Evaluation of Safety Management Factors of Subway Construction Site Based On Risk Preference Information

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Abstract. In order to guarantee the construction quality and personnel safety during the subway construction process, the index system of subway construction safety management factors was established on the basis of questionnaire survey and factor analysis, including a total of 20 items. Introduce a pessimistic coefficient to optimize the hierarchical analysis model of interval numbers, construct a reciprocal judgment matrix of interval numbers that meet the requirements of consistency approximation, give weight to various safety management indicators during subway construction, improve the scientificity of weight setting, and make The key points and difficulties of construction safety management work provide a basis for ensuring the safety of subway construction.

1. Introduction
The first paragraph after a heading is not indented (Bodytext style). The development time of Chinese urban subway is not long. The construction risk of subway is high, due to complex surrounding environment, the lack of construction experience and their construction site at the downtown district. In addition, large investment, short construction period, complex relationship of the project and multiple cross-nodes for simultaneous operations all increase the difficulties of construction. Compared with its preparation phase, design phase, and completion phase, great losses will be suffered due to improper management, if security risk management measures are not that good, more and more security problems will occur owing to unsuitable measures of security risk management [1]. Therefore, subway construction units should attach great importance to on-site safety management during construction. At present, China's research in this area mainly focus on constructing a subway construction safety management evaluation model, establish an evaluation factor index system and determine the weight of each index and rank. For example, Yan et al. [2] established the multi-dimensional track cross-risk coupling cause model of subway accident, selected 16 subway construction risk impact factors, and evaluated the subway construction risk by constructing interaction matrix to find the weight. Chen et al. [3] established a multi-level extension evaluation model of subway construction safety risk with extension method as the core, and used the method of combining AHP and entropy weight to determine the weight.

However, the calculation of the index weights in the above and related studies does not take into account the risk preferences of the decision makers themselves. Therefore, based on the questionnaire and factor analysis to establish a safety management factor index system, this paper introduces the pessimism coefficient α to construct and optimize the hierarchical analysis model of interval numbers based on risk preference information. Finally, the weight of each index is solved through the interval number reciprocal judgment matrix, which improves the scientficity of index setting in the safety evaluation index system of subway construction site safety, so that the site safety management can make it clear what is the primary and the secondary.
2. Establishment of Evaluation Index System for Safety Management of Subway Construction Site

The on-site construction safety evaluation of the subway is inseparable from every link in the whole process of project construction [4]. The premise of constructing a reasonable and rigorous safety evaluation index system is to comprehensively analyze each construction link of the engineering construction process [5]. This requires us to describe the construction site in detail to understand the complex subway construction site. After field visits to the construction units, this paper compiles a questionnaire combined with relevant national norms and standards and related scientific research [6-8], and establishes an index system for the safety management assessment of subway construction sites after factor analysis. The details are shown in Table 1.

| Target layer | Criterion layer                  | Indicator layer                                      |
|--------------|----------------------------------|------------------------------------------------------|
| Construction organization management(A) | A1 Implementation of safety supervision | A1 Implementation of safety supervision |
| | A2 Safety emergency prevention and control measures | A2 Safety emergency prevention and control measures |
| | A3 Labor Employment Management | A3 Labor Employment Management |
| | A4 Work Safety Education | A4 Work Safety Education |
| Construction technology management(B) | B1 Technical briefing | B1 Technical briefing |
| | B2 Advance forecast work | B2 Advance forecast work |
| | B3 Excavation situation | B3 Excavation situation |
| | B4 Waterproof and drainage situation | B4 Waterproof and drainage situation |
| | B5 Supporting strength | B5 Supporting strength |
| | B6 Construction organization planning | B6 Construction organization planning |
| Evaluation of safety management of subway construction site | C1 Geological and hydrological conditions | C1 Geological and hydrological conditions |
| | C2 Surrounding building environment | C2 Surrounding building environment |
| | C3 Climatic conditions | C3 Climatic conditions |
| | C4 Underground pipeline situation | C4 Underground pipeline situation |
| | C5 Civilized production environment | C5 Civilized production environment |
| Construction environment management(C) | D1 Employee years | D1 Employee years |
| | D2 Educational level | D2 Educational level |
| | D3 Employee qualifications | D3 Employee qualifications |
| | D4 Employee safety training | D4 Employee safety training |
| | D5 Safety common sense | D5 Safety common sense |

