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Research the economic characteristics of airline network based on R

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ABSTRACT

According to the large-scale airline network, which presents the scale-free characteristics, the aim of the article is to research the relationship between airline network profit changes and passenger flow changes based on the constraint of the relevant variables. Based on the given mathematical model of airline network revenue, total cost and total profit, we simulate the airline network profit model and analyze the experimental results, which show that: under the action of the driving force of passenger flow, the degree distribution exponent r plays an important role in the analysis of the airline network economic characteristics, while other variables remain unchanged, the airline network profit reaches the maximum when r is equal to 1.8.

KEYWORDS

Airline network; Degree distribution exponent; Airline profit; Airline flow; Scale-free network.

INTRODUCTION

Airline network refers to the connection of airline in a certain way in a region, which is a long-term strategic decision problem of airlines, related to the long-term operation cost, the sustainable development and competitive ability[1]. The airline network is composed of the essential factor which includes airport, airline and aircraft etc., wherein the airport and airline decide the distribution of air transport space and the ground and air support capacity of air transportation, aircraft completes the spatial displacement of passengers and freight through the airline from one airport to another; at the same time, the number of airports and aircrafts is the time evolution, airline will also present dynamics because of the capacity constraints, the budget and the market demand (OD). Airline network belongs to the typical complex system, which has the scale-free connection characteristics[2].

As for the numerical of the power-law index of the degree distribution function, Watts,Barabási and Albert et al[3-11]. found that the power-law index of scale-free network is between 1 and 3 by researching the practical network. According to the connection mechanism between nodes in scale-free network, Barabási and Albert[3,12] proposed the node in the BA model would prefer to connect the target node with the probability of $\Pi_i = k_i / \sum_j k_j$, besides, they introduced the bordering and reconnection mechanism among the nodes; Barrat et al.[13] proposed the node would prefer to connect the target node with the probability of $\Pi_i = (k_i - \alpha) / \sum_j (k_j - \alpha)$ ($\alpha \in [0,1)$); Laird and Jensen[14] proposed to select a node in a network, deleting all its network edges, was connected randomly to the other nodes; Bollobás et al.[15] proposed the linear chordal graph model allowing the node connect itself and the repeated line; Dorogovtsev et al.[16] proposed the original attraction model, which allowed the repeated line not connect itself.

This paper allows the node among network not connect itself and repeated, a node connects to the others randomly according to the node degree value, as a result, there is no isolated node and no redundant degree value of each node. By constructing the relationship between fares and airline distance, airline passenger flow and airline distance, airplane type and node type, we research airline network profit changes with the change of airline passenger flow under the influence of the degree distribution exponent r, which will reflect the economic characteristics of airline network and it is important for the airline to improve the efficiency of transportation, to reduce the transportation cost and to optimize the network design.

ESTABLISHMENT OF AIRLINE NETWORK AND ITS PROFIT MODEL

Various modes of transport and customer demand for personalized, the transportation market competition is becoming increasingly fierce, if the airlines want to be sustainable development, they must ensure that the airline network profitable operation and realize the strategic goal of total revenue is greater than the total cost of airline network. Airline network revenue refers to the sum of income got from the transportation of passenger flow on the network edge. The total cost of airline network, can be divided into the total variable cost and total fixed cost. The total variable cost, which is produced with the number of passengers and the distance of the transport; The total fixed cost of airline network refers to the sum of the cost of flights, which is associated with the passenger flow of network edge, the number of airplane seat, the per kilometer cost of airplane and the distance of network edge. Airline network profit, refers to the difference between the airline network revenue and the total cost of airline network during the fixed structure of network. The steps about studying on the airline network and its profit in this paper are as follows:

Step 1, randomly generated N (city) node $node(s_i, x_{s_i}, y_{s_i}, K_{s_i}, t_{s_i})$ and n×n matrix of OD flow $OD\_flow(s_i, s_j)$. Wherein, s_i expresses as the i node($\mathrm{i} = 1, 2, 3 \ldots \mathrm{n}$), The x_{s_i} and y_{s_i} identify the ordinate and abscissa of the i node, K_{s_i} expresses as the value of the i node degree, t_{s_i} expresses as the kind of the i node($t_{s_i}=0,1$ .if s_i is the hub node, $t_{s_i}=1$), the range of OD flow between s_i and s_j is from 0 to infinity.

