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Evolution trends of the network structure of Spring Airlines in China: A temporal and spatial analysis

Yonglei Jiang^{a, b, *}, Baozhen Yao^c, Lu Wang^d, Tao Feng^e, Lu Kong^a

^a Transportation Management College, Dalian Maritime University, 1 Linghai Road, Ganjingzi District, Dalian, 116026, China

^b Jiangsu Key Laboratory of Urban ITS, Southeast University, Nanjing, 210008, China

^c School of Automotive Engineering, Dalian University of Technology, 1 Linggong Road, Ganjingzi District, Dalian, 116026, China

^d China Academy of Civil Aviation Science and Technology, 24 Beilijia Xibahe, Chaoyang District, Beijing, 100028, China

^e Urban Planning Group, Department of the Built Environment, Eindhoven University of Technology, Eindhoven, PO Box 513, Vertigo 8.16, 5600MB Eindhoven, The Netherlands

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ABSTRACT

Both the sustainable development of China's economy and the deregulation of the China air transport market have acted as a spur for the halting development of low-cost carriers (LCCs) in China. To analyze the development trends of LCCs' network in China, this paper took Spring Airlines, the only LCC in China as an example. First, the winter flight plans of Spring Airlines from 2005 to 2013 were collected. Secondly, the development trends of air transport network of Spring Airlines were explored with methods of mathematical statistics and social network analysis. Additionally, the development trends were analyzed from the levels of navigable cities, air routes and air transport networks. The results show that although Spring Airlines actively launched air routes between tourist cities with non-class I airports, its network has been transformed from a star structure into a complex one with multi-hubs. The development process of the Spring Airlines network can be separated into three stages. In addition, the problems and evolution trends of its network are discussed further.

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1. Introduction

During the past three decades, air transport together with the four other major transport modes has developed rapidly with China's great economic growth. The airports and airlines at the time could not meet the increasing demand for air transport in China. Thus, a market-oriented reform in the air transport industry was conducted by the Chinese government to deregulate the market. However, factors such as the protection of noncompetitive airlines, open-skies blocks, limited capacity of domestic airports (Zhang and Chen, 2003) and concentration of domestic airlines (Zhang and Round, 2008, 2009) have acted as obstacles for the deregulation in China. In addition, incomplete deregulation of China's air transport market has led to new trend in the Chinese civil aviation market. One of these trends is the market access of civil aviation having been eased, many new investors including private ones and

foreign ones have been attracted to the deregulated market of Chinese air transport since 2004. In 2005, the first low cost carriers (LCCs) of China, Spring Airlines, was established in Shanghai City. Since then, because of their distinct advantage of price, more people have begun to consider air transport for long distance journeys. At the same time, the price equilibrium of China's aviation market has been broken by the cheap air tickets of Spring Airlines, which have already gained considerable market shares on some airlines. To respond to the market changes, the Chinese full-service carriers (FSCs) have to cut their prices and offer other discounted services.

There has been fierce competition between LCCs and full-service carriers (FSCs) since the liberalization in the United States in 1978 (Dresner et al., 1996; Windle and Dresner, 1999). In addition, LCCs created a low-cost business model, in which some services offered by FSCs have been canceled to cut down operation costs and maximize profits (Gillen and Morrison, 2003). However, according to some empirical studies (Fu et al., 2011; Yu et al., 2013, 2015, 2016), the key determinant LCCs' success is product differentiation. LCCs, particularly Southwest Airlines, have obtained the lion's share of the air transport markets of North America, Europe

* Corresponding author. Transportation Management College, Dalian Maritime University, 1 Linghai Road, Ganjingzi District, Dalian, 116026, China.

E-mail address: jiangyonglei@dlnu.edu.cn (Y. Jiang).

and Australia with an average annual growth rate of 30%. However, in China the development of LCCs is not that fast. At present there is only one LCCs, Spring Airlines, in China. Other LCCs, such as Okay Airways and Junyao Airlines, have either shut down or changed their operation modes. Compared with the 33% market share in Europe and North America, the Spring Airlines accounts for only 3% of China's air transport market by the end of 2013. Considering the huge potential of air transport, a series of measures aimed at promoting and deregulating the air transport industry was issued by the government, according to the <State Council Issues Opinions on Promoting Civil Aviation Development> published in 2012. Thus, it is believed that LCCs are facing tremendous development opportunities in China. However, the development of LCCs in China suffered many a setback over the past decade, while only Spring Airlines survived. What are the characteristics of the strategic position, operational mode and expansion mode of airline network behind the success of Spring Airlines? Systematical analysis of the development of Spring Airlines can shed lights on the sustainable development of LCCs in China.