3. Interval Number Hierarchy Analysis Model

3.1. Representation of Risk Preference Information – Pessimism (α)

In order to quantify the risk preference of decision makers, the parameter pessimism α is introduced in this paper. Different decision makers have different values of pessimism because of their different risk preferences. The more aggressive decision makers who prefer risk take the value of \( \alpha^+ \), and the more conservative decision makers who prefer risk take the value of \( \alpha^- \). Tendencies with different risks take
values in $\alpha$ and $\alpha^-$. The expression of pessimism parameter $\alpha$ in the language environment is shown in Table 2.

| Absolute pessimism | Extremely high | Very high | High | Medium | Low | Very low | Extremely low | Absolutely optimistic |
|--------------------|----------------|-----------|------|--------|-----|----------|-------------------|----------------------|
| $\alpha \rightarrow +\infty$ | $\cdots$ | $\alpha \rightarrow 8$ | $\alpha \rightarrow 4$ | $\alpha \rightarrow 2$ | $\alpha \rightarrow 1$ | $\alpha \rightarrow 1/2$ | $\alpha \rightarrow 1/4$ | $\alpha \rightarrow 1/8$ | $\cdots$ | $\alpha \rightarrow -\infty$ |

### 3.2. Construction and Consistency of Interval Number Reciprocal Judgment Matrix

Compare the importance of the $i$-th factor and the $j$-th factor in the index system, and express the interval number as $[a_{ij}^l, a_{ij}^u]$, and record it as $\bar{a}_{ij}$, and the corresponding judgment matrix is the interval number reciprocal judgment matrix as follows:

$$
\begin{bmatrix}
[1,1] & [a_{12}^l, a_{12}^u] & \cdots & [a_{1n}^l, a_{1n}^u] \\
[a_{21}^l, a_{21}^u] & [1,1] & \cdots & [a_{2n}^l, a_{2n}^u] \\
\vdots & \vdots & \ddots & \vdots \\
[a_{n1}^l, a_{n1}^u] & [a_{n2}^l, a_{n2}^u] & \cdots & [1,1]
\end{bmatrix}
$$

The matrix is denoted as $A$, and the interval number judgment matrix $A=(\bar{a}_{ij})_{m \times m}$. If it is a consistent interval number reciprocal judgment matrix $^{[10]}$, it needs to satisfy:

$$
\bar{a}_{ij} = \frac{a_{ij}}{a_{kj}} \quad (\forall i < k < j \in I)
$$

where $I = \{1, 2 \cdots n\}$.

According to the interval number to judge the reciprocity of the matrix, there are: $\bar{a}_{ij} = [f_{\bar{a}_{ij}}(0), f_{\bar{a}_{ij}}(1)]$

$$
f_{\bar{a}_{ij}}(x) = (a_{ij}^l)^{1-xa} (a_{ij}^u)^{xa}
$$

According to Equation 2 and the reciprocity of the matrix, we can obtain:

$$
f_{\bar{a}_{ij}}(0) = \begin{cases}
1 & i = j \\
\frac{1}{2}, & i \neq j
\end{cases}
$$

$$
f_{\bar{a}_{ij}}(1) = \begin{cases}
1 & i = j \\
\frac{1}{2}, & i \neq j
\end{cases}
$$

Let $A(0)=f_{\bar{a}_{ij}}(0)_{n \times n}, \ A(1)=f_{\bar{a}_{ij}}(1)_{n \times n}$, then $\bar{A}={A(x)0 \leq x \leq 1}$, $A(x)$ is a set of positive and negative judgment derived matrix of $\bar{A}$. The results can be obtained according to Equations 2 ~ 4:

$$
f_{\bar{a}_{ij}}(x) = (f_{\bar{a}_{ij}}(0))^{1-xa} \left( f_{\bar{a}_{ij}}(1) \right)^{xa}
$$

