Study on the Tourist Tickets Pricing of Urban Rail Transit

Zhe-qi RAN*, Zhi-li LIU and An-na DENG

MOE Key Laboratory for Urban Transportation Complex Systems Theory and Technology,
Beijing Jiaotong University, Beijing, China
*Corresponding author

Keywords: Urban rail transit, Tourist ticket, Travel mode choice, Bi-level programming.

Abstract. A bi-level programming model of rail tourist ticket pricing is set up in this paper. The upper planning aims at maximizing the revenue of rail transit enterprises. The lower planning considers the economy, rapidity, comfort and other costs of tourists’ trips, to achieve a pricing program which can balance the interests of both rail transit operators and tourists. And a hybrid particle swarm optimization and genetic algorithm is designed to solve the problem. The parameters are set according to the current situation of Beijing rail transit and tourism, then the result of model is evaluated, which shows that the model and the algorithm are effective.

Introduction

Compared with domestic cities, the use of rail transit tickets is more widely used in foreign famous tourist cities, and the types and preferences of ticket cards are more abundant. The theoretical research mainly focuses on the evaluation of the implementation effect of existing discount ticket cards and the research on urban rail transit pricing models under different ticketing backgrounds. The research on tourism transportation mainly focuses on the investigation and analysis of the characteristics of tourists’ travel behavior and the road traffic planning of tourist cities. There are no scholars to further study the role of rail transit ticketing system and ticket card products in tourism transport planning. In view of this, this paper combines the characteristics of tourists’ travel selection and rail transit pricing theory to provide a theoretical basis for the pricing of rail transit travel ticket products.

The Generalized Travel Expense Function of the Lower Level Planning

The definition of generalized travel expense function is the comprehensive utility of various factors affecting the travel, which refers to the various costs that the passengers pay in the process of travel, including the direct monetary cost. In addition to considering the purchase price of the transportation product itself, the speed, convenience, and safety are also the influencing factors when making a decision. Based on the above four characteristics, the generalized travel expense function is established.

Economic Cost

1. Economic cost of bus travel:

   \[ p_{b,s}^n = x \cdot p_b \] (1)

   \[ p_{b,s}^n \]: The total cost of passengers staying in the resort for \( n \) days and traveling by bus for \( x \) times (yuan);

   \[ p_b \]: The average cost (yuan) for a bus ride.

2. Economic cost of car travel:
\[ p_{c,x} = x \cdot (r + l \cdot g_{0}) \]  \hspace{1cm} (2)

\[ p_{c,x} : \text{The total cost of passengers who travel in the tourist place for } n \text{ days to travel by car for } x \text{ times (yuan)}; \]
\[ r : \text{The average single parking fee (yuan)}; \]
\[ l : \text{The average distance (km) for each trip}; \]
\[ g_{0} : \text{The average fuel cost per unit distance from the car (yuan/km)}. \]

3. Economic cost rail transit travel:

\[ p_{T,x} = x \cdot p_{T} \]  \hspace{1cm} (3)

\[ p_{m,x} = p_{n} \]  \hspace{1cm} (4)

\[ p_{T,x}, p_{m,x} : \text{The total cost (RMB) of passengers who choose to travel } x \text{ times in a single-trip ticket and travel ticket on a rail transit when staying at a tourist site for } n \text{ days}; \]
\[ P_{T} : \text{The average single one-way fare (yuan)}; \]
\[ p_{n} : \text{The price of travel tickets that are valid for days (yuan)}. \]

Fast Cost

1. Time cost of car travel:

\[ t_{c,x} = \tau_{c} \cdot x \cdot \frac{L_{c}}{V_{c}} \]  \hspace{1cm} (5)

\[ t_{c,x} : \text{The time cost of traveling in a tourist destination for } n \text{ days while riding a car for } x \text{ passengers}; \]
\[ \tau_{c} : \text{The time value conversion factor (yuan/h) for passengers traveling by car}; \]
\[ L_{c} : \text{The average travel distance (km) of passengers traveling by car}; \]
\[ V_{c} : \text{The average speed of the car (km/h), where the average speed is the average traveling speed of the car when the scenic road is congested, and the traveling speed when not traveling freely}. \]

