Comparing of Aviation Network Structure of Mid-south, Northwest and Southwest of China Based on Hierarchical Index Model

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Abstract: In order to compare the aviation network of mid-south, northwest and southwest of China to reveal the structure similarity and difference for providing quantitative evidence to construct regional aviation network and improve its structure, hierarchical index model of regional aviation network was established through dividing the aviation network into layers to research its structure characters. Data matrixes were defined to record the basic state of regional aviation network. Index matrixes were constructed to describe the quantitative features of regional aviation network. On the basis of these indexes, several structure indexes of all layers of aviation network were calculated to show the structure features of aviation network, such as ratio of passenger volume within the region with across the region, share rate of passenger volume among layers, ratio of average number of airline for each airport, ratio of average passenger volume for each airline and ratio of airline rate. According to the statistical data, similar structure of share rate of passenger volume among layers and average passenger volume for each airline in their regional aviation network was found after calculating. But on the side of ratio of passenger volume within the region with across the region, ratio of average number of airlines for each airport and ratio of airline rate were different.

Key words: Regional aviation network, comparing of structure, hierarchical index model, index matrix, structure index.

1. Introduction

Mid-south of China includes Henan, Hubei, Hunan, Guangdong, Guangxi and Hainan provinces. By the end of year 2015 [1], the area was 1.02 million square kilometers, the population was 390 million people in this area and the gross regional product was 18.9 trillion RMB. Northwest of China includes Shanxi, Gansu, Qinghai, Ningxia and Xinjiang provinces. This area was 3.1 million square kilometers, the population was 100 million people in this area and the gross regional product was 3.9 trillion RMB at the end of year 2015. Southwest of China includes Sichuan, Guizhou, Yunnan, Xizang provinces and Chongqing city. This area was 2.35 million square kilometers, the

population was 200 million people in this area and the gross regional product was 7.1 trillion RMB at the end of year 2015. According to the statistics [2], by the end of year 2015 there were 33 airports and 740 airlines in the mid-south of China. There were 35 airports and 324 airlines in the northwest of China. There were 44 airports and 564 airlines in the southwest of China. Hierarchical index model of regional aviation network was proposed with data matrix to record the basic states of regional aviation network and with index matrix to describe the structure characters of regional aviation network. On the basis of reality data, hierarchical index model of regional aviation network was used to analyze and compare the structure features of regional aviation network in mid-south, northwest and southwest of China. Similar structure of passenger volume share rate in each layer and average passenger volume of

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airlines in these three regions was found. Obvious difference about ratio structure of passenger volume between within region and across region in different layers was discovered. There was some local structure difference about the average number airlines of each airport and airline rate in all layers.

2. Hierarchical Index Model of Regional Aviation Network

In Ref. [3], aviation network of southwest China was divided into 5 layers. In order to show the key features and be easy to compare with other regional aviation network, three layers were used here to divide the regional aviation network. The same dividing points were applied here as in Ref. [3], but the third layer, the fourth layer and the fifth layer in Ref. [3] were combined as the third layer in this paper. The airport whose annual passenger volume was more than 10 million people with its airlines consisted the first layer aviation network. The airport of which annual passenger volume was between 10 million and 1 million people with its airlines consisted the second layer aviation network. The airport of which annual passenger volume was less than 1 million people with its airlines consisted the third layer aviation network.

Data matrixes D, D_{within} and D_{across} were defined to record the basic states of regional aviation network.

$$D = \begin{bmatrix} V_1^{in} & L_1 & T_1 \\ V_2^{in} & L_2 & T_2 \\ V_3^{in} & L_3 & T_3 \end{bmatrix} \tag{1}$$

In Eq. (1):

D —basic states matrix of regional aviation network;

V_k^{in}—the number of airports in the layer k of regional aviation network, $k = 1, 2, 3$;

L_k—the number of airlines in the layer k of regional aviation network, $k = 1, 2, 3$;

T_k—the annual passenger volume in the k layer of regional aviation network, $k = 1, 2, 3$.

$$D_{within} = \begin{bmatrix} L_1^{within} & T_1^{within} \\ L_2^{within} & T_2^{within} \\ L_3^{within} & T_3^{within} \end{bmatrix} \tag{2}$$

In Eq. (2):

D_{within} —the basic data matrix of airline and passenger volume within the district of aviation network;

L_k^{within} —the number of airlines within the district in the layer k, $k = 1, 2, 3$;

