

Analysis of Statistical Characteristics of China's Aviation Full-Freight Network based on Complex Network Theory

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Abstract. With the development of air freight, the emergence of specialized freight airports, the gradual increase of full-freight airlines. The full-freight network has a great influence on the development of air freight, so it is necessary to carry out a more comprehensive analysis of the air full-freight network. The complex network theory provides a good method. From the perspective of the research of complex network theory, this paper describes the topology structure of the full-freight network and understands its structural characteristics. The results show that: (1) China's civil aviation all-cargo network shows small world characteristics, degree distribution is fitted as exponential distribution. (2) There is no obvious community structure in the air cargo network. (3) The air full-freight network with Hangzhou, Shenzhen and Nanjing as the hubs.

Keywords: Complex network; aviation full-cargo network; structural characteristics.

1. Introduction

By the end of 2017, China has formed full-freight network that involving a total of 254 cargo segments and a total of 59 domestic airports. The provision of capacity for the entire air cargo market includes all-cargo aircraft and belly cargo, of which the air freighters provide more than 50% of the capacity. From the perspective of the entire industry revenue, the air cargo industry's revenue is contributed by the air-freighter, the belly revenue is contributed by only 10%. From the perspective of fleet size, in recent years, China's air-freighter fleet expansion is relatively fast, from less than 20 in 2005 to 143 in the end of 2017. But in the process of development, there are also some problems, such as the backhaul problem and the profit of the all-freighter. At present, all-freighters' operation are at a loss. Therefore, it is necessary to consider the design of the airline. This paper adopt relevant indicators in the complex network theory and analyzes basic structural characteristics of the full-freight networker,therefore,providing certain theoretical guidance for the design of the full-freight airline.

In recent years, complex network theory and empirical research have achieved fruitful results. The results of empirical research using aviation networks are also very rich. Jiaoe Wang et al[1] used complex network-related index system to evaluate the complex structure characteristics of China's air passenger network space; Yaru Dang et al[2] compared the structure of Chinese passenger weighted network and American passenger weighted network; Fengjie Xie et al [3], from the perspective of the enterprise, analyzing the structural characteristics of the air express network with the complex network; Hongqi Li et al [4]used the flight capacity as a weight, analyzing the structural characteristics of the air cargo network, provides a certain theoretical guidance for the air cargo network of optimizing resource allocation.

Different from the existing research, this paper constructs a network of full-freight segments between airports, analyzes the basic characteristics and centrality of the network, and discovers problems from the entire full-freight network, and also provides some theoretical guidance for designing a full-freight airline.

2. Topology of Aviation Full-Freight Network

The data used in this article is sourced from OAG database, the year of collection data is the end of 2017, its network topology is shown in Figure 1, in the network, a node represents an airport, one

edge represents a segment between two airport nodes, building a no-directed network and to remove duplicate edges. Complex network indicators generally include: degree, degree distribution, clustering coefficient, average path length, network efficiency, centrality and other indicators. This paper focuses on the analysis of the structural characteristics of the network by using the indexes of degree, degree distribution, clustering coefficient, average path length and network efficiency, and analyzes the centrality of the network using degree centrality, closeness centrality and betweenness centrality, and describes the degree of the central position of each node in the network. This describes whether the entire network has a core and what kind of core exists.

