Research on behavior safety evaluation of subway construction personnel based on improved AHP-FCE method

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Abstract: This paper studies the behavior safety evaluation of subway construction personnel. According to expert interviews, accident case analysis and references, the behavior safety evaluation system of subway construction personnel is constructed, including 6 first-class indicators and 20 second-class indicators. The improved AHP method, entropy weight method and difference coefficient linear weighting method is used to calculate the subjective and objective combination weights of each evaluation index, and FCE method is used to evaluate the behavior safety status of the construction personnel of a subway project. The results show that: (1)The evaluation model is scientific and reasonable, and has strong operability; (2) The behavior safety status of subway construction personnel is greatly affected by knowledge and skills, safety atmosphere and management factors. Among them, safety attitude, safe operation skills, exemplary role of team leaders, safety initiative participation, safety education and training, and safety leadership are of great importance. Strengthening their management will effectively improve the level of behavior safety management and put forward new management ideas for the project management idea.

1. Introduction

With the rapid development of the city, more and more attention has been paid to the construction of rail transit[1]. However, the construction experience of subway engineering is not as good as residential construction, and the security management standard of subway construction is not high. Consequently, in recent years, subway engineering accidents occur frequently. In the process of analyzing the causes of subway construction accidents, it is found that people's unsafe behavior is an important incentive to cause accidents, and scientific management of people's unsafe behaviors is an important measure to prevent accidents. Evaluating the behavior safety of constructor is an important segment to enhance the behavior safety management.

On the basis of previous studies[2-7], according to the inherent characteristics of subway construction, this paper takes personal factors, equipment factor, environmental factors, knowledge and skills, management factors and safety atmosphere as 6 first level indicators and 20 second level indicators of behavior safety evaluation system.

According to the advantages and disadvantages of the existing evaluation methods, the weight value of subjective and objective combination of each index is determined by the improved analytic hierarchy process, three scale AHP is used to determine the subjective weight of each evaluation index, the entropy weight method is used to determine the objective weight of each evaluation index, the difference coefficient method is used to calculate the subjective and objective weight coefficient

and carry out linear weighting to determine the combination weight of each index, so as to make the evaluation index weight more scientific[8]. According to the behavior safety of subway construction personnel and the fuzziness of judgment and evaluation, the fuzzy comprehensive evaluation method is used to evaluate the behavior safety of subway construction personnel[9].

2. Construction of behavior safety evaluation system for subway construction personnel

Through expert interviews, accident case analysis and consulting relevant references[10-12], the behavior safety evaluation system of subway construction personnel is constructed, as shown in Figure 1.
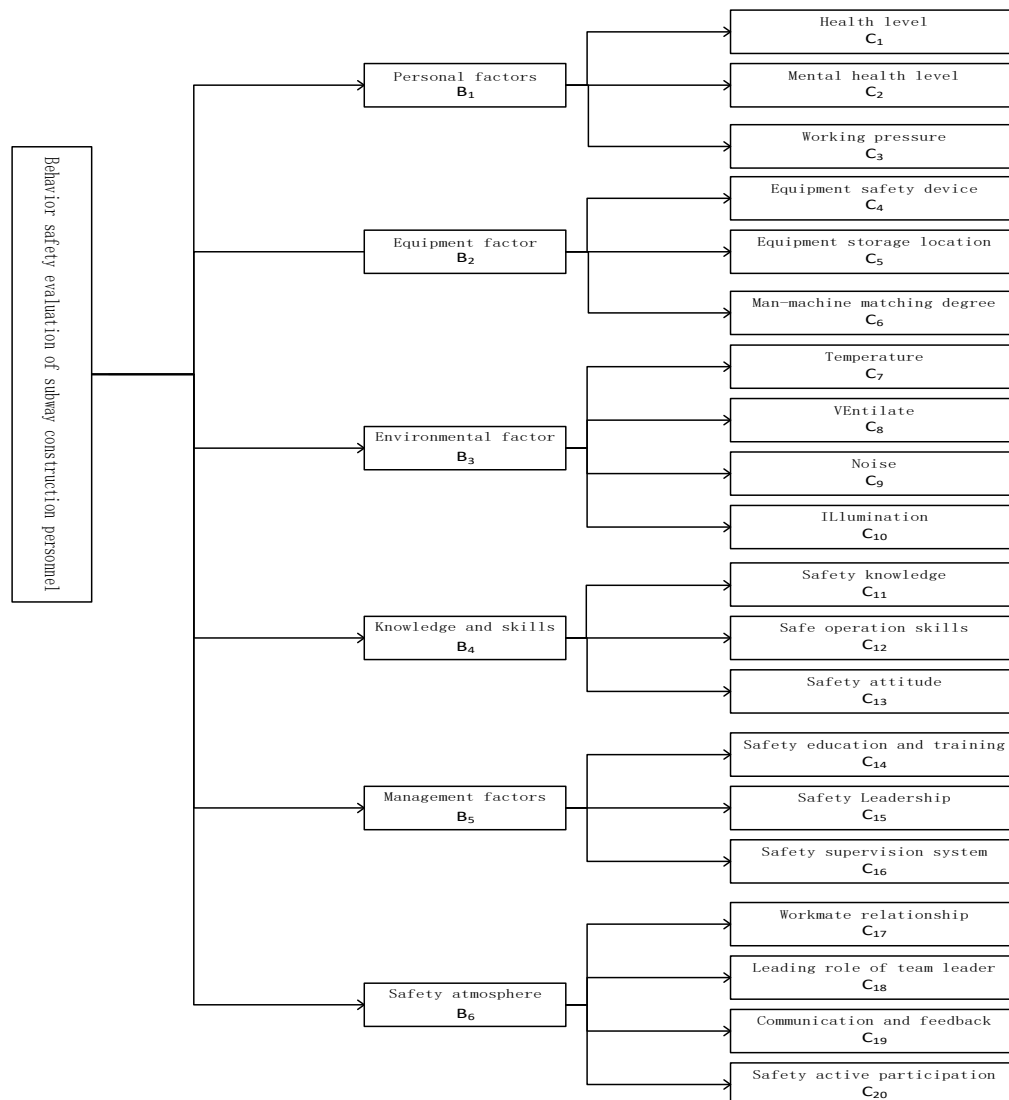

