The Integration and Evolution Mechanism of the COSCO Container Lines and the China Shipping Container Lines Shipping Networks Based on Theoretical Complex Networks

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Abstract. For the shipping industry's competition, the merges among companies bring lots of problems such as routing optimization and integration. Based on this, which is more suitable for the characteristics of shipping system, is studied in this paper. Firstly, taking the reorganization of the COSCO networks and the CSCL networks as an example, choosing the routes and ports of the COSCO Container Lines and the China Shipping Container Lines before the merger as the object of study, constructing the corresponding complex nets. The analysis of topological structures shows that the both of them all have the small world, the scale-free characteristics and the similarity. And the certain gap that comparied with the Maersk shipping networks and the same scale of the simulation network was confirmed. Secondly, the model which matching the the characteristics of the container shipping system was established, based on the analysis of several evolution behaviors and the two shipping nets were combined with certain rules. Eventually, after the integration of the network evaluation, the route network was compared with its net before, the performance of efficiency has been improved, it provides a reliable method for the merger of shipping enterprises in the future.

Keywords: Container transportation, shipping, network, complex network, network evolution.

1. Introduction

Shipping enterprises seek merger and acquisition frequently to enhance their international competitiveness in recent years. Approved by the State Council, the shipping corporate giants COSCO and China Shipping Group also reorganized. The reorganization concentrated on four major areas including container shipping, bulk shipping, tanker transport and financing ports as well as shipping. However, the integration of shipping network is a complex project for the long-term against companies as COSCO and China Shipping Group business scope cover hundreds of global ports. The core issue in the process of integration lies in rationalization of space distribution in terms of core ports and routes achieving the effect of 1+1>2.

Under the influence of geography, politics, economy, market demand and the development strategy of companies, connections between ports and shipping networks are often complex[1]. In addition, the structure of network connections changes from time to time. These enable the shipping network have characteristics of open complex systems. So far the studies of complex network on ocean shipping are mainly in the following aspects: 1) statistical analysis of the topology of static complex networks. [2]Deng investigated the network topology index for Maersk shipping company. The results showed that its shipping network obviously had small-world and scale-free characteristics; 2) complex network evolution models. Some concrete models and methods have emerged towards the evolution among real traffic networks. [3]Sun proposed a complex evolution model based on node attraction, which makes complex network theory more realistic to meet requirements.3) dynamics of complex networks. [4]Notteboom pointed out that due to the influence from the centrality of hub ports and fluctuations of shipping demand, the world shipping network reveals a certain degree of robustness, but under the influence of these unfavourable factors, topological characteristics of the whole network retain considerably stable. However, previous static analyses of networks cannot solve the problem that arise from the reorganization of shipping enterprises from a point view of overall systems, nor can they give more insight into the compound evolution of shipping systems and laws of development.

At present, the evolution mechanism of restructuring shipping companies attracts attention of many scholars such as [5]Wang who discussed the space effect resulting from restructuring shipping enterprises. He also examined the variation of allocating global capacity and route networks in such a way to explore the mechanism between shipping alliances and network space of global ports. It shows that the interaction between competition and cooperation is the inner dynamic that stimulates the formation of coastal port systems; Furthermore, several important channels was also identified with the help of the analysis. At the same time, characteristics of networks[6] were compared and analysed before and after the reorganization.

On the basis of previous researches this paper analyses the evolution of two container shipping networks using complex networks theory. Firstly, we construct container shipping networks for two shipping companies and then characterize the topology of the network; Secondly, the system are compounded through composition of its subnetworks according to a set of rules of evolution. Thirdly, consequences of evolution are discussed to various degrees considering different factors; Finally, we compares the network characteristics before and after combination to verify the validity of this evolution model.

2. Characteristics of Shipping Networks

2.1 Complex Networks and Their Topology Property

A complex network is a large-scale network that has complex topological structures and dynamic behaviour. Average path length, clustering coefficient and degree distribution are their essential statistical features, which reflect the topology of the network. The average path length indicates the degree of separation while clustering coefficient reveals the characteristic of small groups of nodes in the same way the degree distribution exhibits the scale-free property of networks.

