General attraction analysis on high-speed rail and aviation between Beijing and Shanghai, China

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Abstract. High-speed rail and aviation are the two most popular modes of transportation between Beijing and Shanghai. Based on the existing literature, this paper summarized seven key influencing factors of the high-speed rail and civil aviation comprehensive attraction from the Beijing-Shanghai corridor. Furthermore, we constructed five single index models to quantify them. By analysing the logical relationships among various indicators, the generalized travel cost function with different modes of transportation and different user types under different seasons is finally obtained. To ensure the reliability of the analysis results, the collected data were used to calibrate most of the parameters of the generalized cost function model. After that, a series of sensitivity analysis are conducted. The results show that the attractiveness ranking of these two transportation modes is influenced by the purpose of the trip, the characteristics of the passengers, and changes in the season. This paper may offer some valuable references for aviation and railway transport companies.

Keywords: Beijing-Shanghai corridor, High-speed rail, Aviation, attraction, Transportation.

1 Introduction

The Beijing-Shanghai corridor is one of the most important transportation routes in China. Although its length only accounts for 2.8% of the total national transportation mileage, its passenger traffic volume accounts for 25% of the country's total. The amazing passenger turnover on the Beijing-Shanghai line makes the passenger flow density about five times that of the national average, and it is in a continuous rapid growth [1]. The rise of high-speed rail in the Beijing-Shanghai market has seriously affected the market share of civil aviation. Passengers with different travel purposes have different considerations for these two different modes of transportation [2].

Since the Beijing-Shanghai high-speed rail opened to traffic in 2011, the competition between high-speed rail and aviation in the Beijing-Shanghai corridor has been a foregone
conclusion. Here are some examples at home and abroad. Air France had to pull out of Paris to Marseille and Lyon after the TGV high-speed rail project was implemented [3]. JAL had to ground routes from Tokyo to Osaka and Nagoya after the Shinkansen began operating in Japan [4]. In South Korea and Taiwan, after the opening of high-speed rail, civil aviation market share is also sharply reduced. In China, since the Zhengzhou-Xi'an high-speed rail was put into operation in 2010, Joyair has had to suspend the flights from Zhengzhou to Xi'an; the opening of the Wuhan-Guangzhou high-speed rail also forced Wuhan-Guangzhou flights to reduce their prices to maintain their share [5].

This paper analyses the efficiency differences between different modes of transportation to find the factors that affect their comprehensive attractiveness, and establishes a generalized attractiveness function model [6]. According to the data of different passengers, the advantages and disadvantages of different modes of transportation and the attractiveness of passengers can be obtained by comparing with each other.

The rest of this paper is organized as follows. Five single models and generalized cost model are introduced in Section 2. In Section 3, numerical analysis is carried out. Finally, Section 4 gives the conclusions.

2 Comprehensive attractiveness index modelling

The comprehensive attractiveness index quantifies the competitive relationship between Beijing-Shanghai high-speed rail and aviation caused by multiple factors. The attractiveness here mainly refers to the preference of different modes of transportation from the perspective of passengers. It is assumed that passengers choose the mode of travel that minimizes the cost according to their own factors. This paper constructs a generalized function of comprehensive attractiveness, and analyses the influence of different seasons and times, passenger types, and travel purposes on the attractiveness of high-speed rail and aviation. It should be noted that the value of the generalized function only has a relative meaning, not an absolute value.

2.1 Key factors

Based on the current research, this paper summarizes seven key factors that affect the attractiveness of Beijing-Shanghai high-speed railway and aviation, namely rapidity, economy, availability, reliability, comfort, extensibility and simplicity. The definitions for different factors are given as follows.

**Rapidity**: Refers to the time it takes for passengers with different travel purposes to take different modes of transportation. Passengers on the Beijing-Shanghai line mostly travel for business and tourism purposes, and pay more attention to travel time.

