Research on Operation Cost-Benefits of China High-Speed Railway

Qing Yang
School of Economics and Management, East China Jiaotong University, Nanchang, China
Email: 576210082@qq.com
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Abstract
At Present, to satisfy the demand of passengers travelling convenience, China's High Speed Railway has entered an unprecedented rapid development period. Under this background, research on operation cost-benefits of china high-speed railway is most important and meaningful. The article concludes the following three parts. The first part is to give the definition of research scope. The second part is to give analysis and evaluation on opening and operation cost-benefits. This part is to give a detailed evaluation indexes system and FAHP calculation model; furthermore, to give an example to illustrate the application of evaluation indexes system and FAHP calculation model. The final part is to give effective suggestions and measures to improve cost-benefits of CRH.

Keywords
China High-Speed Railway, Operation Cost-Benefits, Evaluation Indexes, FAHP Calculation Model, Effective Measures

1. Introduction
At Present, to satisfy the demand of passengers travelling convenience and saving time, Construction of High-Speed Railway to meet the market demand has become a new trend of railway development in China. According to the <Medium and Long-term Railway Network Planning>, by 2020, our country railway mileage will reach 12,000Km, electrification rate will reach 60%. In which, there will eventually form 30,000 high-speed passenger transportation network with newly built 16,000 Km four vertical and four horizontal passenger railway line and existing line renewal [1]. It can tell us a true fact: China’s High Speed Railway has entered an unprecedented rapid development period. Under this background, research on operation cost-benefits of china high-speed railway is most important and meaningful.

The article focuses on comprehensive benefits of high speed railway train with initial letter G, D and C or with speed more than 200 Km/h [2] (see Table 1-1). Comprehensive benefits include social benefits, economic

<table>
<thead>
<tr>
<th>Range of Trains</th>
<th>Range of Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>High speed railway train with initial letter G, D and C or with speed more than 200 Km/h.</td>
<td>Social benefits</td>
</tr>
</tbody>
</table>

benefits and market benefit.

2. Analysis and Evaluation on Operation Cost-Benefits

2.1. Definition and Composition of Comprehensive Benefits

2.1.1. Social Benefits

Social benefits are promoting effects to region economic and trade exchanges, tourism development, the personnel flow and material circulation brought by opening of high speed railway train in origin station, intermediate station and terminal station [3]. This index can be reflect and explained by the following three detailed indexes:

1) **Number of Train N**
   The index is quantity of opening train to transport predict volume of passengers.

2) **Number of Passengers Carried Q**
   \[ Q_p = \sum N_i \cdot A_i \cdot \lambda \]  
   \(N_i\) Denotes the quantity of train of type \(i\)  
   \(A_i\) Denotes the train quota of train of type \(i\)  
   \(\lambda\) Denotes Train Average Attendance Rate

3) **Train Average Transport Mileage l**
   \[ l = \frac{\sum n \cdot I}{\sum n} \]  
   \(\sum n \cdot I\) denotes total mileage of train  
   \(\sum n\) denotes total number of opening train

2.1.2. Economic Benefits

Economic benefits are earnings equaling to the transportation revenue minus the corresponding costs brought by opening of high speed railway train. It can be explained by the following indexes:

1) **Total Transportation Revenue \(I_t\)**
   It is sum of all types of transportation revenue concluding ticket revenue, package revenue, mail revenue and other revenue. The indexes can be calculated by the following formula:
   \[ I_t = \sum N_i \cdot A_i \cdot \lambda \cdot P_i \]  
   \(P_i\) Denotes fare rate of train

2) **Total Transportation Costs \(C_t\)**
   It is sum of all types of transportation costs. The indexes can be calculated simply by the following formula:
   \[ C_t = c \cdot M \cdot M = Q \cdot Ml \]  
   \(c\) denotes unit costs of a person kilometer  
   \(Ml\) denotes average mileage  
   \(M\) denotes total volume of passengers

3) **Train Average Attendance Rate \(\lambda\)**
   \[ \lambda = \frac{\sum N_i \cdot A_i \cdot l}{\sum N_i \cdot A_i \cdot I} \]  
   \(\sum N_i \cdot A_i \cdot l\) Denotes traffic density  
   \(\sum N_i \cdot A_i \cdot I\) Denotes length of interval station  
   \(\lambda\) Denotes average of \(\lambda_k\)

2.1.3. Market Benefits

Market benefits are effects on improvement of railway passenger traffic, increasing of railway competition capacity and strong attractive to potential passenger market [4]. It can be reflected and explained by two types of indexes as follows:

1) **Service Quality Index** It can be divided the following three types:
   ① **Degree of Convenience Index** It is gotten by the experts grading score.
   ② **Degree of Comfort Index** It is also gotten by the experts grading score.
(3) **Departure Frequency Index** It is the percentage of opening train numbers accounts for total train number.

2) **Market Competition Index** It can be divided the following three types:

① **Available Type of Train Index** It is total type available for passengers to choose.

② **Average Service Frequency Index** It is train number allowing to chosen by passengers.

