RESEARCH ARTICLE

Safety risk control in construction engineering based on the interval analytic hierarchy process and technique for order preference by similarity to ideal solution

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Abstract
To improve the safety management level of construction projects, the housing construction project was taken as the research object and the hierarchical structure model by using the improved analytic hierarchy process (IAHP) was established. Based on the four dimensions of human, material, environment, management, the 12 influencing factor evaluation indexes and 34 scoring items were designed. By the redistribution of weight, the value range of scoring items was determined, and then the construction safety management evaluation system was constructed to evaluate the project safety management. When evaluating multiple projects, if the overall evaluation conclusion is poor, the technique for order preference by similarity to an ideal solution (TOPSIS) was used to evaluate the relative advantages and disadvantages of the project by introducing reference interval \( \alpha \) \([0.5,0.6]\). By calculating the membership relationship between nearness degree \( L_i^+ \) and reference interval \( \alpha \), the decision-making method to improve the level of project safety management was given. The results show that, if \( L_i^+ > 0.6 \), need external interactive learning, if \( L_i^+ < 0.5 \), internal communication and learning can be organized. If \( L_i^+ \in \alpha \), the project safety management level can be improved by the combination of external interactive learning and internal experience exchange.

KEYWORDS
decision method, evaluation index, safety management

JEL CLASSIFICATION
Civil and environmental engineering

1 INTRODUCTION

Construction safety management is an important aspect of project management. During the construction process, due to poor safety behavior,\(^1\)\(^-\)\(^3\) safety awareness,\(^4,5\) working environment,\(^6,7\) and other factors of operators, conduced various safety accidents occur frequently. How to effectively control safety risks and prevent safety accidents, many
scholars have done a lot of research. Wang,8 and Jia et al.,9 stated that effective organizational support from the management toward workers can significantly improve the safety behavior of workers. Zhai et al.,10 proposed that enforcing safety standards related to people is the premise to ensure construction safety. Du et al.11 studied the construction safety evaluation of construction projects using analytic hierarchy process (AHP) and fuzzy comprehensive evaluation method, established a project construction safety evaluation index system, and formulated the specific inspection items and scoring rules of the second-level index for safety evaluation. Wu et al.,12 developed a method to evaluate construction safety management based on factor set fuzzy comprehensive evaluation method, for evaluating the performance of construction safety management. There are many methods to evaluate the safety management of construction projects and each has its own advantages and disadvantages, such as AHP and Delphi method can make better use of expert opinions, but they rely too much on the subjective judgment of experts; TOPSIS evaluation results are objective, but it cannot reflect the preferences of decision-makers. Many scholars have conducted extensive research on the application of Delphi, Analytic Hierarchy Process and TOPSIS in different fields and have obtained corresponding research results. Bui et al.,13 studied sustainable supply chain through literature analysis review by various methods such as the fuzzy Delphi method. It provided guidance for further research. Tu et al.,14 proposed an innovative method that combines fuzzy analytic hierarchy process with fuzzy technology and fuzzy multicriteria decision-making, it provided a reference for solving multicriteria decision-making problem. Koohathongsumrit et al.,15 constructed a new hybrid multicriteria decision-making method based on the analysis of the characteristics of AHP and TOPSIS methods, and used the advantages of the above methods to improve the reliability of decision-making results. Omidi et al.,16 studied the influence relationship between the safety environment and personal behavior based on the integrated entropy-TOPSIS method. It was considered that personal normative behavior and safety awareness were important factors affecting people's safety management performance, and organizational communication at the management level was the highest important psychosocial safety climate factor influencing the safety performance of employees.

Drawing on the basic ideas of the above research results, this article carries out the research on the evaluation of construction engineering safety management based on the TOPSIS method and analytic hierarchy process, seeking a new management method to improve the level of construction engineering safety management. Through the statistical analysis of relevant research results, few researchers used the method of combining AHP-TOPSIS to evaluate building safety management. The blank of early research was the main aspect of this study. Existing results mainly focus on the safety accident cause, construction atmosphere, occurrence mechanism, evaluation system, and avoidance strategy, and so forth, various factors affecting the weight of construction safety accidents and the uncertainties and differences between the various evaluation index research is insufficient. Some studies put forward the inducements leading to safety accidents and put forward some measures to avoid safety accidents within the scope of research, but this kind of method needs a large amount of data and stable warning models to realize. It fails to take into account the complexity and operability requirements of the construction site, and it is difficult to implement.

