nodes' to the third node. In other words, the clustering coefficient of a vertex can be written as $C_i = \frac{2E_i}{k_i(k_i - 1)}$ where E_i represents the number of existing edges between the neighbors of node i. Thus the network clustering coefficient $C = \frac{1}{N}\sum_{i=1}^{N} C_i$ is defined as the mean value of the clustering coefficient of all the nodes, where N is the number of nodes in the network. The clustering coefficient of China's port shipping network maintains the value of 0.5 from 2006 to 2010, which is a little small. However, from the computer simulation, most of vertices have big clustering coefficient value. This is because, in general, the authorities would not go to operate a new through shipping route if there are common routes yet, for the optimization of minimizing the costs and maximizing the return.

In an undirected network with N nodes, we define the average distance L as the shortest path length between the nodes i and j : $L = \frac{1}{N(N-1)}\sum_{i \neq j} d_{ij}$ .Where d_{ij} is the shortest path length from vertex i to vertex j . The average distance L reflects the global efficiency of the network. A small L usually means high efficiency. The average distance in the port shipping network implies the complexity. The smaller the average distance between any two ports, the need for transit shipments less. It is clear that the average distance between any two ports declined from 2006 to 2010 step by step. The average transit times between any two ports were 2.8 in 2006, while they declined to 2.3 in 2010.

Network density, which describes the tightness of a social network, is widely used in social network analysis. Let $\rho = \frac{2M}{N(N-1)}$ be the network density, where N means the number of total vertices, and M represents the number of total edges in the network. Generally, if the density of the overall network is much heavier then the impact for the attitude and behavior of the nodes in the network is greater and the contact between each pair of nodes is closer. Network density describes the ports' tightness of the port shipping network. Its value is between 0 and 1. A value approached 1 means a tight relationship between ports. For example, the value of China's port shipping network's density was about 0.9 from 2006 to 2010, which implied that the ports in China had tight relationship.

IV CHINA'S PORT SHIPPING NETWORK'S "SCALE-FREE" PROPERTY ANALYSIS

The degree distribution is one of the most important statistical characteristics. In recent years, a large number of studies have pointed out that many real networks are characterized by power-law degree distributions and high clustering coefficient. Then a scale-free degree distribution is obtained. In double logarithmic coordinates, power-law distribution can be expressed by a straight line with negative slope. as The formula follows: $p(k) \sim Ck^{-\gamma}$, where the power exponent γ implies not only the degree distribution characteristics but also the absolute value of the line's slope. If γ belongs to the interval of $(0-4)$, then we can say the network has "scale-free" property.

The degree distribution's eigenvalues of China's port shipping network from 2006 to 2010 are listed in table 2, while the degree distribution's graphs are shown in figure 3 (Figure 3 a) to Figure 3 e)).

TABLE2.
THE DEGREE DISTRIBUTION'S EIGENVALUES OF CHINA'S PORT SHIPPING NETWORK

Years	2006	2007	2008	2009	2010
Power exponent $(\lvert\gamma\rvert)$	0.7713	0.7547	0.6478	0.7543	0.7426
Correlation coefficient (ACC)	0.9366	0.9398	0.9311	0.9583	0.9671
R^2	0.9425	0.9244	0.9181	0.9183	0.9382