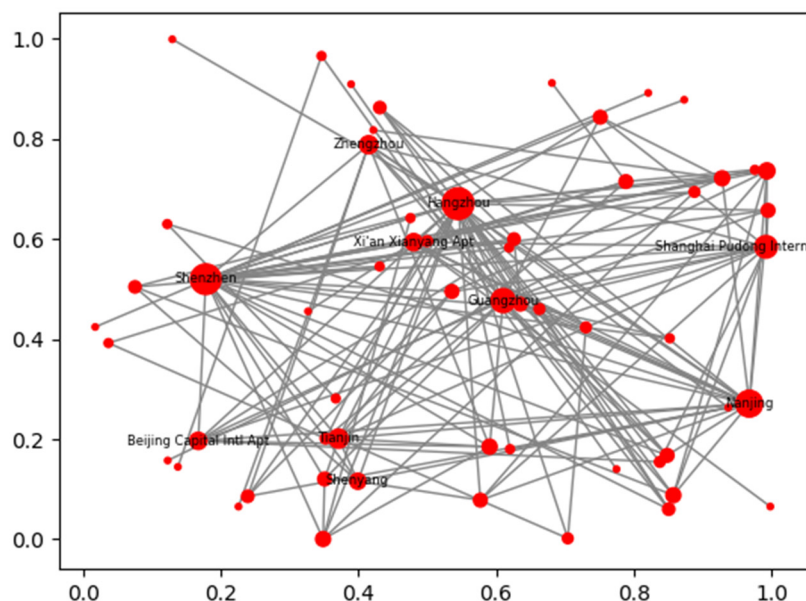


Figure 1. topology diagram of all freight airlines

3. Complex Structural Characteristics of Aviation Full-Freight Network

3.1 Basic Structural Characteristics

If a network with a higher clustering coefficient and a lower average path length than the same random network, such a network is called a Small World Network. the aviation full-freight network based on OAG data, using Python to calculate the average degree of network is 4.949, representing an airport with an average connection of four segments, the average path length is 2.196, which means that the goods need an average of two transfer station to reach the destination, the clustering coefficient is 0.346, the clustering coefficient represents the breadth of air cargo network transportation, and the larger of the clustering coefficient, which indicates the greater aggregation degree of the network. Compared with the random network, it has the same level of average path length and higher aggregation coefficient, showing a certain small world phenomenon.

Table 1. Basic statistical indicators of the network

Year	Aviation full-Cargo network(2017)
Number of nodes	59
Number of segments	254
Average	4.949
Average clustering coefficient	0.346
Diameter	4
Average path length	2.196
Network efficiency	0.344

The degree of the node represents the number of connected edges of the node, the greater degree of the node, the greater number of airports that the airport has direct access to the network. Using Python to calculate it, the top ten airports are shown in the table 2, with Hangzhou, Shenzhen and Nanjing ranked in the top three respectively. In the weighted aviation full-freight network, the rankings from the top ten airports of the in-strength and the out-strength are shown in the table 3. It can be seen that the top 10 airports are not one-to-one correspondence. From the numerical value, there is a certain discrepancy between the round-trip freight volume of the airport. In reality, many airlines also have backhauled problems.

Table 2. Top 10 Airport rankings of aviation all-cargo network

Rank	Aviation full-Cargo network (2017)	
	Airport	Degree
1	Hangzhou	28
2	Shenzhen	26
3	Nanjing	20
4	Guangzhou	16
5	Shanghai(Pudong)	14
6	Tianjin	10
7	Zhengzhou	9
8	Xian	8
9	Beijing	8
10	Shenyang	7

Table 3. Top 10 airport rankings weighted aviation full-freight network

Rank	Weighted aviation all-cargo network (2017)			
	Airport	In-degree	strength	Out-degree strength
1	Shanghai(Pudong)	42.5564		Tianjin 34.6706
2	Nanjing	13.4799		Nanjing 12.6423
3	Shenzhen	12.7281		Hangzhou 12.3483
4	Hangzhou	12.6447		Shenzhen 12.2266
5	Zhengzhou	11.748		Zhengzhou 11.838
6	Xian	6.18		Jinan 9.38
7	Guangzhou	5.2341		Beijing 7.347
8	Tianjin	3.8186		Shanghai(Pudong) 6.9155
9	Changsha	3.7682		Guangzhou 6.6315
10	Chongqing	3.2211		Xian 3.5468

3.2 Degree Distribution Characteristics

Degree distribution is the most important parameter for classifying network structure types. The degree distribution are the frequency of nodes with different degrees in the network. Some existing work has proved that the degree distribution of the air cargo network has a scale-free characteristic, that is, the degree distribution obeys the power law distribution. They prove that the degree distribution obeys the power law distribution is to estimate the power law distribution by approximating the straight line in the double logarithmic coordinate system. At the same time, A. Clauset et al. argued that it is unreasonable to verify the power-law distribution by simply approximating the degree distribution in the double-logarithmic coordinate system. They proposed a statistical framework to identify and quantify the power-law distribution. Parameters such as xmin, power law index, goodness-of-fitted P value can be calculated, and the fit of the power law distribution and other potential possible distributions to the same data can be compared to determine the optimal distribution of the data, Jeff et al. developed powerlaw based on this, a Python package for analyzing power law distribution. Based on powerlaw, this paper calculates the xmin, power law index Alpha, power law index variance Sigma of the power law distribution of the aviation full-freight

network in 2017. And the fitting of the power law distribution and the exponential distribution to these two networks is compared.

Figure 2 shows the degree distribution of the network in 2017. We use powerlaw to plot the complementary cumulative distribution function (CCDF), Cumulative Distribution Function (CDF), and Probability Density Function (PDF) of the degree of the network in a double logarithmic coordinate system. At the same time, the power law distribution (PLD) and exponential distribution (ED) are plotted on the CCDF, CDF and PDF fitting curves of the network. It can be seen from Table 4 that in 2017, the aviation all-cargo network fits the CCDF, CDF, and PDF, and the exponential distribution is better than the power law distribution. From the P value ($P < 0.05$ means the fitting situation is very significant), the degree distribution of the air full-freight network in 2017 is obviously subject to the exponential distribution ($R > 0$ means having an exponential characteristic).