T_k^{within} —the passenger volume within the district in layer k, $k = 1, 2, 3$.

$$D_{across} = \begin{bmatrix} L_1^{across} & T_1^{across} \\ L_2^{across} & T_2^{across} \\ L_3^{across} & T_3^{across} \end{bmatrix} \tag{3}$$

In Eq. (3):

D_{across} —the basic data matrix of airline and passenger volume across the district of aviation network;

L_k^{across} —the number of airlines across the district in layer k, $k = 1, 2, 3$;

T_k^{across} —the passenger volume across the district in layer k, $k = 1, 2, 3$.

$$L_k = L_k^{within} + L_k^{across} \tag{4}$$

$$T_k = T_k^{within} + T_k^{across} \tag{5}$$

$$V^{in} = \sum_{k=1}^{n} V_k^{in} \tag{6}$$

$$V = V^{in} + V^{out} \tag{7}$$

In Eq. (7):

V —the number of airports in the nation;

V^{out} —the number of airports out of the district.

Indexes I, I_{within} and I_{across} were defined to describe the structure features and quantitative relationship of regional aviation network.

$$I = \begin{bmatrix} VLA_1^{in} & LTA_1 & LR_1 \\ VLA_2^{in} & LTA_2 & LR_2 \\ VLA_3^{in} & LTA_3 & LR_3 \end{bmatrix} \tag{8}$$

In Eq. (8):

I —the basic index matrix of airlines of regional aviation network;

VLA_k —the average airline number of each airport in layer k in the district, $k = 1, 2, 3$.

$$VLA_k = \frac{L_k}{V_k^{in}} \qquad (9)$$

where, LTA_k —the average passenger volume of each airline in layer k of the district, $k = 1, 2, 3$;

$$LTA_k = \frac{T_k}{L_k} \qquad (10)$$

where, LR_k —the airline rate in layer k of the district, $k = 1, 2, 3$. It was calculated from the number of actual airline in layer k of the district divided by the number of all possible airline in layer k of the district.

$$LR_k = \frac{L_k}{V_k^{in} \cdot (V - V_k^{in}) + C_{V_k^{in}}^2} \qquad (11)$$

$$I_{within} = \begin{bmatrix} TR_1^{within} & LTA_1^{within} & LR_1^{within} \\ TR_2^{within} & LTA_2^{within} & LR_2^{within} \\ TR_3^{within} & LTA_3^{within} & LR_3^{within} \end{bmatrix} \qquad (12)$$

In Eq. (12):

I_{within} —the index matrix of airlines within the district of regional aviation network;

TR_k^{within} —the passenger volume share rate of airlines in layer k within the district, $k = 1, 2, 3$.

$$TR_k^{within} = \frac{T_k^{within}}{T_k} \times 100\% \qquad (13)$$

where, LTA_k^{within} —the average passenger volume of each airline in layer k within the district, $k = 1, 2, 3$.

$$LTA_k^{within} = \frac{T_k^{within}}{L_k^{within}} \qquad (14)$$

where, LR_k^{within} —the airline rate in layer k within the district, $k = 1, 2, 3$. It was calculated from the number

of actual airline in layer k within the district divided by the number of all possible airline in layer k within the district.

$$LR_k^{within} = \frac{L_k^{within}}{V_k^{in} \cdot (V^{in} - V_k^{in}) + C_{V_k^{in}}^2} \qquad (15)$$

$$I_{across} = \begin{bmatrix} TR_1^{across} & LTA_1^{across} & LR_1^{across} \\ TR_2^{across} & LTA_2^{across} & LR_2^{ar\cos s} \\ TR_3^{across} & LTA_3^{across} & LR_3^{across} \end{bmatrix} \qquad (16)$$

In Eq. (16):

I_{across} —the index matrix of airlines across the district of aviation network;

TR_k^{across} —the passenger volume share rate of airlines in layer k across the district, $k = 1, 2, 3$.

$$TR_k^{across} = \frac{T_k^{across}}{T_k} \times 100\% \qquad (17)$$

where, LTA_k^{across} —the average passenger volume of each airline in layer k across the district, $k = 1, 2, 3$.

$$LTA_k^{across} = \frac{T_k^{across}}{L_k^{across}} \qquad (18)$$

where, LR_k^{across} —the airline rate in layer k across the district, $k = 1, 2, 3$. It was calculated from the number of actual airline in layer k across the district divided by the number of all possible airline in layer k across the district.

$$LR_k^{across} = \frac{L_k^{across}}{V_k^{in} \cdot V^{out}} \qquad (19)$$

3. Hierarchical Data and Index Matrix of Aviation Network in Mid-south, Northwest and Southwest of China

Data matrix of aviation network in mid-south, northwest and southwest of China was get from the statistics [2]. Index matrixes of these regional aviation networks were calculated from the data matrixes.