③ **Train Average Speed** It is average speed of opening train which can be gotten by statistics.

### 2.2. Establishment of Evaluation Indexes System

According to the definition and description above-mentioned, a detailed evaluation indexes system of high speed railway is as follows. See Table 2-1.

### 2.3. Selection of Calculation Model

The article takes Fuzzy Analytic Hierarchy Process Method (FAHP) to establish comprehensive calculation model to evaluate the comprehensive benefits of opening CRH. The comprehensive calculation model is as follows [5]. See Formula 2-6, 2-7.

\[
B_2 = W \cdot R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix} = [b_1, b_2, b_3, b_4, b_5] \]  

(Formula 2-6)

\[
Z = B \cdot V^r = [b_1, b_2, b_3, b_4, b_5] \cdot [V_1, V_2, V_3, V_4, V_5]^T \]  

(Formula 2-7)

In the comprehensive calculation model, W denotes weight vector; \( W_i \) denotes weight of No i evaluation index; R denotes total evaluation matrix of n evaluation indexes; B denotes comprehensive evaluation index matrix; \( b_i \) denotes membership of level i.

### 3. Set an Example to Illustrate the Application of Evaluation Indexes and Calculation Model

According to the FAHP Method and Comprehensive Calculation Model, the detailed five evaluation steps applied in M train are as follows:

<table>
<thead>
<tr>
<th>Objective</th>
<th>Detailed Objective</th>
<th>Types of total indexes</th>
<th>Detailed indexes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social benefits</td>
<td>railway traffic volume index</td>
<td></td>
<td>Number of Train</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Number of Passengers Carried</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Train Average Transport Mileage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total transportation Revenue</td>
</tr>
<tr>
<td>Economics benefits</td>
<td>Economic benefits index</td>
<td></td>
<td>Total Transportation Costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Train Attendance Rate</td>
</tr>
<tr>
<td>Comprehensive benefits</td>
<td></td>
<td></td>
<td>Degree of Convenience Index</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Degree of Comfort Index</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Departure Frequency Index</td>
</tr>
<tr>
<td>Market benefits</td>
<td></td>
<td></td>
<td>Available Type of Train Index</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Market Competition Index</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Average Service Frequency Index</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Train Average Speed</td>
</tr>
</tbody>
</table>
3.1. Establish Hierarchical Structure Chart (See Figure 3-1)

![Hierarchical structure chart.](image)

3.2. Establish Fuzzy Complementary Matrix and Weight Calculation

Table 3-1. Fuzzy Complementary Matrix to determine $T$ and $T_1$-$T_4$.

<table>
<thead>
<tr>
<th></th>
<th>$T_1$</th>
<th>$T_2$</th>
<th>$T_3$</th>
<th>$T_4$</th>
<th>$W$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_1$</td>
<td>0.5</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.175</td>
</tr>
<tr>
<td>$T_2$</td>
<td>0.8</td>
<td>0.5</td>
<td>0.6</td>
<td>0.6</td>
<td>0.3125</td>
</tr>
<tr>
<td>$T_3$</td>
<td>0.7</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
<td>0.275</td>
</tr>
<tr>
<td>$T_4$</td>
<td>0.6</td>
<td>0.4</td>
<td>0.4</td>
<td>0.5</td>
<td>0.2375</td>
</tr>
</tbody>
</table>

Table 3-2. FCM to determine $T_1$ and $T_{11}$-$T_{13}$.

<table>
<thead>
<tr>
<th></th>
<th>$T_{11}$</th>
<th>$T_{12}$</th>
<th>$T_{13}$</th>
<th>$W_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{11}$</td>
<td>0.5</td>
<td>0.3</td>
<td>0.6</td>
<td>0.321</td>
</tr>
<tr>
<td>$T_{12}$</td>
<td>0.7</td>
<td>0.5</td>
<td>0.7</td>
<td>0.383</td>
</tr>
<tr>
<td>$T_{13}$</td>
<td>0.4</td>
<td>0.3</td>
<td>0.5</td>
<td>0.296</td>
</tr>
</tbody>
</table>

Table 3-3. FCM to determine $T_2$ and $T_{21}$-$T_{23}$.

<table>
<thead>
<tr>
<th></th>
<th>$T_{21}$</th>
<th>$T_{22}$</th>
<th>$T_{23}$</th>
<th>$W_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{21}$</td>
<td>0.5</td>
<td>0.7</td>
<td>0.5</td>
<td>0.358</td>
</tr>
<tr>
<td>$T_{22}$</td>
<td>0.3</td>
<td>0.5</td>
<td>0.3</td>
<td>0.284</td>
</tr>
<tr>
<td>$T_{23}$</td>
<td>0.5</td>
<td>0.7</td>
<td>0.5</td>
<td>0.358</td>
</tr>
</tbody>
</table>
Table 3-4. FCM to determine T₃ and T₃₁-T₃₃.