Average path length L shows the average length between any linked nodes in an entire network formulated as:

$$L = \frac{\sum_{i \geq j} d_{ij}}{\frac{1}{2} N(N+1)} \quad 1 \leq i, j \leq n \tag{1}$$

Where d_{ij} represents the geodesic distance between any two points i and j in the network，N is the total number of nodes. L can reflect the extent of dispersion. The shorter the average path is, the lower the dispersion of networks. Applying to container shipping network，it indicates how far a container averagely need to cover through the shipping network from the starting point i to the end point j.

Clustering coefficient C_i measures the probability that any two nodes adjacent to a same node are also connected.

$$C_i = \frac{E_i}{E_m} \tag{2}$$

Where k_i represents the degree of any node i in the network, E_i is the number of interconnected pairs of nodes that directly connect to vertex i, E_m is the total number of pairs of nodes that are adjacent to vertex i. The lager the clustering coefficient is, the stronger the connectivity between ports and their neighbour nodes. In container shipping networks, C_i can indicate the degree of navigation cooperation between port i and its partner port groups. In other words, it shows the probability that ports adjacent to any port in the shipping network also have connected routes.

Degree k is the number of edges adjacent to the selected vertex. In shipping systems, it can be expressed as the number of routes that connect to the same port. Generally, the larger the degree of a certain node in a shipping network, the more routes the node have. These relatively high-degree node are called hub ports, playing an important role in shipping network.

Degree distribution $P(k)$ is the distribution function of degree k . $P(k)$ represents the proportion of nodes that have degree k in the whole network. n represents the number of nodes that have degree k . In terms of statistics, the probability to obtain a node of degree k by choosing randomly is $P(k)$.

$$P(k) \propto ck^{-n}$$

When a shipping network is a large scale-free network that has the power-law degree distribution, most of the nodes in the network are relatively low except a small amount of nodes of high degree. This kind of network is also known as the heterogeneous network where there are a lot of hub-and-spoke network structures. However, a network has the scale-free degree distribution depends on whether its degree distribution has the power law or not.

2.2 Constructing and Analysing the Network

1) Network construction

Before the merger, International container routes of COSCO cover more than 30 countries and regions worldwide along with around 156 ports while China Shipping Group has more than 50 courses for both domestic and foreign trade with about 152 ports. In order to facilitate the analysis of those container shipping networks, raw data were collected from course codes of the two companies in 2015 as well as their main ports. We built two networks and assume:

.1 Undirected networks. The port in two shipping networks interconnect with another port. In other words, the network is an undirected network;

.2 Non-weighted networks. Regardless of departure time, frequency and numbers of shipping, the connections exclude weight factor.

.3 Defined in P space. The nodes in the network are based on docks. If there is a container ship docks both of any two ports, it is considered that there is a connection between the two nodes;

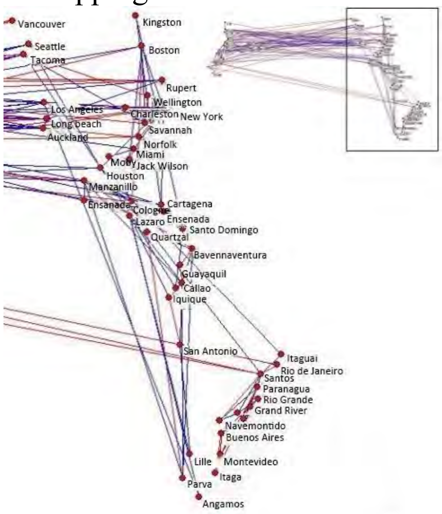
.4 Based on harbours. If a city simultaneously has more than two ports, they will be merged, such as Yantian, Shekou and Chiwan will be merged into Port of Shenzhen, Xingang and Tianjin merged into Port of Tianjin;

.5 Dividing into trade zones. In order to analyse the overlap and similarity of course coverage, the routes for global business will be divided into 4 trade zones, namely the American trade zone, the European trade zone, the Asia Pacific trade zone and other trade zone;

