Analysis of Passenger Satisfaction for Bus Line Based on Analytic Hierarchy Process

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Abstract. Public transportation is the first choice for people to travel nowadays. According to the principle of analytic hierarchy process, the problem of multi-criteria is systematized. Passengers compare several schemes and choose the best route to maximize passenger satisfaction.

Introduction

With the continuous improvement of China’s economic level and comprehensive national strength, national strength has become stronger and stronger, and the construction of public transportation has also developed rapidly. Urban public transport is not only to satisfy citizens’ travel, but also to some extent reflect the level of development of the city and the living conditions of local residents[1]. The development of public transport is the most measure to solve urban traffic congestion[2]. Bus-only lanes have been introduced in most large and medium-sized cities, which make people travel more convenient. When passengers may choose multiple bus lines to travel, they will choose the most satisfying line according to needs. However, each line has its own advantages and disadvantages. For example, people do not need to transfer but need to wait buses for a long time in some lines; people may wait buses for short time in some lines, but it takes a long time to walk to the destination. So it is necessary to comprehensively consider various factors to select more satisfactory lines[3].

The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then[4]. And a multi-objective comprehensive evaluation method, proposed a hierarchical weight decision analysis method[5]. Applying this method, the decision makers decompose the complex problem into several levels and several factors, calculate and compare the mathematical models between the factors, and obtain the weights for different plans to provide the basis for selecting the best decision. The basic steps are shown in Fig. 1[6].
About Bus Lines

Considering actual situation, we are starting from the west gate of Shenyang University to the Shifu Square. Five bus lines are available to be chosen for passengers, and then the paper analyzes which route to choose by using analytic hierarchy process.

Five bus lines are as follows:

- **C1**: bus No.159. People need to walk 208 meters with long waiting time, and the bus passes through 4 stations and the total travel time is about 38 minutes;
- **C2**: transfer from bus No.163 to bus No.265. People need to walk 796 meters with normal waiting time, and the bus passes through 5 stations and the total travel time is about 39 minutes;
- **C3**: bus No.212. People need to walk 1.3 kilometers with short waiting time, and the bus passes through 4 stations and the total travel time is about 36 minutes;
- **C4**: transfer from bus No.212 to bus No.221. People need to walk 245 meters with normal waiting time, and the bus passes through 5 stations and the total travel time is about 34 minutes;
- **C5**: transfer from bus No.131 to bus No.248. People need to walk 319 meters with normal waiting time, and the bus passes through 5 stations and the total travel time is about 38 minutes;

There are three waiting periods for waiting time: short waiting time is less than 10 minutes; normal waiting time is usually 10-20 minutes; long waiting time is longer than 20 minutes.

Establishing a Hierarchy Structure Chart

The analytic hierarchy process divides the factors involved in decision making into the following categories. The structural system of the problem is described by a hierarchical structure chart, as shown in Fig. 2.

- **Target layer A**: satisfaction line for passengers;
- **Criterion layer B**: B1 for walking time; B2 for comfort; B3 for running time; B4 for waiting time; B5 for less transfer;
- **Plan layer C**: C1, C2, C3, C4, C5

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**Figure 1. Step flow chart.**
Hierarchy Single Sorting

Analytic Hierarchy Process (AHP) is a method to analyze the evaluation target layer by layer, refine indexes, evaluate relevant indicators, and multiply the corresponding weight value to reach the final conclusion[7]. Importance degree of each factor for different passengers is different. There are two main types of passengers.

Not in a hurry: B4 > B2 > B1 > B3 > B5;
Rush: B4 > B3 > B1 > B5 > B2.

Assuming that passengers in this paper is the first one, that is, people are not in a hurry. Then the ranking of the criterion layer with respect to the target layer is B4 > B2 > B1 > B3 > B5. For each criterion, the evaluation value of each bus scheme is given, which constitutes a criterion corresponding to the judgment matrix of each bus scheme, and the corresponding weight value is obtained.

