Study on the Influencing Factors of Urban Subway Engineering Construction Safety

Shixia Duan¹, Rui Sun¹

¹Management Engineering College, Zhengzhou University, Zhengzhou, China
duanshixia@zzu.edu.cn, 1506187239@qq.com

Abstract. The application of subway in the construction of urban modernized transportation facilities is increasing day by day. At the same time, the safety of urban subway construction has been paid more and more attention by the society. Based on the AHP-entropy method, this paper constructs the AHP-entropy's safety analysis model of the subway construction. Take Zijingshan Station as an example, the weight of the index is determined from the subjective and objective aspects, finding out the key factors influencing the construction safety of the subway and putting forward reasonable proposals of subway construction safety control measures, hoping to reduce the occurrence of subway safety accidents.

1. Introduction
From the end of 2016, a total of 30 cities in mainland China opened up urban rail operations, with a total length of 4152.8 km, of which 3168.7 km is subway accounting for 76.3% according to the 2016 Annual Urban Rail Transit Statistical and Analysis Report. Moreover, the scale of construction will plan to further expand. With the rapid development of urban rail transit, subway safety accidents occur frequently, resulting in huge economic losses and harsh social impact. Subway construction safety accidents have occurred in China, especially in economically developed cities, such as Beijing, Shanghai, Shenzhen, etc., causing great economic losses and adverse effects to the society. The analysis of subway construction safety factors is helpful for the prevention strategy and countermeasures in the process of subway construction. The reduction of safety accidents is of vital importance to the state, society and people. Domestic scholars have never stopped practice and research on subway construction safety. Hui Zhang applied the hierarchy fuzzy comprehensive evaluation method to evaluate the construction risk of Shanghai rail transit line 12, and put forward the corresponding measures and suggestions. Guixiang Chen studied the major risk factors, probability and loss distribution of the four stages of planning, design, construction and operation of the Metro [2]. Fan Chen constructed the subway construction safety risk warning model to identify potential safety risk factors in subway construction, through the combination of BP neural network technology and factor analysis method [3]. Chengfang Zhang built a information security management model for the time and space of subway construction based on BIM technology, which can be used for the safety management of the construction site [4]. Honglin Wang summed up 132 domestic urban rail transit construction safety accidents and the analysis results showed that collapse, object strike, falling height is the most common type of safety accident [5]. Qunfang Hu analyzed the safety risk accidents occurred in the construction of urban rail transit, and obtained the frequency of construction safety risk accidents. The central tunnel was 2 times as much as that of the station foundation pit [6]. Dongsheng made statistical analysis of the subway construction safety accident and the statistical results showed that the lack of information communication, geological exploration, shortage of construction defects,
design mistakes are the main cause of an accident [7]. Zhipeng Zhou suggested the control of construction safety risk should be considered from the aspects of personnel factors, equipment factors, material factors and environmental factors with the help of fault tree analysis of Hangzhou Metro accident [8].

This paper establishes the evaluation index system of construction safety and the analysis model of subway construction safety based on AHP-entropy method. Taking Zhengzhou line 2 Zijingshan hill station as an example, to find out the key factors affecting the safety of subway construction, put forward reasonable suggestions on construction safety.

2. Establishing the subway construction safety evaluation index system

In the construction of evaluation index system, with the spirit of science, authenticity and validity principle, on the basis of previous studies, questionnaire survey and expert judgment, concludes 14 an index of metro construction safety evaluation system from the unsafe behavior of human, mechanical equipment, construction environment, and construction management, see Table 1.

