Spatio-Temporal Structural Analysis of Inter-Urban Aviation Network in China

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Abstract: As an important transportation infrastructure, air traffic plays a more and more important role in regional development, and related research is gradually increasing. These studies have mainly focused on transport policy, aviation system organization, and so on (Fleming and Hayuth, 1994; Shaw and Ivy, 1994;Taffe, 1996; Hooper, 1997; O'Kelly, 1998; Graham and Guyer, 1999; Vowles, 2000; Burghouwt and Hakfoort, 2001; Goertz, 2002; Jin and Wang, 2004). With the deregulation of civil aviation, some research has focused on hub-and-spoke aviation networks, and research methods have changed from earlier qualitative analysis to a deeper level of quantitative analysis, in order to investigate the spatial structures and dynamic evolutionary characteristics of aviation networks. Graham (1995) indicated that an integrated hub-and-spoke network of city-pairs was an ideal pattern for spatial network organization. Amraral (2000) studied the structural properties of World-wide Airport Networks (WAN) and concluded that WAN is a small-world network. The same result is found by Guimera (2005) that WAN is a scale-free small-world network. It is also found that in WAN the most connected cities are not necessarily the most central because of the multi-community structure of WAN. Moreover, the community of WAN has been detected and the results show that community structure cannot be explained based solely upon geographical constraints: geopolitical considerations have to be taken into account. Beyond the topological properties, WAN has been studied (Barrat, 2004) as a complex weighted network, where the weight is the traffic flow amount — the strength of interactions between the cities; the correlations among

weighted quantities and the topological structure of the WAN are investigated for the first time. A model with geo-political constraints is proposed (Guimera, 2004) to explain the evolution and growth of WAN. However, there is still no much research on the spatial structural characteristics of aviation networks in developing countries by using complex network methods.

Since the practice of reform and the opening-up policy in 1978, civil aviation in China has been developing rapidly (Chen, 1999; Cheng, 2000). Numbers of airports have been built and operated, and the aviation network is expanded(Table.1), so its structure has changed dramatically. However, very little was understood about the fundamental processes of the national air transportation network which was unfolding both temporally and spatially in China. In the current era of globalization, China was predicted to be the world's fastest-growing aviation market, increasing from 69.6 million passengers in 1999 to an estimated 214.7 million passengers by 2014 (Granitsas, 2002). The Chinese air transportation network is economically not as significant as more highly-developed transportation networks in the USA and European countries. Nonetheless, the continued expansion of the air transportation network in China has posed great challenges, not only for our theoretical understanding of national transformation in a transitional planned economy, but also for planning and policy making for the betterment of over one-fifth of humankind (Pannell, 2002). Therefore, in this globalizing world, it is crucial to characterize the spatial structural features, the relevant organizational models, and the responsible evolutionary mechanisms of the air transportation network in such an important developing country.

Table 1. Development of China's air transport

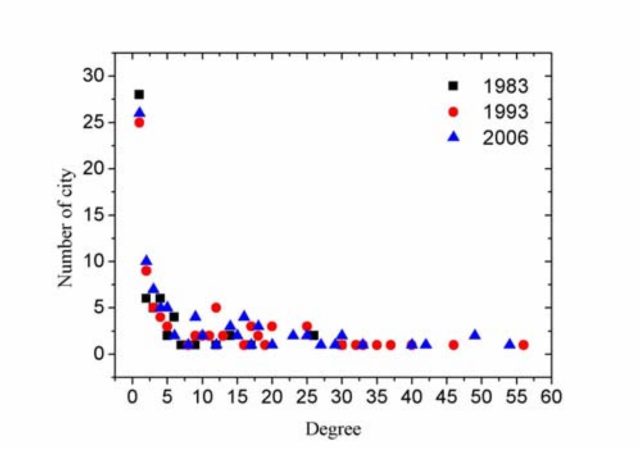
Data source: Statistical Data on Civil Aviation of China, 1981,1986,1991,1996,2001,2007.

Year	1980	1985	1990	1995	2000	2006
Num. of airport	77	80	92	116	139	145
Passenger traffic volume （10^4 persons）	343	747	1660	5117	6722	15968
Turnover volume of passenger traffic （10^6 person. km）	39.6	116.7	230.5	681.3	970.5	2370.6
Freight traffic （10^4 ton）	8.9	19.5	37.0	101.1	196.7	306.7
Turnover volume of freight traffic （10^4 ton. km）	14060	41512	81824	222981	502683	942753
Total turnover volume of air traffic （10^6 ton. km）	4.3	12.7	25	71.4	122.5	305.7

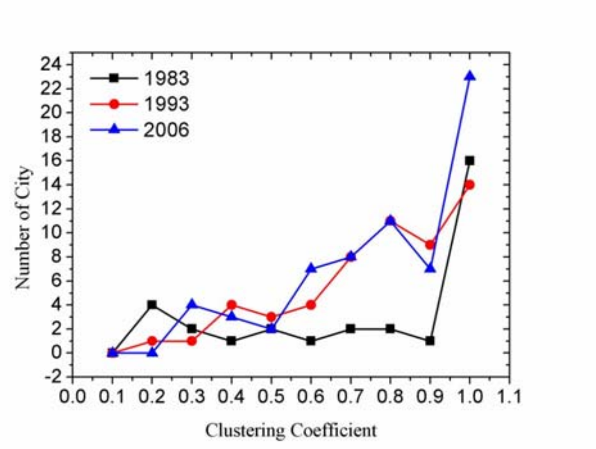
In the present work, by using the inter-city flight data from the national air transportation administration of China, we studied the spatio-temporal evolution of the structural characteristics of the Inter-Urban Aviation network in China (IANC) from 1983 to 2006. An advanced complex network approach, as well as a geographic information system (GIS) analysis method, were used.