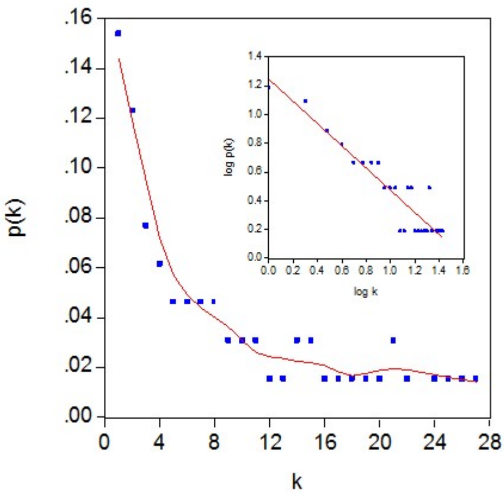

Fig. 3a).Degree distribution of China's port shipping network in 2006

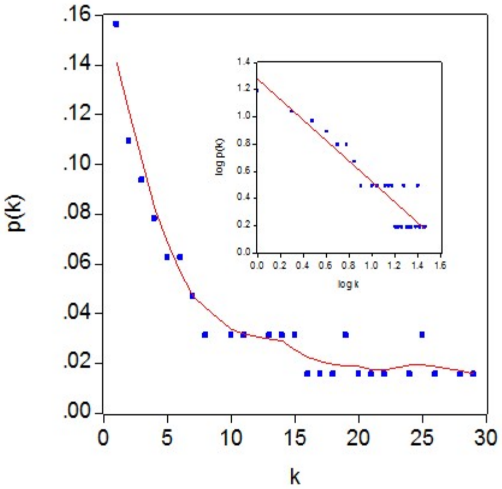

Fig. 3b).Degree distribution of China's port shipping network in 2007

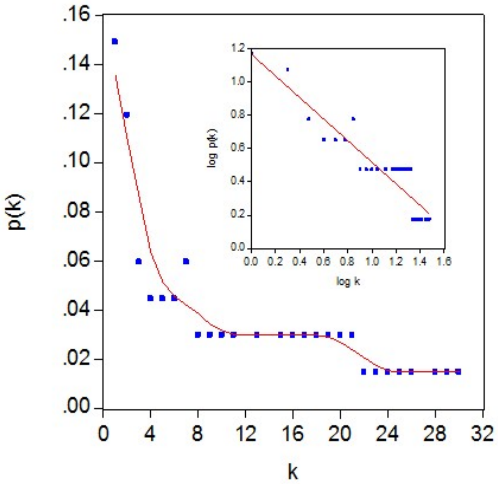

Fig. 3c).Degree distribution of China's port shipping network in 2008

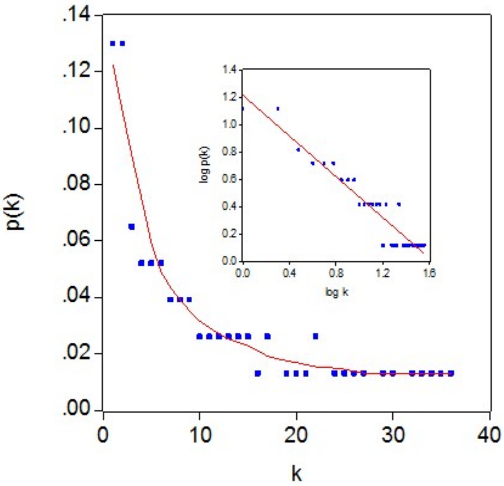

Fig. 3d).Degree distribution of China's port shipping network in 2009

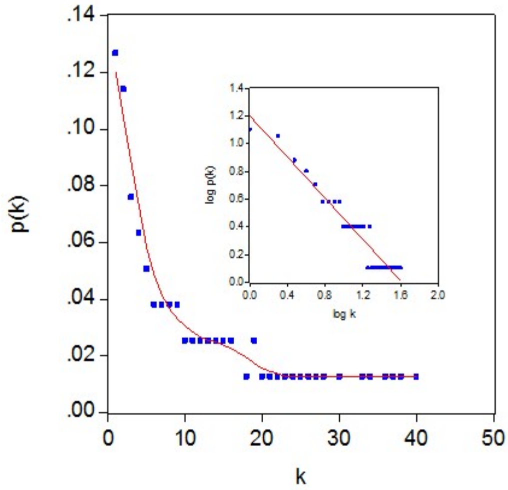

Fig. 3e).Degree distribution of China's port shipping network in 2010

V. CONCLUSION

Based on the shipping statistical data from 2006 to 2010, the paper analyzes the structure characteristic of China’s port shipping network, and obtains the following conclusions:

The China’s port shipping network is constructed with navigation ports being vertices and the shipping routes between ports being edges. The network has small average distance and relatively big network density, which indicates that the ports in China have tight relationship. The clustering coefficient of the network is 0.5 approximately. The relatively small clustering coefficient means that even if the gap is closing, it remains far wider than it should be. However, the disparity also demonstrates the complexity of the realistic port shipping network. Formulating a shipping route is badly affected by policies, geography, environment, economy and other factors.

Based on the analyses to the structure of China’s port shipping network from 2006 to 2010, we may safely draw the conclusion that China's port shipping network is widespread, which has the “scale-free” property with degree distribution following the principle of power-law. So, it belongs to the complex network research categories. The relatively big correlation coefficient and value also show that the data fits well, which also further verifies that China's port shipping network is a “scale-free” network.

Since maritime transport has the characteristics of numerous of process, long transport time and so on, when a shipping route is planned, the authorities should think over all the elements such as geography and climate. Based on the theory of complex network, it discusses the network structure of China’s port shipping network. We expect that it would be useful on ports’ building and shipping routes’ regulations.

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