It should be noticed that the network structure of LCCs is one of the key factors that would determine whether LCCs could survive and even win more market shares in China air transport market. The air transport network (ATN) of concentrated FSCs in China has been established and operated for decades, and is generally considered to be stable and effective. Thus, the construction of the ATN of LCCs should be based on the ATNs of FSCs. To be more specific, the navigable cities and airlines of the ATN of LCCs should be selected from the existing navigable cities and airlines on the ATN of FSCs. This paper explores the evolution characteristics of the ATNs of Spring Airlines from the elements of ATN: navigable city, air route and air transport network based on the data of annual flight schedules of Spring Airlines, and tries to offer insight into the successful experiences of the survival and expansion of Spring Airlines while the deregulation of the air transport market is still incomplete and the state-owned FSCs dominate the air transport market.

2. Literature review

2.1. Structural patterns of air transport networks

The numbers of airports and flights have increased rapidly since the 20th century with the development of the air transport industry, and many complicated ATNs of different scales have been formed. Thus, some research studies have tried to analyze the structural patterns of ATNs to evaluate their service level. Due to the popularity and wide application of the Complex Network Approach (CNA), analysis of the characteristics of ATNs under different spatial-temporal dimensions has drawn much attention since 2004. Research on the structures of ATNs could be generally divided into four groups according to geographical characteristics, as shown in Fig. 1.

- (1) World-Wide Air Transport Networks (Guimer'a & Amaral, 2004; Guimerà et al., 2005; Hsu and Shih, 2008; Dang et al., 2009);
- (2) Air Transport Networks of Europe and North America (Xu and Harriss, 2008; Barrat et al., 2005; Paleari et al., 2010; Jia et al., 2014),
- (3) China Air Transport Networks (Li and Cai, 2004; Liu and Zhou, 2007; Peng and Zhou, 2009; Liu et al., 2009; Wang et al., 2009; Zhang and Round, 2009; Zeng et al., 2011; Wang et al., 2011; Lin, 2012; Wang and Mo, 2014);
- (4) Other regions (Bagler, 2008) and airlines (Jiao and Wang, 2014).

Additionally, their research results can be summarized as follows. First, all types of ATNs are small-world networks, and gradually show the characteristics of scale-free and disassortative mixing over time. Second, there is a spatial hierarchical structure, which is rare in other ATNs, in the air transport network of China (ATNC). Furthermore, it is particularly easy to identify the structure among the backbone airports. Finally, constrained by the data availability, there are few studies that have focused on the evolutions of ATNs.

Although some researchers endeavored to introduce environmental factors such as urban economics and traffic into ATNs, CNA can only be employed to analyze the topological properties. With CNA, the evolution rules and social-economic attributes of real-world ATNs cannot be further explored.

2.2. Socio-economic properties of ATNs

Some other study has concentrated on the socio-economic properties of ATNs within different geographical scopes with statistics, social network analysis and so on. Wang et al. (2003) analyzed the geographic patterns of ANTC from 1980 to 1998 by the Spatial Economics, transport economics and GIS technology. They found that the ANTC was in the stage of development; the rule of distance decay in air traffic was significant; the generation and growth of air traffic lacked regional inequality. Matsumoto (2007) employed a gravity model to analyze the distributions of passengers and freight in the ANTW as well as the passenger densities of the main cities. The results show that many cities, particularly Seoul, Hong Kong and Amsterdam, has the fastest growth rates of passenger density, acting as international air transport hubs. A time-dependent minimum path approach was proposed by Malighettia et al. (2008) to analyze the connectivity of ATNE (Air transport network in Europe), and the result shows that roughly two thirds of the fastest indirect connections are not operated by the airlines alliance system. Pan et al. (2009) divided the airports of China into 5 types based on Factor Analysis, and then, the evolution properties of ATNC were analyzed from the viewpoint of airports and air routes by statistical analysis. The results showed that a hub-and-spoke structure has already formed within ATNC. Bowen Jr. (2012) assessed the evolutions of FedEx's and UPS's ATNs based on graph theory measures. The results showed both of the two firms operate their networks with a high concentration of activity at their principal hubs. With the Core-Peripheral Model, Cui and Pan (2014) found that there is a typical core-periphery model in ATNC with three central nodes: Beijing, Shanghai and Guangzhou. In addition, the radius of the positive influence of these central nodes is in the range of 500–550 km.