Considering the implementation and effectiveness of construction safety management, realizes the advance control and continuous improvement of construction safety risk management. Based on IAHP method, this research takes the housing construction project as the research object, takes the safety inspection and accident investigation in the construction process as the basis, and obtains the main factors leading to the occurrence of safety accidents through expert evaluation. This article constructs the construction engineering safety management evaluation system, used IAHP to establish the hierarchical structure model and calculated the combined weighting value of the evaluation indexes of influencing factors, combined with the application of TOPSIS method for safety evaluation, and through the engineering example to verify the accuracy of evaluation. It provides a basis for improving the level of safety management.

2 CONSTRUCT SAFETY MANAGEMENT EVALUATION SYSTEM

Construction safety management involves a wide range and many influencing factors, and the influence of many factors on safety risk is not easy to accurately evaluate. In this article, the evaluation index of influencing factors is established by statistical method. The Delphi method is used for target screening, through solving the weight of judgment matrix to determine the weight value of the evaluation index.
2.1 CONSTRUCTING SAFETY MANAGEMENT EVALUATION SYSTEM BASED ON IAHP

IAHP is an analysis algorithm that combines interval algorithm and traditional analytic hierarchy process. It uses interval numbers instead of point values to form a judgment matrix, and solves the problem of uncertainty in the comparison of indicators at the same level. It is more consistent with the actual situation to use the interval analytic hierarchy process. Based on the principle of IAHP, improved the 1–9 scale, introduced the 5/5–9/1 fractional scale, and used MATLAB tools to calculate the index weight value based on the existing research results. The specific modeling process is as follows.

Through the statistical analysis of 100 safety accidents in domestic housing construction projects from 2018 to 2020, 33 major or great safety accidents are mainly analyzed. It is classified from four dimensions: human factor B1, machine or matter factor B2, environmental factor B3, and management factor B4, and took it as the criterion layer. The analysis results show that the dominant factors that cause safety accidents are generally easy to identify, while the hidden factors must be investigated and studied in detail before concluding. In most cases, the superposition and accumulation of recessive factors develop into the cause or inducement of dominant factors, and transform into dominant factors under certain conditions, thereby leading to the occurrence of accidents. Recent safety accident statistics of China are listed in Table 1.

Make statistical analysis on the influencing factors of construction safety behavior by using the four dimensions of human, machine or material, environment, and management factors, and the causes of accidents are divided based on these factors. The statistical results are shown in Table 2.

Through further analysis of the number of casualties caused by dominant factors and recessive factors, it can be seen that B2 and B3 are the main factors leading to casualties for explicit factors, as shown in Figure 1 below. For invisible factors, B1 and B4 are the main factors causing casualties, as shown in Figure 2 below. Generally, the safety accidents directly caused by dominant factors do not act alone, and their occurrence probability is related to the action intensity of recessive factors. From the analysis of the relationship between active and passive, the probability of safety accidents caused by factors B1 and B4 is higher than that of B2 and B3, which is the root cause and inducement of factors B2 and B3.

Establishes hierarchical structure analysis table, which is divided into the following layers: A-highest level (target layer), B-intermediate layer (criterion layer), and C-lowest layer (index layer). The upper layer factors dominate all or part of the elements in the adjacent lower layer, forming a hierarchical relationship, as illustrated in Table 3.

2.2 CONSTRUCT COMPARISON JUDGMENT MATRIX

An effective scaling system must possess suitable application characteristics and internal structures. All types of scaling methods have order-preserving properties. Statistical analysis of safety accidents demonstrates the following: The contribution rate of influence factors of the criterion layer to the target layer does not differ significantly, the strength of the nature is similar, and the 1–9 scale is not conducive in accurately expressing the relative significance of each element. Even though we can use a scale of 1–9, the judgment matrix fails to objectively reflect the judgment of decision-makers, resulting in the distortion of decision results and reduced credibility. Guo et al.,17 proposed another fractional scale method (5/5, 5.5/4.5, 6/4, 6.5/3.5, 8.5/1.5, 9/1) and provided their RI results. Compared with the 1–9 scale, it is more reasonable when the nature and strength of influencing factors are similar. Because the 1–9 scale has an effective uniformity, perceptibility, and memorability, it is advantageous to use the 1–9 scale when there are differences in the properties and intensities of the factors affecting the index layer. Combined with the characteristics of construction projects, the criterion layer adopts the 5/5–9/1 scale method to construct the judgment matrix. The index layer adopts the 1–9 scale method to construct the judgment matrix. The relatively crucial criteria are listed in Tables 4 and 5.