**Economy**: Economy represents the money cost of a passenger's trip, including the ticket price of the mode of transportation, the ticket price of the vehicle before the trip and other additional expenses.

**Availability**: Refers to the service frequency, available capacity and occupancy rate of different means of transportation, which can reflect whether passengers can successfully purchase required air tickets and tickets, especially for business passengers, which requires that transportation modes maintain a certain service frequency to meet the travel needs of passengers [7].

**Reliability**: Refers to the punctuality of the mode of transportation. Reliability and rapidity together constitute the time attribute factors affecting the attractiveness of high-speed rail and aviation.

**Comfort**: Refers to the requirements of passengers on the quality of travel services, hardware and software facilities.
Scalability: Refers to the freedom and convenience of passengers in transportation.
Simplicity: Travel time that takes extra energy away from the means of transportation, such as security checks and baggage checks at airports.

2.2 Single index model

Based on the above seven influencing factors, this paper proposes five indicators for quantification. For the convenience of quantifying the selected indicators, the following assumptions are made:
1) All passengers are rational. Under certain social and economic conditions, passengers always choose to travel in a way that maximizes their own utility.
2) Both high-speed rail and aviation on the Beijing-Shanghai line are considered as direct transportation.

2.2.1 Single model of travel time

The model considers two factors: rapidity and reliability. The rapidity and reliability are mutually independent, but will affect the final travel time of passengers at the same time. Therefore, we built this travel time model by adopting the principle of addition as follows.

\[ \text{Budget}_{sp} = \mu_{wp} + \kappa \cdot \sigma_{wp}, \forall s \in S, p \in P, w \in W \]  \hspace{1cm} (1)

In Equation (1), \( \text{Budget}_{sp} \) refers to the travel time index, \( \mu_{wp} \) refers to the travel time expectation of passengers taking different means of transport in different seasons, \( \kappa \) refers to the risk bearing capacity of passengers of different types, and \( \sigma_{wp} \) refers to the travel time standard deviation of passengers. \( s \) refers to season (rainy season June-July, flat season others). \( p \) refers to travel categories (business travel, tourism travel, study and training, visiting relatives and friends). \( w \) indicates the transportation mode (aviation, high-speed rail).

\[ \mu_{wp} = \bar{T}_p + \bar{T}_s + \bar{T}_{wp} \]  \hspace{1cm} (2)

\[ \bar{T}_p = dt_{wp} + yr_{wp} + at_{wp} \]  \hspace{1cm} (3)

In Equation (2) and Equation (3), \( \bar{T}_p \) refers to the pre-departure time related to the mode of transport. \( \bar{T}_s \) refers to the in-transit time of the mode of transport \( w \) in the season \( s \), and \( \bar{T}_{wp} \) refers to the post-departure time of the mode of transport \( w \). \( dt_{wp} \) represents the arrival time of passenger \( p \) choosing transportation mode \( w \). \( yr_{wp} \) represents the baggage check-in time of passenger \( p \) choosing transportation mode \( w \), and \( at_{wp} \) represents the security check time of the mode of transportation.

2.2.2 Single model of travel cost

The travel cost model refers to the narrowly defined expenses spent by passengers with different travel purposes during and before and after the journey. This model considers the influence of economic factors on the comprehensive attractiveness of different vehicles.

\[ \text{Pay}_{sp} = dm_{wp} + tm_{wp} + em_{wp}, \forall s \in S, p \in P, w \in W \]  \hspace{1cm} (4)
In equation (4), $Pay_{sp}^w$ represents the cost index of the transportation mode $w$ with the passenger $p$ in the seasons, $dm_{sp}^w$ represents the cost of the passenger to the station or airport, $tm_{sp}^w$ represents the cost of the passenger to buy a high-speed rail ticket or air ticket in the seasons, and $em_{sp}^w$ represents the passenger's expenses in other aspects such as catering.

