China Aviation Network Characteristics and Robustness Research

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Abstract—Analysis of network characteristics and robustness play an important role for the aviation network overall function. This paper collects the data of the current China's domestic aviation network, and estimates the statistical characteristics of the aviation network. The research results show that: the flight route, resource distribution Chinese aviation network in serious imbalance, a large number of airline and flight concentrated in a city, the total number of flights, routes which point strength ranked the top 20 city accounted for the proportion reached 52% and 68%; transfer role of aviation network in navigable city also differ greatly, a few navigable city plays a central role in transit, and nearly half of the city basic cannot play the role of transfer. On this basis, this paper designs two kinds of simulation systems, the deliberate targeting system and random interference system, and does some simulation experiments. Through analysis of simulation data, obtained for the random interference of China's aviation network showed strong robustness, and in the face of deliberate attacks are more vulnerable to conclusions.

Keywords- aviation network；network characteristics；robustness；complex networks；simulation

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I. INTRODUCTION

In recent years, air transport of passenger, cargo throughput climbed, comprehensive transportation system in China plays a more and more important role. However, air transportation is also a kind of mode of transportation of the vulnerable to outside influence, weather, mechanical failure, airport traffic control will affect air transport, lead to flights are delayed or cancelled. Aviation network as the airport city complex network and the connection of urban routes, navigation city constitutes the basic framework of airline network and route [1]. In the aviation network, different number of flight routes are in an unit time at different, have different influence, so should be network as a weighted network, number of flights can be selected per unit time as the main indexes of determining the weight. In the aviation network, one or a few link would happen delay caused by the coupling relationship between the network nodes delay other nodes, and cause a chain reaction, to form the multiplier effect of delay loss, eventually lead to network loss of part function and even the collapse of the entire network.

Network characteristics and robustness analysis of aviation network, on the one hand, help with the complex network theory further understanding from the perspective of the global aviation network topology structure and the overall structure, explore ways and means of optimizing network; On the other hand, the more help to find important nodes in network and effective protection, avoid the interference caused by delay or even lead to paralysis, ensure the safety of air transport and efficient operation [2].

II. THE EMPIRICAL ANALYSIS OF THE STATISTICAL CHARACTERISTICS OF CHINA AVIATION NETWORK

A. Data collection

Using data from the "flight Ctrip Travel Network" schedule, collected a total of 163 navigable City, 2198 domestic routes, flight 9611. By taking 163 navigable city as a matrix of rows and columns, with flights between two city as the weight of the adjacency matrix of a weighted aviation network, A forms a 163×163.

B. Degree and the node strength

In the network, k_i is defined as the total number of degree and node i is connected to the side of. In the aviation network, a navigable city degree greater means connected city number, the number of routes have more. The flight number is a measure of the importance of key factors of navigable City, only through the "degree" of value is not sufficient to fully reflect the importance of city node [3]. Therefore, the evolution of the degree of k_i into another parameter -- point strength, used to reflect the status of city in the aviation network node, which is defined as:

$$s_i = \sum_{j \in N_i} w_{ij} \tag{1}$$

Of which: N_i representation and navigation route through the city i city set; w_{ij} said navigable city i and j between the arc weights, i.e. i and j between city navigation flight number.

Application of California University Irvine, written by scholars free large network analysis software Ucinet (version 6.212) to calculate the degree and China 163 navigable city point strength, part of the main navigable city strength as shown in table 1.

TABLE I. PART OF THE MAIN NAVIGABLE CITY POINT STRENGTH

city	BJS	SHA	CAN	SIA	KMG	CTU	SZX	CKG	URC
point strength	809	676	498	479	400	390	455	307	183

C. Aviation network average shortest path

The shortest path is the amount in the aviation network two navigable city between the short circuit contains lines; average path length refers to the number of all nodes in the network between the average of the shortest route, passengers from a city reflects the reach mean another city needs the less number of transit, reflect the air two nodes in the network of inter city travel convenience [4]. The calculation formula of the whole network is the average shortest path of the following formula (2).

$$L = \frac{\sum l_{ij}}{\frac{1}{2}N(N+1)} \tag{2}$$

Of which: N is the number of navigable city; city L_{ij} navigation i with the shortest path between the number of edges of the j.

Application of Ucinet software and the adjacency matrix of A, calculate the average Chinese aviation network shortest path is 2.16. The calculation results show that: from the point of view of any China a navigable City, on average only need a transfer can reach other navigable city.

D. Betweenness

Betweenness refers to all the shortest path in the network, after a number of points representing the number of the shortest path of the proportion. It reflects the control node to other nodes between the number of contact, a node can reflect the node in the network of influence[5]. In the aviation network, the number of a navigable city that bigger capacity of the city transit more strongly, in aviation network more important role. The calculation formula of node betweenness of the following formula (3).

$$B_m = \sum_{i,j} \frac{\sum_{k \in S_{ij}} \delta_l^m}{|S_{ij}|} \tag{3}$$

Of which: B_m indicates the number of dielectric m, S_{ij} indicates between the set of *(i,j)*shortest path, δ^m indicates the number of shortest path in the network after m.