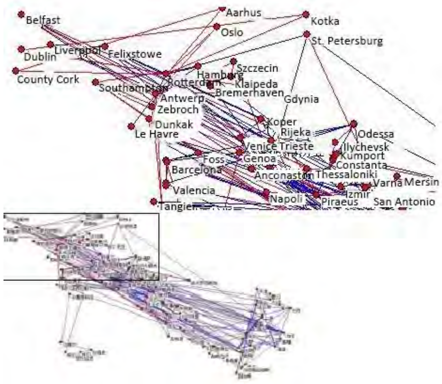
.6 Labelling ports. The ports in the two shipping networks will be numbered in accordance with the order of their construction such that the actual networks are abstracted as a string of characters and adjacency matrix.

Based on assumptions above, liner routes by the end of 2015 were sifted. 1223 routes in actual shipping systems were abstracted into S_i （i=0, 1, 2， ……1223）, the actual shipping network was turned into 0-1 adjacency matrix A_j（ j =1, 2,……）where 0 represents that there does not exist a route between two ports whereas 1 denotes they are connected. Since 203 ports were selected in our study, we constructed a 203*203 0-1 adjacency matrix in virtue of C programming to computerize the data. Then we can obtain the network structure after performing the Mercator projection transformation on the spatial coordinate of each port. Diagram 1 shows the situation of their container shipping courses before the merger where red lines stand for container routes of COSCO and blue ones for CSCL.

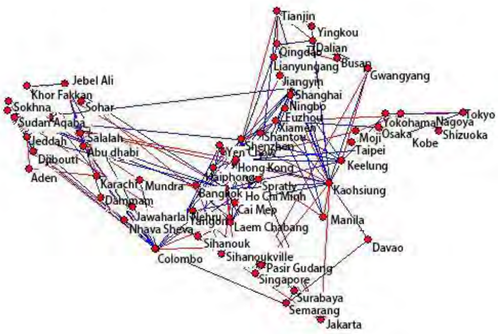
Fig. 1 shows the network structure of the four major maritime trade area from which we find that COSCO and CSCL container routes cover almost all trade area worldwide. From qualitative point of view, the shipping network obviously has the characteristics of hub-and-spoke network structure with high similarity, and many ports also highly overlap. The above characteristics indicate that it is necessary to integrate their container shipping networks for the two enterprises.



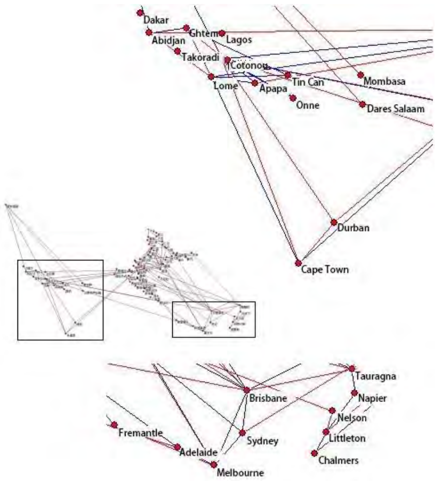
（a）The american trade zone



（b）The european trade zone



（c）The asia pacific trade zone



（d）The african and australian trade zone

Fig. 1 The shipping networks before the merge

2) Analyzing characteristics of the network

We calculated the above indexes of subnetworks for both COSCO and CSCL in P space, which contains: degree of node, average path length and clustering coefficient. The characteristics were compared with those of Maersk container networks.

The degree distribution curve of two shipping network confirmed their high similarity contrary to the bell-shape normal distribution. It thus verifies that most of nodes have a low degree except only a few high-degree nodes and reveals the network has the Matthew effect, which is known for ‘the rich get richer and the poor get poorer’.