Three safety experts and two senior project managers were consulted and were requested to combine the construction characteristics of the housing project, generate the statistical analysis on influencing factors of safety accidents in recent years, provide comprehensive assessment comments, and study and compare the significance of the influencing project safety behavior. After several rounds of discussion and analysis, judgment matrices of the target layer, criterion layer, and index layer were obtained, and are listed in Tables 6–10.
### TABLE 1  Statistical table of safety accidents

| Time       | Location        | Cause                          | Death toll | Dominant factors | Recessive factors |
|------------|-----------------|--------------------------------|------------|------------------|-------------------|
| 2020.10.08 | Shanwei, Guangdong | Formwork collapse              | 7          | B3               | B1, B3            |
| 2020.08.30 | Heze, Shandong  | Tower crane injury              | 3          | B2               | B1, B4            |
| 2020.08.04 | Fengcheng, Jiangxi | Fall from high place          | 3          | B1               | B2, B4            |
| 2020.07.04 | Zhongxiang, Hubei | Tower crane injury              | 3          | B2               | B1, B4            |
| 2020.06.27 | Foshan, Guangdong | Formwork collapse              | 3          | B3               | B4                |
| 2020.05.19 | Baotou, Inner Mongolia | Construction lift failure     | 3          | B2               | B1, B4            |
| 2020.05.16 | Yulin, Guangxi  | Fall of construction lift      | 6          | B2               | B3, B4            |
| 2020.04.18 | Yuanyang, Henan | Soil collapse                  | 4          | B1               | B4                |
| 2020.01.05 | Wuhan, Hubei    | The collapse of high formwork  | 6          | B1               | B4                |
| 2019.11.20 | Qingyang, Gansu | Tower crane overturning        | 3          | B2               | B1, B4            |
| 2019.11.15 | Zhengzhou, Henan | Foundation pit collapse       | 3          | B3               | B1, B4            |
| 2019.10.28 | Guizhou, Guiyang | The collapse of construction body | 8      | B4               | B1, B2            |
| 2019.09.26 | Chengdu, Sichuan | Foundation pit collapse       | 3          | B3               | B1, B4            |
| 2019.09.01 | Nyingchi, Tibet | Tower crane overturning        | 3          | B2               | B1, B4            |
| 2019.08.28 | Zhengzhou, Henan | Tower crane collapse           | 3          | B2               | B1, B4            |
| 2019.06.16 | Langfang, Hebei | Foundation pit collapse       | 3          | B3               | B1, B4            |
| 2019.04.25 | Hengshui, Hebei | Fall of construction lift      | 11         | B2               | B1, B4            |
| 2019.04.10 | Yangzhou, Jiangsu | Foundation pit collapse      | 5          | B3               | B1, B4            |
| 2019.01.23 | Huarong, Hunan | Tower crane collapse           | 4          | B2               | B1, B4            |
| 2018.12.29 | Minhang, Shanghai | Foundation pit collapse     | 3          | B3               | B1, B4            |
| 2018.12.10 | Hanzhong, Shanxi | Tower crane collapse           | 3          | B2               | B1, B4            |
| 2018.10.15 | Heze, Shandong  | Tower crane collapse           | 3          | B2               | B1, B4            |
| 2018.10.04 | Tianmen, Hubei  | Fall of construction lift      | 3          | B2               | B1, B4            |
| 2018.09.10 | Pudong, Shanghai | Poisoning choke               | 3          | B3               | B1, B4            |
| 2018.08.31 | Dezhou, Shandong | Support frame collapse         | 6          | B1               | B2, B4            |
| 2018.08.24 | Hefei, Anhui    | Poisoning choke               | 3          | B3               | B1, B4            |
| 2018.07.02 | Bijie, Guizhou  | Tower crane collapse           | 3          | B2               | B1, B4            |
| 2018.06.29 | Baodi, Tianjin  | Electric shock                 | 3          | B1               | B3, B4            |
| 2018.05.17 | Wuzhishan, Hainan | Tower crane collapse          | 4          | B2               | B1, B4            |
| 2018.04.09 | Shantou, Guangdong | Fall of construction lift     | 4          | B2               | B1, B4            |
| 2018.02.08 | Hechi, Guangxi  | Tower crane collapse           | 3          | B2               | B1, B4            |
| 2018.01.24 | Xuchang, Henan  | Fall of construction lift      | 4          | B2               | B1, B4            |
| 2018.01.21 | Fuyang, Anhui   | Fall of construction lift      | 3          | B2               | B1, B4            |

### TABLE 2  Statistical table consisting the factors contributing to accidents

| Accident statistics | B1 | B2 | B3 | B4 |
|---------------------|----|----|----|----|
| Dominant factors    | 5  | 18 | 9  | 1  |
| Recessive factors   | 26 | 3  | 3  | 31 |
FIGURE 1 Influence analysis chart of dominant factors

