A Safety Risk Evaluation Index System of Subway Projects Based on the Analytic Hierarchy Process

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Abstract—The construction process of the subway project, which is a hidden underground project, is facing many unknown factors, and construction technology is difficult and the quality requirement is high. In order to ensure the safety of subway construction personnel, property and smooth completion of the project, this paper selects and constructs the influencing factors of subway project construction safety risk evaluation according to the 4E1M method, calculates the weight of each index by the analytic hierarchy process, selects 60% of the indexes before the weight ranking, and establishes an index system including 5 criteria indexes and 16 secondary indexes.

1. INTRODUCTION

With the acceleration of urbanization, traffic congestion in major cities is becoming increasingly serious. In order to improve the city’s sustainable development ability, subway construction in major cities in China has entered a new stage of rapid development. However, subway projects are all built in prosperous urban areas, with large traffic volume, more complex surrounding environment and construction risks, and high technical requirements, resulting in many safety accidents and huge personal property and economic losses. Building a comprehensive and effective subway project construction safety risk evaluation index system is an important foundation for subway project construction safety risk evaluation.

At present, relevant scholars have carried out a certain depth of research on the subway project construction safety risk index system. Ding et al [1] proposed a subway construction safety risk identification system based on construction drawings. Through the analysis of precursor information during the construction of subway construction projects, Lu et al [2] identified the safety risks. The case analysis results show that the method has good applicability. Based on the building information model platform, Li et al [3] used the method of data fusion to construct a subway construction project...
construction safety risk identification system. Perlman et al [4] studied the subject of safety risk identification and risk perception from the perspective of construction project management. The research results show that the working experience and working years of project managers are the key influencing factors of safety risk identification. These methods have achieved good research results, but they all have the shortcomings of complex algorithms and difficult direct application in engineering practice. At present, China and other developing countries have a large number of subway engineering practices. It is difficult for project managers to understand and correctly apply the above complex algorithms. How to improve the practical operability of research methods is obviously a top priority. Analytic Hierarchy Process has the characteristics of simple operation and clear principle, and has been widely used in the field of system evaluation research [5,6].

Based on these, this paper uses the AHP method, which is simple in algorithm, strong in operability and can be directly applied to engineering practice, to construct the subway project construction safety risk evaluation index system.

2. PRELIMINARY SELECTIONS OF SAFETY RISK INDICATORS
The risk evaluation index system of subway projects includes three levels of indicators. The first layer is the target layer, the risk evaluation of subway projects. The second layer is the criteria layer, and the third layer is the detailed indicator layer. The first level is the risk evaluation of subway projects. In this paper, the 4M1E method is used to build the second layer of indicators, which are the man factor, the management factor, the materials factor, the equipment factor and the environment factor. The third layer is respectively established according to the second layer. In this paper, the key work of constructing the safety risk index system of subway project construction is to construct the third indexes according to its second indexes.

In the process of subway project construction, the personnel factors are the quality, psychological state, technical proficiency and operation problems of construction personnel and management personnel [7]. Environmental factors are the engineering geology, hydrological conditions, adverse climate impacts, underground water and sand gushing, adjacent pipeline buildings, etc [8]. The material factors are mainly, the storage state of the material, the effectiveness of the material and the applicability of the material, etc. The main factors of the equipment are the quality and performance of the equipment itself, regular maintenance, standardized operation and applicability of equipment procurement. The main management factors are safety education and training, the implementation of various rules and regulations, the formulation of emergency plans, the implementation of safety organization work, etc.

The second-level indicators are obtained through expert interviews with Chengdu Metro Line 11 project as a case study. Each of the experts who participated in the expert interview had risk engineering practical experience and theoretical knowledge, and were very familiar with the construction content, construction technology and project management of Chengdu Metro Line 11 project. The construction safety risk indicators for subway projects are shown in Table 1 below.

| Criteria layer | Indicator layer                          | Weight   | Remarks    |
|----------------|------------------------------------------|----------|------------|
| Man factor     | Physical health                          | 0.0191   | Deleted    |
|                | Psychological quality                     | 0.0383   | Reserved   |
|                | Master of professional skills             | 0.0089   | Deleted    |
|                | Safety awareness                          | 0.0730   | Reserved   |
|                | Working attitude                          | 0.0072   | Deleted    |
|                | Do not operate according to regulations   | 0.0383   | Reserved   |
| Management factor | Safety regulations and systems           | 0.1158   | Reserved   |
|                | Safety education and training             | 0.0517   | Reserved   |
|                | On-site protective measures               | 0.0173   | Deleted    |
|                | Safety technical disclosure               | 0.0370   | Reserved   |
|                | Construction organization design          | 0.0257   | Deleted    |
|                | Safety inspection and monitoring          | 0.0060   | Deleted    |
### 3. Calculation of Index Weights Based on AHP