$$
\bar{A} = (A(0))^{1-xa} (A(1))^{xa}
$$

### 3.3. Consistency Approximation of Interval Reciprocal Judgment Matrix

The actual subway construction site is a complex and huge system with multiple influencing factors, and the various factors affect each other. The uncertainty of the factors that affect construction safety, coupled with differences in personal perception of on-site risk factors and lack of on-site construction safety professional learning, these limitations will lead to differences in personal preferences and ultimately affect decision makers. The judgment results of each influencing factor may lead to the given interval number judgment matrix not necessarily satisfying consistency. In order to solve this problem, this paper gives reasonable constraints, on this basis, the interval number judgment matrix meets the
consistency approximation, so as to ensure that the decision-making results of the subway construction site safety evaluation based on risk preference information are more reasonable and reliable.

In this paper, for the inconsistent reciprocal judgment matrix $A=(a_{ij})_{n \times n}$, the n-1 elements with the best overall consistency are selected from the set $\{a_{ij}|l < j \in I\}$ to construct the consistency matrix $A$ with the smallest overall inconsistency that approximates $A^{[11]}$.

If the positive and negative judgment matrix $A=(a_{ij})_{n \times n}$, if there is a positive normalized vector $(W = w_1, w_2, \cdots, w_n)$ and the parameter $\beta$ makes it satisfy the following Equation 7:

$$a_{ij} = \beta^{w_i - w_j}, \quad (i, j \in I) \quad (7)$$

Then matrix $A$ is the consistency judgment matrix, where $\beta > \frac{1}{\prod_{k=1}^{n} a_{ik}}$

The weight $w_i$ of consistency reciprocal judgment matrix $A=(a_{ij})_{n \times n}$ can be expressed as:

$$w_i = \frac{1}{n} \left( \sum_{k=1}^{n} \log_\beta a_{ik} + 1 \right), \quad i \in I \quad (8)$$

According to Equation 7 and the initial judgment matrix, construct a semi-bias matrix $\Delta = (\delta_{ij})_{n \times n}$, so as to select the n-1 elements with the best overall consistency, $\delta_{ij}$ is expressed as:

$$\delta_{ij} = \left\{ \begin{array}{ll} a_{ij} - \beta^{w_i - w_j}, & i < j \\ - & , i \geq j \end{array} \right. \quad (9)$$

where "-" is undefined. The results can be obtained according to the above Equations 8 and 9:

$$\delta_{ij} = \left\{ \begin{array}{ll} a_{ij} - \frac{1}{\prod_{k=1}^{n} a_{ik}}, & i < j \\ - & , i \geq j \end{array} \right. \quad (10)$$

For the derived matrix $A(x)$ of the matrix $A=(a_{ij})_{n \times n}$, its semi-deviation matrix can be expressed as:

$$\delta_{ij}(x) = \left\{ \begin{array}{ll} a_{ij} - \frac{1}{\prod_{k=1}^{n} f_{a_{ik}}(x)}, & i < j \\ - & , i \geq j \end{array} \right. \quad (11)$$

Then the element $\tilde{\delta}_{ij}$ in the semi-bias matrix $\tilde{A}(\delta_{ij})$ of the risk preference information matrix $A^{-}$ is introduced as the value:

$$\tilde{\delta}_{ij} = \int_{0}^{1} \delta_{ij}(x) \, dx \quad (12)$$

According to Equations 11 and 12, the following optimization model is established:

$$\min Z = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} (|\tilde{\delta}_{ij}|x_{ij}) \quad (13a)$$

$$st \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} x_{ij} = n - 1 \quad (13b)$$

$$X_{ik} + X_{jk} + X_{ij} \leq 2, \quad i < j < k \in I \quad (13c)$$

$$X_{ij} = 0 \text{ or } 1, \quad i < j \in I \quad (13d)$$

Among them, when constructing the approximate consistency positive and negative judgment matrix, if this element $X_{ij} = 0$ is selected. If not, the element is not selected. Based on the solution of the optimization model and Equation 1, the interval number reciprocal judgment matrix $A'$ can be constructed. If $\tilde{a}_{ij} \in [1/9, 9]$ exists in $A'(\tilde{a}_{ij})$, then $\exists m > 9$ makes $\tilde{a}_{ij} \in [1/m, m]$, the reciprocal judgment matrix of the consistency interval number can be obtained from $A'' = f(A')$. Where $m = \max \{a_{ij}^+\}$:

$$g(x) = x^{\log_\beta m}, \forall x \in [\frac{1}{m}, m] \quad (14)$$
3.4. Determine Index Weights Based on Risk Preference Information