FIGURE 2 Influence analysis chart of recessive factors

TABLE 3 Hierarchy structure analysis table

| Target layer                  | Criterion layer | Index layer                                           |
|-------------------------------|-----------------|-------------------------------------------------------|
| Engineering safety accident A | Human B1        | Professional quality of operators C1                  |
|                               |                 | Safety awareness of operators C2                      |
|                               |                 | Provide personal safety protection articles C3        |
| Machine or matter B2          | The integrity of mechanical guards and facilities C4    |
|                               |                 | Standardization of mechanical installation and removal C5 |
|                               |                 | Machine operation, maintenance, and management C6     |
| Environment B3                | Hydrogeological natural environment of the project site C7 |
|                               |                 | Construction work environment C8                      |
|                               |                 | Force majeure causes the environmental change C9      |
| Management B4                 | Management and control of project implementation C10    |
|                               | Management structure and management system C11         |
|                               | Control measures and management countermeasures C12     |

TABLE 4 Criteria for judging the significance of indicators

| Scale selects | Equally significant | Marginally significant | Least significant | Moderately significant | Reasonably Significant | Significant | Very significant | Highly significant | Most significant |
|---------------|---------------------|------------------------|-------------------|------------------------|------------------------|-------------|------------------|-------------------|------------------|
| 5/5–9/1       | 5/5                 | 5.5/4.5                | 6/4               | 6.5/3.5                | 7/3                    | 7.5/2.5     | 8/2              | 8.5/1.5           | 9/1              |
| 1–9           | 1                   | 2                       | 3                 | 4                       | 5                       | 6                | 7                | 8                 | 9                |
### Table 5  R.I. values of random consistency indices

| Order and Scale | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   |
|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 5/5–9/1         | 0.00| 0.00| 0.19| 0.26| 0.33| 0.41| 0.49| 0.57| 0.67|
| 1–9             | 0.00| 0.00| 0.52| 0.89| 1.26| 1.36| 1.41| 1.16| 1.16|

### Table 6  A-B judgment matrix

| A-B  | B1   | B2   | B3   | B4   |
|------|------|------|------|------|
| B1   | 5/5  | 6/4  | 7/3  | 4/6  |
| B2   | 4/6  | 5/5  | 6.5/3.5 | 3.5/6.5 |
| B3   | 3/7  | 3.5/6.5 | 5/5  | 2.5/7.5 |
| B4   | 6/4  | 6.5/3.5 | 7.5/2.5 | 5/5  |

### Table 7  B1-Ci (i = 1,2,3) judgment matrix

| B1-Ci | C1   | C2   | C3   |
|-------|------|------|------|
| C1    | 1    | 1/3  | 4    |
| C2    | 3    | 1    | 5    |
| C3    | 1/4  | 1/5  | 1    |

### Table 8  B2-Ci (i = 4,5,6) judgment matrix

| B2-Ci | C4   | C5   | C6   |
|-------|------|------|------|
| C4    | 1    | 1/6  | 3    |
| C5    | 6    | 1    | 7    |
| C6    | 1/3  | 1/7  | 1    |

### Table 9  B3-Ci (i = 7,8,9) judgment matrix

| B3-Ci | C7   | C8   | C9   |
|-------|------|------|------|
| C7    | 1    | 1/5  | 3    |
| C8    | 5    | 1    | 7    |
| C9    | 1/3  | 1/7  | 1    |

### Table 10  B4-Ci (i = 10,11,12) judgment matrix

| B4-Ci | C10  | C11  | C12  |
|-------|------|------|------|
| C10   | 1    | 1/3  | 5    |
| C11   | 3    | 1    | 7    |
| C12   | 1/5  | 1/7  | 1    |
2.3 | CALCULATE THE COMBINED WEIGHT OF THE EVALUATION INDEX TO THE OVERALL OBJECTIVE

The weight calculation methods include the arithmetic average method, geometric average method, and characteristic root method. In this study, the geometric average method is used.

Weight calculation includes the following steps:

1. The elements of the judgment matrix are multiplied by rows.
2. Elevate the result to the $N$th power.
3. Normalize the resulting vector and then obtain the weight vector.

The calculation formula is as follows:

$$w_i = \left( \prod_{j=1}^{n} a_{ij} \right)^{1/n} / \sum_{k=1}^{n} \left( \prod_{j=1}^{n} a_{kj} \right)^{1/n}, \ i = 1, 2, \ldots, n \ .$$

By substituting the data of judgment matrix $A-B$ of Table 6 into Equation (1), the weight vector of the criterion layer can be obtained as follows:

$$w = (0.2831, 0.2070, 0.1206, 0.3893).$$

Consistency check:

- the maximum eigenvalue is obtained and the calculation formula is

$$\lambda_{\text{max}} = \sum_{i=1}^{n} \left( Aw_i \right) / nw_i .$$

Through calculation, the maximum eigenvalue of matrix $A-B$ is 4.007.