2. Time cost of public transportation:

\[ t_{b,x} = \tau_{b} \cdot x \cdot \left( \frac{L_{b}}{V_{b}} + t_{b}^{m} \right) \]  \hspace{1cm} (6)

\[ t_{m,x} = t_{T,x} = \tau_{m} \cdot x \cdot \left( \frac{L_{m}}{V_{m}} + t_{m}^{m} \right) \]  \hspace{1cm} (7)

\( t_{b,x}, t_{m,x}, t_{T,x} : \text{The time cost of choosing a bus, a rail transit ticket and a one-way ticket for a rail transit to travel } x \text{ times when staying in the tourist destination for } n \text{ days}; \)
\[ \tau_{b}, \tau_{m} : \text{The time value conversion factor (yuan/h) of passengers travelling by bus and rail transit}; \]
\[ L_{b}, L_{m} : \text{The average distance (km) for passengers traveling by bus and rail}. \]
\[ V_{b}, V_{m} : \text{The average speed of buses and rail transit (km/h)}; \]
\[ t_{b}^{m}, t_{m}^{m} : \text{The average departure interval (h) between buses and rail transit}. \]
Convenience Cost

1. Convenience costs for bus travel:

\[
B_{b,x}^n = \tau_b \times x \times \left( \frac{L_{2b}}{V_3} + t_1^b \right)
\]

\( B_{b,x}^n \): The convenience cost of traveling on a bus for \( x \) passengers in a tourist destination for \( n \) days;

\( L_{2b} \): The average transfer distance (km) of passengers traveling by bus;

\( V_3 \): The average walking speed of passengers (km/h);

\( t_1^b \): The average departure interval of the bus, the passenger transfer waiting time indicator (h).

2. Convenience costs for car travel:

\[
B_{c,x}^n = \tau_c \times x \times \left( \frac{L_{2c}}{V_3} + t_4^c \right)
\]

\( B_{c,x}^n \): The convenience cost of traveling in a tourist destination for \( n \) days while riding a car for \( x \) passengers;

\( L_{2c} \): The average distance (km) from the entrance of the scenic spot to the parking lot of the scenic spot;

\( t_4^c \): The average time (h) for a passenger seeking a parking space by car.

3. Convenience costs for rail transit:

\[
B_{r,x}^n = \tau_m \times x \times \left( \frac{L_{2m}}{V_3} + t_5 + t_1^m \right)
\]

\[
B_{m,x}^n = \tau_m \left[ x \times \left( \frac{L_{2m}}{V_3} + t_1^m \right) + t_5 \right]
\]

\( B_{r,x}^n, B_{m,x}^n \): The convenient cost of selecting a one-way ticket for rail transit and \( x \) times for a tourist ticket when staying in a tourist destination for \( n \) days;

\( t_5 \): The average passenger's time spent queuing each ticket (h);

\( L_{2m} \): The average transfer distance (km) of passengers traveling by rail.

\( t_1^m \): The average departure interval of the rail transit, that is, the passenger transfer waiting time indicator (h).

4. Security cost

When the accident rate of a certain traffic mode is 0, the safety credibility is 1, when the accident rate exceeds a certain limit, the credibility is 0, considered as unsafe.

\[
S_k = \frac{1}{1 + \theta_k \cdot e^{\theta_k}}
\]

\( S_k \): The safety and credibility of the \( k \) modes of transportation;
\( \lambda_k \): The accident rate of \( k \) transportation modes;
\( \theta_1, \theta_2 \): The undetermined coefficient.

To sum up, the general travel cost of choosing \( i \) when staying at a tourist site for \( n \) days can be expressed as:

\[
F_i^n = \left( \alpha_1 p_i^n + \alpha_2 t_i^n + \alpha_3 B_i^n \right) / S^n
\]  
(13)

In the formula, \( \alpha_1, \alpha_2, \alpha_3 \) represents the service feature weight coefficient.