Table 1. The safety evaluation index system of subway construction

| First grade evaluation index | Second grade evaluation index                      |
|------------------------------|----------------------------------------------------|
| Unsafe behavior of human being $U_1$ | Professional skills and abilities $U_{12}$ |
|                              | Physiological status $U_{13}$                      |
|                              | Psychological quality $U_{14}$                     |
|                              | Mechanical structure $U_{21}$                      |
|                              | Operation method $U_{22}$                         |
| Mechanical equipment $U_2$ | Maintenance and repair $U_{23}$                    |
| Construction environment $U_3$ | Geological and hydrological conditions $U_{31}$ |
|                              | Pipeline distribution $U_{32}$                     |
|                              | The density of adjacent buildings $U_{33}$        |
|                              | Operating environment(ventilation, power supply, etc.) $U_{34}$ |
| construction management $U_4$ | Management organization and staff $U_{41}$        |
|                              | Management system $U_{42}$                         |
|                              | The level of enforcement $U_{43}$                  |
On the basis of the analysis of index synthesis, we modeled the risk grade. Risk grade is: Grade I - unacceptable; Grade II - unwilling to accept; grade III - acceptable; Grade IV - negligible. Thus, the city subway construction safety can be divided into 5 levels as follows: Grade I - serious unsafety; Grade II - no serious safety; Grade III - less safe; Grade IV - safety; Grade V - very safe. See table 2 for details.

**Table 2. Safety grade division of Metro Construction.**

| Grade   | Security          | Scaling  |
|---------|-------------------|----------|
| Grade I | serious unsafety  | (0, 0.2) |
| Grade II| no serious safety | (0.2, 0.5)|
| Grade III| less safe       | (0.5, 0.7)|
| Grade IV| safety           | (0.7, 0.9)|
| Grade V | very safe        | (0.9, 1) |

3. Safety analysis model of subway construction based on ahp- entropy method

According to the actual situation of the construction of subway construction project, select the appropriate analysis method for the evaluation index, determine the key parameters affecting the safety of subway construction, and puts forward effective measures. In this paper, AHP-entropy method is used to determine the weight value of subway construction safety evaluation index.

3.1. Using AHP method to calculate weight

AHP method belongs to the system analysis method, using the principle of combining qualitative and quantitative, calculates the corresponding index weight [9]. First of all, we need to analyse the problems in detail, compare the indicators one by one, get the judgment matrix, calculate the feature vector, and then unify the processing to get the weight of each evaluation index.

3.2. Using entropy method to calculate weight

The Entropy method is a method to determine the weight by evaluating the index value matrix. According to the magnitude of index information, entropy is obtained through a series of calculations, and the entropy is inversely related to the amount of information. This method can effectively eliminate the interference of subjective factors, and more objectively reflect the index weight. We can rely on the security level node and the evaluation index value to constitute the original data, and then calculate the weight through the entropy method, then get the weight of each index.

1) The acquisition of raw data

A number of experts and personnel participating in the subway construction are selected to assign the indexes and take the average value to form the evaluation matrix $A_{1 \times n}$, remember as $A = [x_{01}, x_{02}, x_{03}, \ldots, x_{0n}]$. According to a security grade node, the benchmark evaluation matrix is constituted, remember as $B_{(m-1) \times n}$. 
2) Constructing evaluation matrix
The evaluation matrix is composed of the evaluation index data and the reference matrix made up of safe and reliable nodes. Remember as $X_{m \times n}$:

$$
A = \begin{bmatrix}
    x_{11} & x_{12} & x_{13} & \ldots & x_{1n} \\
    x_{21} & x_{22} & x_{23} & \ldots & x_{2n} \\
    \vdots & \vdots & \vdots & \ddots & \vdots \\
    x_{m1} & x_{m2} & x_{m3} & \ldots & x_{mn} \\
\end{bmatrix}
$$

$$
B = \begin{bmatrix}
    M & M & M & \ldots & M \\
\end{bmatrix}
$$

3) Making results dimensionless:

$$
y_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}
$$

In the formula (3): $m$ is the number of objects to be evaluated.

