Application of Fuzzy Analytic Hierarchy Process in The Optimization of Railway Schemes

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Abstract. The rapid development of economy is inseparable from the continuous construction of railways. Railway selection as the most important link in project construction must meet the requirements of national politics, economy and national defense. In this paper, the fuzzy analytic hierarchy process is used to take The Xuyong-Bijie Railway as an example to establish an evaluation system and calculate the evaluation grades of each index. The application of this method in the optimization of railway scheme can provide reference for actual route decision, and also verify the applicability and superiority of fuzzy analytic hierarchy process in railway line selection.

1. Introduction

In recent years, railway transportation laid a good foundation for economic activities. It has provided a carrier for the rational allocation of various resources in a wide space with its long distance and large-scale intensive [1]. For this reason, the state has always emphasized the acceleration of the construction and development of railways. However, in the process of building a railway project, the correct choice of the route plan is directly related to the quality of the project and the operational effects, even the national politics, economy and national defense.

The Xuyong-Bijie Railway is an important part of the Longchang-Yubao Railway. It is located at the junction of Sichuan, Yunnan and Guizhou provinces. This railway passes through three geomorphic units, which are the hills, the middle and low mountains, and the Yunnan-Guizhou Plateau. There are three schemes in the railway design: the east line, the middle line and the west line, and there are different landforms and large influencing factors among them.

Many domestic scholars have conducted a variety of methods for the comparison of line schemes. For example, Yiliang Zhou combined with the design process of railway line selection, proposed the extension method for each stage of railway line selection design [2]. Yuanfu Li gave an evaluation index system for the comprehensive optimization system of railway line selection design, which has very important reference and guiding significance for solving practical engineering problems [3]. Xiaoping Wu established a model that can assist the economic evaluation method to obtain more comprehensive evaluation results, thus providing a new method for comprehensive evaluation and investment decision-making of railway programs [4].

Based on the analytic hierarchy process, the weights of the index factors at various levels of the line plan are calculated. After that, this paper takes the mid-line plan as an example to calculate the scores of different lines. It is providing a reference for making decisions by comparing the scores of
the three lines with the evaluation set, and reflecting the advantages and disadvantages of different programs.

2. Fuzzy analytic hierarchy process

The fuzzy analytic hierarchy process is a method that combines the fuzzy comprehensive evaluation method with the analytic hierarchy process\(^5\). Firstly, establish the factor set and the evaluation set. Then, the analytic hierarchy process is used to calculate the weight value of each evaluation factor to the evaluation object. Finally, the comprehensive evaluation result could be obtained through the fuzzy evaluation method.

The comprehensive evaluation method converts the qualitative evaluation into quantitative evaluation according to the fuzzy mathematics. It can deal with multi-factor and fuzziness, so that is suitable for railway scheme selection. Therefore, the scores of the three route schemes of The Xuyong-Bijie Railway are calculated and compared with the evaluation set, which can reflect the advantages and disadvantages of different schemes.

2.1. Specific evaluation steps

1) A set of factors is established. The various influencing factors \(u_i (i = 1, 2, ..., n)\) that influence the object of judgment are grouped as elements, that is, \(U = \{u_1, u_2, ..., u_n\}\).

2) An evaluation set is established. A set of various evaluation results that may be made by the evaluation object \(v_i (i = 1, 2, ..., m)\), namely: \(V = (v_1, v_2, ..., v_m)\).

3) A weight set is established. Determine the relative weight of each factor by using the analytic hierarchy process and the expert scoring method. Weight set: \(W = (w_1, w_2, ..., w_n)\) satisfies:

\[
\sum_{i=1}^{n} w_i = 1 
\]

(1)

4) A single factor judgment matrix is established. Use the expert evaluation score to generate the judgment matrix \(R = (r_{ij})_{n \times m} (i = 1, 2, ..., n, j = 1, 2, ..., m)\). Where \(r_{ij}\) denotes the membership of factor \(u_i\) for decision \(v_j\), and \(R_i = (r_{i1}, r_{i2}, ..., r_{im}, i = 1, 2, ..., n)\) is the fuzzy subset on the evaluation set.

2.2. First-level fuzzy comprehensive evaluation

1) The commonly used fuzzy comprehensive evaluation model has large size and large product, etc. This study adopts large size and small size, namely:

\[
B = \{b_j = \bigvee_{i=1}^{n} (w_i \land r_{ij}) | (j = 1, 2, ..., m)\} 
\]

(2)

2) After \(b_j\) is obtained, the result \(V_j\) of the judgment is determined according to the maximum membership degree rule.

2.3. Multi-level fuzzy comprehensive evaluation

In this article, the elements in the factor set \(U\) are divided into two levels, which are calculated from the low level to the high level. It means that a fuzzy comprehensive evaluation of each level is carried out first, and then the fuzzy evaluation operation is performed on the upper level until the final evaluation result is obtained.