Furthermore, there are some other studies related to ATN. Both Wu and Pan (2010) and Wu et al. (2012) compared the structure of ATNs and inbound tourism flow networks. Lordan et al. (2014a, 2014b, 2015) concentrated on the robustness of ATN. Xu et al. (2014) and Santos and Antunes (2015) employed planning models to optimize the structures of ATNs.

2.3. Development characteristics of LCCs

As a novel business model, the fast increase of LCCs' market share and the rapid expansion of their networks have drawn the attention of some researchers. Dobruszkes (2006, 2013) observed the fast development of LCCs in Europe, and analyzed the structure of European LCCs by statistical analysis and social network analysis. He found that LCCs prefer to provide air service in large cities, tourist destinations and cities with secondary airports, and LCCs also prefer to launch new air routes to supplement the services of FSCs. Furthermore, the competition on pre-existing routes between

Fig. 1. Researches on air transport network with CNA.

LCCs and traditional airlines is becoming fiercer. Recently some scholars have considered the fast development of Spring Airlines in China. Fu et al. (2015) analyzed the competitive ways of Spring Airlines in route entry in China's regulated aviation market.

Current study has already provided comprehensive analysis of the structural characteristics of ATNs under different spatial and temporal scales. However, so far, few studies have specialized in evaluating the evolution of LCC networks, particularly in China; most Chinese scholars have explored the characteristics of ATNs in China, including both the LCCs' and FSCs' networks. In this paper, the network of Spring Airlines, which is the first and the only LCC in China, is taken as an example to analyze the characteristics of the LCC network in China. The evolutionary features and rules of networks of Spring Airlines' from 2005 to 2013 are analyzed based on statistical analysis and social network analysis, and the results should be the guidelines for constructing of LCC networks in China.

3. Data

Spring Airlines, aiming to be the first Chinese LCC, was founded on July, 18, 2005. With a series of low-cost operation strategies such as cheap tickets and unified aircrafts, Spring Airlines has survived and successfully remained profitable during the following 9 years in China's air transport market, which was previously dominated by several FSCs.

According to Table 1, during the second half of 2005, Spring Airlines operated 12 domestic air routes, scheduled 1068 flights, and served over 180,000 passengers (0.13% of China's air transport market) with only 2 aircraft. At the end of 2013, Spring Airlines had 39 aircraft, flying 64 air routes with 65,767 flights, and over 10,550.8 million passengers (3% of China's air transport market) had been transported by Spring Airlines.

All the data of scheduled domestic routes and flights (including routes between the Mainland and Hong Kong, Macau and Taiwan) of the winter flight plans from 2005 to 2013 were provided by Spring Airlines. Although Taiwan Province differs from China's

Table 1

Statistics of Spring Airlines' production scales from 2005 to 2013.

	Fleet		Routes		Flights		Passengers	
	Num.	Share	Num.	Share	Num.	Share	Num. (0,000)	Share
2005	2	0.23%	12	0.95%	1068	0.08%	18.05	0.13%
2006	4	0.40%	12	0.90%	6745	0.43%	113.71	0.71%
2007	8	0.71%	25	1.66%	14,201	0.80%	235.31	1.27%
2008	10	0.79%	26	1.70%	17,583	0.94%	294.38	1.53%
2009	14	0.99%	41	2.58%	25,577	1.19%	431.29	1.87%
2010	20	1.25%	36	1.91%	35,494	1.48%	585.97	2.19%
2011	27	1.53%	48	2.10%	43,909	1.72%	715.08	2.44%
2012	32	1.65%	55	2.24%	56,583	2.03%	911.10	2.85%
2013	39	1.82%	64	2.23%	65,767	2.13%	1055.08	2.98%

Data source: <Statistics Compilation of China Civil aviation 1949–2011>.

mainland in the IATA specific code, Spring Airlines attaches the same importance to flights to/from Taiwan as to those to/from Mainland China. This paper tries to explore Spring Airlines' network characteristics including routes between the Mainland and Taiwan.

4. Evolution analysis of ATN of Spring Airlines

In this paper, statistical analysis and social network analysis are used to analyze the evolution of ATN of Spring Airlines spatially and temporally, and the analysis are implemented according to three levels: navigable cities, air routes and air transport networks.

4.1. Navigable city level

4.1.1. Spatial-temporal evolution of navigable cities

According to the geographical factors and regional economic development, the territory of China is divided into 7 regions by the Civil Aviation Administration of China (CAAC): North China Region, Northeast Region, East China Region (including Taiwan), Central

Southern Region (including Hong Kong and Macau), Southwest Region, Northwest Region and Xinjiang Region (Fig. 2), and each regional administration of CAAC is responsible for the planning and management of the regional airport transport market. Furthermore, this division has already become the analysis unit for most statistics reports and research in China (e.g., Jiao and Wang, 2014).