4) The entropy of the index of J is:

$$
e_j = -k \sum_{i=1}^{m} y_{ij} \ln y_{ij}, K = \frac{1}{\ln m}
$$

5) The difference coefficient of the index of J is:

$$
d_j = 1 - e_j
$$

6) Calculating the weight of the J index:

$$
w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}
$$

3.3. Using AHP-entropy method to calculate the weight of the model
Firstly, the subjective weight of the evaluation index is obtained by AHP method, then the corresponding objective weight is obtained by the entropy method. Finally, the AHP-entropy method is used to modify the subjective weight. The new method reduces the impact of human subjective reasons, so that the results are more reasonable.

$$
\beta_j = \frac{v_j w_j}{\sum_{j=1}^{n} v_j w_j}
$$

In the formula (3): the subjective weight of the index is obtained by AHP method, remember as $v_j$, $n$ is the number of indicators.

4. Engineering example

4.1. Project Overview
Zhengzhou Metro Line 2 is basically a north-south direction of the line, starting from the Huiji District, only to Zhengzhou Xinzhou International Airport T2 Terminal 6 kilometers east of Zhengzhou South
Station, a total length of 71.25 kilometers. Zijingshan subway station is Zhengzhou Metro Line 1 and 2 transfer station and is the first underground four-store building. Zijingshan subway station is surrounded by the main commercial buildings, shopping plaza, municipal traffic roads, and traffic flow has been great.

4.2. Analysis on Construction Safety Evaluation Index of Zijingshan Station on Zhengzhou No.2 Line

(1) Using AHP method to calculate the weight
According to the evaluation index to prepare the corresponding questionnaire, the site staff and experts are invited to score the construction process of the indicators with the nine scale method, and calculate the weight of the evaluation index system in Table 3.

| First grade evaluation index | Weigh t | Second grade evaluation index | Weigh t | Combination weight |
|------------------------------|---------|-------------------------------|---------|-------------------|
| $U_1$                        | 0.27    | $U_{11}$                      | 0.245   | 0.066             |
|                              |         | $U_{12}$                      | 0.265   | 0.072             |
|                              |         | $U_{13}$                      | 0.260   | 0.070             |
|                              |         | $U_{14}$                      | 0.230   | 0.062             |
|                              |         | $U_{21}$                      | 0.349   | 0.073             |
| $U_2$                        | 0.21    | $U_{22}$                      | 0.336   | 0.071             |
|                              |         | $U_{23}$                      | 0.315   | 0.066             |
|                              |         | $U_{31}$                      | 0.285   | 0.080             |
|                              |         | $U_{32}$                      | 0.251   | 0.070             |
|                              |         | $U_{33}$                      | 0.264   | 0.074             |
| $U_3$                        | 0.28    | $U_{34}$                      | 0.200   | 0.056             |
|                              |         | $U_{42}$                      | 0.318   | 0.076             |
| $U_4$                        | 0.24    | $U_{42}$                      | 0.335   | 0.080             |
|                              |         | $U_{43}$                      | 0.347   | 0.083             |

(2) Using the entropy method to calculate the weight
According to the index system established in Table 1, the relevant experts and construction personnel of the construction site were invited to complete the professional assignment of 14 indicators according to the situation of construction safety management. The assignment data are from 1 to 10, indicating that the greater the value, the greater the impact of the index. And then form an evaluation matrix together with a reference matrix composed of a security level table, remember as $X$.

$$X = \begin{bmatrix}
0.45 & 6.55 & 6.25 & 5.75 & 6.60 & 7.65 & 7.80 & 7.80 & 6.60 & 5.80 & 7.50 & 7.75 & 8.00 \\
0.20 & 0.20 & 0.20 & 0.20 & 0.20 & 0.20 & 0.20 & 0.20 & 0.20 & 0.20 & 0.20 & 0.20 & 0.20 \\
0.50 & 0.50 & 0.50 & 0.50 & 0.50 & 0.50 & 0.50 & 0.50 & 0.50 & 0.50 & 0.50 & 0.50 & 0.50 \\
0.70 & 0.70 & 0.70 & 0.70 & 0.70 & 0.70 & 0.70 & 0.70 & 0.70 & 0.70 & 0.70 & 0.70 & 0.70 \\
0.90 & 0.90 & 0.90 & 0.90 & 0.90 & 0.90 & 0.90 & 0.90 & 0.90 & 0.90 & 0.90 & 0.90 & 0.90
\end{bmatrix}$$