Figure 1 Behavior safety evaluation system of subway construction personnel

3. Establishment of behavior safety evaluation model for subway construction personnel

3.1. Weight calculation of subjective and objective compose of evaluation index based on Improved AHP

The improved AHP has made three improvements on the basis of AHP this paper. One is to change the scale of index importance judgment and adopt three scale method. Secondly, the quasi optimal consistency matrix is added to reduce the repeated consistency test. Thirdly, the difference coefficient method is used to linearly weight the subjective and objective weights calculated by the two methods.

The improved AHP method is used to calculate the weights of subjective and objective linear combination are as follows:

① Construct index comparison matrix and calculate importance ranking index according to formula (1);

② Construct judgment matrix and calculate transfer matrix and optimal transfer matrix according to formula (2) (3) (4);

③ Calculate quasi optimal consistent matrix according to formula (5);

④ Calculate maximum eigenvalue of quasi optimal consistent matrix and the corresponding eigenvector[13];

⑤ According to the importance of each index and the normalization method, the normalized evaluation matrix is determined[13];

⑥ The information entropy of each index is calculated according to formula (6)[13];

⑦ The objective weight of each index is calculated according to formula (7)[13];

⑧ The combination weight of each index is calculated by using the linear weighting method of difference coefficient and formula (8) (9)[13] .

$$\begin{cases} r = \sum_{j=1}^{n} a_{ij} \\ r_{max} = \max\{r_i\} \\ r_{min} = \min\{r_i\} \end{cases} \tag{1}$$

$$b_{i,j} = \begin{cases} \dfrac{(r_i - r_j)(k_m - 1)}{r_{max} - r_{min}} + 1 & r_i \geq r_j, \\ \left[\dfrac{(r_i - r_j)(k_m - 1)}{r_{max} - r_{min}} + 1 \right]^{-1} & r_i < r_j \end{cases} \tag{2}$$

$$k_m = \frac{r_{max}}{r_{min}}$$

$$c_{ij} = \log_{10} b_{ij} \tag{3}$$

$$d_{ij} = \frac{1}{n} \sum_{k=1}^{n} (c_{ik} - c_{jk}) \tag{4}$$

$$e_{ij} = 10^{d_{ij}} \tag{5}$$

$$H_j = -\frac{1}{\ln m} \sum_{i=1}^{m} p_{ij} \ln p_{ij} \tag{6}$$

$$U_j = \frac{1 - H_j}{\sum_{i=1}^{n} (1 - H_j)} \tag{7}$$

$$W = \alpha W_1 + \beta W_2 \tag{8}$$

$$\begin{cases} \alpha = \dfrac{n}{n-1} \left[\dfrac{2}{n} (1,2,\dots n)^T (P_1, P_2, \dots, P_n) - \dfrac{n+1}{n} \right] \\ \beta = 1 - \alpha \end{cases} \tag{9}$$

3.2. Construction of fuzzy comprehensive evaluation model

Fuzzy comprehensive evaluation is to use the knowledge of fuzzy mathematics, using the evaluation level, membership degree and matrix to quantify the indicators to get the overall evaluation[14].