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3.1 Data Matrix and Index Matrix of Aviation Network in Mid-south of China

$$D^{M-S} = \begin{bmatrix} V_1^{in} & L_1 & T_1 \\ V_2^{in} & L_2 & T_2 \\ V_3^{in} & L_3 & T_3 \end{bmatrix} = \begin{bmatrix} 8 & 525 & 19718.6 \\ 9 & 195 & 2783.9 \\ 16 & 97 & 586.1 \end{bmatrix} \quad (20)$$

$$D_{within}^{M-S} = \begin{bmatrix} L_1^{within} & T_1^{within} \\ L_2^{within} & T_2^{within} \\ L_3^{within} & T_3^{within} \end{bmatrix} = \begin{bmatrix} 100 & 3092.2 \\ 58 & 937.2 \\ 37 & 245.6 \end{bmatrix} \quad (21)$$

$$D_{across}^{M-S} = \begin{bmatrix} L_1^{across} & T_1^{across} \\ L_2^{across} & T_2^{across} \\ L_3^{across} & T_3^{across} \end{bmatrix} = \begin{bmatrix} 425 & 16626.4 \\ 137 & 1846.6 \\ 97 & 340.5 \end{bmatrix} \quad (22)$$

$$I^{M-S} = \begin{bmatrix} VLA_1^{in} & LTA_1 & LR_1 \\ VLA_2^{in} & LTA_2 & LR_2 \\ VLA_3^{in} & LTA_3 & LR_3 \end{bmatrix} = \begin{bmatrix} 65.5 & 37.6 & 0.33 \\ 21.7 & 14.3 & 0.11 \\ 6.1 & 6.0 & 0.046 \end{bmatrix} \quad (23)$$

$$I_{within}^{M-S} = \begin{bmatrix} TR_1^{within} & LTA_1^{within} & LR_1^{within} \\ TR_2^{within} & LTA_2^{within} & LR_2^{within} \\ TR_3^{within} & LTA_3^{within} & LR_3^{within} \end{bmatrix} =$$

$$\begin{bmatrix} 15.7\% & 30.9 & 0.44 \\ 33.7\% & 16.2 & 0.23 \\ 41.9\% & 6.6 & 0.094 \end{bmatrix} \quad (24)$$

$$I_{across}^{M-S} = \begin{bmatrix} TR_1^{across} & LTA_1^{across} & LR_1^{across} \\ TR_2^{across} & LTA_2^{across} & LR_2^{ar\cos s} \\ TR_3^{across} & LTA_3^{across} & LR_3^{across} \end{bmatrix} =$$

$$\begin{bmatrix} 84.3\% & 39.1 & 0.31 \\ 66.3\% & 13.5 & 0.09 \\ 58.1\% & 3.5 & 0.036 \end{bmatrix} \quad (25)$$

3.2 Data Matrix and Index Matrix of Aviation Network in Northwest of China

$$D^{N-W} = \begin{bmatrix} V_1^{in} & L_1 & T_1 \\ V_2^{in} & L_2 & T_2 \\ V_3^{in} & L_3 & T_3 \end{bmatrix} = \begin{bmatrix} 3 & 189 & 7351.7 \\ 7 & 111 & 2142.6 \\ 25 & 83 & 509.8 \end{bmatrix} \quad (26)$$

$$D_{within}^{N-W} = \begin{bmatrix} L_1^{within} & T_1^{within} \\ L_2^{within} & T_2^{within} \\ L_3^{within} & T_3^{within} \end{bmatrix} = \begin{bmatrix} 48 & 2004.5 \\ 33 & 1186.3 \\ 49 & 413 \end{bmatrix} \quad (27)$$

$$D_{across}^{N-W} = \begin{bmatrix} L_1^{across} & T_1^{across} \\ L_2^{across} & T_2^{across} \\ L_3^{across} & T_3^{across} \end{bmatrix} = \begin{bmatrix} 141 & 5347.2 \\ 78 & 956.3 \\ 34 & 96.8 \end{bmatrix} \quad (28)$$