The basic principle of AHP is to divide various factors in a complex system into a hierarchical structure according to their interrelation and affiliation. Rely on expert experience and intuition to judge the relative importance of factors in the same level, and use consistency criteria to test the accuracy of the judgment. And then synthesizing in a hierarchical sub-structure. The overall ranking relative to the importance of the decision factors of the target can be obtained.

The comparison between many factors in these decision-making systems is often unable to be described in a quantitative way. At this time, the semi-qualitative and semi-quantitative problems need to be transformed into quantitative calculation problems. Analytic Hierarchy Process is an effective method to solve such problems. Analytic Hierarchy Process hierarchizes the complicated decision-making system and provides quantitative basis for analysis and final decision-making by comparing the importance of various related factors layer by layer.

The analytic hierarchy process method does not only pursue advanced mathematics, but also does not pay one-sided attention to behavior, logic and reasoning. Instead, it organically combines qualitative methods and quantitative methods to decompose complex systems, which can make people's thinking process mathematical and systematic and easy for people to accept. Moreover, it can transform multi-objective, multi-criteria and difficult to fully quantify decision-making problems into multi-level single-objective problems. After determining the quantitative relationship between the elements of the same level and the elements of the previous level through two-to-two comparison, it finally carries out simple mathematical operations. The calculation is often simple and the result is simple and clear, which is easy for decision makers to understand and master.

In this paper, a scale of 1~9 levels is used to represent the relative importance between any two indexes. The 1 means that two indicators are equally important; the 3 means that one indicator is more important than the other; the 5 means that one indicator is much more important than the other; the 7 means that one indicator is more important than the other; the 9 means that one indicator is extremely important than the other. The most important thing in AHP is to calculate feature vector, index weight and consistency test.

Step1 Judging the product of each element in each row of matrix $A$:

$$m_j = \prod_{i=1}^{n} a_{ij}$$  \hspace{1cm} (1)

Step2 Calculation of index weights:

$$\omega_j = \frac{\overline{m_j}}{\sum_{j=1}^{n} \overline{m_j}}$$  \hspace{1cm} (2)

Step3 Multiplies matrix $a$ and index weight set to obtain $AW$ matrix.

Step4 Solving the Maximum Eigenvalue:

$$\lambda_{\text{max}} = \sum_{j=1}^{n} (AW)_{ij} / m_{ij}$$  \hspace{1cm} (3)
where, \( w_i \) indicates the weight of factor \( i \), \( (\mathbf{AW})_i \) represents the i-th component of a matrix \( \mathbf{AW} \).

Step 5: Calculating consistency index:

\[
CI = \frac{\lambda_{max} - n}{n - 1} \quad (4)
\]

\[
CR = \frac{CI}{RI} \quad (5)
\]

Considering that the deviation of consistency may be caused by random reasons, it is necessary to compare \( CI \) with the average random consistency index to obtain the test coefficient \( CR \) when testing whether the judgment matrix has satisfactory consistency. Where \( RI \) is the average random consistency index and is the average of consistency indexes calculated according to enough randomly occurring judgment matrices.

Experts are invited to score according to the importance between any two indexes to obtain matrix \( \mathbf{A} \), and the weight and the \( CR \) of each index are calculated according to the above formulas (1) - (5). Due to space constraints, this paper only lists the weight calculation results in Table 1, and does not give detailed weight calculation process and \( CR \) results.

As can be seen from Table 1, the safety regulations and systems have the greatest weight. This shows that safety regulations and safety systems play an important role in the construction project management and safety management of subway projects. Generally speaking, the perfection of safety regulations and safety systems determines the level of construction project management. It can effectively improve the safety management ability of project managers, especially those who have no safety management experience.

Considering the needs of engineering practice, the 27 primary indexes obtained in the primary election are too many. It is generally believed that the greater the weight of the index is, the greater the impact it will have on the construction safety risks of subway projects. Therefore, this paper combines expert opinions and engineering practice needs, and selects the index with the top 60% weight as the final index. These detailed screening results are shown in Table 1.