As we know, the civil airport is an important transportation hub for the communication of passengers and freight with the outside in a city, which acts as an engine of regional economic growth. Meanwhile, a navigable city needs to supply enough passengers to maintain the operation of air routes for the airlines, the selection of suitable navigable airports is closely related to the social and economic development of the airports' catchment area (navigable city). In this paper, in order to analyze the spatial patterns of nodes in the ATN of Spring Airlines, navigable cities are substitutes for navigable airports. In particular, multi-airport cities (Beijing and Shanghai) are seen as one single navigable city. The spatial and temporal distributions of navigable cities of Spring Airlines for 7 regions from 2005 to 2013 are shown in Fig. 3, and the evolution of navigable cities is discussed based on distributions of navigable cities.

Expansion trends of navigable cities in different regions are very different as shown in Fig. 3. First, the number of navigable cities has risen from 13 (the number of nodes at the bottom of Fig. 3) in 2005 to 42 (the number of the arrows reaching the top of Fig. 3) in 2013. It could be concluded that the total number navigable cities had increased by 29 in just 9 years. Second, although both of the principal hubs (Shanghai Hongqiao International Airport and Shanghai Pudong International Airport) of Spring Airlines are located in the East China Region, the East China Region is not the region with the most navigable cities among the 7 regions. There are 16 navigable cities (28.1%) in the East China Region. However, the Central Southern Region is the region with the most navigable cities, which is 18 (31.6%). Finally, the amount of navigable cities in the Northwest Region and Xinjiang Region is really small because of their remote geographical positions. It is also found that the Pearl River Delta and the Yangtze River Delta, which are the most developed two economic areas in China, are chosen as ideal regions to establish navigable cities. Thus, Spring Airlines found that setting navigable cities in these regions would yield better profit than other regions according to their annual financial statements.

Moreover, in each region the distribution and number of navigable cities are always changing. First, the total number of Spring Airlines' navigable cities is increasing over time with the development of the company. In the early days of Spring Airlines from 2005 to 2006, 71.4% of new navigable cities were opened in the Central Southern Region and East China Region, both of which were considered the company's principal market at that time. Then, the total number of navigable cities of Spring Airlines was significantly adjusted and increased twice, once in 2007 and once in 2009. Since then, the navigable cities of Spring Airlines have almost become spread throughout China, with the exception of the Xinjiang Region. Second, while the total number of navigable cities continues to increase, the specific spatial distribution of navigable cities in each region are under constant adjustment. The East China Region has experienced the most frequent adjustments in navigable cities, with 64% of the established navigable cities in the region having had their air service gradually canceled.

As shown in Fig. 3 12 navigable cities, including Taiyuan, Heihe, Yantai and Huaihua, have had their service canceled by Spring Airline, and 7 of them are capital cities. The annual passenger traffic numbers of most canceled navigable cities, except for 3 extreme cases (Heihe, Zhoushan and Zhangjiajie), were scattered from the 13th to the 41st in 2013 in the second rank of the index of China's airports.

In addition, the base city, Shanghai City, together with some other significant navigable cities: Tianjin, Xiamen, Guilin, Sanya, Zhuhai, Changde, Mianyang and Kunming, are backbone nodes of the air transport network of the Spring Airlines.

Finally, since 2009 China has been make large-scale investment on the HSR (High Speed Rail), particular in the coastal regions of China (Yang and Zhang, 2012). The HST acts as new entries on certain routes to compete with the airlines (Janic, 1993). Thus, the operation of HST on given routes resulted in the cancelling of some navigable cities (for example, the operation of Wuhan-Guangzhou HST and the cancelling of Wuhan, Changsha in 2009). So the inefficient operation of air routes in these cities results in high-frequent changes of navigable cities during the period of 2007–2010. After considering the impacts of HST, Spring Airlines adjusted its network instantly, and the scale of navigable cities are increasing steadily.

Data Source: The Civil Aviation Administration of China (CAAC)

Fig. 2. Area division of China airspace.

Data Source: Spring Airlines' Winter Flight Schedules (2005-2013)

Fig. 3. Spatial-temporal distributions of navigable cities of Spring Airlines¹¹.