$$I^{N-W} = \begin{bmatrix} VLA_1^{in} & LTA_1 & LR_1 \\ VLA_2^{in} & LTA_2 & LR_2 \\ VLA_3^{in} & LTA_3 & LR_3 \end{bmatrix} = \begin{bmatrix} 63 & 38.9 & 0.31 \\ 15.9 & 19.3 & 0.08 \\ 3.3 & 6.1 & 0.017 \end{bmatrix} \quad (29)$$

$$I_{within}^{N-W} = \begin{bmatrix} TR_1^{within} & LTA_1^{within} & LR_1^{within} \\ TR_2^{within} & LTA_2^{within} & LR_2^{within} \\ TR_3^{within} & LTA_3^{within} & LR_3^{within} \end{bmatrix} =$$

$$\begin{bmatrix} 27.3\% & 41.8 & 0.48 \\ 55.4\% & 35.9 & 0.15 \\ 81\% & 8.4 & 0.089 \end{bmatrix} \quad (30)$$

$$I_{across}^{N-W} = \begin{bmatrix} TR_1^{across} & LTA_1^{across} & LR_1^{across} \\ TR_2^{across} & LTA_2^{across} & LR_2^{ar\cos s} \\ TR_3^{across} & LTA_3^{across} & LR_3^{across} \end{bmatrix} =$$

$$\begin{bmatrix} 72.7\% & 37.9 & 0.28 \\ 44.6\% & 12.3 & 0.066 \\ 19\% & 2.8 & 0.008 \end{bmatrix} \quad (31)$$

3.3 Data Matrix and Index Matrix of Aviation Network in Southwest of China

$$D^{S-W} = \begin{bmatrix} V_1^{in} & L_1 & T_1 \\ V_2^{in} & L_2 & T_2 \\ V_3^{in} & L_3 & T_3 \end{bmatrix} = \begin{bmatrix} 4 & 337 & 13385.4 \\ 9 & 146 & 2316.1 \\ 31 & 184 & 1082.9 \end{bmatrix} \quad (32)$$

$$D_{within}^{S-W} = \begin{bmatrix} L_1^{within} & T_1^{within} \\ L_2^{within} & T_2^{within} \\ L_3^{within} & T_3^{within} \end{bmatrix} = \begin{bmatrix} 92 & 2641.2 \\ 49 & 1513.8 \\ 80 & 695.1 \end{bmatrix} \quad (33)$$

$$D_{across}^{S-W} = \begin{bmatrix} L_1^{across} & T_1^{across} \\ L_2^{across} & T_2^{across} \\ L_3^{across} & T_3^{across} \end{bmatrix} = \begin{bmatrix} 245 & 10744.2 \\ 97 & 802.3 \\ 104 & 387.8 \end{bmatrix} \quad (34)$$

$$I^{S-W} = \begin{bmatrix} VLA_1^{in} & LTA_1 & LR_1 \\ VLA_2^{in} & LTA_2 & LR_2 \\ VLA_3^{in} & LTA_3 & LR_3 \end{bmatrix} = \begin{bmatrix} 84.3 & 39.7 & 0.42 \\ 16.2 & 15.9 & 0.082 \\ 5.9 & 5.9 & 0.032 \end{bmatrix}$$

(35)

$$I_{within}^{S-W} = \begin{bmatrix} TR_1^{within} & LTA_1^{within} & LR_1^{within} \\ TR_2^{within} & LTA_2^{within} & LR_2^{within} \\ TR_3^{within} & LTA_3^{within} & LR_3^{within} \end{bmatrix} =$$

$$\begin{bmatrix} 19.7\% & 28.7 & 0.55 \\ 65.4\% & 30.9 & 0.14 \\ 64.2\% & 8.7 & 0.092 \end{bmatrix}$$

(36)

$$I_{across}^{S-W} = \begin{bmatrix} TR_1^{across} & LTA_1^{across} & LR_1^{across} \\ TR_2^{across} & LTA_2^{across} & LR_2^{arcos s} \\ TR_3^{across} & LTA_3^{across} & LR_3^{across} \end{bmatrix} =$$

$$\begin{bmatrix} 80.3\% & 43.9 & 0.39 \\ 34.6\% & 8.3 & 0.068 \\ 35.8\% & 3.7 & 0.021 \end{bmatrix}$$

(37)

4. Comparing of Aviation Network Structure in Mid-south, Northwest and Southwest of China

The total connection way among components of system was called system structure in system science [4, 5]. Ratios among components of aviation network were calculated to show the structure of regional aviation network of China.

