Research on competition between High-speed rail and air transport in China

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Abstract—As Beijing-Tianjin and Wuhan-Guangzhou high-speed rail opened to traffic, China railway passenger transport line is coming into a high-speed era while the operation of high-speed rail will squeeze air transport market share. This paper has chosen four measure indexes of analysis, time cost, economic cost, comfort and safety, on the basis of the elaboration of the competition between high-speed rail and air transport as well as the analysis of recessive factors which influence travelers’ transportation choice. In addition, taking the transport distance as the primary variable, we established a competition model of high-speed rail and air transport by means of the Logit equation based on utility theory. Through the application example of the calculation of the constructed models and analysis by combining high-speed rail and air transportation competitive chart, a conclusion has been obtained that when the transport distance falls in the 600-1400 kilometers range, the substituted effect of high-speed rail reaches the peak and competition becomes most fierce. Finally, we analyzed the influence of the price fluctuation of high-speed rail upon the changes of the competition for the distance between the two.

Keywords-Impact factor; utility function; competition model; relative competitive

I. INTRODUCTION

High-speed rail and air transport are both the main mode of high-speed passenger transport. The main basis for the choice between the two modes of transport includes the length of driving distance, driving time and charges. Air transport in the long-distance transport has a distinct advantage, while high-speed railway has advantages in the short-distance passenger transport. The completion and operation of high-speed railway make the transportation system in all regions of our country more perfect, the modes of transport more diverse, the transportation companies can support more appropriate transport products to meet the needs of different levels travelers based on the length of transport distance. At the same time the completion of high-speed railway will divert part of the source from the civil aviation undoubtedly, lead to the decline of civil aviation industry, the relevant experts believe that the high-speed rail will impact the aviation industry for his price, safety, comfort and other advantages. When the transport distance is 800-1400 km, the high-speed railway has a strong alternative with the air transport. In the research of competition among various transport modes, it is a relatively mature approach that Logit equation analyze contribution rate of passenger flow (the market share ). In the study of competition between the high-speed rail and air transport, the Logit model which is based on generalized cost theory and disaggregates theory has been applied. At present, the quantitative analysis about the choice of behavior between high-speed rail and air transport is not adequate, and do not fully consider the factors that passengers will choose high-speed rail or air. In addition, there is no in-depth study that with the transport distance changes, the competition between high-speed rail and air transport will change accordingly. The paper makes use of the factors which impact the competition between high-speed rail and air transport to establish a competitive model through the utility function, then analyze the change of transport market share when the transport distance changes. And to further discuss the change that the high-speed rail plays a alternative role to the air transport with the high-speed rail fare changes.

A. Factors influence travelers to choose the transport modes

The choice of mode of transport for tourists is one that based on meeting their own transport needs in an ideal state, and it is also a continuous implementation process from understanding, evaluation to decision. Passengers usually consider the factors as follows, when they are making a choice of transport modes.

1) Time cost

From the perspective of choosing a transport mode for travelers, the traveling consumption includes not only the time of choosing a traffic mode, but also the needed time of interrelating between several modes of transport and waiting in the traffic points.

The travel time cost will be denoted by \( T \), as formula(1) shown.

\[
T = \frac{S}{V} + t_1 + t_2 + t_3 \tag{1}
\]

In the formula: \( S \) mean the delivery distance of the chosen transport mode \( \text{(km)} \), \( V \) mean the average delivery rate of the chosen transport mean \( \text{(km/h)} \);

\( t_1 \) --the required time of connecting between the travel termini point and the main transport mode \( \text{(h)} \);

\( t_2 \) --the time waiting the chosen mode of transport in traffic station \( \text{(including the departure interval of transport mode and the delayed time of departure and arrival)} \. \text{(h)} \);

\( t_3 \) --the required time of departure and arrival of transport \( \text{(h)} \).

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\( t_3 \) -- the corresponding time consumed by public transport tickets (h).

2) **Economic cost**

The economic cost is an important factor when travelers make a choice of transport modes. For simplicity, the economic cost will be described by the tariff rate.

The tariff rate is denoted by \( K \), as formula (2) shown.

\[
K = \frac{s}{p_1 + p_2 + p_3}
\]

In the formula:

\( p_1 \) -- the fares of the chosen mode of transport (yuan);

\( p_2 \) -- the cost of connecting the travel termini point with the main transport mode (yuan);

\( p_3 \) -- the economic loss of passengers caused by delay (yuan);

\( \alpha \) -- adjustment coefficient.