Establishment of Index Weights

Structure of the Judgment Matrix

The relative importance of the factors in the layer to a certain factor of the upper layer can be expressed by a judgment matrix. Assuming that passengers is not in a hurry, according to the score scale given by T.L. Saaty[7] shows the judgment matrix of B1-B5 relative to the target layer A, as shown in Table 1.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The two factors are of equal importance</td>
</tr>
<tr>
<td>3</td>
<td>One is slightly more important than the other</td>
</tr>
<tr>
<td>5</td>
<td>One is obviously more important than the other</td>
</tr>
<tr>
<td>7</td>
<td>One is highly more important than the other</td>
</tr>
<tr>
<td>9</td>
<td>One is extremely more important than the other</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>The median of the above two adjacent judgments</td>
</tr>
</tbody>
</table>

If the waiting time is obviously more important than the comfort, B4/B2 = 3, and the specific scales of other items are shown in Table 2.
Table 2. B1-B5 Five order judgment matrix and its relative weight vector.

<table>
<thead>
<tr>
<th></th>
<th>B1 Walking time</th>
<th>B2 Comfort level</th>
<th>B3 Running time</th>
<th>B4 Waiting time</th>
<th>B5 Less transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>1</td>
<td>1/3</td>
<td>3</td>
<td>1/5</td>
<td>5</td>
</tr>
<tr>
<td>B2</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>1/3</td>
<td>7</td>
</tr>
<tr>
<td>B3</td>
<td>1/3</td>
<td>1/5</td>
<td>1</td>
<td>1/7</td>
<td>3</td>
</tr>
<tr>
<td>B4</td>
<td>5</td>
<td>3</td>
<td>7</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>B5</td>
<td>1/5</td>
<td>1/7</td>
<td>1/3</td>
<td>1/9</td>
<td>1</td>
</tr>
</tbody>
</table>

Calculating Relative Weights between Indicators and Verifying Consistency

Example of Calculation of Judgment Matrix Weights is shown Table 3.

Table 3. Example of Calculation of Judgment Matrix Weights.

<table>
<thead>
<tr>
<th></th>
<th>Geometric mean</th>
<th>Weights $\omega$</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>$\frac{1}{1} \times \frac{1}{3} \times 3 \times \frac{1}{5} \times 5 = 1.0000$</td>
<td>1.0000/7.7176=0.1296</td>
</tr>
<tr>
<td>B2</td>
<td>$\frac{3}{3} \times 1 \times 5 \times \frac{1}{3} \times 7 = 2.0362$</td>
<td>2.0362/7.7176=0.2638</td>
</tr>
<tr>
<td>B3</td>
<td>$\frac{1}{3} \times \frac{1}{5} \times 1 \times \frac{1}{7} \times 3 = 0.4911$</td>
<td>0.4911/7.7176=0.0636</td>
</tr>
<tr>
<td>B4</td>
<td>$\frac{5}{5} \times \frac{3}{3} \times 7 \times 1 \times 9 = 3.9363$</td>
<td>3.9363/7.7176=0.5100</td>
</tr>
<tr>
<td>B5</td>
<td>$\frac{1}{5} \times \frac{1}{7} \times \frac{1}{3} \times \frac{1}{9} \times 1 = 0.2540$</td>
<td>0.2540/7.7176=0.0329</td>
</tr>
</tbody>
</table>

Consistency checking: Since various factors of the judgment matrix are determined based on experience, it is inevitable that one-sidedness will occur. Therefore, to avoid this one-sidedness error, it is necessary to check the consistency of the judgment matrix and check its correctness. The specific test method is: using random consistency ratio $CR = CI/RI$, when $CR<0.1$, the judgment matrix has a satisfactory consistency, that is, the weight calculation is correct. $CI = \frac{\lambda_{max} - n}{n-1}$, $RI$ is the average random consistency indicator, T.L. Saaty gives the specific corresponding value, as Table 4 is shown:

Table 4. Index Values of Average Random Consistency for 1-9 Order Matrices.