4.1.2. Evolution of types of navigable cities

To provide further research on the evolution of navigable cities, all the navigable cities are classified according to the following standards:

- (1) **Provincial Capital or other²**: The capital of a province is a political, economic, population and cultural center with the biggest air transport market in the province.
- (2) **Tourist City or other³**: Tourism is a key driver for the demand of air transport, and at the same time air transport could also provide new destinations for tourism. A tourist city means an enormous amount of tourism traffic demand.
- (3) **Class I Airport or not⁴**: According to the <Reform Plan of Charging Policies for Civil Airports> issued by CAAC in 2007, the charge level of airport is related with the volume of its throughput. And at present, the airports in Beijing, Shanghai, Guangzhou, Shenzhen, Chengdu and Kuming are in the Class I list. Take-off and landing at non-class I airports would lower the operational cost of airlines.

All the navigable cities from 2005 to 2013 are classified and shown in Venn diagrams (Fig. 4) based on 3 standards mentioned before. And the characteristics of evolution of the three types of navigable cities are discussed. From 2005 to 2013, cities that match more than one standard are more likely to be selected as navigable nodes of Spring Airlines. And the primary type of navigable city for Spring Airlines varies with the development of the Airlines. For instance, the primary type in 2005 is the cities, which are tourist cities and do not have a class I airport as shown in Fig. 4.3 (a). In regard to 2013, the primary type becomes the cities with all the three standards as shown in Fig. 4.3 (i).

At the beginning (2005–2006) Spring Airlines set the tourist cities with second-class airports (55%) as its navigable nodes instead of cities that are up to all the three standards (approximately 25%). Because Spring Airlines is founded by China's largest travel service provider, Spring Travel (Shanghai Spring International Travel Service Co., Ltd), Spring Airlines tried to take tourist traffic demand of secondary airports as a niche to gain profits relying on the resource of its parent company.

Later, Spring Airlines had begun to launch more flights in cities that fulfilled the 3 standards (Fig. 4 (c) & (d)). The fleet scale had grown rapidly during this period (Table 1) to improve its production capacity and to open other kinds of navigable cities. To make a profit efficiently, the cities that fulfilled 3 standards were given preferential considerations.

Spring Airlines has been able to have a more flexible and diverse choice of navigable cities because of its fast-expanded fleet scale. As shown in Fig. 4 (e)–(i), in addition to the cities with all 3 standards, more and more cities that are up to two standards are selected. The percentage of these navigable cities has increased from 9% in 2009 to 33% in 2013.

According to the changes in types of navigable cities, two characteristics can be concluded: first, according to the China Excellent Tourist Cities List, all the navigable cities of Spring Airlines since 2005 have been famous tourist cities because all of them were selected before 2003. Second, Spring Airlines will continue to

concentrate on launching air routes to capital cities and cities without class I airports in the future, because these cities could provide adequate traffic flows and cheaper airport fees for Spring Airlines.

4.2. Air routes level

As shown in Table 1, the number of air routes of Spring Airlines is growing at an annual rate of 23.8%, which means the number of air routes had increased from 12 in 2005 to 64 in 2013. Two clear trends could be identified from the evolution of air routes as follows.

4.2.1. Evolution of the length of air routes

First, the total mileage (non-repeat) of air routes of Spring Airlines has been growing steadily over recent years, notwithstanding occasional fluctuations. The total length of air routes of the airlines increased from 16,533 km to 102,946 km from 2005 to 2013, and its growth rate has followed a quadratic polynomial function as shown in Fig. 5. Meanwhile, the aggregate length of air routes has a periodic fluctuation. The aggregate length of 2006, 2008, 2010 and 2013 are less than those of their previous years respectively. It might because Spring Airlines adjusted the air routes promptly according to the operational benefits of each air route in the previous year.

Meanwhile, according to the volatility rate of air routes⁵ in Fig. 6, the air routes of Spring Airlines changed more significantly than those of China's total air routes. At the beginning, due to the constraint of fleet size, Spring Airlines changed its air routes widely according to the previous year's operational performance. When the number of aircrafts increased rapidly, the annual volatility rate of air routes decreased step by step, and in 2013, the volatility rate of Spring Airlines was the same as the total air routes of China's air transport market.

4.2.2. Evolution of distributions of length of air routes

As shown in Fig. 7, the distribution of air routes' length has gradually followed a Partial Normal Distribution, and that of the national air route length has also followed the distribution (Fig. 7 (j)). The evolution of air routes' distribution of Spring Airlines has its own characteristics, which helps the airline to maintain profitability.