Application of Ucinet software and the adjacency matrix of A, the calculated 163 seat navigable City betweenness, part of the main navigable City betweenness as shown in table 2.

TABLE II. PART OF THE MAIN NAVIGABLE CITY BETWEENNESS

city	BJS	SHA	CAN	SIA	KMG	CTU	SZX	CKG	URC
point strength	7411	3430	3460	2391	1909	1478	917	1395	2417

The calculation results show that: with the route 20 city most in Chinese almost is the largest number of flight 20 city. At present, the total number of flights strength ranked the top 20 city accounted for the proportion of the total national flight reached 52% and 68%, that Chinese air transport resources are distributed unevenly, a large number of routes and flights to concentrate in the minority in the city.

Differences between the 163 seat Chinese navigable City betweenness disparity, Beijing high betweenness up to 7410.88 ranked first, but there are 79 seat betweenness navigable city is 0. Show that there are nearly half of the city is still not play a role in China transit.

III. CHINA AVIATION NETWORK ROBUSTNESS ANALYSIS

A. The connotation of the network robustness

Aviation network robustness and fragility part mainly use the network navigation city affected by emergencies paralyzed, aviation network connectivity at this time to reflect. In the aviation network, if a navigable city affected by emergencies paralyzed, means also cancelled all linked to the navigable city routes, which may make the network of some of the other navigable city transportation path. If navigable city transport paths between i and j, interrupt some of them may lead to the increase of the distance between two points d_{ij}, so that the increasing average path length L of the whole network. And if the navigable city all path between i and j is interrupted, then the two navigable city is no longer connected. If after the removal of part of the navigable city most of the node in the network is connected, then call the airline network connectivity with the breakdown of navigable city robustness [6].

B. Aviation network robustness metrics

Aviation network robustness in general use "remove node number accounts for the proportion of the original network to the total number of nodes f" and the "largest connected sub-graph relative size s", "average path length L" to measure the relationship between [7]. Network connectivity robustness refers to the impedance of the network connectivity to remove a certain number of network nodes. Available in the network the "largest connected sub-graph relative size s" as the network connectivity robustness metrics[8].

The "largest connected sub-graph" is the main measure of network connectivity[9], the greater the "largest connected sub-graph" said network connectivity, the better, as the "largest connected sub-graph" equals the number of network nodes, show that between all nodes in the network can be interconnected. The "largest connected sub-graph relative size s" is in the network "maximum number of nodes connected sub-graph" and the ratio of all network nodes[10]. As "remove node number accounts for the proportion of the original network to the total number of nodes f" because of the network "largest connected sub-graph" will continue to decrease, even can form a number of isolated subnet[11]. When the f value must be, s value, the greater the show network connecting the better robustness. When the f value must be, L value is smaller, shows that the network connecting the better robustness[12].

IV. AVIATION NETWORK ROBUSTNESS SIMULATION SYSTEM DESIGN

Remove certain navigable city network is the precondition of robustness analysis, by removing a navigable city often means the loss of service capacity, paralyzed state, therefore the simulation analysis is a major means of study of robustness. In real life cause of navigable city paralyzed mainly include two categories: that is caused by uncertain factors, such as weather, and is caused by factors such as a terrorist attack, war deliberately. The influence of the random some navigation city, while the latter can selectively destroy some important navigable city.

A. Random disturbance type simulation system design

Random disturbance simulation system design of the main idea is: in the aviation network, on the basis of adjacency matrix A, generating random Numbers, adjacency matrix of the random number corresponding to aviation network navigation city as an object of the affected in the aviation network adjacency matrix to remove the navigable city and other navigable city all flights, sent to form A new airline network adjacency matrix R. Repeat the above steps until met the requirement of the number of navigable city in the network paralysis.

B. Beliberately attacking type simulation system design

Deliberate attack simulation system design of the main idea is: in the airline network middle intensity and the size of the betweenness are two key indicators reflect the importance of navigable city. Adjacency matrix of the aviation network, therefore, respectively calculated for each point of navigable city strength and betweenness and sorted, then USES the navigable city point strength rank order and the sum of betweenness ranking order reflecting the importance of navigable city judge index, according to the sorting sequence of growing up. To the top, said the navigable city, the more important. According to the sorting result, select each navigation city, and in the aviation network adjacency matrix to remove the navigable city and other navigable city all flights, adjacency matrix X to form new aviation network. Repeat the above steps until met the requirement of the number of navigable city in the network paralysis.

V. CHINA AVIATION NETWORK ROBUSTNESS ANALYSIS OF THE SIMULATION

A. f and s relationship analysis

In the design of the above two kinds of simulation system, to interfere with the city, in turn, increases 163 times interference simulation respectively, and the way that the first simulation, the influence strategies are only according to the two different airlines in the network a navigable city, get new airline network adjacency matrix R1 and X1; Second city simulation will interference increased to 2, get network adjacency matrix and X2 R2; And so on, a total of 163 times simulation, get 163 group R, X matrix. According to the different network adjacency matrix R, X, f, s, L three parameter values.In the random disturbance and deliberate attack system relation between f and s is shown in Fig .1.