According to the entropy method, the information entropy, the difference coefficient and the combined weight of each index are calculated. As the calculation amount is large, it cannot be presented in the limited layout. The weight data of each index are shown in Table 4.
### Table 4. Evaluation Index System Entropy Method Weight Calculation

| First grade evaluation index | Combination weight | Second grade evaluation index | Combination weight |
|-----------------------------|-------------------|-------------------------------|-------------------|
| $U_1$                       | 0.2854            | $U_{11}$                      | 0.0712            |
| $U_2$                       | 0.2146            | $U_{12}$                      | 0.0715            |
| $U_3$                       | 0.2857            | $U_{13}$                      | 0.0714            |
| $U_4$                       | 0.2154            | $U_{14}$                      | 0.0713            |

Using AHP-entropy method to calculate the weight

The weight of the index calculated by the AHP method and the weight obtained by the entropy method are determined by the formula (7), and the final comprehensive weight of the index is determined. See table 5.

### Table 5. AHP-entropy method to determine the weight

| Second grade evaluation index | Weight of AHP | Weight of entropy | Comprehensive weight | First grade evaluation index |
|-------------------------------|--------------|-------------------|----------------------|-----------------------------|
| $U_{11}$                      | 0.066        | 0.0712            | 0.0671               |                             |
| $U_{12}$                      | 0.072        | 0.0715            | 0.0736               |                             |
| $U_{13}$                      | 0.070        | 0.0714            | 0.0714               |                             |
| $U_{14}$                      | 0.062        | 0.0713            | 0.0631               |                             |
| $U_{21}$                      | 0.073        | 0.0716            | 0.0747               |                             |
| $U_{22}$                      | 0.071        | 0.0718            | 0.0728               | $U_1 = 0.2752$             |
| $U_{23}$                      | 0.066        | 0.0713            | 0.0672               |                             |
| $U_{31}$                      | 0.080        | 0.0711            | 0.0812               |                             |
| $U_{32}$                      | 0.070        | 0.0718            | 0.0728               |                             |
| $U_{33}$                      | 0.074        | 0.0715            | 0.0756               |                             |
| $U_{34}$                      | 0.056        | 0.0713            | 0.0570               |                             |
| $U_{41}$                      | 0.076        | 0.0718            | 0.0779               |                             |
| $U_{42}$                      | 0.080        | 0.0718            | 0.0820               | $U_3 = 0.2857$             |
| $U_{43}$                      | 0.083        | 0.0719            | 0.0851               | $U_4 = 0.2452$             |
From Table 6 we can draw in the first-level indicators, that is, $U_3 > U_1 > U_4 > U_2$. In the subway construction process, the construction environment is the highest degree of insecurity for the safety of accidents.

According to incomplete statistics, more than 20 security incidents occurred in 2010 to 2016, and the construction environment of the project collapse of the accident up to 10. In the subway safety accident classification, the proportion of collapse accidents is the highest frequency as high as 55%; In addition, water damage, mechanical damage, object strikes and other accidents occur frequently. The collapse of the accident is because of subway project construction characteristics and construction process. Construction of the subway, the first is to dig tunnels. There is a high degree of difference in the subway mouth if the material and soil are improper accumulation, this prone to collapse accident. And the occurrence of water damage accidents due to underground construction in the process of underground pipe rupture, groundwater penetration in the tunnel and so on.

Located in the top four are respectively $U_{43}$, $U_{42}$, $U_{31}$, $U_{41}$, is the level of enforcement, management system, geological and hydrological conditions and management organization and staff. In the 14 secondary indicators, the construction management of the three indicators are located in the forefront, indicating that in the construction process from the bottom of the management is particularly important. Perfect construction management can effectively reduce the safety accidents, to avoid casualties and economic losses.