<table>
<thead>
<tr>
<th>Degree</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>0.00</td>
<td>0.00</td>
<td>0.58</td>
<td>0.90</td>
<td>1.12</td>
<td>1.24</td>
<td>1.32</td>
<td>1.41</td>
<td>1.45</td>
</tr>
</tbody>
</table>

Firstly, the maximum eigenvalue $\lambda_{max}$, $\lambda_{max} = \sum_{i=1}^{n} \frac{(a_{ii})^n}{\alpha}$ of the judgment matrix is obtained, that is, the product of the judgment matrix $A$ and the evaluation index weight $\omega$ of each passenger satisfaction for bus line. The formula for calculating $A\omega$ in Table 2 is as follows:

$A\omega = \begin{bmatrix} 1 & 1/3 & 3 & 1/5 & 5 \\ 3 & 1 & 5 & 1/3 & 7 \\ 1/3 & 1/5 & 1 & 1/7 & 3 \\ 5 & 3 & 7 & 1 & 9 \\ 1/5 & 1/7 & 1/3 & 1/9 & 1 \end{bmatrix} \begin{bmatrix} 0.1296 \\ 0.2638 \\ 0.0636 \\ 0.5100 \\ 0.0329 \end{bmatrix} = \begin{bmatrix} 0.6750 \\ 1.3712 \\ 0.3312 \\ 2.6911 \\ 0.1744 \end{bmatrix}$\quad (1)

Substituting the formula $\lambda_{max} = 5.23719$, so $CI = 0.0593$, $CR = 0.0529 < 0.1$, in line with the requirements, this judgment matrix has a more satisfactory consistency. According to the above method, the judgment matrix of $C1-C5$ with respect to $B1$ is calculated, and the consistency checking is performed, and the following results are obtained in Table 5. The calculation method of the judgment matrix of $C1-C5$ with respect to the other four criteria is the same as that described above, and will not be described here.
Table 5. C1-C5 Relative to B1 Judgment Matrix and Relative Weight Vectors.

<table>
<thead>
<tr>
<th>B1 walking time</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>Ao</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>1</td>
<td>3</td>
<td>9</td>
<td>7</td>
<td>5</td>
<td>2.7102</td>
</tr>
<tr>
<td>C2</td>
<td>1/3</td>
<td>1</td>
<td>7</td>
<td>5</td>
<td>2</td>
<td>1.2550</td>
</tr>
<tr>
<td>C3</td>
<td>1/9</td>
<td>1/7</td>
<td>1</td>
<td>1/3</td>
<td>1/5</td>
<td>0.1753</td>
</tr>
<tr>
<td>C4</td>
<td>1/7</td>
<td>1/5</td>
<td>3</td>
<td>1</td>
<td>1/3</td>
<td>0.3340</td>
</tr>
<tr>
<td>C5</td>
<td>1/5</td>
<td>1/2</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>0.7266</td>
</tr>
</tbody>
</table>

$\lambda_{max}=5.1933$, $CR=0.0431 < 0.1$. This judgment matrix has more satisfactory consistency.

Total Ordering

Weight values of every layer relative to the previous layer are calculated, and the following steps are used to calculate the weight of the under layer in the overall target. The final ranking of the quantified results is to obtain the importance of its relative total goal. The results are as follows:

\[
\begin{bmatrix}
0.5150 & 0.0436 & 0.1111 & 0.0655 & 0.3333 \\
0.2456 & 0.2285 & 0.1111 & 0.1896 & 0.1111 \\
0.0332 & 0.0889 & 0.2222 & 0.3656 & 0.3333 \\
0.0643 & 0.4104 & 0.4444 & 0.1896 & 0.1111 \\
0.1419 & 0.2285 & 0.1111 & 0.1896 & 0.1111
\end{bmatrix}
\begin{bmatrix}
0.1297 \\
0.1996 \\
0.2394 \\
0.2452 \\
0.1861
\end{bmatrix} =
\begin{bmatrix}
0.1297 \\
0.1996 \\
0.2394 \\
0.2452 \\
0.1861
\end{bmatrix}
\]

The order of the total level is $C4>C3>C2>C5>C1$. Therefore, the most satisfactory route for passengers who are not in a hurry is $C4$, that is, transfer from bus No.212 to bus No.221.

Summary

The actual case is given, and five bus lines are analyzed by using analytic hierarchy process from five aspects, including waiting time, comfort, walking time, running time and little change, which can help passengers choose satisfactory bus lines.

Acknowledgements

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References

[1] Zhao Linhui. The Comparison and Promotion Recommendations of the Satisfaction on Tiajin Public Transportation Service—Taking the Buses and Subways as an Instance[D]. Tianjin University of Commerce China