In addition, the weighted degree distribution plot of the nodes strength under the weighted air full-freight network is shown in Fig. 3. By comparing the values in Table 4 and 5, it can be seen that the nodes strength distribution differs greatly from the degree distribution. The exponential characteristics of the weighted air full-freight network in 2017 are less obvious than those of the unweighted network. This shows that the cargo flow in the air cargo network presents a certain imbalance.

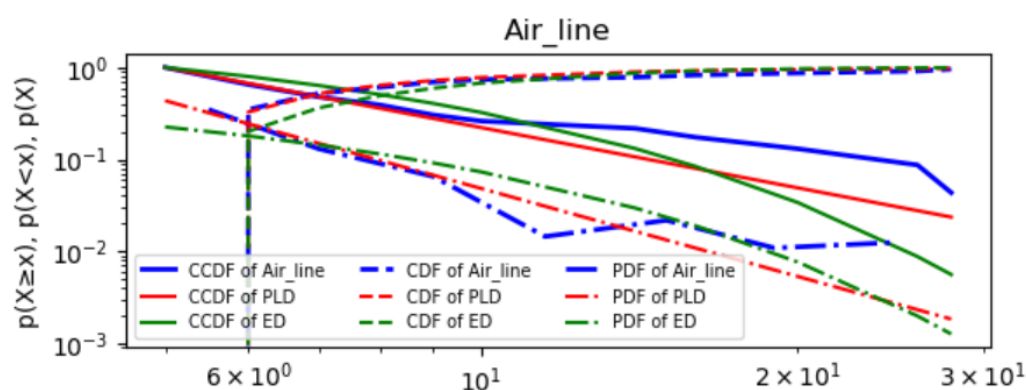


Figure 2. Air full-freight network degree distribution

Table 4. degree distribution statistical indicator value

Year	Aviation full-Cargo network(2017)
xmin	5
Exponent	3.175
Variance of exponent	0.454
R value	4.541
P value	0.027

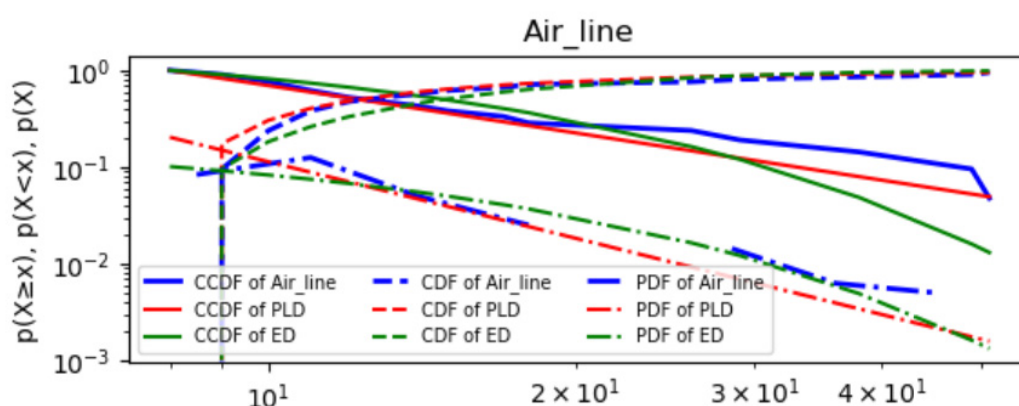


Figure 3. Weighted Air cargo network degree distribution

Table 5. degree distribution statistical indicator value

Year	Weighted aviation all-cargo network (2017)
xmin	8
Exponent	2.626
Variance of exponent	0.355
R value	1.784
P value	0.313

3.3 Analysis of Community Structure

A community is a group of nodes that have a relatively close relationship in the network. There are relatively dense links between nodes in the group and fewer links between communities and communities. The so-called community division is an in-depth study of the physical meaning and mathematical meaning of the nature of the network, which refers to the community structure in the network. Community division of the network is to attribute the network nodes with the same structure and characteristics to a small group, so that each group has the same nature. This process of dividing the group structure is called the division of the community.

In this paper, using the module degree index proposed by Girvan and Newman [5], the module degree of the aeronautical all-freight network in 2017 is calculated to be 0.256, and the network is divided into 6 communities. When the modularity of the network is greater than or equal to 0.3, there is an obvious community structure in the network.