Spring Airlines launched only a few air routes constrained by its fleet scale from 2005 to 2006, and the characteristics of the distribution of air route length are not clear. The fleet scale was expanded much from 2007 to 2009, and it could be found that the distribution of air routes length has nearly followed a partial normal distribution, which means both of the proportions of short-haul air routes (<600 km) and long-haul air routes (>2000 km) are small, and most of the air routes are close to the mean value. During this period, the lengths of 75% air routes have ranged from 600 km to 1600 km; the proportion of short-haul air routes together with long-haul ones are approximately 18%. According to the statistical report of the CAAC in 2013, the lengths of the hottest air routes fall into the range of 1200–1600 km. In order to improve its operation performance, Spring Airlines gradually concentrated on opening and increasing the number of air routes with length of 1200–1600 km. Meanwhile, short-haul routes (<600 km) has been confirmed academically (Wan et al., 2016) and empirically to be the battlefield of market share between the HST and air transport. Therefore, most of Spring Airlines' air routes have been concentrated in the range from 600 km to 1800 km since 2009, while the

¹ there are two airports (SHA & PVG) in Shanghai City.

² Hong Kong, Macau, cities in Taiwan and special municipalities are included as provincial capitals.

³ The "China Excellent Tourist Cities List" was updated by the China National Tourism Administration in 1998, 2000, 2001, 2003, 2004, 2005, 2006 and 2007.

⁴ The classifications of civil airports are based on the calculation released in the "Reform Plan of Charging Policies for Civil Airports".

⁵ Volatility rate is the ratio that the sum of the increment and canceled numbers of air routes in the following year to the number of air routes in the previous year.

Data Source: Spring Airlines' winter flight schedules (2005-2013)

Fig. 4. Venn diagrams of three types of navigable cities.

proportion of short-haul air routes has decreased from 7.1% in 2009 to 4.0% in 2013.

4.3. Air transport network level

There were only 13 navigable cities and 12 air routes in the network of Spring Airlines in 2005. However, in 2013 the airline had

Data Source: Spring Airlines' winter flight schedules (2005-2013)

Fig. 5. Variations of total length and average length of air routes of Spring Airlines.

Fig. 6. The annual volatility rate of Spring Airlines' air routes.

a large-scale network with 43 navigable cities and 64 air routes (Fig. 8).

4.3.1. Evolution of network connectivity

Four types of evaluation indexes (Jiao and Wang, 2014) are used to evaluate the connectivity of the ATN of Spring Airlines, and the formulations of the indexes are shown as follows.

$$\begin{aligned}
 \mu &= m - n + g \\
 \alpha &= 2(m - n + 1)/[(n - 1)(n - 2)] \\
 \gamma &= 2m/(n(n - 1)) \\
 \beta &= m/n
 \end{aligned}
 \quad (1)$$

where μ is the number of circuits in a network; α is the ratio of number of circuits to all the possible ones; γ is the ratio of number of air routes to all the possible ones; β is the average air routes of each navigable city; m is the number of air routes; n is the number of navigable cities; g is the number of disconnected subgraphs and

is usually set to 1.

In Table 2, the values of four types of indexes are all growing, so that the network connectivity is being improved. In addition, the network structure development of the Spring Airlines can be divided into three stages.

At the beginning, to gain maximized profit with limited planes, Shanghai City was taken as the center to build a simple "star structure" for Spring Airlines ($\alpha=0$, $\mu=0$, $\gamma \approx 1/3$).

Then new air routes were opened based on the established star structure to expand the network scale. Meanwhile Spring Airlines also tried to improve the network connectivity by launching air routes between other city pairs. By the end of 2010, the values of both β and γ were increased by approximately 20% compared with those of 2005, and 20% is really a considerable improvement of network connectivity.

From 2011 to 2013, the network connectivity had been improved greatly. The values of β is increased by 50%, while the values of α and μ were multiplied several times over this period. In

Fig. 7. Distributions of mileages of air routes of Spring Airlines.

addition, more circuits were designed in the network ($\gamma > 1/3$), and the network structure had been changed from the star structure to a more complex one.

4.3.2. Evolution of hub cities

According to Fotheringham & O'Keyll (1989)'s opinion, a hub is a type of facility located in a network in such a manner to provide a switching point for flows between other interacting nodes. To identify the hubs in ATNs, the index of hub degree (Jin et al., 2005) is introduced to analyze the evolution of hub cities.

$$S_i = \sum_{j=1}^n D_{ij} / (V - 1) \quad (2)$$

where S_i is the hub degree of city i ; D_{ij} is the topological distance between city i and city j ; V is the number of cities. Based on the value of hub degree of each navigable city from 2005 to 2013, a histogram (Fig. 9) is drawn to show the changes of the hubs of Spring Airlines. In each year, the area of each rectangle equals the value of the city's hub degree. According to the value of hub degree of each navigable city, the network of Spring Airlines has experienced a transformation from a single-hub network to a multiple-hub one. Additionally, 5 navigable cities are or at least had been hub bases.