2.2.2 Single model of travel availability

In this paper, the whole day is divided into a period of half an hour, and different availability models are calculated according to different periods.

$$Availability_p^w = \sum_{i} \lambda_p^i \cdot A_i^w, \forall p \in P, w \in W$$

(5)

$$A_i^w = \frac{(1 + \tau_w \cdot \delta_i^w) \cdot Cap_{i}^w}{\sum_{w} Cap_{i}^w}, \forall i \in N, w \in W$$

(6)

In equation (5), $Availability_p^w$ represents the overall availability of the transportation mode $w$, and $A_i^w$ represents the availability index of the transportation mode $w$ during the time period $i$. Because different passengers have different travel needs at different time periods, $\lambda_p^i$ is used to represent the demand parameters of the time period $i$ related to the purpose of passenger travel. In equation (6), $\tau_w$ represents the parameter related to the mode of transportation, $\delta_i^w$ represents the average vacancy rate of the mode of transportation $w$ during the time period $i$, and $Cap_{i}^w$ represents the number of seats that the mode of transportation $w$ can provide during the time period $i$.

2.2.3 Single model of travel experience

This model considers the factors of comfort and extensibility. The higher the passenger comfort extensibility index is, the more comfortable the transportation mode is, and the passengers are more freer during the journey, which means the perceived travel time is relatively shortened. Therefore, the inverse proportional function is considered:

$$Restrict_p^w = \left(1 + \frac{\theta}{\text{comfort}_p^w + \text{expnsibility}_p^w}\right) \mu_p^w, \forall s \in S, p \in P, w \in W$$

(7)

In equation (7), $Restrict_p^w$ represents the overall index of travel experience of this mode of transportation, $\text{comfort}_p^w$ represents the journey comfort index related to the mode of transportation and the type of passengers, and $\text{expnsibility}_p^w$ represents the journey extensibility index related to the mode of transportation and the type of passengers. These two data are obtained through questionnaires and $\theta$ is parameter.

2.2.4 Single model of travel simplicity

The simplicity model mainly considers the extra travel time at airports or stations and the convenience of transportation vehicles:

$$Spirit_p^w = y_t_p^w + \eta_p^w \cdot at_p^w, \forall p \in P, w \in W$$

(8)
In equation (8), \( \text{Spirit}_p^w \) refers to the convenience index related to the mode of transportation and the purpose of travel, \( \eta_p^w \) refers to the sensitivity of passenger \( p \) to time consumption when taking the mode of transportation \( w \), \( \nu_t^w \) refers to the baggage checking time related to the purpose of travel and the mode of transportation, and \( \alpha_t^w \) refers to the security check time of the mode of transportation \( w \).

It can be seen that the five index models given in this paper respectively cover all influencing factors and do not overlap with each other.

### 2.3 Generalized index model

Among the above single index models, the single model of travel time and travel experience is the time attribute model, and the single model of travel cost is the cost attribute model. The single item model of travel availability is the parameter property model.

In this paper, the time value of passengers on the Beijing-Shanghai line is obtained based on the survey and calculation, and the time attribute model is converted into a generalized cost model:

\[
\text{General}^w_{sp} = \text{Avability}^w_{sp} \cdot \{ \nu_t^w \cdot ( \varphi_1 \cdot \text{Budget}^w_{sp} + \varphi_2 \cdot \text{Restrict}^w_{sp} + \varphi_3 \cdot \text{Spirit}^w_{sp}) + \text{Pay}^w_{sp} \} \forall s \in S, p \in P, w \in W \tag{9}
\]

In equation (9), \( \text{General}^w_{sp} \) represents the comprehensive attraction of transportation mode \( w \) to passenger \( p \) in season \( s \). \( \text{Avability}^w_{sp} \) indicates the overall availability of the transportation mode \( w \), \( \text{Budget}^w_{sp} \) refers to the travel time-consuming index, \( \text{Restrict}^w_{sp} \) represents the overall index of the travel experience of this type of transportation, \( \text{Spirit}^w_{sp} \) represents the convenience index related to the mode of transportation and the purpose of travel, \( \text{Pay}^w_{sp} \) represents the passenger cost index related to the purpose of travel, season and mode of transportation, \( \nu_t^w \) represents the time value of passengers, and \( \varphi_1, \varphi_2, \varphi_3 \) represents the corresponding weight.

