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Characteristics Study for Airline Network Structure and Airline Network Economy

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Abstract: The airline network analysis means to make analysis of all possibly connected airlines one by one and even the whole network, including two parts: airline structure analysis and airline network economy analysis. In detail, the airline network structure analysis is made to further improve the airline network by learning about the network structural characteristics; and the airline network economy characteristics analysis is for various costs and revenues of different aircraft types generated by the specific transport tasks. Therefore, the airline network analysis has certain effects on the survival and development of Airlines, the achievement of Airline business target, the overall competitiveness of World Airline Alliance, and the operation cost in the long run.

Key words: airline; airline structure; airline network; analysis
JEL codes: R410

1. Introduction

The airline is the transport market of passengers and freight. The airline network topology is the precondition of production plans such as flight schedules etc., which only depend on the existing airline network. With unreasonable network topology, the airline company cannot ensure best benefits despite the proper flight scheduling. Hence, the airline network topology has great effects on operation of airline company, and the scientific and reasonable airline network design has significant meanings for effective production, full mobilization of civil air transport potential, and promotion of production efficiency and quality.

For airline network analysis, lots of typical researches have been made by the scholars. Bai et al. (2006) studied the relationship between fares of direct flight and the flight frequency, the relationship between operating costs and seating capacity of one-way flight. Also Bai et al. (2006) focused on that the clustering method not concise enough for airline selection, and the constraints for integer number was evaded in the flight frequency calculation. Wu et al. (2013) made analysis of the absolute robust optimization design of internal-type multi-allocated central radiation airline network without capacity limitation. Wang et al. (2014) introduced the overflow factor of passengers to study the planning design of airline network. Liu et al. (2007) studied the basic statistics features and network correlation property of Chinese urban aviation network. Jiang et al. (2006; 2007; 2007) investigated the robust optimization method for selection of hub airports by the airline company.

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2. Characteristics Analysis for Airline and Airline Network Economy

From perspective of the airline, the airline analysis was made to determine the final flight plan such as direct flight, one-stop, two-stops or multi-stops. E.g., one OD (origin-destination) can make different choices for A→B air route, including direct flight A→B, one stop A→C→B, two stops A→C→E→B/A→D→E→B/A→D→C→B, or stops for three times A→D→C→ E→B as shown in Figure 1.

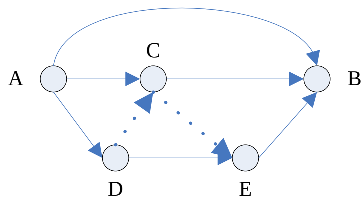

Figure 1 OD Air Route Between A→B.

From the perspective of fleets, without the fleet management, the analysis for specific airline cannot be made. The airline transport is finished by specific aircraft type, and without considering the aircraft type, the analysis shall become utterly groundless. Suppose there str three aircraft types A1, A2 and A3 used for the six kinds of airline transport tasks shown in Figure 1, 18 different transport schedules shall be generated. with different aircraft types flying in different transport routes, the passenger market demands shall vary. When passengers choose direct flight or transfer flight, besides the flight type and airlines, the flight frequency and timeline should be also considered. In the condition of same flight frequency and time, compared with other flight mode, there will be more demands for the direct flight; and the transfer flight shall also be popular with some passengers for its high flight frequency and good flight time. Therefore, the economy characteristics presented in airline network operation, depends on four factors, including plane type, flight routes, flight timetable and flight frequency.

For the transport tasks in Figure 1, one contrastive analysis study between the simulation on different schedules and actual results was made to determine the best schedule, i.e., suppose that the one-stop transfer flight by A1 is changed to A2, then with the other constraints conditions unchanged, what is the influence on costs and revenues? or the one-stop transfer fight for A1 A→C→B is changed to direct route A→B, then what is the influence on costs and revenues? Or with the other constraints unchanged, only change the flight timetable or flight frequency, what is the influence on costs and revenues?

The analysis above shows that the characteristics analysis of airline network economy is made mainly to the airline, the cost and revenue of airline network. And the costs/revenues are expressed specifically as the following 4 indicators shown in Table 1.