The basic steps are as follows:

① The factor set U of comprehensive evaluation is established;

② Determine the factor weight vector W;

③ The evaluation set V of comprehensive evaluation is established;

④ The evaluation matrix R was obtained by single factor fuzzy evaluation;

⑤ Establish a comprehensive evaluation model B = W° R, where "°" is called comprehensive evaluation synthesis operator

4. Empirical analysis

For verify the practicability and operability of the behavior safety evaluation model of subway construction personnel in reality, a subway construction project is selected as the evaluation object, and the behavior safety level of the construction personnel of the project is evaluated according to the methods and steps in the model.

In the early stage, we conducted on-the-spot investigation on a subway project, deeply observed the operation behavior of the construction personnel, communicated with the construction personnel and relevant management personnel, consulted the education and training records, management system, safety and technical disclosure records and other reference materials for the study, a total of 113 questionnaires were distributed, including construction personnel, safety management personnel and project leaders.

4.1. Calculate the weight of evaluation index combination

Ten experts in the field of safety management and subway construction are invited to judge the significance of each evaluation index. According to formula (1) - (9), the weight of each index combination is calculated, as shown in Table 1.

Table 1 Weight value of behavior safety evaluation index of subway construction personnel

Goal	First-rank evaluation index	Improve AHP	Entropy weight method	linear combination	Second-rank evaluation index	Improve AHP	Entropy weight method	linear combination
Behavior safety evaluation of subway construction personnel	Personal factors B_1	0.1351	0.1555	0.1469	Health level C_1	0.1255	0.3106	0.2423
					Mental health level C_2	0.4943	0.4542	0.4690
					Working pressure C_3	0.3802	0.2352	0.2887
	Equipment factor B_2	0.1232	0.1432	0.1348	Equipment safety device C_4	0.4537	0.3532	0.3903
					Equipment storage location C_5	0.2347	0.3242	0.2912
					Man-machine matching degree C_6	0.3116	0.3226	0.3185
	Environmental factor B_3	0.0612	0.1321	0.1023	Temperature C_7	0.0669	0.1972	0.1319
					Ventilate C_8	0.2904	0.2948	0.2926
					Noise C_9	0.1289	0.2174	0.1731
					Illumination C_{10}	0.5138	0.2906	0.4024
	Knowledge and skills B_4	0.3429	0.2753	0.3037	Safety knowledge C_{11}	0.2269	0.2642	0.2537
					Safe operation skills C_{12}	0.2655	0.2677	0.2671
					Safety attitude C_{13}	0.5076	0.4681	0.4792
	Management factors B_5	0.1544	0.1421	0.1473	Safety education and training C_{14}	0.1047	0.3538	0.2095
					Safety leadership C_{15}	0.6840	0.5318	0.6200
					Safety supervision system C_{16}	0.2113	0.1144	0.1705

				Workmate relationship C_{17}	0.1598	0.2824	0.2280
				Leading role of team leader C_{18}	0.1065	0.3940	0.2663
Safety atmosphere B_6	0.1832	0.1518	0.1650	Communication and feedback C_{19}	0.1951	0.1834	0.1886
				Safety active participation C_{20}	0.5386	0.1403	0.3171

4.2. Fuzzy comprehensive evaluation on behavior safety of subway construction personnel

The evaluation level is divided into 5 levels, V={V_1,V_2,V_3,V_4,V_5}={ very dangerous, relatively dangerous, relatively safe, safe, very safe,}, eight experts are invited to grade the secondary evaluation index. According to the expert scoring, the membership matrix is formed, combined with the weight vector, the evaluation vector of each level index and the whole system is calculated[15]. According to the maximum membership principle, the behavior safety evaluation grade of subway construction personnel is determined.

Take the first grade rating index of safety atmosphere as an example:

The membership matrix: $R_6 = \begin{bmatrix} 0 & 0 & 0.12 & 0.88 & 0 \\ 0 & 0 & 0.75 & 0.25 & 0 \\ 0 & 0 & 0.63 & 0.37 & 0 \\ 0 & 0.5 & 0.5 & 0 & 0 \end{bmatrix}$

The combination weight value: W_6=(0.2140,0.2657,0.1884,0.3319)

The fuzzy comprehensive evaluation vector: $B_6 = W_6 \cdot R_6$=(0,0.1659,0.5096,0.3245,0)

In the same way, it can be concluded that:

B_1=(0,0.1068,0.3912,0.5020,0)

B_2=(0,0.1178,0.6611,0.2211,0)

B_3=(0,0.3784,0.5485,0.0731, 0)