Table 1 Topology characteristics and topological properties of the nets

The name of nets	topology characteristics				Topology properties	
	Nodes	Edges	Average path length	Clustering coefficient	Scale-free	Small-word
The nets of COSCO	165	102	3.567	0.213	Significant	Significant
(the simulated network by BA model)	165	759	2.003	0.412	-	-
The nets of CSCL	152	514	3.680	0.239	Significant	Significant
(the simulated network by BA model)	150	746	2.640	0.564	-	-
The nets of Maersk	185[2]	1000[2]	1.505	0.722	Significant	Significant

The above results show that container shipping networks of COSCO and China Shipping Group have similar average path length as well as clustering coefficient, which validates the high similarity between the two sub networks. In fact, two companies are constantly in a long-term competitive relationship thus their container shipping networks become progressively more alike; Compared with the world leading Maersk and the simulated network model, the average path length of COSCON and CSCL seems larger indicating the goods need to transit frequently. In addition, smaller clustering coefficient shows that within shipping networks internal nodes interact less closely leaving much room for optimization; Like the container shipping networks of average level of the world, have larger clustering coefficient and shorter average path length in line with the small world effect.

3. Shipping Network Analysis of COSCO and CSCL

3.1 The Compound Evolution Model of Container Shipping Networks

Owing to the high similarity, scale-free property and small world effect, which we found from the shipping networks of COSCO and CSCL, and considering the actual network evolution mechanism is affected by the degree of network nodes and other factors, we regards the shipping networks as an open complex based on the BA scale-free evolution model. Moreover, we also take some possible circumstances into account during the evolution process such as quantitative fluctuations of routes and ports along with expanding navigation areas. In order to achieve compound evolution, a model that aligns with the reorganization of shipping enterprises is built to perform the integration of networks for COSCO and CSCL. Operations comprise adding and deleting edges, inserting nodes and making lengthy edges.

1) Influencing factors and parameters

We define the Clustering of ports A_i as

$$A_i = \gamma\beta_i + \omega\theta_i \tag{3}$$

Where β_i , θ_i are influencing factors evaluated in different perspectives denoting throughput capacity of node i and its significance in the network, γ , ω represent their weight. The Clustering of ports can systematically reflect the attraction of node i for new comers in the network.

Probability of priority connection π_i determines the probability of connecting the new comer with existing nodes, which also affects the process of adding new edges to current nodes. It interacts with the Clustering of nodes A_i and the quantity of docking routes k_i simultaneously in such a way that the probability of priority connection π_i of each node i influences the evolution of networks together.

$$\pi_i = \frac{\alpha k_i + A_i}{\sum_j (\alpha k_j + A_j)} = \frac{\alpha k_i + \gamma\beta_i + \omega\theta_i}{\sum_j (\alpha k_j + \gamma\beta_j + \omega\theta_j)} \tag{4}$$

$$\alpha + \gamma + \omega = 1$$

The reasonable range of relevant parameters can be acquired through examining the degree distribution of networks. According to the mean field theory, the initial quantity of nodes is set to m_0 . A new node will be inserted every evolution step in such a way that after t steps the degree of node i at time t will be $k_i(t)$. When e edges are added at time t with the priority probability π_i connecting the two nodes, then the sum of degree becomes $\sum_j k_j = 2et$.

According to the continuity theory, regarding $k_i(t)$ as a continuous function of dynamics then it satisfies the equation:

$$\frac{\partial k_i}{\partial t} = e\frac{\alpha k_i + \gamma\beta_i + \omega\theta_i}{\sum_j (\alpha k_j + \gamma\beta_j + \omega\theta_j)} = e\frac{\alpha k_i + \gamma\beta_i + \omega\theta_i}{2\alpha et + \sum_j (\gamma\beta_j + \omega\theta_j)} \tag{5}$$

Because a node i must be chosen randomly to analyse the degree distribution, i in $k_i(t)$ is deemed as a random variable. In virtue of mean field theory, all nodes follow the uniform distribution. When node i joins the network at time t_i with $k_i > 0$, then the probability function of $k_i(t)$ is:

$$P\left(k_i(t) < k\right) = P\left[t < \frac{2et_i + \frac{\gamma}{\alpha}\sum\beta_i + \frac{\omega}{\alpha}\sum\theta_i}{2e\left(e + \frac{\gamma}{\alpha}\beta_i + \frac{\omega}{\alpha}\theta_i\right)^2}\left(k + \frac{\gamma}{\alpha}\beta_i + \frac{\omega}{\alpha}\theta_i\right)^2 - \frac{\gamma\sum\beta_l}{2e\alpha} - \frac{\gamma\sum\theta_l}{2e\alpha}\right] \tag{6}$$

This function $P(k_i(t) < k)$ represents the proportion of nodes that have degree k at time t .