Step 2, for any node s_i in the network, it can connect the other node within less than 2 transit times, while the network edge $link(s_i,s_j,t_s,d(s_i,s_j))$ was set up(Wherein, $d(s_i,s_j)$ expresses as the distance of network edge s_is_j), the value of K_{s_i} and K_{s_j} were reduced by 1 automatically, if K_{s_i} or K_{s_j} is greater than 1, the node s_i and s_j can connect with the other node s_m; the node s_n whose degree value is equal to 0 would be connected with any node s_l of degree value greater than 1. As a result, each node is assigned the new degree value of K'_{s_i}, the path between node s_i and node s_j can be the direct path $transfer0(s_i,s_j,d(s_i,s_j))$, can also be a once transfer path $transfer1(s_i,s_m,s_j,d(s_i,s_j))$ and the secondary transfer path $transfer2(s_i,s_m,s_n,s_j,d(s_i,s_j))$; there are three different types of airline between node s_i and node s_j: both direct airline and transit airline (numbered as 1), no direct airline but transit airline (numbered as 2), direct airline but no transit airline (numbered as 3).

Step 3, according to the paths and $OD\_flow(s_i,s_j)$ between the node s_i and the node s_j, we can follow the rule 1 to determine each edge $linkflow(s_i,s_j)$ in the network.

Rule 1: For the randomly selected two nodes s_i and s_j, If there are direct path and transfer path between them, $OD\_flow(s_i,s_j)$ would be composed by the direct path flow $d\_flow(s_i,s_j)$ and the transfer path flow $t\_flow(s_i,s_j)$; If there is only the direct path, $d\_flow(s_i,s_j)=OD\_flow(s_i,s_j)$; If there is only transfer path, $t\_flow(s_i,s_j)=OD\_flow(s_i,s_j)$. In order to facilitate the analysis, if there exists the transfer path between the node s_i and s_j, we make the $direct\_ration$ as the proportion of the direct path flow $d\_flow(s_i,s_j)$ accounted for the node flow $OD\_flow(s_i,s_j)$, that is $d\_flow(s_i,s_j)=OD\_flow(s_i,s_j)*direct\_ration$.

Aside from the direct path between nodes only, each edge flow $linkflow(s_i,s_j)$ in the network not only related with the original random assignment flow, but also with the edge length, the total length of the transit path and the transit path flow. For example, there are direct path, once transfer path and secondary transfer path between the nodes s_i and s_j, as shown in Figure 1.

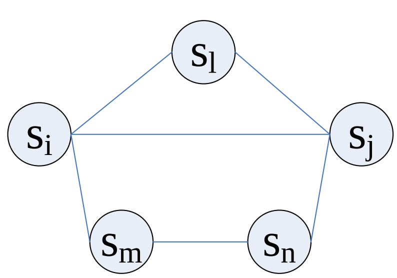

Figure 1 : The path between the nodes s_i and s_j

Now there are 5 edges in the transfer path, named as $s_i s_l$, $s_l s_j$, $s_i s_m$, $s_m s_n$ and $s_n s_j$, the corresponding edge flow can be obtained by the following guidelines. Exemplified by the edge $s_i s_l$, it is assumed that the original random distribution of flow is $linkflow(s_i, s_l)$ and the total flow between the node s_i and the node s_j is $OD\_flow(s_i, s_j)$, after the redistribution the edge flow $linkflow(s_i, s_l)$ can be described as: $linkflow(s_i, s_l) = linkflow(s_i, s_l) + t\_flow(s_i, s_j)[total1 \div total]$. wherein,

$$t\_flow(s_i, s_j) = OD\_flow(s_i, s_j) * (1 - direct\_ration)$$

$$total1 = [1/d(s_i, s_l) + 1/d(s_l, s_j)]$$

$$total = [1/d(s_i, s_l) + 1/d(s_l, s_j) + 1/d(s_i, s_m) + 1/d(s_m, s_n) + 1/d(s_n, s_j)]$$

Step 4, according to the following rule 2, rule 3, we can respectively determine the fares, the type of the selected aircraft, the number of seats and cost per km of air transportation, combined with the network edge flow determined in step 3, we will establish the airline network mathematical model of total revenue, total cost and profit.