<table>
<thead>
<tr>
<th>T₃</th>
<th>T₃₁</th>
<th>T₃₂</th>
<th>T₃₃</th>
<th>W₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₃₁</td>
<td>0.5</td>
<td>0.4</td>
<td>0.6</td>
<td>0.333</td>
</tr>
<tr>
<td>T₃₂</td>
<td>0.6</td>
<td>0.5</td>
<td>0.7</td>
<td>0.371</td>
</tr>
<tr>
<td>T₃₃</td>
<td>0.4</td>
<td>0.3</td>
<td>0.5</td>
<td>0.296</td>
</tr>
</tbody>
</table>

Table 3-5. FCM to determine T₄ and T₄₁-T₄₃.

<table>
<thead>
<tr>
<th>T₄</th>
<th>T₄₁</th>
<th>T₄₂</th>
<th>T₄₃</th>
<th>W₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₄₁</td>
<td>0.5</td>
<td>0.3</td>
<td>0.4</td>
<td>0.296</td>
</tr>
<tr>
<td>T₄₂</td>
<td>0.7</td>
<td>0.5</td>
<td>0.6</td>
<td>0.371</td>
</tr>
<tr>
<td>T₄₃</td>
<td>0.6</td>
<td>0.4</td>
<td>0.5</td>
<td>0.333</td>
</tr>
</tbody>
</table>

3.3. Determining Membership of Evaluation Index and Judgment Matrix

\[
R_{1} = \begin{bmatrix} 0.324 & 0.394 & 0.282 & 0 & 0 \\ 0.335 & 0.404 & 0.261 & 0 & 0 \\ 0.328 & 0.417 & 0.255 & 0 & 0 \end{bmatrix},
R_{2} = \begin{bmatrix} 0.325 & 0.380 & 0.295 & 0 & 0 \\ 0.371 & 0.369 & 0.284 & 0.026 & 0 \\ 0.302 & 0.378 & 0.320 & 0 & 0 \end{bmatrix},
R_{3} = \begin{bmatrix} 0.392 & 0.405 & 0.190 & 0.013 & 0 \\ 0.294 & 0.375 & 0.331 & 0 & 0 \\ 0.351 & 0.402 & 0.247 & 0 & 0 \end{bmatrix},
R_{4} = \begin{bmatrix} 0.360 & 0.386 & 0.254 & 0 & 0 \\ 0.295 & 0.370 & 0.335 & 0 & 0 \\ 0.401 & 0.378 & 0.221 & 0 & 0 \end{bmatrix}\]

3.4. Establish Comprehensive Evaluation Model

\[
B_{i} = W_{i} \cdot R_{i} = \begin{bmatrix} 0.324 & 0.394 & 0.282 & 0 & 0 \\ 0.335 & 0.404 & 0.261 & 0 & 0 \\ 0.328 & 0.417 & 0.255 & 0 & 0 \end{bmatrix},
B_{1} = W_{1} \cdot R_{1} = \begin{bmatrix} 0.321 & 0.383 & 0.296 \\ 0.328 & 0.417 & 0.255 & 0 & 0 \end{bmatrix},
B_{2} = W_{2} \cdot R_{2} = \begin{bmatrix} 0.358 & 0.283 & 0.358 \end{bmatrix},
B_{3} = W_{3} \cdot R_{3} = \begin{bmatrix} 0.333 & 0.371 & 0.296 \end{bmatrix},
B_{4} = W_{4} \cdot R_{4} = \begin{bmatrix} 0.296 & 0.371 & 0.333 \end{bmatrix},
B = W \cdot R = \begin{bmatrix} 0.175 & 0.3125 & 0.275 & 0.2375 \end{bmatrix}\]
3.5. Calculate Comprehensive Evaluation Value

\[
Z^{(1)} = B^{(1)} \cdot \nu^T = \begin{bmatrix} 0.3294 & 0.4046 & 0.2660 & 0 & 0 \\ 0.3153 & 0.3758 & 0.3005 & 0.007 & 0 \\ 0.3435 & 0.3930 & 0.2592 & 0.004 & 0.334 \\ 0.3495 & 0.3774 & 0.2731 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 0.334 & 0.386 & 0.277 & 0.003 & 0 \end{bmatrix}
\]

According to the comprehensive evaluation value, the M train gets 7.102 score. It indicate that M train’s comprehensive benefit is more than middle-level.

4. Conclusion

In conclusion, China’s High Speed Railway has gradually become the main and important mode of transportation in railway enterprise. Under the background, the objects of opening and operation of high speed railway is pursuit of maximum comprehensive benefits, which including social benefits, economic benefits and market benefits. Based on the three parts benefits, the article establishes a comprehensive evaluation indexes system and to further set an example to verify it taking the FAHP (Fuzzy Analytic Hierarchy Process) Calculation Model, it proves that comprehensive evaluation indexes system is reliable and feasible and high speed railway train should pursue comprehensive benefits. For this purpose, some effective measures to improve comprehensive benefits of CRH should be taken. Optimizing the opening plan of CRH, Improving transportation revenues based on flexible pricing strategy, strengthen costs control, actively expanding the market and improving service quality, which are all effective measures [6].

References