3) **Comfort**

Comfort is one of the main service features which are pursued by the modern passenger transportation service, mainly manifested in the vehicle driving stability, seat comfort, as well as the flexibility of transport operations, etc. Comfort can be defined by \( C \) as follows.

\[
C = c_1 + \frac{1}{c_2} + c_3
\]

In the formula,

\( C_1 \) -- the space occupied by passengers in the chosen mode of transport \((m^3)\);

\( C_2 \) -- the vibration acceleration in the vehicle operation \((m/s^2)\);

\( C_3 \) -- comfort variables, \( C_3 = S \cdot \lambda \), \( \lambda \) means the coefficient of transport associated with the transport distance, which can be calculated as follows:

\[
\lambda_{\text{vib}} = (-0.0002 \times S + 1.04) \times 0.2
\]

\[
\lambda_{\text{accel}} = (-0.0002 \times S + 1.04) \times 0.2
\]

4) **Security**

Since the technical characteristics and operational environment of transport modes are both different, its security is also different. We can use Q which is the number of casualties of unit volume of passenger transportation to quantify and describe the security. Aircraft accident mortality rate was 0.41, while the train accident mortality rate was 0.018.

5) **Passenger Preference**

In general, passenger preferences include a passenger’s own features, as well as his travel characteristics. Passenger’s own features are the traveler’s personality factors (gender, income, psychological factors), these personalities will affect traveler’s value of expectation for the various service attributes. The main travel characteristics are the purpose and time of travel.

II. **COMPETITION MODEL BETWEEN HIGH-SPEED RAIL AND AIR TRANSPORT**

The study of competition between high-speed rail and air transport, in essence, is the competition of passenger traffic. Thus the competitive study can be converted to research passengers’ behavior of choosing between the two modes of transport. As two different transport modes, high-speed rail and air transport have different service attributes, as a result of the different technical conditions, business strategy and operational environment. Generally, passengers take the overall utility maximization as a selection criterion to choose the transport mode. The utility is decided by time cost, economic cost, comfort, security and passenger preference jointly. The utility is used to measure the value of chosen mode of transport for tourists, then the problem to choose between two modes of transport can be considered to be a multi-attribute decision-making issue.

A. **There are two modes of transport between termini points for passengers.**

Suppose that the decision of choosing a transportation mode is determined by \( k \) impact factors, then the vector representation of the impact factors for choosing between two modes as the formula(4) shown.

\[
\mathbf{y}_i = (y_{i1}, y_{i2}, y_{i3}, \ldots, y_{i6})(i = 1, 2)
\]

In the formula, \( y_{ia} \) means the first \( k \) kinds of factors in the first \( i \) kinds of transportation modes.

Because of \( k \) kinds of factors, we should make use of the combination rules which are got by the principle of vector addition or multiplication to compute each vector weighted. Taking into account the independent of the impact factors influencing the passengers’ choice, we use the additive principle to weight the various factors affecting the mode of transport and constitute the overall utility value \( U_i \), which can be expressed by equation (5).

\[
U_i = \theta_1 y_{i1} + \theta_2 y_{i2} + \ldots + \theta_k y_{ik} + \varepsilon
\]

In the equation:

\( \theta_k \) -- the preference adjustment coefficient that the factor \( y_{iak} \) influence the utility value \( U_i \);

\( \varepsilon \) -- passenger preference;

B. **By calculating the \( U_i \), the utility of two transport modes under different transport distances \( S_i \) can be worked out.**

C. **Assume that the utility of two transport modes are equal when the transport distance is \( S_i \).**

At the same time when the \( S_i \) changes, in addition to economic costs and time costs, the other factors do not change. Logit equation can be used to get the traveler’s contribution rate \( P^{\text{con}}_i \) under different transport distance \( S_i \), \( P^{\text{con}}_i \) can be expressed as equation (6).
In the equation:

\[ U_i^S = \frac{\exp U_i^S}{\sum \exp U_i^S} \]

The overall utility of the first \( i \) kinds of transport modes under the transport distance \( S_i \).

D. According to the contribution rate \( P_i^S \), which is calculated by the different transport distance \( S_i \) of two modes, we can define the relative degree of competition \( \gamma_i^S \) between high-speed rail and air transport, as formula (7) shows.

\[ \gamma_i^S = \left| \frac{P_i^S_{\text{high-speed}} - P_i^S_{\text{air}}}{P_i^S_{\text{high-speed}}} \right| \]

III. AN EMPIRICAL ANALYSIS OF COMPETITION

A. The competitive relationship between high-speed rail and air transport under the condition of different distances

The utility function of high-speed rail and air transport can be got through formula (5) and the impact factors of choosing a transport mode as the previous description, and it can be shown as follows.

\[ U_{\text{high-speed}} = \theta_i T_{\text{high-speed}} + \theta_i K_{\text{high-speed}} + \theta_i C_{\text{high-speed}} + \epsilon \]

\[ U_{\text{air}} = \theta_i T_{\text{air}} + \theta_i K_{\text{air}} + \theta_i C_{\text{air}} + \theta_i Q_{\text{air}} + \epsilon \]

The setting of several key variables of the impact factors is shown in Tab 1 shown below.