Rule 2: when airlines operate the air transport, the fares particularly direct fares $OD\_p(s_1, s_2)$ is established according to the distance of the airline $d(s_i, s_j)$, if we take the correlation coefficient is set to $relation\_ration$, so $OD\_p(s_1, s_2) = d(s_i, s_j) * relation\_ration$ (wherein, $d(s_i, s_j) = \sqrt{(x_{s_1} - x_{s_2})^2 + (y_{s_1} - y_{s_2})^2}$); there exists certain deviation coefficient in the transit airline relative to the direct airline, the corresponding transit airline fares $transfer\_p(s_1, s_2)$ has certain discount of direct airline fares, if the discount factor is set to $transfer\_ration$, so $transfer\_p(s_i, s_j) = OD\_p(s_i, s_j) * transfer\_ration$.

Rule 3: in order to reflect the scale-free degree,distribution($p(K) = K^{-r}$,r$\in$[1,3]), we can divide the node into three types according to the degree of diminishing: hub node, the node whose degree value is not 1, the node whose degree value is 1. when airlines operate the air transport, they will choose the type of the airplane u_i ($i = 1, 2$)with larger number seats in the airline, which includes hub nodes. Based on the airlines composed by different type of nodes, the corresponding types of airplane and cost per km can be set shown in TABLE 1.

TABLE 1 : The airplane types and cost per km of airlines of different nodes

edge contains hub nodes	yes	no
the numbered of airplane	u_1	u_2
the seat number	$ap\_t(u_1)$	$ap\_t(u_2)$
the cost per km	$ap\_c(u_1)$	$ap\_c(u_2)$

Therefore, the total revenue ($t\_revenue(n)$), the total variable cost($c\_\cos t(n)$), the total fixed cost($s\_\cos t(n)$), the total cost($t\_\cos t(n)$) and profit($net\_profit(n)$) of airline network can be expressed as:

$$t\_revenue(n)=\sum_{i=1}^{n}\sum_{j=1}^{n}[d\_f(s_i,s_j)*OD\_p(s_i,s_j)+t\_f(s_i,s_j)*transfer\_p(s_i,s_j)]$$

$$c\_\cos t(n)=\sum_{i=1}^{n}\sum_{j=1}^{n}linkflow(s_i,s_j)*d(s_i,s_j)$$

$$s\_\cos t(n)=\sum_{l=1}^{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{linkflow(s_i,s_j)}{ap\_t(u_l)}*ap\_c(u_l)*d(s_i,s_j)$$

$$t\_\cos t(n)=c\_\cos t(n)+s\_\cos t(n)$$

$$net\_profit(n)=t\_revenue(n)-t\_\cos t(n)$$

Step 5, the real driving force of the airline network profit changing is the change of the passenger flow. The change rate of passenger flow is larger in the airline, which includes both the direct airline and the transit airline; for only the transit airline but no direct airline, the change rate of passenger flow is the smallest, the average change rate of passenger flow of different types of airline is shown in TABLE 2.

TABLE 2 : The average change rate of passenger flow of different types of airline

the numbered of airline			
the average change rate of passenger flow	dt_m	t_m	d_m

With the given change rate of airline passenger flow, according to the mathematical model established in step 4, we research the relationship between airline network profit and the airline passenger flow while the parameter scenarios are determined.