Consistency test of the judgment matrix. The consistency index calculation formula is

$$C.I. = \frac{\lambda_{\text{max}} - n}{n - 1} .$$

The consistency ratio is calculated using

$$C.R. = \frac{C.R.}{R.I.} .$$

The R.I. value is found in Table 5, if $C.R. < 0.1$, the judgment matrix satisfies the consistency.

After calculation, the consistency test result is $C.R. = 0.0089 < 0.1$, which satisfies the test criteria.

Based on the above calculation, the weight value of the criterion layer index is $W_1 = 0.2831, W_2 = 0.2070, W_3 = 0.1206,$ and $W_4 = 0.3893$.

Similarly, the weight value of each index in the index layer can be obtained. After calculation, the $B_i-C$ ($i = 1,2,3,4)$ matrix satisfies the consistency test. The calculation results are presented in Table 11.
3 | PRINCIPLE OF TOPSIS ALGORITHM

The TOPSIS method is a common method in finite scheme multiobjective decision analysis. By calculating the relative closeness between the evaluation scheme and ideal solution, and simultaneously considering the distance between the positive and negative ideal solutions, scientific, and reliable conclusions can be obtained.

3.1 | CONSTRUCTION OF THE WEIGHTED STANDARDIZED DECISION MATRIX

Suppose there are A schemes to form a scheme set \( A = \{A_1, A_2, \cdots, A_m\} \), each scheme has X attributes. Attribute set \( X = \{X_1, X_2, \cdots, X_n\} \) and the corresponding judgment index is denoted as \( X_{ij}(i = 1, 2, \cdots, m; j = 1, 2, \cdots, n) \), where \( X_{ij} \) represents the \( j \) evaluation index in the \( i \) program. Establish an initial judgment matrix \( D = (X_{ij})_{m \times n} \). The low priority index of judgment matrix \( D \) is homogenized and is dimensionless. The weight vector \( w = (w_1, w_2, \cdots, w_n) \) determined by the AHP is multiplied by each column element of matrix \( D \) to obtain weighted decision matrix \( V \).

\[
V = \begin{bmatrix}
v_{11} & v_{12} & \cdots & v_{1n} \\
v_{21} & v_{22} & \cdots & v_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
v_{m1} & v_{m2} & \cdots & v_{mn}
\end{bmatrix}
= \begin{bmatrix}
w_1X_{11} & w_2X_{12} & \cdots & w_nX_{1n} \\
w_1X_{21} & w_2X_{22} & \cdots & w_nX_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
w_1X_{m1} & w_2X_{m2} & \cdots & w_nX_{mn}
\end{bmatrix}.
\] (5)

3.2 | CALCULATE THE IDEAL SOLUTION AND THE NEARNESS DEGREE

The TOPSIS method is an order optimization method based on the similarity of ideal targets in multiattribute decision-making. The sum of positive and negative ideals solutions \( V^+ \) and \( V^- \) are expressed as follows:

\[
V^+ = \left\{ \max V_{ij} | j = 1, 2, \cdots, n \right\},
\] (6)

\[
V^- = \left\{ \min V_{ij} | j = 1, 2, \cdots, n \right\}.
\] (7)

The distance of each scheme is measured using the N-dimensional Euclidean distance, and the distance between each scheme and the positive and negative ideal solutions is calculated using

\[
S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_{ij}^+)^2},
\] (8)

\[
S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_{ij}^-)^2}.
\] (9)

The degree of closeness with the ideal solution is calculated using

\[
L_i^+ = \frac{S_i^-}{S_i^+ + S_i^-}, \quad 0 \leq L_i^+ \leq 1, \quad i \in m.
\] (10)

\( L_i^+ \) is the nearness degree between the evaluation object and positive ideal solution; the larger the \( L_i^+ \) value, the shorter the distance between the corresponding object and positive ideal solution (when the scheme is optimal, \( L_i^+ = 1 \)). When the scheme is unsuitable (\( L_i^+ = 0 \)), as the distance to the optimal solution decreases, the \( L_i^+ \) value tends to reach 1. Conversely, as the distance to the unfavorable solution decreases, the \( L_i^+ \) value tends to reach 0. By sorting the value of the closeness degree of the evaluation object, the evaluation of the scheme is realized.
Take the second-level indicators as the detection target, design the trigger test points of influencing factors respectively, and complete the comprehensive score of each indicator from the following 34 scoring items. The weight of scoring items shall be determined after fine adjustment according to the weight value of each secondary index in Table 11 and the score range is designed according to the weight of scoring items. For the facilitate scoring, the score range is designed according to the full score of 1000 points and converted into the percentage system after scoring. The score values are divided into four grades A, B, C, and D. Grade A is excellent, and the score range is 90–100; Grade B is good, and the score range is 76–89 points; Grade C is qualified, and the score range is 60–75 points; Grade D is a failure, less than 60 points. The scoring table of the project safety evaluation system is shown in Table 12 below.