Table 1 Analysis Index System of Airline Network Economy Characteristics

Main Observation points of airline network economy characteristics	Analytic index of airline network economy characteristics
Costs revenues	Cost seat kilometres (CSK)
	Revenue seat kilometre (RSK), revenue passenger kilometre (RPK)
	Passenger load factor (PLF), plane use rate (PUR)
	Passenger overflow, seat loss

Therein, CSK means the cost per seat generated for the transport task by specific aircraft type; CSK means the revenue per seat for transport task by specific aircraft type; RSK the revenue per passenger for transport task by specific aircraft type; PLF the percentage of passenger seats in the total seats; PUR is the number of hours of one aircraft for flight tasks in certain periods, and the more the flight hours, the more frequently the airplane is utilized; Passenger Overflow means the difference between seat capacity and actual seat demands by the passengers, and for the airline company, it fails to earn more revenues for limited seat capacity, which can also be taken as opportunity cost of the airline company; the Seat Loss means the difference between the seat capacity and actual passenger demands, and for this relatively large aircraft, the insufficient passengers shall cause the increase of cost per passenger/km in transport, further influencing the total revenue in this airline operation for the airline company. Then, it is found that the passenger overflow, seat loss and PLF is closely related: the higher the PLF, the more the passenger overflow; the lower the PLF, the more the seat loss. Hence, it is necessary to make balance between passenger overflow and seat loss when selecting the aircraft type by the airline company.

3. Characteristics Analysis of Airline Economy

If one air route includes two flight segments AC and CB and this route serves three OD pairs: A→B, A→C and C→B. Then suppose the passenger market demands of the three known OD as 120, 75 and 50 respectively shown in Figure 2.

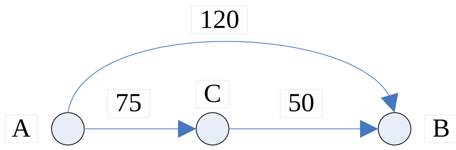

Figure 2 Passenger Market Demands for OD Pair in A→B.

To finish the OD passenger transport in A→B, A1 and A2 aircraft type with 150 seats and 200 seats respectively can be chosen. If using A1, for the airline company, the demands for direct flight A→B should be met as much as possible, i.e., allocating 120 seats of A1 type to the passengers in direct route A→B; 30 seats to the passengers in flight segments A→C, and here for A→C, the passenger overflow $Spill_{A\text{-}C}$ = 75-30 = 45; in C segment, the 30 passengers in A→C reach destination, and then re-allocate the spared 30 seats to the passengers in air route C→B with the passenger overflow $Spill_{B\text{-}C}$ = 50-30 = 20. Therefore, by A1 type, it had no seat loss, but leading to much passenger overflow, which meant for the airline company that the chance to make money was lost due to choosing the small aircraft type, and this could be taken as opportunity cost even though included in the financial cost calculation of the airline company.

If selecting 200-seat A2 type, for the airline company, firstly allocate the 120 seats to the passenger in direct route A→B, and then allocate 80 seats to the passenger in flight segment A→C, leading to seat loss in A→C with $Poilage_{A\text{-}C}$ = 80-75 = 5; in C segment, the 75 in flight segment reach destination, and then the spared 75 seats were re-allocated to the passenger in flight segment C→B with seat loss $Poilage_{B\text{-}C}$ = 80-50 = 30. Therefore, by A2 type, there was no passenger flow but with serous seat loss, which influenced the operation of the whole airlines for the airline company.

Then, for the airline company, in the condition of multi-aircraft types, it can make a compromised plan by calculating the passenger flow and seat loss of every type of aircraft in specific airline transport, e.g., take both the passenger overflow and seat loss as costs, and make calculation to determine the best plan with the minimum value, i.e., make selection of the final air route on the basis of cost minimization.

4. Characteristics Analysis of Airline Network Economy

Suppose that there existed the transport among four cities (A, B, C and F), and the volume of passengers for each OD pair was 200 in the point-to-point transport mode as shown in Figure 3; if using the hub transport mode cantered around F, the volume of passengers for each OD pair shall be 600 as shown in Figure 4.

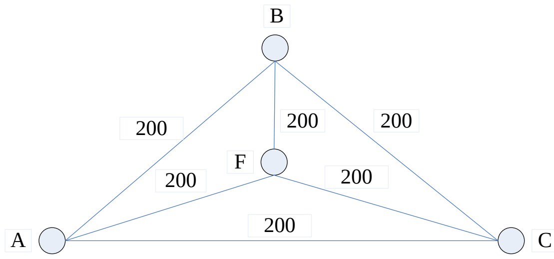

Figure 3 Distribution of Passenger Volume in Point-to-Point Airline Network Structure.

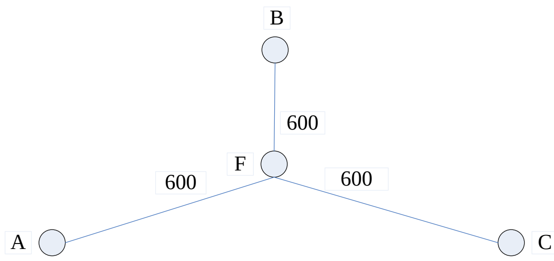

Figure 4 Distribution of Passenger Volume in Hub Airline Network Structure.

Here, if using the what-if analytical method to judge the two network structures above, what changes shall happen to economy characteristics of airline network if adding one new air route EF as shown in Figures 5 and 6.