For the convenience of description, $\hat{A}$ is used to denote the initial consistency judgment matrix, and $\hat{A}''$ is used to indicate the approximate consistency judgment matrix. For the reconstructed consistency interval reciprocal judgment matrix, it can be obtained from Equation 8:

$$w_i(x) = \frac{1}{n} \left( \sum_{k=1}^{n} \log_\beta f_{\hat{a}_{ij}} + 1 \right)$$

The weight vector obtained by the reciprocal judgment matrix of the consistency interval number is:

$$w_i = \int_{0}^{1} w_i(x) dx$$

4. Example Application and Analysis

In this paper, based on the established subway construction site safety management index system (Table 1), the interval number reciprocal judgment matrix is determined by the expert interview method, and the weights of each index of the interval number reciprocal judgment matrix based on risk preference information are solved to guide Layer security organization management as an example, the specific solution processes are as follows:

1) Construct a Reciprocal Judgment Matrix

According to the constructed safety index system of the subway construction site, experienced and responsible experts establish a reciprocal judgment matrix, as shown in Table 3.

| A  | A_1 | A_2 | A_3 | A_4 |
|----|-----|-----|-----|-----|
| A_1 | [1,1] | [2,4] | [2,6] | [1,7] |
| A_2 | [1/4,1/2] | [1,1] | [1,3] | [1,3] |
| A_3 | [1/6,1/2] | [1/3,1] | [1,1] | [1,2] |
| A_4 | [1/7,1] | [1/3,1] | [1/2,1] | [1,1] |

2) Create matrices $A(0)$ and $A(1)$

$$A(0) = \begin{bmatrix} 1 & 2 & 2 & 1 \\ 1/2 & 1 & 1 & 1 \\ 1/4 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix}$$

$$A(1) = \begin{bmatrix} 1 & 4 & 6 & 7 \\ 1/4 & 1 & 3 & 3 \\ 1/6 & 1/3 & 1 & 2 \\ 1/7 & 1/3 & 1/2 & 1 \end{bmatrix}$$

3) Build matrix $A(x)$

$$A(x) = \left[ \begin{array}{cccc} 1 & 2^{1-xa}4^{xa} & 2^{1-xa}6^{xa} & 7^{xa} \\ \frac{1}{2} & \frac{1}{2}^{1-xa}4^{xa} & \frac{1}{2}^{1-xa}6^{xa} & 7^{xa} \\ \frac{1}{3} & \frac{1}{3}^{1-xa}4^{xa} & \frac{1}{3}^{1-xa}6^{xa} & \frac{1}{3}^{1-xa}7^{xa} \\ \frac{1}{2}^{1-xa}4^{xa} & \frac{1}{2}^{1-xa}6^{xa} & \frac{1}{2}^{1-xa}7^{xa} & 1 \end{array} \right]$$

4) Create matrix $\Delta$

$$\Delta = \begin{bmatrix} -2^{1-xa}4^{xa} - (8)^{\frac{1-xa}{3}} & 2^{1-xa}6^{xa} - (8)^{\frac{1-xa}{3}} & 7^{xa} - (4)^{\frac{1}{3}(1764)^{xa}} \\ - & - & 3^{xa} - \left(\frac{61}{7}^{xa}\right) & 3^{xa} - \left(\frac{1}{7}^{\frac{1}{4}(189)^{xa}}\right) \\ - & - & - & 2^{xa} - \left(\frac{1}{7}^{\frac{1}{4}(28)^{xa}}\right) \\ - & - & - & - \end{bmatrix}$$