Our results led to the following conclusions: 1) The IANC exhibits the densification trends and long-tail distribution characteristics typical of a small-world network(fig.1-fig.4). 2) The IANC is characterized by the "hub-and-spoke" network organization model, where Beijing, Shanghai, Guangzhou, and Shenzhen act as the multi-hubs, and the spatial connections among them act as the spokes. 3) A "saddle-type" model has been followed by the evolution of the IANC, specifically, the structures of the eastern and western regions' aviation networks are better formed than that of the central region. 4) The hub status of 35 important cities in the network varied with the development of the IANC. Meanwhile, tourist cities such as

Huangshan and Lijiang, coastal cities such as Dalian and Qingdao, and western cities such as Lhasa have strong spatial disparities.

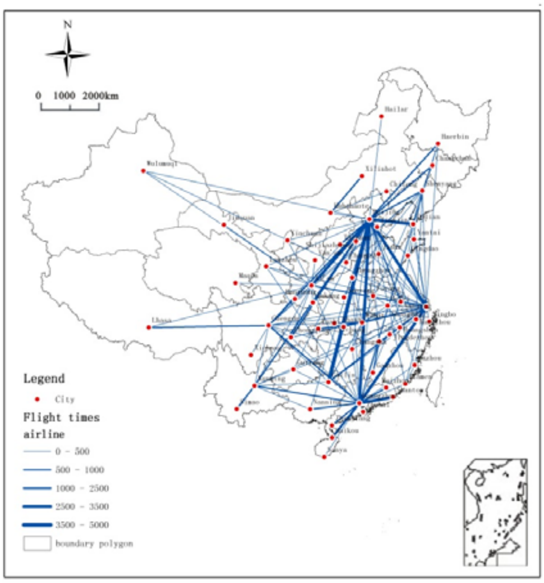


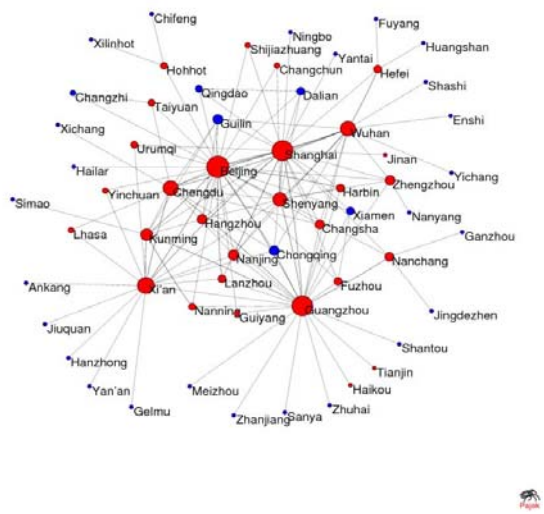
(a) **The distribution of number of nodes by V.S. degree**



(b) **The distribution of number of nodes by V.S. clustering coefficient**

Fig. 1. The distribution of number of nodes by V.S. degree and clustering coefficient





(a) **Airline connection between cities** (b) **The topology of the IAN[1]C[2]**

Fig. 2. The structure of the Aviation Network of China in 1983

Data source: Statistical Data on Civil Aviation of China, 1984.

