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RESEARCH PAPER

# Empirical Analysis on Flight Flow Network Survivability of China

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**Abstract:** From the aspect of the complex network, this paper makes empirical analysis on the flight flow network structure of China from 2001 to 2010. The calculation of network statistical indicators reveals that the flight flow network has the small-world characteristics and the scale-free property. Then two indicators, the decline rate of the maximum connected sub-graph size and the decline rate of the overall efficiency are proposed to study the network survivability. Comparative analysis is conducted for different years, which indicates that the survivability of China flight flow network has an increasing trend and the network is more dependent on several key airports. Comparative analysis is also made for various attacks, which demonstrates that the flight flow network has strong robustness against random attack, but is vulnerable to deliberate attack. The reliability of the entire network is dominated by a few major airports, thus, the safe and effective operation of these airports should be ensured and it is essential to build some multi-hub systems in the future.

**Key Words:** air transportation; survivability; complex network; flights; scale-free property

## 1 Introduction

In recent years, the complex network theory research has shown a sharp increase. Some complex systems in nature and the social fields can be described using the complex network theory, in which the nodes represent different individuals or organizations in the real systems, and the edges represent the relationships between them. As one of the most important research issues in complex network theory, complex network survivability has drawn extensive attention from researchers and scholars. Albert *et al.*[1] studied the complex network survivability at first. They focused on the influence of the topological structures on complex network survivability, and parted random networks and scale-free networks into two failure modes—random failure and deliberate attack. Their results showed that the scale-free network has stronger survivability than the random network in the random failure mode, but it is very vulnerable under deliberate attack, in other words, "robust butvulnerable." Holme *et al*.[2] conducted a simulation analysis on the internet network under two attacks from nodes and edges, respectively, and verified the conclusion of Albert *et al*.[1] At present, the complex network survivability researches have infiltrated into many fields; Dunne *et al*.[3] studied the food chain network; Shen[4] analyzed the U.S. western grid; Chen[5] studied the securities market network; Jin[6] argued the regional highway traffic network of China.

Air transport is an important part of transportation; with the development and application of complex network theory, many scholars discussed the topology characteristic of air transport networks, and revealed that parts of air transport networks have scale-free characteristics[7–10]. It is extremely useful to study the air transport network function and efficiency. However, the issue of network reliability is seldom discussed. In 2008, due to the severe impact of natural disasters, civil aviation enterprises suffered huge losses, which made people pay more attention to the reliability of air transport networks in the event of natural disasters or hostile forces of deliberate attacks or various other uncertainties. Therefore, this paper establishes the flight-weighted network of China with flight data over 10 years. It then proposes the measurement indicators of survivability and makes

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comparative analyses, both of different years and of different attack modes on the basis of characteristics of the network structure analysis. It may provide a reference for the development of air transport in China.

## 2 Network construction and structure

### 2.1 Construction of flight flow network

Considering that long-term historical data can better reflect the dynamic development trends of the flight flow network structure in China, this paper selects domestic airlines flight data records over 10 years from the Statistical Data on Civil Aviation of China (2002–2011) as samples. It chooses navigable cities as network nodes (if a city has more than one airport, then the corresponding data records will be merged), the direct routes as network edges, and the number of flights as the edge weight between two cities, so as to construct the flight flow network of China. The flight flow network can be denoted by a matrix $(k_{ij})n\times n$ ($n$ is the number of network nodes), in which $k_{ij}$ represents the number of flights from city $i$ to city $j$.

### 2.2 Structure of flight flow network

By visualizing the flight data in China from 2001 to 2010, this paper provides diagrams of the structure of the flight flow network. Due to the length limitation, we provide pictures for the flight flow network in 2001, 2004, 2007, and 2010, as shown in Fig. 1. In these figures, the edge weight between the nodes reflects the degree of the flight crowd.