3. Comprehensive evaluation of the line selection scheme

During the selection process of line plan, there are many influencing factors that cannot be quantitatively described, and most rely on the judgment of the professional or the decision of the leader. As the Delphi method has the characteristics of sufficient resource utilization and good uniformity, this method is adopted\(^6\). After designing expert questionnaires, multiple comparisons and comprehensive analysis, the final score of different schemes could be determined.

3.1. Expert assessment process

1) Create a team of experts. According to the scope of the profession, the project team selected a group of 10 experts with rich decision-making experience to form an expert group.
2) Design expert questionnaire. Design the expert questionnaire will meeting the project requirements, and attached the line survey data to the table, finally get the experts’ written reply.

3) Collect and summarize the first-round opinions of the expert group. Make and compare a chart, then return the result to the experts and make the revision of the opinions again.

4) Repeat the summary and collate the opinions of the experts, then distribute and modify the opinions again (collect and modify a total of four rounds) until the opinions of these experts are no longer changed.

5) Analyze the expert's opinion and get the final evaluation result.

After the above process, the factors that ultimately influence the decision-making of The Xuyong-Bijie Railway schemes are mainly divided into four categories: technology, economy, environment and society. On this basis, the weights shown in Table 1 are calculated using the evaluation index system and the analytic hierarchy process.

Table 1. The Xuyong-Bijie Railway mid-line scheme evaluation index system and weight

| Primary indicator          | Secondary indicators                                      | Index                  | Weights |
|----------------------------|----------------------------------------------------------|------------------------|---------|
| Technology u₁              | Total length of line u₁₁                                 | w₁₁=0.154              |         |
|                            | Minimum curve radius u₁₂                                 | w₁₂=0.029              |         |
|                            | Number of major projects u₁₃                               | w₁₃=0.229              |         |
|                            | Number of demolition projects u₁₄                          | w₁₄=0.344              |         |
|                            | Curve length u₁₅                                          | w₁₅=0.244              |         |
|                            | Demolition costs u₁₆                                       | w₁₆=0.323              |         |
| Economic u₂                | Engineering investment u₂₃                                 | w₂₃=0.314              |         |
|                            | Operating expenses u₂₂                                     | w₂₂=0.021              |         |
|                            | Promoting the economy u₂₄                                 | w₂₄=0.342              |         |
|                            | Occupied farmland area u₂₅                                | w₂₅=0.293              |         |
| Environment u₃             | Destroy forest area u₃₃                                     | w₃₃=0.172              |         |
|                            | Destruction of environment along the line u₃₄              | w₃₄=0.304              |         |
|                            | Geological terrain u₃₅                                     | w₃₅=0.231              |         |
|                            | National defense and political significance u₃₄           | w₃₄=0.129              |         |
| Society u₄                 | Improve industrial layout u₄₂                              | w₄₂=0.106              |         |
|                            | Impact on planning through the city u₄₃                   | w₄₃=0.442              |         |
|                            | The layout significance of the railway u₄₄                | w₄₄=0.323              |         |

3.2. Identify the influencing factors

This study considers the influence degree of various factors on the decision of the whole line scheme, and finally divides the evaluation into five grades, namely $V = (v_1, v_2, v_3, v_4, v_5) = (\text{very poor, poor, general, good, very good})$, and give the corresponding score 1~5, as shown in Table 2. Therefore, the influence value of the influencing factor can be obtained $K: K = B \times S^T$, where: $S = (5, 4, 3, 2, 1)$.

Table 2. Impact indicator evaluation set

| Program evaluation Score | Very poor 1 | Poor 2 | General 3 | Good 4 | Very good 5 |
|--------------------------|-------------|-------|-----------|--------|-------------|

3.3. Perform fuzzy comprehensive evaluation

1) Through the statistics of the questionnaire, the evaluation level can be obtained. Take u₁₁ as an example: the number of very good evaluation grades is 3, the number of good evaluation grades is 3, the number of general evaluation grades is 4, the numbers of poor and very poor evaluation grades are 0. After the normalization, the u₁₁ single factor evaluation vector $R_{u₁₁}$ can be obtained:

$$R_{u₁₁} = (0.3, 0.3, 0.4, 0.0, 0.0)$$

2) Create an evaluation model by influencing the factors affecting the centerline scheme of The Xuyong-Bijie Railway, and construct a fuzzy relationship matrix $R$ to establish a fuzzy relation matrix
3) First-level fuzzy evaluation: The first-line fuzzy evaluation of the influential factors in the mid-line scheme of the Xuyong-Bijie Railway is selected, and the single factor evaluation level is obtained.

Total score for u1:
\[
B_1 = W_1 R_1 = \begin{bmatrix} 0.054 \\ 0.129 \\ 0.344 \\ 0.244 \end{bmatrix}^T \begin{bmatrix} 0.0 & 0.3 & 0.4 & 0.0 \\ 0.0 & 0.2 & 0.3 & 0.2 \\ 0.1 & 0.4 & 0.1 & 0.4 \\ 0.0 & 0.1 & 0.5 & 0.4 \end{bmatrix} = \begin{bmatrix} 0.27 \\ 0.40 \\ 0.17 \\ 0.10 \end{bmatrix} \]

\[K_1 = B_1 \times ST = 3.724\]

K1 = B1 × ST = 3.724, and the technical factors were evaluated as “general” in the comparison of the mid-line plan of the Xuyong-Bijie Railway.