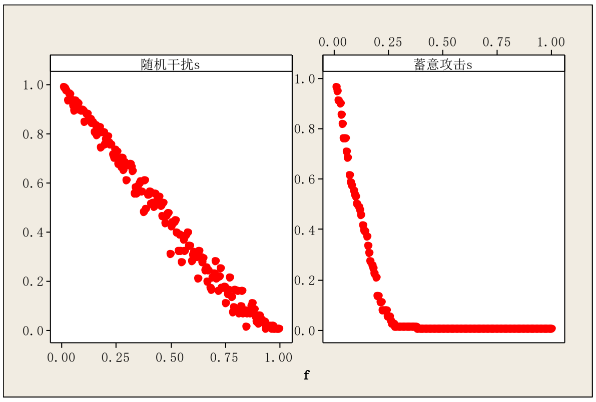

Figure 1. f and s simulation system of the two trends

As can be seen from the Fig .1:

(1) in a deliberate attack system s decline significantly faster than the speed of the random disturbance system;

(2) in a deliberate attack system f value is 0.25, the s value is close to 0; In the random disturbance system f value of 0.25, s value about 0.6.

The results show that the same is affected, about 40 navigable city caused by the weather factors such as random disturbance, though a certain effects on the network, but did not interference in most cities can still play a role, aviation network can still play the transport function; And if there is interference choose 40 navigable city, it could lead to all navigable city, the whole network completely paralyzed. Therefore, can be seen from the changes of f and s China aviation network has strong robustness to random disturbance. But in the face of deliberate attack, is more fragile.

B. f and l relationship analysis

In the random disturbance and deliberate attack system relation between f and l is shown in figure 2.

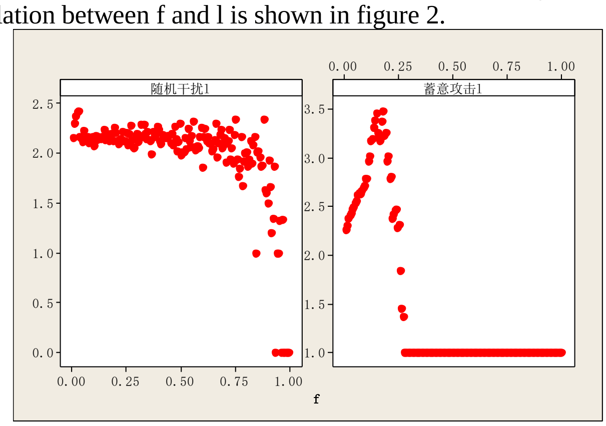

Figure 2. f and l simulation system of the two trends

Average path length l reflects the aviation network for ease of travel between any two navigable city, l value of the said, on average, transfer, the more convenience, the worse. As can be seen from the Fig .2:

(1) in two kinds of simulation system l eventually reduced to 1, this is because with the affected city keeps increasing, the network connected to the city in less and less, when all cities are isolated, l value is 1.

(2) in the random disturbance in the system, when f < 0.75, l haven't changed much, suggesting that the random

disturbance to the whole network has a little influence on the convenience of; In a deliberate attack system, presents the l fell rapidly after the first rapid increase trend. Show that at the beginning of the deliberate attacks had a great effect on the convenience of for aviation network as a whole, in the later a rapid decline in function of the network is the result of the rapid loss of.

The results also indicated that China aviation network has strong robustness to random disturbance; Which is more vulnerable to deliberate.

VI. CONCLUSION

(1) China aviation network connectivity to the random disturbance has stronger robustness

In systems with random disturbance, s only when f large drop to zero, that is navigable city under the random factors such as weather, only the most navigable city encountered bad weather at the same time, is likely to lead to the entire network paralysis. Due to the vast Chinese territory, across multiple climate zone, most of the navigable city encountered bad weather at the same time the probability is very small, so it is of higher robustness.

(2) Chinese aviation network function of random interference has strong robustness

In systems with random disturbance, relative to the average path length l f changes relatively slowly, shows that the influence of random factors for aviation network functions such as the weather is relatively small, namely direct flights in time affected, navigable city can transfer between the I and j air transport in the form of implementation; But direct flights and one transit line relatively quickly, along with the change of f shows that the random factors will convenience brought a certain degree of impact on the network.

(3) Chinese aviation network is of high vulnerability to deliberate attack

In a deliberate attack system, s, l, and the number of routes are different transit times, along with the rapid decline in f, and when f = 0.25, each value converge to zero. Indicates that the current Chinese aviation network is highly dependent on the more than 40 core navigation city, once the disturbance of more than 40 a navigable city or attack, the whole network will completely paralyzed and showed higher vulnerability.

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