### 4. CONSTRUCTION OF SAFETY RISK EVALUATION INDEX SYSTEM OF SUBWAY PROJECTS

According to the previous analysis, this paper finally established the safety risk evaluation index system of subways projects as shown in Table 2 below. The index system has five primary indexes and 16 secondary indexes. In addition, combined with the engineering practice of Chengdu metro line 11, the meaning of each index is described in detail in Table 2. These qualitative descriptions will help project managers to understand and apply the index system.

| Criteria layer | Indicator layer | Indicator interpretation |
|----------------|----------------|--------------------------|
| Man factor     | Physical health| Night construction or long-term overtime work will lead to poor mental state. Fatigue construction will lead to low work efficiency. |
| Safety awareness| Weak safety awareness. No habit of wearing protective equipment. Take chances in dangerous operations. Don’t find hidden dangers attentively. |
| Do not operate according to regulations | Opportunistic and convenient. Not in accordance with the operating procedures for construction work |
| Management factor | Safety regulations and systems | Formulation and implementation of site safety regulations |
| Safety education and training | Regular safety education and training. Whether special equipment operators receive training. Whether the general construction personnel meet the safety education and training standards. |
Safety technical disclosure

Whether safety disclosure is made to frontline construction personnel. Whether the construction personnel understand the disclosure intention.

Material property quality

Specification, performance, size, strength and fire resistance of materials.

Material transportation storage status

The placement of hazardous and toxic materials. Material placement to avoid failure. Whether the transportation and placement of materials are safe.

Effectiveness of materials

Whether the materials can be used for engineering construction.

Safety protection device

Equipment safety protection device is not set. The safety protection device is not properly used.

Equipment selection

Equipment selection is not suitable for subway engineering practice. The lifting capacity of the equipment cannot meet the requirements.

Equipment failure

Equipment is out of repair and often fails. Equipment hardware aging.

Underground utilities

Communication lines, heating and ventilation lines, power supply lines and rainwater pipes, etc.

Complex geological conditions

Underground cavity. Hard rocks and ancient tombs. The distribution of soil layer is changeable.

The complicated surrounding conditions

Adjacent to roads, railways, bridges, etc. Adjacent rivers, river water, underground rivers, etc.

Construction conditions

The site construction environment is dirty and messy. Disorderly arrangement of sundries. Poor lighting conditions.

According to the weight calculation results in Table 1, the weight of each retained secondary index was normalized to obtain the weight of each index as shown in Table 3 below.

TABLE 3. WEIGHT CALCULATION RESULTS OF EACH INDEX AFTER NORMALIZATION

| Indicator layer | Weight | Ranking |
|-----------------|--------|---------|
| Physical health | 0.048  | 12      |
| Safety awareness| 0.091  | 2       |
| Do not operate according to regulations | 0.048 | 13 |
| Safety regulations and systems | 0.144 | 1 |
| Safety education and training | 0.064 | 8 |
| Safety technical disclosure | 0.046 | 14 |
| Material property quality | 0.061 | 9 |
| Material transportation storage status | 0.048 | 11 |
| Effectiveness of materials | 0.064 | 7 |
| Safety protection device | 0.08 | 3 |
| Equipment selection | 0.08 | 4 |
| Equipment failure | 0.068 | 5 |
| Underground utilities | 0.068 | 6 |
| Complex geological conditions | 0.039 | 15 |
| The complicated surrounding conditions | 0.053 | 10 |
| Construction conditions | 0.048 | 12 |
It was worth mentioning that safety regulations and systems had the largest weight among all secondary indicators. This showed the importance of Safety regulations and systems in subway construction safety management. Project managers should focus on this factor and use the main management resources to improve the safety system of the project. Among the five first-class indexes, management-related indexes had the largest weight, while material-related factors had the smallest weight. These weight distribution laws were basically similar to previous research results [7,8].

5. CONCLUSIONS
In this paper, the 4M1E method and Analytic Hierarchy Process are used to try to build a scientific and operable subway project construction safety risk index system. First of all, the first-level indicators are constructed from five aspects, man factor, management factor, materials factor, machine factor and environment factor. Then, 27 secondary indicators are selected according to the practice of subway project safety risk management engineering and expert opinions. Finally, the weights of 27 secondary indicators are calculated by using Analytic Hierarchy Process, and the 16 indicators with the top 60% of the weight are selected as the secondary indicators of the formal index system. How to carry out the safety risk management of subway projects according to the research results of the index system in this paper will be the content worthy of further research in the future.

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