B_4=(0,0,   0.5349,0.4651,0)

B_5=(0,0.3624,0.5524,0.0853,0)

The behavior safety evaluation vector of construction personnel in a project:

$$A = W \cdot B = (0.1469, 0.1348, 0.1023 \quad 0.3037, 0.1473, 0.165) \cdot \begin{pmatrix} 0 & 0.1068 & 0.3912 & 0.5020 & 0 \\ 0 & 0.1178 & 0.6611 & 0.2211 & 0 \\ 0 & 0.3784 & 0.5485 & 0.0731 & 0 \\ 0 & 0 & 0.5349 & 0.4651 & 0 \\ 0 & 0.3624 & 0.5524 & 0.0853 & 0 \\ 0 & 0.1659 & 0.5096 & 0.3245 & 0 \end{pmatrix}$$

$$= (0,0.1511,0.5306,0.3183,0)$$

4.3. Evaluation results

(1) The maximum value of the comprehensive evaluation vector of subway construction personnel behavior safety is 0.5306. According to the principle of maximum membership degree, the behavior safety evaluation result of project construction personnel is relatively dangerous.

(2) From the first level evaluation index evaluation, it can be seen that equipment factors, environmental factors, knowledge and skills, management factors and safety atmosphere belong to the relatively dangerous level, among them, safety education and training, team leader's exemplary role, safety knowledge, safe operation skills and safety attitude indicators are relatively dangerous, and safety leadership index is dangerous.

4.4. Measures and suggestions on improving the behavior safety level of construction personnel

The measures to improve the behavior safety level of construction personnel should be put forward according to the evaluation results of the secondary index. According to the subordinate function value of the evaluation index, it can be seen that the construction personnel of the project are lack of safety knowledge, strong subjectivity of safety operation skills, low safety attitude or safety awareness, team leaders do not play an exemplary role, poor communication and feedback within the team and between the superior and the subordinate, there are not only their own reasons, but also the potential causes of the project. The secondary index evaluation under the management factors also reflects the problems of inadequate safety education and training, imperfect safety supervision and management system, and low safety leadership. The project can improve the behavior safety level of construction personnel from the following aspects.

(1) Improve the safety management ability of managers

Appropriate training should be conducted for management personnel, and safety awareness training for management personnel should be increased, pass on the thinking of "key minority" to make the management mode of safety management personnel more scientific and improve the management ability,to promote the management personnel to enter the scene more, understand the needs of workers, understand the management defects with team leaders, grasp the "key minority" of workers, and improve their "key minority" ability[16-17].

(2) Give full play to the role of safety bridge of construction team leader

In daily work and life, the relationship between team leaders and workers is relatively close, and workers have a strong sense of trust in them[17]. Most of the safety knowledge, safety awareness and safety habits of most workers are attributed to the face-to-face instruction and on-site work guidance given by the team leader in daily work, so the special status and important role of team leaders can be highlighted. Make a systematic training plan for construction team leaders, so that some high-quality team leaders can be transformed into their own workers. Through continuing education, further study and other ways, we can create a team of construction team leaders with high skills, high quality and high ability.

(3) Innovating education and cultivate methods to improve the behavior safety of operators

The subject of entry needs to attach importance to the construction of project safety culture, create a fine safety atmosphere, and accelerate the construction personnel to establish the safety concept of "unsafe construction". According to the characteristics of subway operation, risk analysis is carried out to improve the risk awareness of construction personnel[17-18]. Modern safety training techniques such as experiential and VR are adopted to further strengthen the safety skills of construction personnel. The monitoring system of subway personnel's operation behavior is developed to dynamically monitor the operation behavior, and timely warn the unsafe behavior to ensure that the construction personnel work in a safe state.

5. Conclusion

(1) The behavior safety evaluation model is used to evaluate the behavior of the construction personnel of a subway construction project[19-20], and the results are relatively dangerous, in line with the actual situation and achieve the expected effect.

(2) The evaluation model is scientific, reasonable and operable, which has certain reference value for the behavior safety evaluation of subway construction personnel.

(3) In the evaluation model, the improved AHP is used to calculate the subjective weight of the index, the entropy weight method is used for the objective weight, and the difference coefficient linear weighting method is used for the combination of subjective and objective weights, the advantages of each method make the weight of evaluation index more scientific and reasonable[21].

(4) The behavior safety status of subway construction personnel is greatly affected by knowledge and skills, safety atmosphere and management factors. Among them, safety attitude, safe operation skills, exemplary role of team leaders, safety initiative participation, safety education and training, and safety leadership are of great importance. Strengthening their management will effectively improve

the level of behavior safety management and put forward new management ideas for the project management idea.

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