4.3. Measures to Improve the Construction Safety of Zijoushan Station

The safety status of subway construction depends on the coordination effect of people, machine, environment and management, and the people is subjective and dynamic. Therefore, the quality of the operator will directly affect the security of the operating system. To reduce the casualties and property losses during the construction of the subway, the safety risk of the subway construction stage is to be well controlled. It is necessary to strengthen the construction safety operation education and understand the safety situation of the construction interface. So that every site operator spontaneously comply with the rules and regulations of the construction site, the formation of the whole process of construction safety risk production concept.

There are many machines and equipment in Zijingshan subway station construction site. Mechanical injury is one of the reasons for the safety accident and some prominent equipment to be controlled for the safety of subway construction is very vital. In the subway construction site, the performance of machinery and equipment need to be normal, the operator to certificates, with the ability to temporarily solve the problem.

Zijingshan station with open excavation construction, the construction environment is complex, affected by multiple factors, such as foundation excavation, groundwater, etc.. It may cause the settlement of the surrounding facilities deformation. Therefore, it is necessary to monitor settlement deformation during the construction of Zijingshan station and to protect the surrounding residents and buildings safety. According to the geological characteristics of Zijingshan and underground pipeline distribution, the surrounding buildings sinking, envelope displacement, underground pipelines, and steel pipe support the internal are forced to monitor.

In the management of the organizational structure, the responsibility of reciprocity is clearly. During the construction of the subway project, the safety responsibilities and corresponding rights of each department shall be clarified first. Second, the security management system will be developed. At the same time, strengthen the simultaneous construction of multi-type coordination and subway construction safety management.

5. Conclusion

The analysis of safety factors is of great significance to the subway construction of modern city in the construction of urban subway project. AHP-entropy method is used to construct the model, and the weight of the index is determined synthetically from the two aspects of subjective and objective, and the example of Zijingshan station on Zhengzhou No.2 is analyzed. The results of the study are important to the indicators, and the key factors influencing the construction safety of the subway in
Zijingshan Railway are found out. The results of the existence of bias, we need to collect more data to conduct empirical research so that the results more scientific and reasonable.

6. References

[1] Hui Zhang, Wenyong Li and Zhifang Ni 2010 Study on Risk Assessment and Control Measures of Shanghai Rail Transit Line 12 Project Construction J. Urban Rail Transit Research. 11 46-51

[2] Guixiang Chen 2004 Study on Risk Management of Subway Project J. Shanghai: Tongji University. 5 89-90

[3] Fan Chen and Hongtao Xie 2012 Study on Safety Early Warning of Subway Construction Based on Factor Analysis and BP Neural Network J. Journal of Chinese Society for Safety Science. 8 1-4

[4] Chengfang Zhang and Chao Li 2013 Application of BIM technology in subway construction safety J. Henan Science and Technology. 5 130-131

[5] Honglin Wang 2013 Study of risk management of the urban rail transit construction project. J. Xuzhou: China University of Mining and Technology. 9 20-22

[6] Qunfang Hu and Jiabao Qin 2013 Statistical analysis of accidents of subway tunnel construction from 2003 to 2011 in China J. Chinese Journal of Underground Space and Engineering. 3 51-55

[7] Dongsheng Xie, Qihu Qian and Xiaoli Wan 2012 Risk management rail transit construction J. Journal of Civil Engineering and Management. 29 61-67

[8] Zhipeng Zhou, Qiming Li and Xiaopeng Deng 2009 Analysis of Metro collapse accidents based on accident mechanism and management factors: With the collapse of Hangzhou Metro as an example J. China Safety Science Journal. 9 139-145

[9] Yang Xu, Yan Zhou and Xin Sun 2009 Comprehensive evaluation of mine safety based on fuzzy analytic hierarchy process J. Journal of Chinese Society for Safety Science. 15 147-153