**Table 12 Safety evaluation system table**

| Risk categories (impact value) | Scoring item risk description | Category Properties | Scoring item weight | Score interval |
|-------------------------------|-------------------------------|---------------------|---------------------|----------------|
| Human factor (28%)             | Operation behavior of workers working at heights | C1                   | 4%                  | 0–40           |
|                               | Normative operation of construction machines and tools | C1                   | 4%                  | 0–40           |
|                               | Prevention and protection of occupational hazards | C2                   | 5%                  | 0–50           |
|                               | Standardization of temporary power utilization | C2                   | 5%                  | 0–50           |
|                               | Systematicness and integrity of safety protection measures | C2                   | 7%                  | 0–70           |
|                               | Safety protection facilities for high place operation | C3                   | 1%                  | 0–10           |
|                               | Allocation of labor protection articles for operators | C3                   | 1%                  | 0–10           |
|                               | Labor protection measures for special types of work | C3                   | 1%                  | 0–10           |
| Machine or matter factor (21%) | Normative installation of scaffold and unloading platform | C4                   | 2%                  | 0–20           |
|                               | The integrity of inherent safety facilities | C4                   | 2%                  | 0–20           |
|                               | Rationality of construction equipment layout and protection | C5                   | 7%                  | 0–70           |
|                               | Installation and disassembly of hoisting machinery | C5                   | 8%                  | 0–80           |
|                               | Maintenance and inspection of large construction machinery | C6                   | 2%                  | 0–20           |
| Environment factor (12%)       | Seasonal Construction Countermeasures | C7                   | 2%                  | 0–20           |
|                               | Foundation pit excavation and support scheme | C8                   | 3%                  | 0–30           |
|                               | Implementation of formwork construction scheme | C8                   | 2%                  | 0–20           |
|                               | Construction scheme of scaffold (including climbing frame) | C8                   | 2%                  | 0–20           |
|                               | Group tower crane operation scheme | C8                   | 2%                  | 0–20           |
|                               | Emergency plan for sudden disaster safety | C9                   | 1%                  | 0–10           |
| Management factor (39%)        | Review of construction scheme of extremely dangerous works | C10                  | 1%                  | 0–10           |
|                               | Fire safety and fire prevention management | C10                  | 2%                  | 0–20           |
|                               | Construction organization design and scheme implementation | C10                  | 1%                  | 0–10           |
|                               | Work personnel health check and safety file construction | C10                  | 1%                  | 0–10           |
|                               | Safety accident report and risk source statistics | C10                  | 2%                  | 0–20           |
|                               | Standardized control and management of construction site | C10                  | 2%                  | 0–20           |
|                               | Temporary power uncontrollable or exist systemic risks | C10                  | 2%                  | 0–20           |
|                               | Safety regulations and organizational integrity | C11                  | 12%                 | 0–120          |
|                               | Warning and emergency system of major hazard sources | C11                  | 10%                 | 0–100          |
|                               | Emergency drill and related safety activity plan | C11                  | 1%                  | 0–10           |
|                               | Safety objectives and planning plan | C11                  | 1%                  | 0–10           |
|                               | Implementation plan of special work safety education | C11                  | 1%                  | 0–10           |
|                               | Safety education and training organized by the developer | C12                  | 1%                  | 0–10           |
|                               | Safety culture construction and safety education and training | C12                  | 1%                  | 0–10           |
|                               | Safety accident prevention and control measures | C12                  | 1%                  | 0–10           |
5  |  APPLICATION

5.1  |  PROJECT EVALUATION

The enterprise plans to conduct a project safety management review for four self-built projects. Number the projects are P1, P2, P3, and P4, the initial scoring of the project shall be carried out according to Table 12. The scoring items not involved in the project will not be evaluated, and the number of scores that they occupy will be distributed to other scoring items of the same category according to the weight. The initial scoring values of the projects are shown in Table 13 below.

Table 13 shows that the P4 conversion score is 76.4, which is the best project by management and control, and the project ranking is P4 > P2 > P3 > P1. To further study the ways to improve the overall safety management level of the enterprise, based on the TOPSIS method, the relative advantages and disadvantages of the project are evaluated. Calculate the nearness degree between the evaluated projects and the ideal solution, analyze the distance between the nearness degree $L_i^+$ of the optimal project and 1, and introduce the reference interval $\alpha[0.5,0.6]$. If the optimal project nearness degree $L_{i^*}^+ > \alpha_{\text{max}}$, it shows that enterprises must conduct external interactive learning to improve the level of security management. $L_{i^*}^+ < \alpha_{\text{min}}$, it shows that enterprises can achieve ideal results through internal experience exchange. $L_{i^*}^+ \in \alpha$, it shows that enterprises can jointly improve the level of project safety management through the combination of external interactive learning and internal experience exchange.

