Comprehensive evaluation of construction effect of small and medium sized water conservancy projects during construction stage based on FAHP

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Abstract: With the development of water conservancy projects, evaluation of water conservancy projects has become an indispensable link. The article selects 16 evaluation indexes from four aspects of construction safety, construction quality, construction management and construction environment, and uses fuzzy analytic hierarchy process to establish the construction effect evaluation model of medium and small water conservancy projects in the construction stage, and applies the evaluation model to the construction effect evaluation of Ma Xiongou II Hydropower Station. The results show that the evaluation grades in four aspects are good, excellent, good and medium, and the overall construction effect rating is good. The model is well applied in this case and is in good agreement with the actual situation. Finally, some suggestions are put forward for the construction enterprises, such as improving the management system of enterprises, improving the overall level of enterprise management, especially the environmental protection, and reducing the noise pollution in the construction process.

1. Introduction
In recent years, large scale water conservancy projects have been decreasing, and small and medium-sized water conservancy projects have become the main trend of development[1]. Small and medium-sized water conservancy project evaluation has also become a hot spot of some scholars. The construction stage of water conservancy project is an important part of the construction project of water conservancy project. It has the characteristics of complex process, large personnel participation and high risk[2]. It can guarantee the quality and benefit of water conservancy project by holding the construction stage.

The evaluation of the construction stage of water conservancy project is an important part of self-evaluation and self-examination during the construction process. The evaluation of the construction process can be used to find out the shortcomings and problems in the construction process[3]. It is also the affirmation of some aspects of the work. The key to its evaluation lies in the construction of evaluation indexes and the formulation of evaluation criteria[4]. For example, Shu Chen[5] selected 47 comprehensive evaluation indexes from 13 aspects, such as safety production target, and divided the evaluation grade into five grades by using maturity evaluation model, and then comprehensively evaluated the construction safety of water conservancy and hydropower projects, and verified the effectiveness of the method through the case. Jing Li[6] et al from three aspects of environmental protection, energy and resource utilization and comprehensive management choose 31
evaluation indexes as green construction evaluation system for water conservancy and hydropower projects, and use fuzzy matter-element method to evaluate the green construction of small and medium water conservancy and hydropower projects, and apply the model to the project of Crane beach hydropower station. The results of the comprehensive evaluation are qualified. Wei Zhang[7] selected 39 evaluation indexes as evaluation system from 7 aspects of the three stages of construction project preparation, project construction and project completion. The fuzzy comprehensive evaluation method was used to evaluate the construction quality of small and medium water conservancy and hydropower projects. The results show that the fuzzy comprehensive evaluation method can be better used in the small and medium-sized water conservancy and hydropower engineering construction quality evaluation.

The above scholars use the maturity evaluation method, fuzzy matter element method and fuzzy comprehensive evaluation method to evaluate the construction process of water conservancy project from three aspects: safety, green and quality of water conservancy and hydropower projects. This paper will make a comprehensive evaluation of the construction effect in the construction stage of small and medium water conservancy and hydropower projects by using Fuzzy Analytic Hierarchy Process (FAHP) from security, quality, economic and other aspects.

2. Comprehensive Evaluation Model of Construction Effect in Construction Stage of Water Conservancy Project

This study is aimed at the evaluation of the construction effect of small and medium sized water conservancy and hydropower projects in the construction stage, and carries out a comprehensive evaluation by using FAHP. FAHP[8] is based on the improvement of AHP model.

(1) Establishing hierarchical structure and judgment matrix

1) Combining the characteristics of water conservancy project and the principle of selecting evaluation index[9], the evaluation index system of construction effect in construction stage of medium and small water conservancy and hydropower project is established.

2) The evaluation of the model is generally divided into three evaluation indexes: the target layer, the criterion layer and the sub-criterion layer. The hierarchical structure[10] reflects the relationship between the evaluation indexes of the construction effect of water conservancy and hydropower projects, but the proportions of the criteria in the criteria layer are not necessarily the same in the target measurement. In the minds of policy makers, they each occupy a certain proportion.