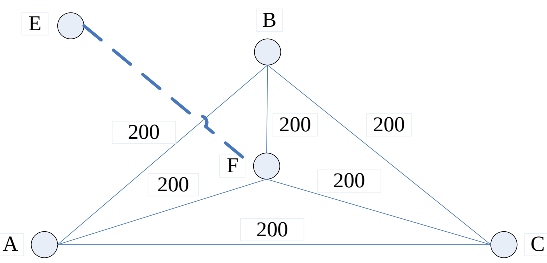

Figure 5 Point-to-Point Network Structure and Passenger Distribution After Adding One New Air Route EF.

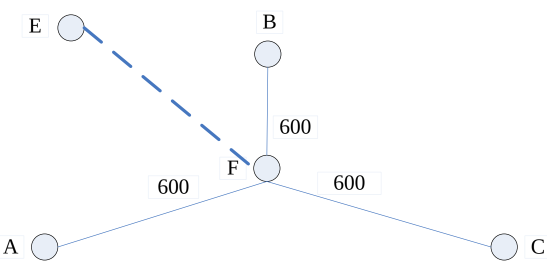

Figure 6 Hub Airline Network Structure and Passenger Distribution After Adding One New Air Route EF

In Figure 5, launch one new air route EF, and the increment of passengers in this point-to-point airline network ($f_{E\text{-}F}$) equals the transport volume in E-F ($D_{E\text{-}F}$): $f_{E\text{-}F}= D_{E\text{-}F}$, which shows that the costs and revenues in terms of network economy characteristics change only with the air route E-F. In Figure 6, launch one new air route between E and F in the hub airline network, and the passengers in this segment E-F, including not only those between node E and node F, and also between node E and A/B/C, i.e., with the new air route E-F, the served OD pairs becomes four sides rather than one side, producing better network effects, and by this time the increments of passengers in the network can be shown in formula (1):

$$f^{\circ}_{E-F} = D_{E-F} + D_{E-A} + D_{E-B} + D_{E-C} \tag{1}$$

The analysis above shows that with the same condition changing, different airline network structure and economy characteristics present differently to some extent, $f_{E\text{-}F} \leq f^{o}_{E\text{-}F}$. Therefore, for hub-and-spoke airline network, owing to its network scale effect, the large type and high frequency flight can be selected: the larger the aircraft type is, the less the CSK and the better the economic characteristics, which is also the reason for the hub network operation formed quickly after American aviation market opening; also the higher the flight frequency is, the more the volume of passengers and the less the passenger overflow, then the economic characteristics shall present in better performance.

Then, whether was the hub-and-spoke airline network better than point-to-point network? If in the hub-and-spoke airline network shown in figure 6, the passengers in A shall make direct flight to F, or some passengers transferred from F to B/C/E, but now the flight is delayed in A due to the bad weather or some other reasons, and the passengers in direct or transfer route cannot all reach hub F on schedule, further influencing the punctuality of the A→B route and then causing a chain of flight delays: passengers in E→B and C→B cannot transfer to B through hub F etc. Hence, there exists some defect for hub airline network structure, carrying rather large operational risks for the airline company without the related support and scheduling capacity.

And also in Figure 6, the passengers in flight segment E-B has higher time cost, because the transfer waiting time in flight segment E→F and E→F is far above the direct flight time E→F; with the increased landing fee and air route fee caused by multi-landing, and the longer transfer waiting time in F, the plane use rate (PUR) in hub airline network structure is normally lower than that in direct flight condition, which is also the reason for the low-cost airline company to use direct-flight; in direct flight, it has shorter transfer time, while for hub operation, the transfer time cannot be shortened for involving multi-flight connection and step-by-step waiting, then causing lower PUR and higher operation cost for the airline company.

5. Characteristics Analysis of Airline Network Structure

Generally, the observation points for airline network structure characteristics mainly include reliability, stability and robustness, which are expressed in the following index for the airline network analysis in Table 2.

Table 2 Analysis Index System of Airline Network Structure Characteristics

Main observation points of airline network structure characteristics	Analysis index of airline network structure characteristics
Reliability Stability Robustness	Degree of nodes
	…….
	……
	Network diameter

The network diameter was the average value of path length between any two points in the network. In the point-to-point network, for the airline connector for any two nodes, the diameters in such structure was 1; for hub airline network, except that the nodes between non-hub node and hub nodes and between hub nodes were directly connected, more non-hub nodes need to be connected with each other by means of hub nodes, to have larger diameter in such structure than in point-to-point airline network structure.