According to Table 13, to establish initial judgment matrix $D$, the dimension of matrix $D$ must be uniform. The safety evaluation system score table designed in Table 12 is established based on the weight table established in Table 11, so matrix $D$ is the weighted decision matrix.

$$V = D = \begin{bmatrix}
63 & 131 & 21 & 29 & 117 & 11 & 15 & 64 & 8 & 77 & 162 & 19 \\
63 & 138 & 20 & 26 & 115 & 13 & 15 & 63 & 7 & 73 & 185 & 20 \\
62 & 133 & 18 & 26 & 120 & 12 & 13 & 63 & 7 & 72 & 184 & 19 \\
69 & 133 & 19 & 33 & 110 & 14 & 16 & 70 & 6 & 82 & 193 & 19
\end{bmatrix}$$

According to formulas (6) and (7), positive, and negative ideal solutions were determined as follows:

$$V^+ = \begin{bmatrix}
69 & 138 & 21 & 33 & 120 & 14 & 16 & 70 & 8 & 82 & 193 & 20
\end{bmatrix}$$

$$V^- = \begin{bmatrix}
62 & 131 & 18 & 26 & 110 & 11 & 13 & 63 & 6 & 72 & 162 & 19
\end{bmatrix}$$

The Euclidean distance was calculated according to Formulas (8), (9), and (10), and the nearness degree was calculated as shown in Table 14.

The calculation results show that P4 is the best project of safety management and its nearness degree of comprehensive indicators is $0.75 > 0.6$. It shows that the overall evaluation of P4 project safety management and control is close to the ideal solution. Indicating that the project was undertaken by the enterprise has no obvious control advantages in the control of various subitems of safety, and there is no learning and reference value of safety management among various projects. The enterprise is generally poor in safety management, so it must carry out external learning, actively introduce

| Project | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | Summation | Conversion |
|---------|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----------|------------|
| P1      | 63 | 131| 21 | 29 | 117| 11 | 15 | 64 | 8  | 77  | 162 | 19 | 717       | 71.7       |
| P2      | 63 | 138| 20 | 26 | 115| 13 | 15 | 63 | 7  | 73  | 185 | 20 | 738       | 73.8       |
| P3      | 62 | 133| 18 | 26 | 120| 12 | 13 | 63 | 7  | 72  | 184 | 19 | 729       | 72.9       |
| P4      | 69 | 133| 19 | 33 | 110| 14 | 16 | 70 | 6  | 82  | 193 | 19 | 764       | 76.4       |
TABLE 14 Calculation results of relative proximity

| Projects | $S_i^+$ | $S_i$ | $L_i^+$ |
|----------|---------|-------|---------|
| P1       | 33.81   | 10.10 | 0.23    |
| P2       | 17.55   | 24.88 | 0.59    |
| P3       | 19.42   | 24.29 | 0.56    |
| P4       | 11.58   | 35.09 | 0.75    |

new technologies and systems, and improve the level of project safety control. This indicates that the project built by the enterprise has no obvious control advantages in the control of various subitems of safety, and there is no learning and reference value of safety management among the projects. The enterprise is generally poor in safety management, so it is necessary to carry out external learning, actively introduce new technologies and systems, and improve the level of project safety control.

5.2 DISCUSSION

The positive ideal solution in the TOPSIS method refers to the virtual optimal scheme that does not exist in scheme set A. Each attribute value in the virtual scheme is the optimal value of the attribute in the decision matrix. The negative ideal solution is the worst value of each attribute in the decision matrix. Through the more in-depth analysis and research of the operation results, the results show that: Although Table 13 shows that the overall performance of the project is mediocre, with the highest score is 76.4 and the average value is 73.7, which is at the pass level. But the above data can only be used as the overall evaluation of the project, however, the dispersion of the evaluation value of a certain index cannot be accurately reflected. Therefore, it leads to a new problem: how to improve the level of project safety management? What are the ways to improve the level of safety management? Is it through experience exchange between internal projects or external interactive learning? In order to solve the above problems, this study uses the TOPSIS method to conduct further theoretical research. Analysis showed that when the overall evaluation of multiple projects is relatively mediocre, the greater the dispersion of index evaluation values, the more obvious the advantages and disadvantages of project safety management, and the greater the distance between positive and negative ideal solutions, and the lower of the nearness between the optimal project and the ideal solution. How to make correct decisions between internal experience exchange or external interactive learning, the relationship between nearness $L_i^+$ and reference interval $\alpha$ needs to be further studied. Based on the following assumptions, this example uses MATLAB tools to make simulation research.