Under the conditions of setting the utility model and parameters mentioned above, the MATLAB software can calculate the market share of high-speed rail and air transport at different distances through the formula (7). At the same time, analyze both the rate of market share, through the different price comparison of high-speed rail and air. The results are shown in Figure 1.

It can be got clearly by Figure 1 that the high-speed rail has an absolute advantage in the transport market, when the transport distance is less than 600 kilometers. As the transport distance increases, the market share of high-speed rail reduced gradually, while the air transport’s increase gradually. Both the rate of market share are equal in the transport distance of 1000 kilometers. Thus, the air and the high-speed rail from the most intense competition at the point of 1000km of transport distance. When the transport distance is greater than 1000 kilometers, the air transport contribution rate will be larger than the high-speed rail’s. When the transport distance is about 1600 km, the high-speed rail’s contribution rate is close to 0, and the air transport takes possession of the basic fully market. Finally, when the transport distance is greater than 1.8 thousand kilometers, the choice of passengers will tend to be stable, so that the curves on market share of high-speed rail and air transport tend to a straight line. In order to study clearly the change about the market share rate in the different transport distance of high-speed rail and air transport, we can get the relative competition between the two transport modes through the formula (7), as Figure 2 shows. In Figure 2, we can see that there are two obvious turning point of the relative competition curves which are at the 600 km and 1400 km separately. Considering that high-speed rail’s market share will decrease in the relative ease at 600 ~ 1000km as described in Figure 1, in addition, high-speed rail plays a role in partial substitution to air transport; When the transportation distance is greater than 1000km, the high-speed rail’s market share will decline rapidly, in contrast, air transport’s will rising greatly. It can be seen that when the transport distance is greater than 1000 kilometers, due to many factors such as transit time, the advantage of high-

<table>
<thead>
<tr>
<th>Item</th>
<th>( V )</th>
<th>( t_i )</th>
<th>( P_i )</th>
<th>( c_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-speed Rail</td>
<td>250 km/h</td>
<td>0.7 h</td>
<td>0.5 yuan / passenger km</td>
<td>20 yuan</td>
</tr>
<tr>
<td>Air</td>
<td>750 km/h</td>
<td>1.5 h</td>
<td>0.75 yuan / passenger km</td>
<td>122.8 yuan</td>
</tr>
</tbody>
</table>

Figure 1. The share of high-speed rail and air transport market.

Figure 2. The relative competitive relationship between high-speed rail and air transport.
speed rail will reduce greatly, and air transport will occupy the passengers market quickly. When the transport distance is greater than 1400 km, the air transport has a dominant position of passengers’ market share, and high-speed rail occupies a very low market share.

B. Changes of competition between high-speed rail and air transport, when high-speed rail fares changes.

The difference of passengers’ types and travel purposes also will influence the market share of transport market. Taking into account that China’s passenger transport line primarily covers the economically developed eastern region. The appearance of high-speed railway has attacked the original air transport which is exclusive in the high-speed passenger transport market. Therefore, it is necessary to study the competitive effects caused by high-speed rail fares change. When \( P_{\text{air}} = P_{\text{air}}^* \), the competition between high-speed rail and air transport is the most fierce. According to the formula (6), if \( P_{\text{air}} = P_{\text{air}}^* \), then \( \exp P_{\text{air}}^* = \exp P_{\text{air}} \), that is \( U_{\text{air}}^* = U_{\text{air}}^* \). Set up a function \( F(S,x,y) \), the transport distance is denoted by \( S \), \( x \) means the high-speed rail fares, and \( y \) means air fares, then:

\[
F(S,x,y) = U_{\text{air}}^* - U_{\text{air}}^*
\]  

Suppose \( y \) is a given value of 0.75, then the equation (9) is an implicit function about \( x \). Then the derivative of the equation (9) is:

\[
\frac{\partial F(S,x,y)}{\partial x} = \frac{\partial (U_{\text{air}}^* - U_{\text{air}}^*)}{\partial S} \times \frac{\partial S}{\partial x}
\]  

The formula (10) expressed the influence caused by the change of high-speed rail fare \( x \) to the highly competitive range \( S \) of transport distance between high-speed rail and air transport. Take each parameter into the equation (10), and set \( x = 0.1 \) (i.e. high-speed rail fares change into 0.4 yuan/passenger km), then \( \frac{\partial F(S,x,y)}{\partial x} = 124.7 \). This means that for every high-speed railway fares decline of 0.1 yuan / passenger km, the most competitive transport distance of high-speed rail and air transport will increase 124.7 kilometers. On the other hand, the decline of high-speed rail to test and verify the conclusion reached from the formula (10).