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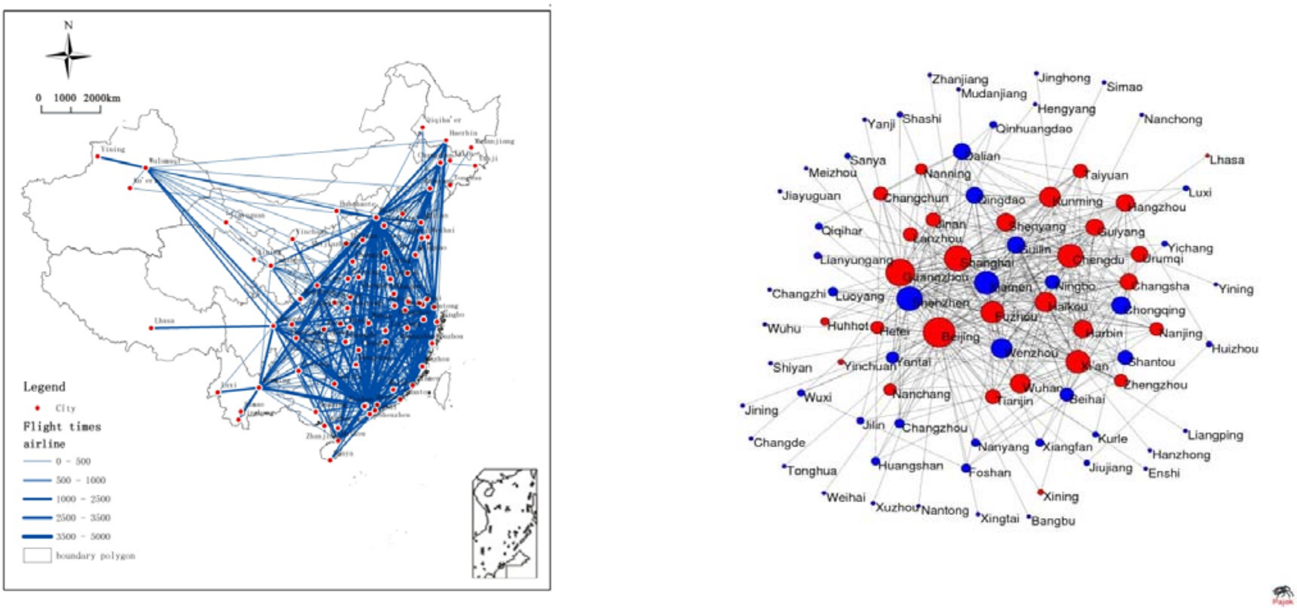
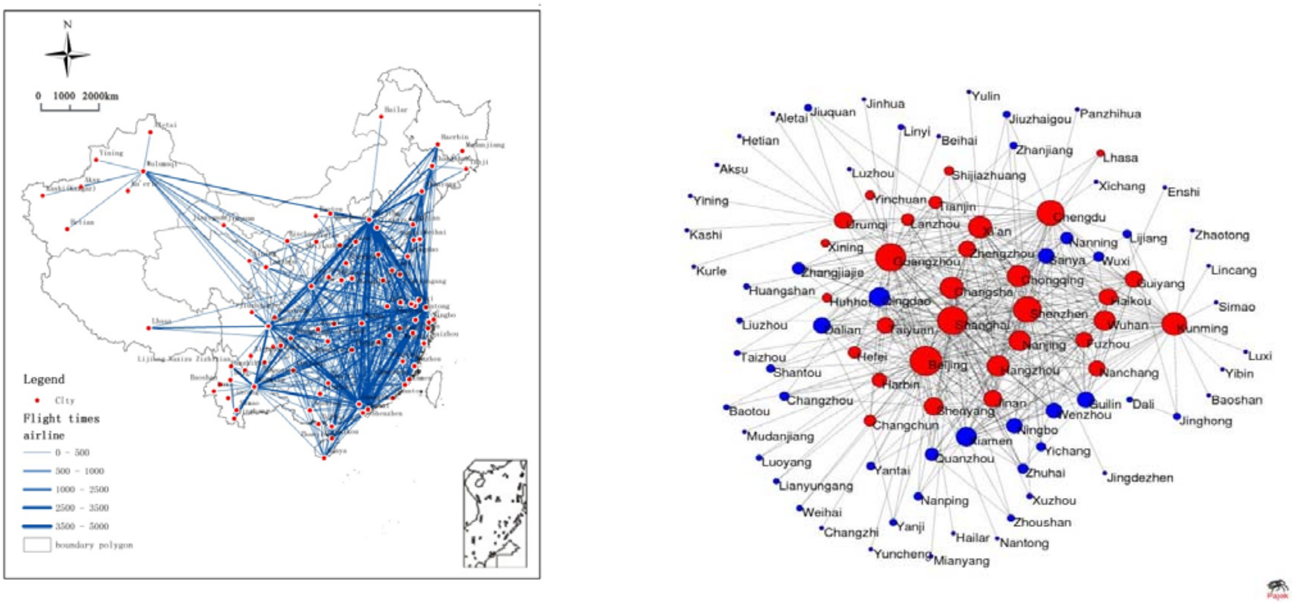
Note: In Fig. 2(b)、Fig. 3(b)、and Fig. 4(b), the red points represent the provincial cities or capital cities in China, and the blue points in represent local cities. The size of the points has a proportional relationship to their degrees. The network was visualized by Pajek (in Batagelj, 1998).



(a) Airline connection between cities **(b) The topology of the IANC**

Fig. 3. The structure of the Aviation Network of China in 1993

Data source: Statistical Data on Civil Aviation of China, 1994.



(a) Airline connection between cities **(b) The topology of the IANC**

Fig. 4. The structure of the Aviation Network of China in 2006

Data source: Statistical Data on Civil Aviation of China, 2007.

In sum, the formation and evolution of the IANC's structure reflect the spatial interactions and associations among cities in its network and the understanding of the civil aviation system and its changes over the past twenty years is important for reasons of policy, administration and efficiency. Thus, this forthcoming analysis will hopefully provide decision-makers and planners with relevant indications on the national as well as global effect of new infrastructure.

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