From 2005 to 2008, Spring Airlines took Shanghai (Shanghai

Hongqiao International Airport) as its only hub for its network. The value of hub degree of Shanghai was approximately 0.3 before 2006. Since 2007, Spring Airlines has begun to launch air routes from Shanghai Pudong International Airport, another airport in Shanghai, but the hub degrees of Shanghai with the two airports was still approximately 0.3, which is large enough to make sure Shanghai was the only hub.

Then, the production scale of Spring Airlines was largely expanded so that the airline needed to develop of a second or even a third hub city. In 2009, Spring Airlines declared that Sanya had been chosen as its second hub city.⁶ Furthermore, the value of Sanya City's hub degree increased from 0.038 in 2008 to 0.094, which was second to the value of hub degrees of Shanghai City. However, Spring Airlines abandoned this plan in 2010, and the hub degree of Sanya was decreased to 0.027 in 2010. Because Sanya is a world-famous seaside resort, the city positioned itself as a luxury tourist destination. The competition in the local air transport market was very fierce among many China and international FSCs. Thus, it was almost impossible for Spring Airlines, a LCC, for which the selling point is cheaper tickets with less comfort, to survive among the competition of the air transport market of the luxury tourist island.

⁶ <http://www.chinanews.com/cj/news/2009/08-20/1826117.shtml>.

Data Source: Spring Airlines' winter flight schedules (2005-2013)

Fig. 7. (continued).

In 2011, Spring Airlines chose Shijiazhuang and Shenyang as candidates for its second hub cities. The values of hub degree of Shijiazhuang and Shenyang increased from 0.036 to 0.028 in 2011 to 0.070 and 0.048 in 2013, respectively, while the value of hub degree of Shanghai decreased to 0.235. Finally, Spring Airlines constructed an ATN that took Shanghai as its principal hub and Shijiazhuang and Shenyang as its second and third hubs,

respectively.

4.3.3. Network's operational mode

According to the results of Wang and Mo's (2014) research, in Chinese domestic market, airlines try to increase both the flight frequency and aircraft size as their operational mode to accommodate the rapid traffic growth, and there is a negative

Fig. 8. Networks of Spring Airlines 2005–2013 (Data source: Spring Airlines' winter flight schedules (2005–2013)).

Table 2
Values of connectivity indexes.

	2005	2006	2007	2008	2009	2010	2011	2012	2013
α	0.00	0.12	0.09	0.07	0.16	0.08	0.43	0.51	0.40
β	1.85	2.18	2.25	2.17	2.55	2.23	3.57	3.85	3.44
μ	0	2	4	3	10	5	30	38	32
γ	0.36	0.44	0.41	0.39	0.45	0.39	0.63	0.68	0.60

relationship between market concentration and flight frequency. However, the operational modes of Spring Airlines may lead to a different path. According to the research of Dobruszkes (2006), the operational mode of a network is usually gained based on available seat kilometers (ASKs) and the number of flights by the comparison of ratios' of ASKs/aircrafts and flights/ASKs (Eq. (3)).

$$\text{Network's operational mode} = \frac{\text{ASKs}}{\text{Aircrafts}} \text{ V.S. } \frac{\text{Flights}}{\text{ASKs}} \quad (3)$$

In Table 3, the types of the network's operational mode of Spring Airlines have been changed from the type of "More ASKs/less freq" to the type of "Stable ASKs/more freq" between 2005 and 2013. At the beginning, Spring Airlines designed its networks based on the method of "More ASKs/less freq". In 2005, the ratios of ASKs/aircrafts and flights/ASKs were 1,489,770 and 0.0004, respectively. In

other words, Spring Airlines tried to launch as many ASKs as possible to earn a profit.

Then the type of network's operational mode gradually changed to the type of "Stable ASKs/more freq", while the production scale of Spring Airlines continued to grow. The changes in the types of network's operational mode were achieved in 2010. The ratio of ASKs/aircraft was stable at approximately 550,000, and simultaneously, the ratio of flights/ASKs increased to 0.0035 in 2013. During this period, Spring Airlines concentrated on increasing the number of flights to grab market share.