Assumption 1. In terms of human factors, project P1 has the best control. In terms of material factors, project P2 has the best control. In terms of environmental factors, project P3 has the best control and in terms of management factors, project P4 has the best control.

Assumption 2. On the condition that the total score of each project is not changed, adjust the scores of each evaluation index to improve the measures of dispersion. The adjustment range can refer to the scoring grade. This research assumes that the adjusted score is the maximum numeral value of this index, the adjusted score values are shown in Table 15 below.

After the first round of adjustment, it is assumed that the indicators of human factors in project P1 achieve the maximum value. According to the weight reduce the other factors index scores and keep the total score unchanged, at this time, the nearness degree of project P4 is calculated as 0.59. On this basis, carry out the second round of adjustment, it is assumed that each index of project P2 about machine or matter factors reaches the maximum value. At this time, the nearness degree of project P4 is calculated as 0.52. On this basis, carry out the third round of adjustment, it is assumed that each index of project P3 about environmental factors reaches the maximum value. At this time, the nearness degree of project P4 is calculated as 0.5. Because the management factor of the project P4 is the optimal value in the evaluation projects, no more adjusted.

The results show that with the increase of the dispersion of the index evaluation value, the nearness degree shows a decreasing trend. When the nearness degree is 0.5, project P4 can through internal experience exchange and learn by
| Projects | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | Summation | Conversion |
|----------|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----------|------------|
| P1       | 80 | 170| 30 | 25 | 103| 9  | 13 | 56 | 7  | 67  | 139 | 16 | 717        | 71.7       |
| P2       | 57 | 126| 18 | 40 | 150| 20 | 14 | 57 | 6  | 65  | 167 | 18 | 738        | 73.8       |
| P3       | 59 | 126| 17 | 24 | 114| 11 | 20 | 90 | 10 | 67  | 173 | 18 | 729        | 72.9       |
| P4       | 69 | 133| 19 | 33 | 110| 14 | 16 | 70 | 6  | 82  | 193 | 19 | 764        | 76.4       |

*Note: The bold values are the adjusted score.*

**Table 1** Evaluation index adjusted value

**Figure 3** Traditional elevator shaft protection of enterprises

human factors in project P1, machine or matter factors in project P2, and environmental factors in project P3, to improve the overall safety management level.

To facilitate understanding and calculation, the above analysis makes ideal classification and adjustment of the score values of each indicator. Make the above adjustment for the randomly selected indicators, it is consistent with the above results in theory. Therefore, defining the reference interval as $[0.5, 0.6]$ has a certain theoretical basis. In order to verify the research results, the enterprise organized project managers to carry out external interactive learning and achieved good results. As far as the elevator shaft protection process is concerned, the traditional method of the projects undertaken by the enterprise is to use steel mesh for protection, as shown in Figure 3 below; After the visit and study, better shaped protection is adopted, as shown in Figure 4 and 5 below.

Compared with the traditional elevator shaft protection practice, stereotyped protection has the following advantages:

1. Can provide a reliable working surface for operators to work.
2. It provides convenience for moving the elevator shaft formwork.
3. Reduce workload and material consumption, effectively save cost.
FIGURE 4  Elevator shaft protection finalized products

FIGURE 5  Practical application of stereotyped protection
CONCLUSION

Through the combined application of TOPSIS method and IAHP method, based on the analysis of recent construction engineering safety accidents in China, this article analyzes from the four dimensions of human, machine or matter, environment, and management, designs 12 safety impact factor evaluation indexes, and 34 scoring items, and constructs the construction project safety management evaluation system.

1. Used the IAHP method to establish the hierarchical structure model and constructed judgment matrix. Calculate the weight value of the evaluation index and distribute the weight of scoring items, and then design the value range of scoring items. The example shows that the evaluation system can comprehensively reflect the safety management level of construction engineering. It can provide a basis for multi projects safety evaluation and ranking.

2. When the overall evaluation of multiple projects is relatively general, the TOPSIS method is further used to make decisions on the methods to improve the project safety management level by calculating the nearness degree between the optimal project and the ideal solution. The research shows that when the nearness degree is greater than 0.6, external learning needs to be carried out to improve the level of enterprise safety management. When the nearness degree is less than 0.5, the safety management level can be improved through internal communication and learning between projects.

In the next step, The main work is analysis the functional relationship of the sample variance and nearness degree based on this study, to further standardize the safety management evaluation system and provide guidance for improving the level of project safety management.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

Tongyin Han: Conceptualization (supporting). Yanliang Shang: Writing – review and editing (supporting).

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DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

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