(2) Calculating single-level weight ordering and consistency check

By calculating the judgment matrix, the weights of the same layer of evaluation indexes are obtained, and finally the weights of the evaluation indexes of all layers are obtained. Then the eigenvalues of each judgment matrix are calculated:

\[ A_\omega = \lambda_{\text{max}} \omega \] (1)

Calculated by the formula (1), the weight \( \omega \) of each of the obtained evaluation indexes is processed, and the matrix composed of the weights of each evaluation index is recorded as the weight order of \( B_1 \), \( B_2 \), ..., and \( B_n \) under \( A_k \). After calculating \( \lambda_{\text{max}} \) and \( \omega \), the calculation result is tested for consistency. If the consistency test is passed, the weight result of the indicator can be used. The consistency index CI is calculated:

\[ CI = \frac{\lambda_{\text{max}} - n}{n-1} \] (2)

After calculating the CI value, combined with the average random consistency indicator RI, the consistency ratio index CR is calculated:

\[ CR = \frac{CI}{RI} \] (3)

If the consistency ratio index CR<0.1, the judgment matrix of each evaluation index is considered to be consistent; on the contrary, the consistency test is not satisfied, and the index weight result cannot be used, and the judgment matrix should be recalculated until the consistency test condition is met.

(3) Hierarchical total ordering and test consistency
It is also necessary to pass the consistency test of hierarchical total sorting after passing the hierarchical test. Hierarchical total ranking is the weight ranking of each evaluation index relative to the evaluation index of the target layer, and the total ranking weight of evaluation index is:

\[ Q_i = \sum_{j=1}^{m} p_{ij} q_j, \quad i = 1, 2, \ldots, n \]  

In the formula: Let the Q layer have n evaluation indexes, namely \( Q_1, Q_2, \ldots, Q_n \), and the weights relative to the total target are \( q_1, q_2, \ldots, q_n \); \( p_{1j}, p_{1j}, p_{2j}, \ldots, p_{mj} \) is the single ranking weight of the evaluation index at the criterion layer. The total order is calculated by formula (4). Check the consistency of the total sort:

\[ CR = \sum_{j=1}^{m} \frac{p_{ij} CI_j}{\sum_{i=1}^{n} p_i R I_j} \]  

In the formula: CIj is the consistency index of each evaluation index to sub-criteria layer of the criterion layer, and RIj is called the randomness index of fuzzy comprehensive evaluation. When \( CR < 0.1 \), it is considered that the judgment matrix composed of the evaluation index passes the test.

4. Structural indexes, indicator sets and membership evaluation matrix

According to the water conservancy project examples and expert experience, the evaluation set[11] \( V \) of each evaluation index is set up and expressed in vector form:

\[ V = \{v_1, v_2, \ldots, v_n\} \]  

In the formula: \( V \) represents a set of comments for pre-evaluation of each indicator, and \( v_i \) represents a different comment for evaluation of each indicator. Generally, the evaluation grades are divided into 3-5. In combination with engineering construction, this article sets the rating into 4 levels. Then, the evaluation index set U is established, and each evaluation index \( u_i \) is judged one by one, and the membership degree of the evaluation level \( v_j \) is obtained from the evaluation index \( u_i \) as \( r_{ij} \):

\[ r_{ij} = v_j(u_i), \quad j = 1, 2, \ldots, m \]  

Thus can be obtained, between the various fuzzy vector \( u_i \) evaluation and evaluation set \( V \) can be expressed as:

\[ r_i = (r_{i1}, r_{i2}, \ldots, r_{im}), \quad i = 1, 2, \ldots, n \]  

The fuzzy relationship between each of the above evaluation indexes is integrated to obtain a fuzzy relation matrix between U and V:

\[ R = \begin{bmatrix}
  r_{11} & r_{12} & \cdots & r_{1m} \\
  r_{21} & r_{22} & \cdots & r_{2m} \\
  \vdots & \vdots & \ddots & \vdots \\
  r_{n1} & r_{n2} & \cdots & r_{nm}
\end{bmatrix} \]  

According to R, the final evaluation index grade of water conservancy project construction effect is judged.