As can be seen from Figure 3, with the high-speed rail fares reduces from 0.5 yuan/passenger km to 0.4 yuan/passenger km, the most competitive transport distance between high-speed rail and air transport changes from 1,000 km into the 1125 kilometers, thereby verifying the conclusions reached by the formula (10). On the other hand, the transport distance that high-speed rail alternative to air transport changes from 600~1000 km to 600~1125 km, and the utility of high-speed rail has been upgraded.

IV. INFLUENCED ANALYSIS OF AIR TRANSPORT

From the passenger traffic distribution of the domestic voyage legs in 2008 in Figure 4, we can see that there are 400 voyage segments whose transport distance is less than 1000 km. Passenger transport volume and turnover accounted the total passenger traffic for 20.6% and 10.4%. The average rate for the aircraft carrying is 61%. Combining with the "China's long-term railway development plan" issued by the state, the voyage segments impacted by the high-speed rail network have 180 items. Considering the regional distribution, high-speed rail network has covered Beijing, Shanghai, Guangzhou, Shenzhen, Chengdu, Hangzhou, Harbin, Dalian, Kunming, Zhengzhou, Wuhan, Changsha and other densely populated, economically active and medium-sized cities. And these medium-sized cities are also an important short-haul domestic air transport market. Affected by this, some golden short-haul routes of the eastern region along the high-speed rail, such as Shanghai - Qingdao, Beijing - Qingdao, Beijing - Shenyang, Beijing - Nanjing, Jinan - Shanghai, Wuhan - Guangzhou, Dalian -
Harbin, and other routes will be faced with high-speed rail’s fierce competition. In the western region, Chengdu, Chongqing, Xi’an, Kunming, Lanzhou and other major aviation markets get a less impact of high-speed rail. Some of the more mature branch routes, such as Kunming - Xishuangbanna, Kunming - Lijiang, Xian - Yinchuan and Chengdu - Kunming, Xi’an - Chengdu route was less affected. However, with the completion of high-speed rail network, these routes will be affected.

When the transport distance is between 1000-1600 km, the air transport has greater advantages. It is worth to concern the Beijing-Shanghai high-speed railway whose transport distance is 1300 km and Beijing-Guangzhou, Shanghai and Shenzhen high-speed rail lines connected by the high-speed rail network. In accordance with the present high-speed rail speed, the running time of these lines is approximately 5-7 hours. That is because these cities are located along the important north-south transport corridor of the eastern region. The average traffic of 24 existing segments has reached 100 million, if the hardware facilities and services provided by the Beijing, Shanghai, Shenzhen, Guangzhou and other airports cannot meet the demand of tourists, it may result in the market share in this part of air transport decrease, and the superiority of air transport will be lost.

When the transport distance is greater than 1,600 km, with the increase in transport distance, the advantage of low fares will cease to exist, in addition, even appeared higher fare than the air due to the price controls. And thus in terms of price-sensitive passengers, the cost will be not very different whether they select high-speed rail or air travel. Furthermore, high-speed rail journey time is much longer than air transport, so that the fatigue of passengers will be rapid increase. Therefore, advantages of air transport will not change in the voyage segment whose transport distance is longer than 1600 km.

V. CONCLUSION

Logit equation is an effective way to study the competition between two transport modes. This paper make use of the competition model of high-speed rail and air transport constructed by the Logit equation, then study the intensity of competition between high-speed rail and air transport with the change of transport distance through a series of figures. And combined with the reality of air transport, the paper analyzed the related conditions of affected routes. The results show that competition model can give a more complete description of the passengers’ choices for the two kinds of modes of transport. Along with economic development, the time value of passengers will be gradually increased, the visitors will pay more attention to pre-and post-trip time. Therefore, the convenience of high-speed rail passengers should be given full consideration when in the process of high-speed railway stations’ selection. High-speed rail fare is also an important factor which could not be ignored. A rational pricing mechanism of high-speed rail fare will be beneficial to the operation of high-speed rail in the short-distance passenger market.

REFERENCES