Coal Mine Safety Evaluation Based on EWM- Fuzzy comprehensive evaluation Method

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Abstract. In view of the difficulty in identifying the risk factors in coal mine production system and the subjectivity and complexity of the evaluation methods, a safety evaluation system based on entropy weight method and fuzzy comprehensive evaluation method is proposed. Firstly, the entropy weight method is applied to determine the objective weight of the secondary index of the four mines, which overcomes the disadvantages of strong subjectivity and incomplete information degree. Then the fuzzy comprehensive evaluation method is used to obtain the weight of the first level index, and the safety evaluation value of the whole system is obtained.

1. Introduction
Coal as the main primary energy in China, provides powerful motivation for economic and social development, but due to the expansion of demand, mining condition deteriorated, frequent safety accidents and its huge economic loss and personal injury, make the coal industry situation is not optimistic. Therefore, a more scientific method for safety assessment, to reduce or even avoid shift coal mine accidents has theory and practical significance.

At present, safety evaluation methods for coal mines have been greatly improved. Tingfeng Li in view of the local variable weight combination empowerment and the study of coal mine safety evaluation [1], the application of subjective and objective performance based on the least square method and the local variable weight theory respectively of coal mine safety evaluation index system of weights and different coal mine of local variable weight vector, through comparing weights as well as the local variable weight, finally it is concluded that combination of empowerment of local variable weights to optimizing the allocation of index weight vector, and improve the reliability of evaluation results. The evaluation results are relatively accurate, but the complicated mathematical operation in the process cannot be avoided, which is not conducive to the promotion and application in the actual production. Using the grey correlation analysis method [2], Xiangyou Gui studied the theory, process and calculation steps of gas outburst risk assessment in detail. Gas emission, air volume, gas volume fraction and other parameters were used to analyze the gas risk degree in roadway and make quantitative analysis. Finally, the correlation degree of gas outburst risk was obtained. This method has a low requirement for the accuracy of basic data, and is highly subjective and accidental in the case of incomplete information.
2. Construction of coal mine system safety production risk evaluation index system

2.1. Principles for establishing the evaluation index system

The risk evaluation index system of coal mine system safety production has a complex hierarchical structure and needs to be guided by certain principles [3]. Therefore, the selection of indicators follows the principles of systematicness, independence and scientificity.

(1) Systematicness: the selected indicators should cover all attributes within a functional domain of the object system and fully reflect its characteristics.

(2) Independence: the attributes of the object system reflected by each indicator in the indicator system should be independent of each other to avoid overlapping and inclusion.

(3) Scientific nature: the selection of indicators should have a scientific theoretical basis.

2.2. Evaluation index system of coal mine system safety production

![Coal mine safety evaluation index system](image)

*Figure 1. Coal mine safety evaluation index system.*
Coal mine production system is a complex system with multiple factors, and its risk factors are numerous and hidden. Combined with the principle of safety essence, four factors affecting the coal mine production system are summarized as: human factor, equipment factor, management factor and environment factor as \( X = \{X_1, X_2, X_3, X_4\} \), the weight of the first index is denoted as \( W = \{w_1, w_2, w_3, w_4\} \), combined with the actual operation situation on the site, the second-level evaluation index is set up, namely, the first-level evaluation index and the second-level evaluation index are denoted as \( X_i = \{x_{i1}, x_{i2}, \ldots, x_{in}\} \) the weight of secondary evaluation index is denoted as \( W_i = \{w_{i1}, w_{i2}, \ldots, w_{in}\} \).

3. The model is established based on EWM- Fuzzy comprehensive evaluation method

3.1. Establishment of entropy weight method model
At present, there are mainly analytic hierarchy process AHP and Delphi methods for qualitative determination of index weight. These methods directly assign weights according to the value given by experts, which is difficult to avoid the subjectivity of evaluation results. Entropy weight method is adopted to objectify some of the obtained subjective data, so as to improve the scientific weight.

1. Forming the original data matrix the importance of the comprehensive index and the information provided by the index are used to determine the final weight of each index. There are \( m \) projects to be evaluated and \( n \) evaluation indicators to form the original data matrix \( R=(r_{ij})_{m \times n} \).

2. Conduct dimensionless processing of the original data.

For the bigger the better indicator

\[
V_{ij} = \frac{r_{ij} - (r_j)_{\text{min}}}{(r_j)_{\text{max}} - (r_j)_{\text{min}}}
\]

(1)

For the smaller the better indicator

\[
V_{ij} = \frac{(r_j)_{\text{max}} - r_{ij}}{(r_j)_{\text{max}} - (r_j)_{\text{min}}}
\]

(2)

3. Calculate the characteristic proportion of the \( i \)th evaluation object in item \( j \)

\[
p_{ij} = \frac{V_{ij}}{\sum V_{ij}}
\]

(3)

4. Calculate the information entropy value of the \( j \)th index

\[
e_j = -\frac{1}{\ln m} \sum_{i=1}^{n} p_{ij} \ln p_{ij}
\]

(4)

5. Calculate the entropy weight of the \( j \)th index

\[
W_j = \frac{1 - e_j}{\sum 1 - e_j}
\]

(5)

6. The comprehensive evaluation value of each evaluation object is calculated separately

\[
V_{ij} = W_j * r_{ij}
\]

(6)
3.2. Establishment of Fuzzy evaluation model

(1) Establish the mathematical model of fuzzy comprehensive evaluation

Set $U = \{u_1, u_2, \ldots, u_n\}$ as the set of evaluation factors, in which $u_i$ of each factor is the main component that affects the evaluation object.