3. Case Application --- Ma Xionggou II Hydropower Station

Ma Xionggou is the primary tributary of Sichuan Province. The Ma Xionggou II Hydropower Station is the second stage hydropower station in the cascade planning scheme of Ma Xionggou Hydropower Station. The hydropower station draws water from the dam at the lower reaches of Ma Xionggou Bridge on the S217 Provincial Road, and draws water from the 2769.417m tunnel on the left bank to the 90m upstream of the Ma Xionggou III hydropower station for power generation.

3.1. Establishment of evaluation index

The construction process of the project has a decisive influence on its effectiveness[12]. Therefore, this paper makes a comprehensive evaluation of the process of small and medium-sized water conservancy and hydropower construction projects, and as the first level. According to the characteristics of small and medium-sized water conservancy projects, these secondary indexes are subdivided into 16 three-level indexes, as shown in Figure 1.
3.2. *Building the hierarchical analysis judgment matrix*

According to the hierarchical structure diagram, each evaluation index is compared and scored by using the analytic hierarchy process. The judgment matrix of the criterion layer is shown in Table 1, and the judgment matrix of the construction safety sub-criteria layer is shown in Table 2. Due to space limitations, other judgment matrices are omitted.

![Evaluation index system of construction effect in construction stage of water conservancy project](image_url)

**Figure 1. Evaluation index system of construction effect in construction stage of water conservancy project**

| Table 1. Matrix judgment table E-(A, B, C, D) |
|-----------------|--------|--------|--------|
| E               | A      | B      | C      | D      |
| A               | 1      | 2      | 4      | 4      |
| B               | 0.5    | 1      | 2      | 2      |
| C               | 0.25   | 0.5    | 1      | 1      |
| D               | 0.25   | 0.5    | 1      | 1      |

| Table 2. Matrix judgment table A-(A₁, A₂, A₃, A₄) |
|-----------------------------------|--------|--------|--------|
| A                                | A₁     | A₂     | A₃     | A₄     |
| A₁                               | 1      | 0.33   | 0.5    | 0.25   |
| A₂                               | 3      | 1      | 1      | 0.5    |
| A₃                               | 2      | 1      | 1      | 0.5    |
| A₄                               | 4      | 2      | 2      | 1      |
3.3. Hierarchical single sorting, total sorting and consistency check

The judgment matrix \( A \) corresponds to the eigenvector \( W \) of the maximum eigenvalue \( \lambda_{\text{max}} \). After normalization, it is the ranking weight value of the relative importance of the corresponding factors at the same layer to a certain factor at the previous layer. And this process is called hierarchical single sorting. The weight coefficients of each index are calculated in Table 3.

| Table 3. Weights and CR values of individual evaluation indexes |
|---------------------------------------------------------------|
| Construction safety | Construction quality | construction management | Construction environment | CR value |
|----------------------|-----------------------|--------------------------|--------------------------|----------|
| Criterion layer      | 0.4531                | 0.2265                   | 0.1602                   | 0.1602   | 0.0449   |
| Single layer index 1 | 0.1367                | 0.324                    | 0.1353                   | 0.365    | 0.0783   |
| Single layer index 2 | 0.2033                | 0.2178                   | 0.2481                   | 0.2139   | 0.0704   |
| Single layer index 3 | 0.2734                | 0.2291                   | 0.3217                   | 0.1961   | 0.0709   |
| Single layer index 4 | 0.3866                | 0.2291                   | 0.295                    | 0.225    | 0.0650   |

After testing, the CR values are all less than 0.1, and the level consistency test is considered to be qualified.