### 3 Numerical analysis

In this section, the operation data of high-speed rail and aviation in the Beijing-Shanghai corridor in April 2018 are taken as an example to solve the five single-indicator models and conduct sensitivity analysis on the parameters.

#### 3.1 Calculation of generalized index function

This paper conducted a passenger survey, collected and classified the income of passengers of different categories. The time value of different passengers is calculated according to equation \( \nu_t = \frac{\text{Average}}{\text{Days}} \cdot T_{\text{work}} \), and the generalized function is shown in table 1. In the equation, \( \text{Average} \) represents the average monthly income of passengers, \( \text{Days} \) represents the average number of days per month (30 days), and \( T_{\text{work}} \) represents the assumed daily working hours (10 hours). In this paper, the weight parameter of the generalized function is assumed to be \( \varphi_1 = \varphi_2 = \varphi_3 = 1/3 \).
Table 1. Generalized function table of attraction.

<table>
<thead>
<tr>
<th>Month</th>
<th>Business</th>
<th>Non-Business</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rail</td>
<td>Aviation</td>
</tr>
<tr>
<td>Jan (peak)</td>
<td>919.07+45.59 $\kappa_{biz}$</td>
<td>851.36+26.74 $\kappa_{biz}$</td>
</tr>
<tr>
<td>Feb (peak)</td>
<td>919.07+45.59 $\kappa_{biz}$</td>
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</tr>
<tr>
<td>Mar</td>
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<td>836.78+26.74 $\kappa_{biz}$</td>
</tr>
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</tr>
<tr>
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<td>919.07+45.59 $\kappa_{biz}$</td>
<td>851.36+26.74 $\kappa_{biz}$</td>
</tr>
<tr>
<td>Jun (Rainy)</td>
<td>919.07+45.59 $\kappa_{biz}$</td>
<td>1090.07+26.74 $\kappa_{biz}$</td>
</tr>
<tr>
<td>Jul (Rainy/peak)</td>
<td>919.07+45.59 $\kappa_{biz}$</td>
<td>1104.66+22.04 $\kappa_{biz}$</td>
</tr>
<tr>
<td>Aug (peak)</td>
<td>919.07+45.59 $\kappa_{biz}$</td>
<td>851.36+26.74 $\kappa_{biz}$</td>
</tr>
<tr>
<td>Sep</td>
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3.2 Attractiveness analysis

In this section, the influence of passenger type, mode of transportation and time on comprehensive attractiveness of transportation is analysed.

In general, business passengers have higher requirements for punctuality, so their risk tolerance is generally lower than that of other passengers. In addition, during the rainy season (June and July) in Shanghai, flight delays between Beijing and Shanghai are very serious, so business passengers generally take high-speed rail. Therefore, this paper assumes $\kappa_{biz} = 9, \kappa_{nor} = 11$, the final generalized cost can be obtained as shown in figure 1 combined with table 1.

![Fig. 1. High-speed rail and civil aviation attraction of Beijing-Shanghai line.](image-url)

4 Conclusions

The main conclusions of this paper are listed below:

1) For business passengers, aviation is more attractive. However, the punctuality rate of aviation in the rainy season is low, while the high-speed rail is more stable and punctual. So, the competition between the two modes of transportation for business passengers is more intense.

2) For non-business passengers, the attractiveness of high-speed rail and aviation is very close.
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2. For non-business passengers, the attractiveness of high-speed rail and aviation is very close.

3. Business passengers who choose aviation during non-rainy seasons can greatly reduce travel time. Considering the tickets price and the punctuality, aviation is a wise choice for non-business passengers in off-season.

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