5) Create a matrix $\Delta$

When $a = 1/2$:
When \( \alpha = 1 \):

\[
\bar{\Delta} = \begin{bmatrix}
-0.4503 & 0.2897 & -0.6479 \\
- & - & 0.1187 & 0.1448 \\
- & - & - & 0.2252 \\
- & - & - & -
\end{bmatrix}
\]

When \( \alpha = 2 \):

\[
\bar{\Delta} = \begin{bmatrix}
-0.6329 & 0.1658 & -1.0641 \\
- & - & 0.3294 & 0.0829 \\
- & - & - & 0.3165 \\
- & - & - & -
\end{bmatrix}
\]

6) Establish the optimal solution matrix

\[
X' = \begin{bmatrix}
- & 0 & 1 & 0 \\
- & - & 0 & 1 \\
- & - & - & 1
\end{bmatrix}
\]

7) Second establishment of interval number judgment matrix

\[
A' = \begin{bmatrix}
[1,1] & [2,4] & [2,6] & [2,12] \\
[1/4, 1/2] & [1,1] & [1,3/2] & [1,3] \\
[1/6, 1/2] & [2/3, 1] & [1,1] & [1,2] \\
[1/12, 1/2] & [1/3, 1] & [1/2, 1] & [1,1]
\end{bmatrix}
\]

8) Establish consistent interval judgment matrix

\[
A'' = \begin{bmatrix}
[1,1] & [1.8458, 3.4069] & [1.8458, 4.8760] & [1.8458, 9.0000] \\
[0.2935, 0.5418] & [1,1] & [1.0000, 1.4312] & [1.0000, 2.6417] \\
[0.2051, 0.5418] & [0.6987, 1.0000] & [1,1] & [1.0000, 1.8458] \\
[0.1111, 0.5418] & [0.3785, 1.0000] & [0.5418, 1.0000] & [1,1]
\end{bmatrix}
\]

9) Solve the interval number matrix based on the parameters \( \alpha \) and \( \beta \), and get the weight of each index

| Table.4 A-Ai Judgment Matrix Weight Vector |
|---|
| \( \alpha \) | \( \beta \) | \( A_1 \) | \( A_1 \) | \( A_1 \) | \( A_1 \) |
| \( \alpha = 1/2 \) | \( e^{10} \) | 0.3207 | 0.2383 | 0.2288 | 0.2122 |
| \( \alpha = 1 \) | \( e^{10} \) | 0.3419 | 0.2432 | 0.2239 | 0.1910 |
| \( \alpha = 2 \) | \( e^{10} \) | 0.3845 | 0.2528 | 0.2142 | 0.1485 |

10) The weights of safety management evaluation indicators for subway construction sites are the same, and the weight calculation of indicators in other criterion layers is carried out using the principle of solving the reciprocal judgment matrix of intervals based on risk information. The results are shown in Table 5.

| Table 5 Weights of Safety Evaluation Indexes of Subway Construction Site under Different Pessimism |
|---|
| Target layer Criterio n layer | \( \alpha = 1/2 \) | \( \alpha = 1 \) | \( \alpha = 2 \) | Indicator layer | \( \alpha = 1/2 \) | \( \alpha = 1 \) | \( \alpha = 2 \) |
| Safety Evaluation Index System of | \( A_1 \) | 0.3041 | 0.3254 | 0.3680 | \( A_1 \) | 0.1040 | 0.1044 | 0.1415 | \( A_2 \) | 0.0740 | 0.0775 | 0.0930 |
5. Conclusions
The survey questionnaire was prepared through various methods such as field investigations and expert interviews, and the index system for the safety management evaluation of subway construction sites via factor analysis to collect the data. The objective factors that affect the safety of the subway construction site provide a theoretical basis for the construction unit to solve the hidden dangers and problems of the accident, which comprehensively reflects the actual safety situation of the construction site.

By introducing the pessimism parameter $\alpha$ to reflect the risk information preference of decision makers, and combining it with the interval number hierarchy analysis method, the index weight of the safety management of the subway construction site was calculated. It was concluded that the subway was affected under three different pessimism. The factors that have the greatest impact on the safety of the construction site are the implementation of safety supervision, which shows that whether the safety management is good enough is the top priority to ensure the safety of subway construction.

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