3.4. Fuzzy hierarchical overall index evaluation

Standard hierarchy index set \( U = \{ \text{Construction Safety, Construction quality, Construction Management, Construction environment} \} \), sub-criteria hierarchy index set \( U = \{ A_1, A_2, A_3, A_4, B_1, B_2, B_3, B_4, C_1, C_2, C_3, C_4, D_1, D_2, D_3, D_4 \} \), index evaluation set \( V = \{ \text{Excellent, Good, Medium, Poor} \} \). Sixteen experts in this field or related fields are invited to rate the construction effect evaluation index and form a judgment matrix as shown in Table 4.

| Table 4. Expert evaluation matrix for construction effect evaluation index |
|--------------------------------------------------------------------------|
| Construction safety | Construction quality | construction management | Construction environment |
|----------------------|-----------------------|--------------------------|--------------------------|
| Single layer index 1  | [3 4 1 0]             | [4 3 2 0]                 | [3 3 2 0]                 | [2 2 1 2]   |
| Single layer index 2  | [4 4 0 0]             | [4 4 0 0]                 | [3 3 1 1]                 | [3 3 1 1]   |
| Single layer index 3  | [3 3 2 0]             | [3 3 1 0]                 | [3 4 1 0]                 | [3 2 3 1]   |
| Single layer index 4  | [4 4 0 0]             | [3 3 1 0]                 | [3 3 1 0]                 | [3 3 1 0]   |

According to formula (9) and table 8, the fuzzy membership matrices of each evaluation index are \( R_1 \), \( R_2 \), \( R_3 \) and \( R_4 \). According to the principle of FAHP comprehensive evaluation model, the fuzzy matrix calculation formula of construction safety, construction quality, construction management and construction environment is:

\[ E_i = P_i \cdot R_i \]  \hspace{1cm} (10)

According to equation (10), the calculation is obtained.

\[ E_1 = [0.1497 \ 0.1633 \ 0.1567 \ 0.1360] \]
\[ E_2 = [0.2408 \ 0.2084 \ 0.2072 \ 0.1855] \]
\[ E_3 = [0.1794 \ 0.2042 \ 0.1720 \ 0.1767] \]
\[ E_4 = [0.1804 \ 0.2158 \ 0.2336 \ 0.1933] \]

According to the principle of maximum membership degree, construction safety \( E_1 \in v_2 \) can be obtained and the evaluation grade of construction safety is good; construction quality \( E_2 \in v_1 \), construction quality evaluation grade is excellent; construction management \( E_3 \in v_2 \), construction management evaluation grade is good; construction environment \( E_4 \in v_2 \), construction environment evaluation grade is medium. The fuzzy evaluation matrix membership matrix \( R \) of the criterion layer evaluation index composed of the result of the fuzzy evaluation of the sub-criteria layer evaluation index \( E_1, E_2, E_3 \) and \( E_4 \) is obtained as follows:

\[ E_c = B_8 \cdot E_8 = [0.1800 \ 0.1885 \ 0.1829 \ 0.1629] \]
According to the principle of maximum membership degree, the fuzzy evaluation result can be obtained from the evaluation index of criterion layer. Comprehensive evaluation of the construction effect of Ma Xiongou II Hydropower Station, Sichuan Province is $E \in \nu_2$, that is, the comprehensive evaluation grade is good. It shows that the construction stage of Ma Xiongou II Hydropower Station is more standardized from management to implementation, and its overall construction effect is better.

4. Conclusion and Suggestion
The FAHP is used to establish a comprehensive evaluation model for the construction effect of small and medium-sized water conservancy projects, and the evaluation model was successfully applied to the construction effect evaluation of the construction stage of Ma Xiongou II Hydropower Station in Sichuan Province. The evaluation results are obtained, the construction safety evaluation grade is good, the construction quality evaluation grade is excellent, the construction management evaluation grade is good, the construction environment evaluation grade is medium, and the overall construction effect evaluation grade is good. The model is better applied in this example and is more consistent with the actual situation.

According to the analysis of the evaluation results, the construction effect of the project is good overall, but the construction safety, construction management and construction environment are not good enough, especially the construction environment. Therefore, in future projects, the construction enterprise should strengthen the training of construction safety, improve the overall quality of construction personnel, improve the management system of enterprises, improve the overall level of enterprise management, and pay special attention to environmental protection during construction. Such as reducing noise pollution during construction and avoiding pollution of water and air by construction garbage.

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