Total score for u2:
\[
B_2 = W_2 R_2 = \begin{bmatrix} 0.232 \\ 0.021 \\ 0.314 \\ 0.342 \end{bmatrix}^T \begin{bmatrix} 0.4 & 0.3 & 0.2 & 0.1 \\ 0.5 & 0.2 & 0.3 & 0.1 \\ 0.4 & 0.4 & 0.2 & 0.0 \\ 0.4 & 0.2 & 0.3 & 0.0 \end{bmatrix} = \begin{bmatrix} 0.40 \\ 0.30 \\ 0.24 \\ 0.03 \end{bmatrix} \]

K2 = B2×ST= 3.999, the economic factor is evaluated as “general” in the comparison of the mid-line scheme of the Xuyong-Bijie Railway.

Total score for u3:
\[
B_3 = W_3 R_3 = \begin{bmatrix} 0.293 \\ 0.172 \\ 0.304 \\ 0.231 \end{bmatrix}^T \begin{bmatrix} 0.5 & 0.2 & 0.1 & 0.1 \\ 0.3 & 0.4 & 0.3 & 0.0 \\ 0.4 & 0.3 & 0.3 & 0.0 \\ 0.4 & 0.3 & 0.2 & 0.1 \end{bmatrix} = \begin{bmatrix} 0.41 \\ 0.29 \\ 0.22 \\ 0.05 \end{bmatrix} \]

K3 = B3×ST=4.001, the environmental factors scored higher during the comparison of the mid-line scheme of the Xuyong-Bijie Railway, which is “good”.

Total score for u4:
\[
B_4 = W_4 R_4 = \begin{bmatrix} 0.129 \\ 0.106 \\ 0.442 \\ 0.323 \end{bmatrix}^T \begin{bmatrix} 0.4 & 0.3 & 0.3 & 0.0 \\ 0.5 & 0.4 & 0.1 & 0.0 \\ 0.4 & 0.4 & 0.1 & 0.0 \\ 0.5 & 0.3 & 0.1 & 0.0 \end{bmatrix} = \begin{bmatrix} 0.44 \\ 0.35 \\ 0.13 \\ 0.03 \end{bmatrix} \]

K4 = B4×ST = 4.120, social factors are more prominent in the comparison of the mid-line scheme of the Xuyong-Bijie Railway, and the evaluation level is “good”.

4) The second-level fuzzy evaluation: the second-level fuzzy assessment of the influencing factors in the comparison process of the mid-line scheme can obtain the overall risk score of the scheme.

\[
B = W_2 R = W_2 T R_2 = \begin{bmatrix} 0.134 \\ 0.132 \\ 0.326 \\ 0.408 \end{bmatrix} = \begin{bmatrix} 0.27 \\ 0.40 \\ 0.29 \\ 0.41 \end{bmatrix} \]

\[K = B \times ST = 4.012\]

After the overall risk assessment, it is concluded that the mid-line evaluation level
of The Xuyong-Bijie Railway scheme is “good”.

In this article, the same method is used to score the east and west lines of The Xuyong-Bijie Railway. The east-line scheme scores 3.025 while the west-line scheme scores 3.231, that means, the evaluation grades are all “general”. It is consistent with the selection of the mid-line scheme in the actual project construction.

3.4. Analysis of program evaluation
From the analysis of engineering geological conditions, the east-line and the west-line schemes bring greater impact on the mining area compared with the mid-line scheme. From the investment analysis and operating expenses, the east-line scheme is more economical than the mid-line scheme which is in the middle. From the perspective of advantageous local economic development analysis, the mid-line scheme fully considers the local opinions and planning arrangements in the selection of relevant sites. And it also promotes the economic development of the adjacent two counties.

There are distinct advantages and disadvantages of each of the three line schemes. Through the fuzzy analytic hierarchy method, the midline scheme is the most superior in the feasibility of the three schemes. This is consistent with the results of the actual engineering selection.

4. Conclusion
Based on the fuzzy analytic hierarchy process, the project carried out a comprehensive evaluation of the actual project case, the east-line, the mid-line and the west-line of The Xuyong-Bijie Railway, and achieved relatively reliable results. The evaluation result of the east-line is 3.025, the result of the mid-line is 4.012, and the result of the west-line is 3.231. Comparing the results, it is concluded that the engineering geological conditions of the mid-line scheme are reliable, the engineering risk are small. And the investment benefit of mid-line is good, which meets with the actual engineering decision. This fully demonstrates that the proposed line plan evaluation system and the adopted analytic hierarchy process and fuzzy comprehensive theory are reasonable and scientific. It can provide guidance and reference for practical engineering decision-making, and have certain application value. According to the consistency of evaluation results and actual engineering selection of three lines, it can be seen that in the study of railway route schemes, the social effects of them should be fully considered. Combining the economic, industrial structure and development planning of the cities that have passed through, the projects can make a comprehensive evaluations and decisions.

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