General cost of car travel:

\[
F_{c,i}^n = \left[ \alpha_1 x \left( r + l g_i \right) + \alpha_2 \tau_i x \frac{L_c}{V_c} + \alpha_3 \tau_i x \left( \frac{L_{c2}}{V_3} + t_i^c \right) + \alpha_4 x \left( \tau_c g_c + h_c \right) \right] \left( 1 + \theta_i e^{\theta_i^c} \right)
\]  
(14)

General travel cost of bus travel:

\[
F_{b,i}^n = \left[ \alpha_1 x p_b + \alpha_2 \tau_b x \frac{L_b}{V_b} + \alpha_3 \tau_b x \left( \frac{L_{b2}}{V_3} + t_i^b \right) \right] \left( 1 + \theta_i e^{\theta_i^b} \right)
\]  
(15)

Generalized travel costs of single track and tourist tickets for rail transit:

\[
F_{r,i}^n = \left[ \alpha_1 x p_T + \alpha_2 \tau_m x \frac{L_m}{V_m} + \alpha_3 \tau_m \left( \frac{L_{2m}}{V_3} + t_i^m \right) \right] \left( 1 + \theta_i e^{\theta_i^m} \right)
\]  
(16)

\[
F_{m,i}^n = \left[ \alpha_1 p_n + \alpha_2 \tau_n x \frac{L_n}{V_n} + \alpha_3 \tau_n \left( \frac{L_{2n}}{V_3} + t_i^n \right) \right] \left( 1 + \theta_i e^{\theta_i^n} \right)
\]  
(17)

The Two-layer Planning Pricing Model for Rail Transit Travel Tickets

To sum up, the rail transit ticket pricing model for double-tier planning is as follows:

\[ (P_1) \]

\[
\max R = \sum_n \sum_m p_m x d^m_{r,n} + \sum_n \sum_m p_m d^m_{m,i,n} - c \sum_n \sum_m d_{m,i,n} \]

subject to:

\[
\omega_{m,n} p_m \leq p_n \leq \omega_{m,n} p_m \quad \forall n \in \{1, 2, \ldots, N\}
\]  
(18)

\( d_{r,x}, d_{m,x} \): The number of visitors who spent \( n \) days in the tourist destination to purchase one-way tickets and travel tickets \( x \) times.

\( c \): The production cost of each tour ticket

\( \omega_{m,n} \): The minimum number of trips and the maximum number of trips per day.

\[ (P_2) \]

\[
\min \sum_n \sum_m \sum_d d_{a,x} F^n_{a,x} = \sum_n \sum_m d_{r,x} F^n_{r,x} + \sum_n \sum_m d_{b,x} F^n_{b,x} + \sum_n \sum_m d_{m,x} F^n_{m,x} + \sum_n \sum_m d_{b,x} F^n_{b,x}
\]  
(19)
\[
\begin{align*}
&\text{s.t.} & \sum_d \sum_a \sum_x d_{a,x}^n = D \\
& & d_{a,x}^n \geq 0 \\
& & d_{c,x}^{\text{min}} \leq \sum_d \sum_x d_{c,x}^n \\
& & \sum_t x d_{b,t,x}^n \leq K_b^n \\
& & \sum_t x d_{m,t,x}^n \leq K_m^n
\end{align*}
\]

(20)

\(D\): The total number of tourists.

\(K_b^n\) and \(K_m^n\) respectively represent the maximum capacity of buses and rail transit within \(n\) days.

The decision variables of the upper model are the fare of each tourist ticket valid for days. The decision variables of the lower model are the number of tourists who choose various passenger products to travel, the upper rail transit company controls the fare, and affects the lower passenger product sharing rate.

The Solving Algorithm Urban Rail Transit Ticket Pricing Model—Particle Swarm Optimization

The specific solution steps for the bi-level planning model for rail transit tourist ticket pricing are as follows:

Step1: Initialize PSO parameter
Step2: Population initialization
Step3: Calculate the fitness function value.
Step4: Update the individual extremum and global extremum. Generate the next generation of population \(pop1\).
Step5: Algorithm termination condition
Step6: A set of optimal individuals is output as the fare corresponding to different travel days.