Take the derivative and simplify,

$$P\left(k_i(t) < k\right) = \frac{-1}{m_0 + t}\left(t + \frac{\gamma\sum\beta_j + \omega\sum\theta_j}{2\alpha e}\right) \bullet \left(\alpha e + \gamma\beta_i + \omega\theta_i\right)^2\left(-2\alpha\left(\alpha k + \gamma\beta_i + \omega\theta\right)^{-3}\right) \tag{7}$$

When t approximates to infinity,

$$\begin{aligned} p(k) &\approx \lim_{t\to\infty} p\left(k_i(t) < k\right) \\ &= 2\alpha\left(\alpha e + \gamma\beta_i\right)^2\left(\alpha k + \gamma\beta_i + \omega\theta\right)^{-3} \end{aligned} \tag{8}$$

From what we discussed above, when $\alpha=1$, $\gamma=\omega=0$, the network turns into the BA network namely $p(k)=2e^2k^{-3}$; when $\alpha=0$, $\gamma+\omega=0.5$ evolution of the model only relies on the degree. Therefore the reasonable range of parameters indicates the evolution mechanism of the network though the integration model for reorganization of shipping enterprises is affected by various factors. Basically, it corroborate the characteristics of scale-free complex networks.

Considering some possible circumstances that may be encountered in the process of reorganising shipping enterprises, the connecting mechanism is designed as：

.1 Expand the navigation area. That is adding a new network with probability p which has m_1 nodes and e_0 edges.

.2 Add new ports. A new node will be added into the network with probability q . The probability of connecting node i is π_i in such a way it repeats m_2 times.

.3 Add routes. A node i will be chosen randomly in the current network with probability r and then link the other end node j according to π_i . The process is repeated m_3 times.

.4 Delete routes. It is related to the behaviour of shipping companies when they try to reduce excess capacity to improve the efficiency of operating. One end of the route is selected randomly from the network, and the other end is determined by $\pi_i^{'}=\frac{1\text{-}\pi_i}{N\text{-}1}$, N denotesthe quantity of nodes, the process should be repeated m_4 times.

.5 Create lengthy edges. It aims to expand the navigation area after the evolution in case a large number of isolated nodes emerge in some region of the network as a result of above operations. It repeats m_5 times with the probability $\pi_i^{'}=\frac{1\text{-}\pi_i}{N\text{-}1}$.

2)The procedure of algorithm

.1 Initialize the network. At the initial time, the number of nodes is determined along with the number of edges, the degree of nodes and the adjacency matrix of the initial state. the weight and degree aggregation are also set correspondingly.

.2 Optimize connections. According to the network evolution mechanism described above, we simulate the structural variation of two superimposed networks under the influence of external factors, and the evolution is carried out according to a certain probability.

.3 Terminate the evolution. When there is less than n nodes in the system, it terminates; otherwise, it continues until the next step.

.4 Calculate the characteristic value. The total number of the nodes, the degree of nodes, the average path length and the clustering coefficient are calculated.

3.2 The Evolution Results and Comparison With Real Networks

1) The evolution results

The subject of this study is global container routes and dock ports, which are released by COSCO and in 2015. Because some container shipping networks of China Shipping Group were acquired the container ships were leased and operated by COSCO. In this research shipping networks of China Shipping Group were superimposed onto those of evolution in Matlab.