5. Conclusions and discussions

Spring Airlines, the first and only LCCs in China, is used as an example in this paper to explore the evolution characteristics of its network structure from three main aspects: navigable cities, air routes and networks. The evolution process of the network of Spring Airlines could be roughly divided into three periods: the founding period, the developing period and the stable period.

During the founding period (2005–2006), Spring Airlines took its principal hub city as a center to select navigable cities and launch air routes. However, the navigable cities of Spring Airlines are mainly tourist cities with second-class airports in the most highly developed East China Region and Central Southern Region because of limited fleet scale. Additionally, a Star Structure network

Fig. 9. Changes of navigable cities' hub degrees from 2005 to 2013.

Table 3

Network's operational mode of Spring Airlines 2005–2013.

	2005	2006	2007	2008	2009	2010	2011	2012	2013
ASKs/aircrafts	1,489,770	690,705	839,408	558,522	735,621	485,685	653,627	609,069	475,135
Flights/ASKs	0.0004	0.0024	0.0021	0.0031	0.0025	0.0037	0.0025	0.0029	0.0035

was operated in a “More ASKs/less freq” mode to win market share.

In the developing period (2007–2009), the production scale of Spring Airlines expanded fast due to the growth of the fleet scale. More air routes were opened among provincial capitals with both second-class airports and tourist attractions. Furthermore, the lengths of new air routes were mainly between 600 km and 1000 km. The connectivity of its network was being improved while the operational mode was changing.

In the stable period (2010–2013), Spring Airlines had begun to improve its service level and the operational mode. Spring Airlines lowered the selection standards for navigable cities, the selection scopes of which had been enlarged, and the preferred length of air routes was between 800 km and 1800 km. More importantly, Spring Airlines succeeded in building its secondary hubs so that the connectivity of the networks was improved significantly. In addition, the node of the network's operational mode had totally changed from the type of “More ASKs/less freq” into the type of “Stable ASKs/more freq”.

Aimed at being the first private LCC and as a new entrant, Spring Airlines is always trying to popularize the air transport and increase the market scale with cheap ticket prices in 2nd and 3rd class airports. Spring Airlines has shown significant development; however, some failures have been inevitable. First, the Spring Airlines failed in operating in 12 navigable cities and 16 related air routes. Most of the aborted operations in supposed navigable cities were canceled in 2008 and 2009 during the fast development period of Spring Airlines. Although tourist cities with 2nd and 3rd class airports are the mainstays of navigable cities, they are also the types of cities Spring Airlines failed to conduct operating business in. In addition,

most of the related canceled air routes were long haul ones between Shanghai City and other cities. All these indicate that the tourist cities with non-first class airports are the most important and difficult market of Spring Airlines. Second, in addition to the principal hub, Shanghai City, Spring Airlines has begun to set secondary hubs.⁷ Since 2006, it consecutively announced that Sanya, Zhengzhou, Shijiazhuang and Shenyang would be the second hubs formally or informally. However, due to the low air transport demand, Zhengzhou was overtaken by Sanya in 2009. Dramatically, both the lack of assistance by local governments and the strong disagreement of Hainan Airlines later foiled Spring Airlines' plans.

According to the development properties of Spring Airlines, we can conclude that Spring Airlines will show the following trends in future. First, although the tourist cities with non-class I airports have been difficult to tackle successfully, Spring Airlines will bounce back in these potential markets when the time is ripe. Second, Spring Airlines has already established hub cities in the North China Region (Shijiazhuang), Northeast Region (Shenyang) and East China Region (Shanghai). As Spring Airlines' important markets, hub cities in the Central Southern Region and Southwest Region will be on the agenda of Spring Airlines' network construction plan.

Meanwhile, considering the huge potential of air transport market, both domestic and international aviation giants have created or planned to create low-cost subsidiaries (airlines-within-airlines, AWA) to grab the market share. Due to the fierce

⁷ <http://news.carnoc.com/list/70/70375.html>.

competition on hot routes, the inefficient dissimilarity, late entry of the market (Pearson and Merkert, 2014), the future of these AWAs in China will keep uncertain. However, Spring Airlines has succeeded to survive while the regulation and competition from the FSCs were much harsher in the past 9 years. And the characteristics of Spring Airlines' network expansion can shed some lights on the development of the AWA in China.

Finally, this paper tries to find the successful experiences behind the ATN evolution of Spring Airlines. With statistical analysis and social network analysis, the evolution trends and characteristics are gained to shed lights on the development of potential entrants in China's air transport market. However, due to the data absence of Spring Airlines' operation situation, the deeply analysis of Spring Airlines' development should be the highlights of our further research.

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