From Fig. 1, we can clearly see that the scale of the flight flow network in China expands increasingly. Both the number of navigable cities and the number of air routes are increasing year by year, with more flights and more complicated network structures. The flight flow network structure has obvious hierarchical levels. From the perspective of airline distribution, the domestic airlines are centralized on the east of the Harbin–Beijing–Xi'an–Chengdu–Kunming line, particularly in the triangular areas of Beijing, Shanghai, Guangzhou, and Shenzhen. They connect to most of the edges, especially the thick edges in the network, indicating that the number of flights on this route is large, which occurs due to China's economic development. As a result, the flight flow network structure of China is quite imbalanced, with dense flight distribution to the east, and a centralization trend in the eastern and central areas. While in the western region, there are some cliques centered on Kunming, Chengdu, and Urumqi, which represent the effect of regional economic development, geographic conditions, and tourism functions on the flight flow network structure.

## 3 Structural statistic characteristics of flight flow network

In an undirected network, the basic statistical measures are normally the node degree ($K$), the average node degree ($<K>$), the average path length ($L$), and the clustering coefficient ($C$), etc. Compared with the random network on the same scale, if the average path length of the network $L\geq L_{rand}$, the clustering coefficient $C\geq C_r$ and where $L_{rand}$ and $C_{rand}$ represent the average path length and the clustering coefficient of a random network, respectively, then the network has small world characteristics.

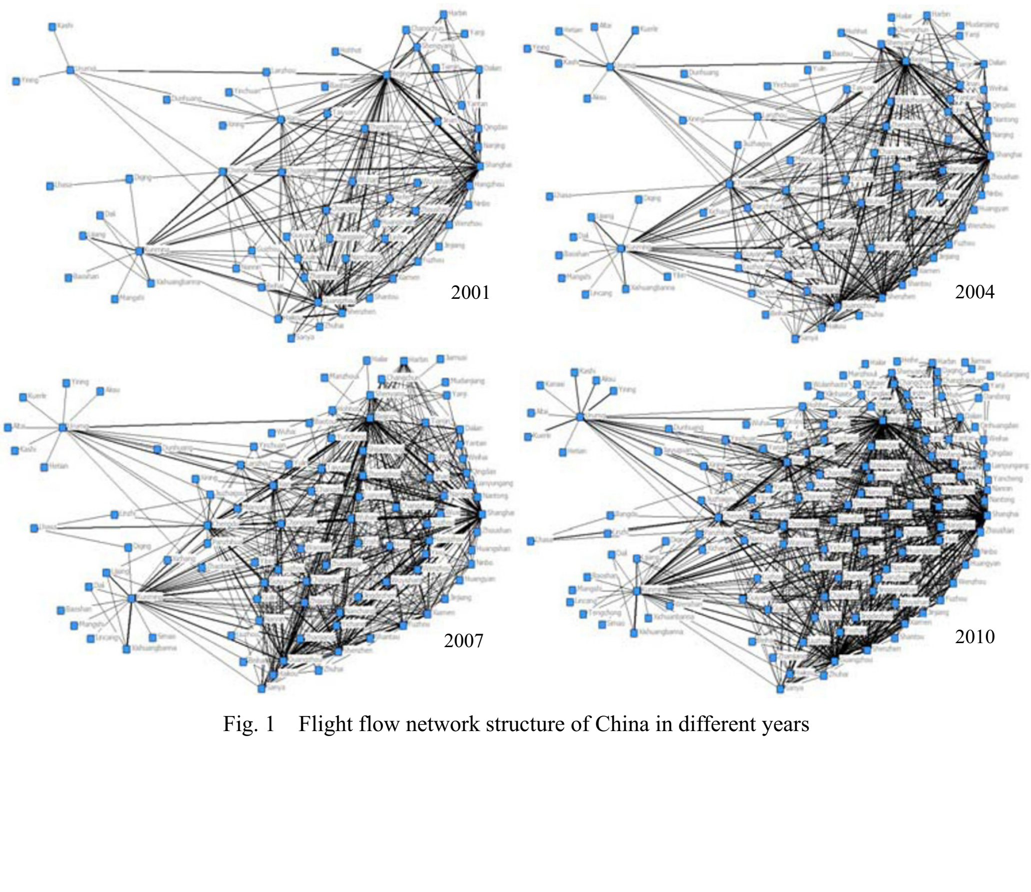


Fig. 1 Flight flow network structure of China in different years