The degree of nodes in the network had different size and the distribution of node degree in different network structures also varied. E.g., in the point-to-point airline network, every node degree was the same: n-1 (n stands for total of nodes), and its distribution was pulse as shown in Figure 7 (x-axis represent degree size, and y-axis represent the percentage of nodes number in the total number of nodes).

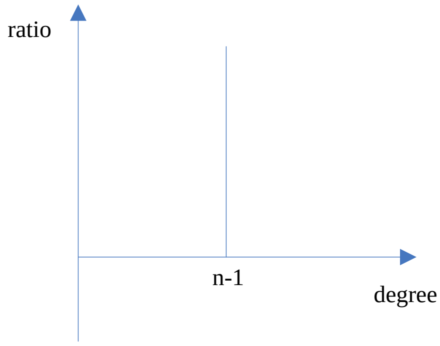

Figure 7 Distribution of Node Degree in Point-to-Point Airline Network

For the other common network, refer to the degree distribution in Figure 8. In the situation with ② degree distribution, the small-degree nodes occupied a larger proportion of the total nodes, and the large-degree nodes a smaller proportion. In such situation, once there occurred some abnormal issues for the large-degree modes such as delay etc., the reliability and stability of the whole network shall be greatly affected, similar to the operation state of hub airline network. Hence, the distribution of node degree in hub airline network was often expressed in the ② form; in the ① situation of degree distribution, it often shows in the form of stochastic network.

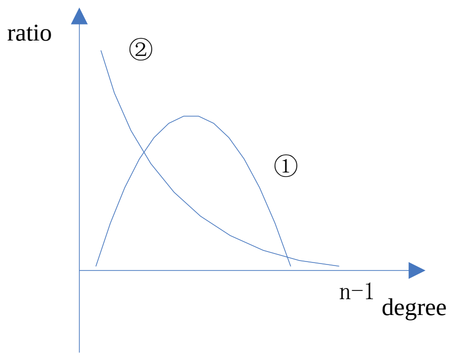

Figure 8 Distribution of Nodes Degree in Normal Network Structure

Refer to Table 3 for the characteristics contract of stochastic network and scale-free network.

Table 3 Characteristics Contrast of Stochastic Network and Scale-Free Network

Reference parameters	Stochastic network	Scale-free network
Distribution of nodes degree	Poisson distribution	power-law distribution
Characteristics scale	Mean value	Non-feature scale
Average inter-node distance	Small	Large
Network clustering coefficient	Small	Large
……	……	……

The reliability meant the probability of normal operation, e.g., within 10 days of observed period for airline network operation, it remained in normal operation for 8 days, showing 80% reliability for the airline network at that time.

Stability was generally the dynamic concept related to time. For one system, the stability meant whether the system worked stably, contrary to instability, i.e., for one system, under no exogenous action, it remains the operation status as shown in Figure 9; under exogenous action, it might remain the intrinsic equilibrium or deviate from the equilibrium, but after cancelling the exogenous action, if it can resume its original equilibrium, this system shall be guaranteed stability as shown in Figure 10, otherwise, it is called in-stability. Generally speaking, the air transport network is stability-based.

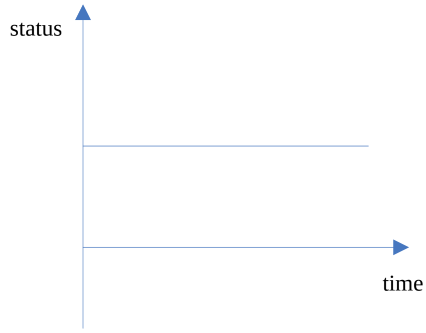

Figure 9 Operation State Under No Exogenous Action

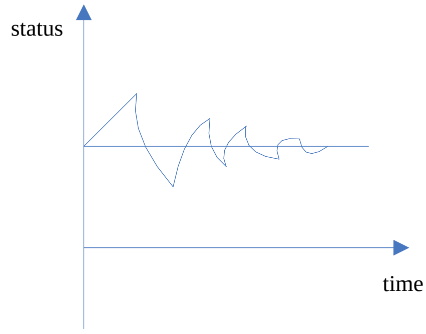

Figure 10 Operation State Under Exogenous Action

6. Conclusion

Robustness is the self-heading ability or anti-interference capacity for the system, that is, capacity of resisting the external action. The robustness of air transport system means that when there happen some issues such as external interference or delays etc. for the air transport system, whether the system can resume its normal operation state after removing the external inferences

For the reliability, stability and robustness of airline network, it is easier to make qualitative study for these concepts, but rather complex to make quantitative study and provide specific calculation mode, especially, the reliability of airline network as a hot research topic nowadays, which generally comprises two parts: reliability of nodes and reliability of airline, and then to be re-divided into capacity reliability and time reliability, therein, capacity reliability means whether there is capacity limitation in network operation, and time reliability is often related to flight on-time performance.

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