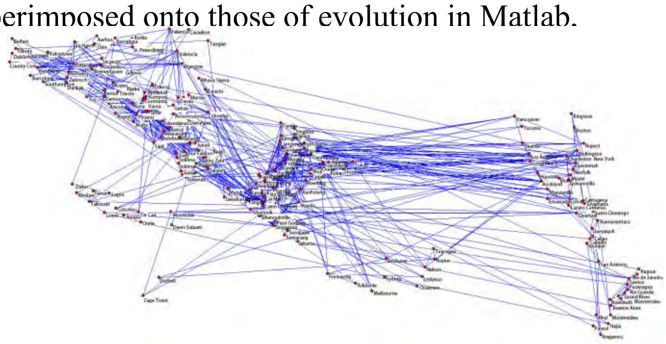


Fig. 2 The evolution result of the world networks in topology

Table 2 Topology properties of the nets

The name of nets	topology characteristics			
	Nodes	Edges	Average path length	Clustering coefficient
The nets of COSCO	165	102	3.567	0.213
The nets of CSCL	152	514	3.680	0.239
The compound network	203	771	3.412	0.398
The nets of Maersk	185	1000	1.505	0.722

we visualized the outcome by pajek, which is a piece of software for network analysing., the composite after the shipping network analysis software visualization with the pajek network, the situation after their integration and corresponding degree distribution of shipping network are shown in Figure 3 respectively.

It can be illustrated that the optimized shipping networks are still scale-free with enhancement to the closeness of the network confirming the small-world effect. Intuitively, the hub-and-spoke structure becomes more clear, indicating a trend of port aggregation i.e. ‘the rich richer’. Shanghai, Hongkong, Singapore and the like that own a high degree of aggregation are still keep a strong sense of attraction showing the characteristics of hub ports, which is consistent with the actual situation.

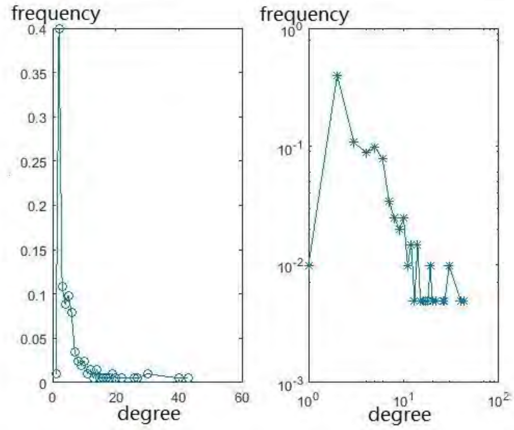


Fig. 3 The degree distribution of the world shipping networks in COSCO and CSCL

2) Network comparison before and after the integration

We analyse the related index after evolution of the network reconstruction, and compared with prior subnetworks. It shows that after the integration the overall performance has improved. The reorganization would make the operation scope of COSCO and CSCL expand significantly after a period of time, supported by the increased number of nodes and edges. In addition, owing to the increase of dock ports as well as routes, the clustering coefficient has grown and clustering effect emerges all of which makes the improved shipping network outperforms any of the two in efficiency. But there is nevertheless a gap compared to the Maersk shipping network, this may be due to the shortage of routes for COSCO and CSCL.

4. Conclusion

In the special background and development mode between COSCO and China Shipping Group restructuring their container shipping networks reveals special characteristics and evolution mechanism. In this paper we apply complex network theory to approaching the problem that arises in the reorganization and merger between shipping enterprises. From the analysis above, conclusions follow:

.1) Based on the characteristics of complex networks and their illustrations CSCL and COSCO are highly similar in terms of topology and spatial distribution of courses verifying the extraordinary overlap in service scope due to long-term competition. At the same time, they are compared with worldwide shipping network horizontally. We find that before the reorganization between COSCO and CSCL their development of container shipping networks is still at a lower level with much room for improvement.

.2) With the aid of last step combining the process of restructuring, we put forward an evolution model for shipping network integration which makes hub-and-spoke network structure clearer after optimization. Moreover, the efficiency of shipping networks has improved as well as interoperability between regions. Aggregation of shipping networks has increased slightly avoiding vicious competition and internal friction within the same region. Chinese shipping companies can benefit from all of those for their long-term steady development, and gain some innovative ideas for the integration between shipping companies in the future.

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