An Example of the Two-layer Planning Pricing Model for Rail Transit Travel Tickets

Parameter Value of the Model

Referring to the situation of tourism and traffic in Beijing, we set up the parameters of the model. The total amount of visitors to Beijing within 7 days is \(\sum_d \sum_t \sum_x d_{a,x}^n = 3260000\). The values of each parameter are shown in the following table.

| Table 1. Tourists’ Preference for Different Travel Factors. |
|-----------------|-----------------|-----------------|
| \(\alpha_1\)    | \(\alpha_2\)    | \(\alpha_3\)    |
| 23.54\%         | 40.52\%         | 35.94\%         |

| Table 2. Value of Single Trip Cost for each Travel Mode [unit: RMB]. |
|-----------------|-----------------|-----------------|
| \(P_c\)         | \(P_b\)         | \(P_T\)         |
| 35.5            | 3               | 4.5             |

| Table 3. Value of Time Value of Travellers in each Travel Mode [unit: RMB/hour]. |
|-----------------|-----------------|-----------------|
| \(\tau_c\)      | \(\tau_b\)      | \(\tau_m\)      |
| 55.23           | 34.56           | 43.18           |
Table 4. Time Cost of the Single Trip of each Travel Mode [unit: RMB].

<table>
<thead>
<tr>
<th></th>
<th>(t_{e,i})</th>
<th>(t_{b,i})</th>
<th>(t_{m,i})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24.37</td>
<td>36.13</td>
<td>23.99</td>
</tr>
</tbody>
</table>

Table 5. Convenience Values of each Travel Mode [unit: RMB].

<table>
<thead>
<tr>
<th></th>
<th>(B_{e,i})</th>
<th>(B_{b,i})</th>
<th>(B_{T,i})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7.04</td>
<td>5.34</td>
<td>9.00</td>
</tr>
</tbody>
</table>

Table 6. Security Values of each Travel Mode.

<table>
<thead>
<tr>
<th></th>
<th>(S_e)</th>
<th>(S_b)</th>
<th>(S_m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.9</td>
<td>0.95</td>
<td>1</td>
</tr>
</tbody>
</table>

Genetic Iterative Graph

Result Analysis

We use Matlab to solve the hybrid particle swarm optimization genetic algorithm for the bi-level planning model of rail transit ticket. Average daily travel ticket for a period of 1 to 7 days is between 13.37 and 20.51 yuan. Compared with the price of a one-way ticket for Beijing rail transit, when the average number of trips per day is more than three times, the tourists can enjoy the discount. The longer the travel distance for tourists, the greater the discount for using the travel ticket. At this fare level, tourist tickets can attract a large
number of tourists. This is consistent with the results of the survey on the purchase of rail travel tickets.

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Product</td>
<td>unit: ten thousand people</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$d_c$</td>
<td>$d_s$</td>
<td>$d_r$</td>
<td>$d_{m_1}$</td>
</tr>
<tr>
<td>24.0588</td>
<td>60.2774</td>
<td>34.8820</td>
<td>206.7818</td>
</tr>
</tbody>
</table>

Table 8. Tourist Ticket Price of 1-7 Days (unit: RMB).

<table>
<thead>
<tr>
<th>$n$</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20.51</td>
</tr>
<tr>
<td>2</td>
<td>34.64</td>
</tr>
<tr>
<td>3</td>
<td>47.89</td>
</tr>
<tr>
<td>4</td>
<td>61.04</td>
</tr>
<tr>
<td>5</td>
<td>74.85</td>
</tr>
<tr>
<td>6</td>
<td>85.44</td>
</tr>
<tr>
<td>7</td>
<td>93.59</td>
</tr>
</tbody>
</table>

Summary

In recent years, traveling abroad has become an important way for people to relax. Convenient and comfortable travel traffic is an important link to enhance the overall travel experience of residents. To guide tourists to choose a reasonable travel mode and improve the service level of rail transit, many domestic and foreign tourism Cities have introduced travel ticket cards designed for tourist groups. Studies abroad have shown that certain volume sales and discount policies can guide tourists to transfer from private transportation to public transport. Your summary/conclusions of your work.

Acknowledgement

Thanks for all authors who have contributed to the development of the paper and the financial support for this project.

References