RESULT AND DISSCUSS

In order to meet the simulation research and to reveal the economic characteristics of airline network largely, we assume the value and the range of some parameters after the analysis of the information of related civil aviation enterprises and institutions. We make the degree value of hub node be from 0.2m_d to 0.53m_d ($m\_d=n-1$, the maximum degree value of the node) based on the thought of the dominance of hub node and the node capacity restriction in the airline network; the randomly generated OD flow are no more than 2500 people, that is $OD\_flow(s_i,s_j)\in[0,2500]$; In addition, we also give the value of certain variables directly, $direct\_ration=0.6$; $relation\_ration=1.5$; $transfer\_ration=0.6$; $dt\_m=0.05$; $t\_m=0.02$; $d\_m=0.04$; $ap\_t(u_1)=350$; $ap\_c(u_1)=0.001$; $ap\_t(u_2)=200$; $ap\_c(u_2)=0.0007$.

The study of the relationship between airline network profit and the degree distribution exponent

Scale-free network distribution satisfies the expression $p(K)=K^{-r}$ ($r\in[1,3]$), the probability of a node degree value is 0 or 1 will decrease with the decreasing of the degree distribution exponent r, the appearing probability of the high degree node will increase with the decrease of r. Does it mean that r is small, nodes especially the hub node can connect more edges with the other nodes, the average degree of nodes is greater, the airline network profit will increase? We select the number of network nodes n=150, the number of hub nodes k=6, the maximum number of airline passenger flow increase $\max runtime = 100$, to research the variation of airline network profit with the influence of the times of the passenger flow increases under the given degree distribution exponent r, as shown in Figure 2.

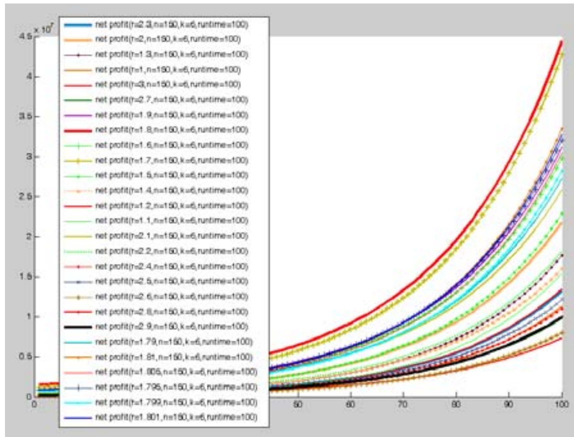

Figure 2 : The relationship between airline network profit and the increasing times of passenger flow based on the degree distribution exponent r

The Figure 2 shows that when the total number of network nodes, the number of hub nodes and the passenger flow growth rate of different types of airline remain unchanged, the scale-free network profit presents increasing trend with the increase of airline passenger flow under every kind of degree distribution exponent r, and the rate of growth is becoming bigger. When different types of airline passenger flow increases to 100 times (the assuming maximum times), the airline network profit reaches the maximum, as shown in Figure 3.

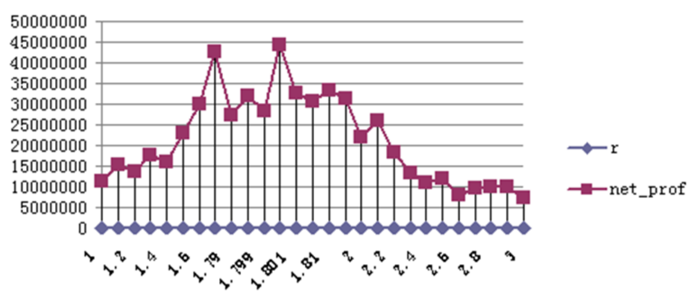

Figure 3 : The relationship between airline network profit and the degree distribution exponent r under the passenger flow increases to 100 times

According to the Figure 4 and Figure 5, we can see that the airline network profit is the biggest when the r is equal to 1.8.

CONCLUSIONS

For airlines, the fundamental purpose of operating flights is to win profit. But the above results mean that the bigger airline network profit is neither the better connectivity of each node, nor the smaller average degree of network, this conclusion has very important reference value to research the characteristics of complex networks, such as the economic characteristics of airline network and the structural characteristics of airline network.

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