The structure indexes in Table 1 were calculated by index matrixes of three regional aviation network. In Table 1, the ratio of airline passenger volume within district with across district indicated the share rate of passenger volume in each layer. The main passenger volume of aviation network in each layer was across district in mid-south of China. The main passenger volume of aviation network in the first and second layer was across district in northwest of China but in the third layer was on the contrary. The main passenger volume of aviation network in the first layer was across district in southwest of China but in the second and third layer the main passenger volume was within district.

The index indicated that the passenger volume across district was much more than the passenger volume within district in these three regions. The former was about 2.7-5 times than the latter. The index $T_1 : T_2 : T_3$ recorded the ratio of passenger volume among layers. It showed share rate of passenger volume in each layer of regional aviation network. The share rate of passenger volume among layers was approximate in the three regions: the share of the first was about 74%-86%, the share of the second layer was about 12%-22%, the share of the third layer was about 2.5%-6.5%. These data illustrated that the first layer undertook the main volume. The index $VLA_1^{in} : VLA_2^{in} : VLA_3^{in}$ indicated the relationship between airport and airline. This index

Table 1   Structure index of regional aviation network in mid-south, northwest and southwest of China.

Regional aviation network	The ratio of airline passenger volume within district with across district			The ratio of passenger volume in each layer
	$TR_1^{within} : TR_1^{across}$	$TR_2^{within} : TR_2^{across}$	$TR_3^{within} : TR_3^{across}$	$T_1 : T_2 : T_3$
Mid-south	1:5	1:2	1:1.4	85.4%:12.1%:2.5%
Northwest	1:2.7	1:2	4.3:1	73.5%:21.4%:5.1%
Southwest	1:4.1	1.9:1	1.8:1	79.7%:13.8%:6.5%
Regional aviation network	The ratio of average airline number of airport in each layer	The ratio of average passenger volume of airline in each layer	The ratio of airline rate in each layer	
	$VLA_1^{in} : VLA_2^{in} : VLA_3^{in}$	$LTA_1 : LTA_2 : LTA_3$	$LR_1 : LR_2 : LR_3$	
Mid-south	3.0:1:0.28	2.6:1:0.42	3.0:1:0.4	
Northwest	4.0:1:0.21	2.0:1:0.32	3.9:1:0.2	
Southwest	5.2:1:0.36	2.5:1:0.37	5.1:1:0.4	

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showed that the average number of airlines of each airport in southwest aviation network of China was more than other two regions in the field of ratio structure of the first layer. The index $LTA_1 : LTA_2 : LTA_3$ indicated the relationship of airline with passenger volume in each layer. This index was in the range of (2.0-2.6):1:(0.32-0.42). It showed the similar structure in the aspect of the relationship between airline and passenger volume in the three regions. The index $LR_1 : LR_2 : LR_3$ showed the quantitative relationship in the field of airlines aturability in each layer. This index indicated that the airlines aturability in the first layer of southwest aviation network of China was much more than the other two.

Generally, there were similar structure in aspect of passenger volume share rate and airline average passenger volume in each layer of regional aviation network in mid-south, northwest and southwest of China. There were differences in aspect of passenger volume share rate between within district and across district in each layer of the three regions. There were local distinctions in aspect of average airline number of airport and airline rate in each layer of these regions.

5. Conclusion

There were huge differences in aspect of geography location, weather feature, population distribution and economy development of the regions in mid-south, northwest and southwest of China. Despite the regional aviation network in different region and in different scale, they had some similar features in structure. The hierarchical index model of regional aviation network was established to study the structure characters of regional aviation network by dividing the aviation network into layers, defining data matrixes to record the basic states of aviation network and setting index matrixes to describe the structure features of regional aviation network. On the basis of the former work, the ratio of passenger volume between within district and across district in each layer, passenger volume share rate in each layer, the ratio of average number of airport in each layer, the ratio of average passenger volume in each layer and the airline rate in each layer were calculated to illustrate the structure features of aviation network. According to the calculation, there was similar structure in aspect of passenger volume share rate and airline average passenger volume in each layer of regional aviation network in mid-south, northwest and southwest of China. There were differences in aspect of passenger volume share rate between within district and across district in each layer of the three regions. There were local distinctions in aspect of average airline number of airport and airline rate in each layer of these regions.

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