Table 6. value of Community structure indicators

Year	Aviation full-Cargo network
Number of associations	6
Modularity	0.256

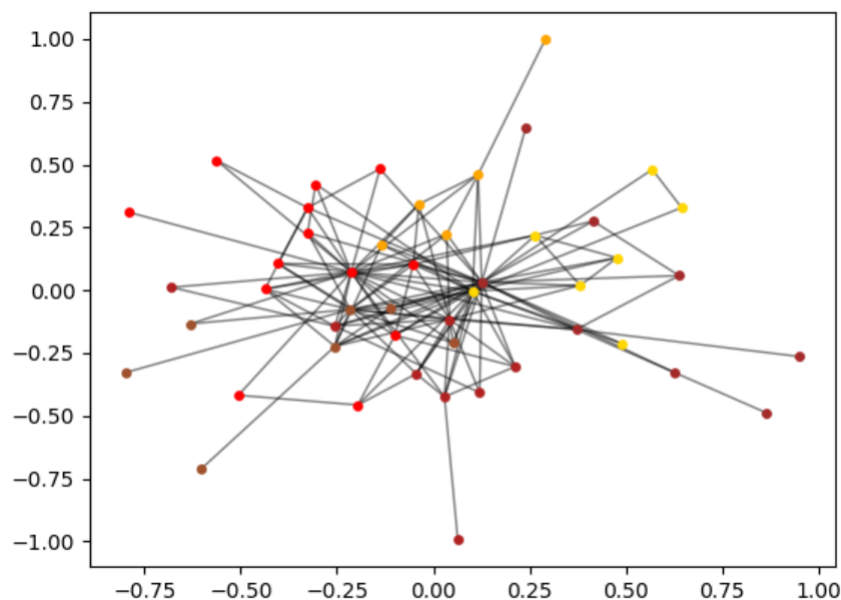


Figure 4. Community Chart

4. Node Centrality

In 2017, the aviation full-freight network, the top 10 airports ranked as the node centrality, Hangzhou, Shenzhen and Nanjing are in the leading position. The reason is that Hangzhou has the all-cargo operation base of Yuantong Express, and Shenzhen and Nanjing are the all-cargo operation bases of SF Express. In 2017, the top three airports with out-degree centrality and in-degree centrality were: Hangzhou, Shenzhen and Nanjing, and the remaining seven rankings were almost the same as the in-degree and out-degree centrality rankings. This shows the comparison of the full freight

network of these airports. Symmetry, no matter from which point of view, the air cargo network has gradually formed an air transportation network with Hangzhou, Shenzhen and Nanjing as the hubs.

Table 7. Aviation full-Cargo network centrality top 10 airport rankings

Rank	Aviation full-Cargo network(2017)					
	Degree Centrality	Value	Closeness Centrality	Value	Betweenness Centrality	Value
1	Hangzhou	0.483	Hangzhou	0.577	Hangzhou	0.227
2	Shenzhen	0.448	Shenzhen	0.552	Shenzhen	0.184
3	Nanjing	0.345	Nanjing	0.501	Nanjing	0.091
4	Guangzhou	0.276	Guangzhou	0.459	Xian	0.06
5	Shanghai (Pudong)	0.241	Shanghai (Pudong)	0.443	Guangzhou	0.057
6	Tianjin	0.172	Zhengzhou	0.428	Zhengzhou	0.033
7	Zhengzhou	0.155	Xian	0.428	Changsha	0.03
8	Xian	0.138	Tianjin	0.428	Jinan	0.029
9	Beijing	0.138	Beijing	0.419	Shanghai (Pudong)	0.028
10	Shenyang	0.121	Jinan	0.414	Tianjin	0.014

Table 8. Weighted aviation all-cargo network in-degree and out-degree centrality top ten airport rankings

Rank	Aviation full-Cargo network(2017)			
	Excentrality	value	Degree centrality	value
1	Hangzhou	0.448	Shenzhen	0.431
2	Shenzhen	0.414	Hangzhou	0.431
3	Nanjing	0.328	Nanjing	0.328
4	Guangzhou	0.259	Guangzhou	0.241
5	Shanghai(Pudong)	0.224	Shanghai(Pudong)	0.224
6	Zhengzhou	0.155	Zhengzhou	0.155
7	Beijing	0.138	Tianjin	0.155
8	Tianjin	0.138	Xian	0.138
9	Xian	0.121	Jinan	0.103
10	Jinan	0.103	Beijing	

5. Conclusion

This article uses complex network indicators to research on the structural characteristics of air full-freight network, and obtaining the following main conclusions

(1)China's civil aviation all-cargo network exhibits a small world characteristics, and the degree distribution is fitted to an exponential distribution.

(2)There is no obvious community structure in the air cargo network.

(3)The whole network forms an air cargo network with Hangzhou, Shenzhen and Nanjing as hubs.

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