(2) Establish the set of evaluation levels

Set $V = \{v_1, v_2, \ldots, v_n\}$ as the set of rating factors, each of which is the rating level of rating factors.

Construct the judgment matrix.

(3) According to the fuzzy relation of each factor from $U$ to $V$, the single factor evaluation matrix $R$ is constructed. Each factor $r_{ij}$ represents the degree of membership of factor $U_i$ to its evaluation result $V_i$.

(4) Determine the weight set of each evaluation factor.

(5) Calculation of fuzzy evaluation results.

4. Empirical analysis

Four mines in different urban areas of Shanxi Province were selected and named as A, B, C and D. Through the expert empowerment, the following evaluation results were obtained.

| Table 1. Personnel factors |
|-----------------------------|
|                            | A  | B  | C  | D  |
| Qualification rate          | X_{11} | 90 | 77 | 89 | 90 |
| of management personnel (%) |     |    |    |    |
| Proportion of mine          | X_{12} | 68 | 58 | 41 | 45 |
| technicians (%)             |     |    |    |    |
| Special type of personnel   | X_{13} | 80 | 100| 94 | 92 |
| license rate (%)            |     |    |    |    |
| Qualified rate of all       | X_{14} | 86 | 76 | 84 | 68 |
| migrant workers (%)         |     |    |    |    |

| Table 2. Management factors |
|-----------------------------|
|                            | A  | B  | C  | D  |
| Mine certificate complete   | X_{21} | 100| 100| 96 | 92 |
| rate (%)                    |     |    |    |    |
| Employee monthly training   | X_{22} | 6  | 7  | 5  | 14 |
| time (h)                    |     |    |    |    |
| Implementation of safety    | X_{23} | 56 | 89 | 58 | 70 |
| management system (%)       |     |    |    |    |
| Ore chart acceptance rate   | X_{24} | 96 | 90 | 87 | 84 |
| (%)                        |     |    |    |    |

| Table 3. Equipment factors |
|-----------------------------|
|                            | A  | B  | C  | D  |
| Support equipment integrity | X_{31} | 97 | 95 | 90 | 78 |
| rate (%)                    |     |    |    |    |
| Mine ventilation equipment  | X_{32} | 79 | 94 | 71 | 86 |
| integrity rate (%)          |     |    |    |    |
| Safety rate of explosion-   | X_{33} | 90 | 100| 92 | 86 |
| proof facilities (%)        |     |    |    |    |
| Availability of gas         | X_{34} | 97 | 94 | 97 | 85 |
| drainage facilities (%)     |     |    |    |    |
| Rate of fire protection     | X_{35} | 92 | 93 | 88 | 70 |
| facilities (%)              |     |    |    |    |
| Test water equipment        | X_{36} | 69 | 83 | 74 | 74 |
| integrity rate (%)          |     |    |    |    |
| Integrity of dust control   | X_{37} | 92 | 83 | 88 | 81 |
| equipment (%)               |     |    |    |    |

| Table 4. Environmental factors |
|-------------------------------|
|                               | A  | B  | C  | D  |
| Integrity of communications  | X_{41} | 94 | 85 | 82 | 77 |
| and protection facilities (%)|     |    |    |    |
| Good rate of lighting and     | X_{42} | 93 | 91 | 96 | 90 |
| protection (%)                |     |    |    |    |
| Soundness rate of noise       | X_{43} | 88 | 87 | 90 | 92 |
| detection equipment (%)       |     |    |    |    |
| Downhole high temperature     | X_{44} | 0.07| 0.09| 0.09| 0.34|
| point                         |     |    |    |    |
4.1. Determination of first-level index weight of safety evaluation system

(1) According to the actual situation of production, a judgment matrix is formed by combining formula (1) or (2).

Table 5. Evaluation value of comprehensive index of each mine

| X11 | X12 | X13 | X14 | X21 | X22 | X23 | X24 | X31 | X32 | X33 | X34 | X35 | X41 | X42 | X43 | X44 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| A   | 1   | 1   | 0   | 1   | 1   | 0.11| 0   | 1   | 0.35| 0.29| 1   | 0.96| 1   | 1   | 0.47| 0.29| 0   |
| B   | 0   | 0.63| 1   | 0.44| 1   | 0.22| 1   | 0.5 | 0.9 | 1   | 1   | 0.75| 1   | 1   | 0.18| 0.5 | 0.83| 1   |
| C   | 0.92| 0.7  | 0.89| 0.5  | 0   | 0.06| 0.25| 0.63| 0   | 0.43| 1   | 0.78| 0.36| 0.64| 0.2  | 0   | 0.60| 1   |
| D   | 1   | 0.15 | 0.6  | 0   | 0   | 1   | 0.42| 0   | 0   | 0.65| 0   | 0.36| 0   | 0   | 0.93| 0.93| 1   |

(2) Standardize the matrix and calculate the characteristic proportion according to formula (3).

Table 6. The evaluation value of the comprehensive index of each mine is standardized

| X11 | X12 | X13 | X14 | X21 | X22 | X23 | X24 | X31 | X32 | X33 | X34 | X35 | X41 | X42 | X43 | X44 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| A   | -0.37| -0.32| 0   | -0.36| -0.37| -0.21| 0   | -0.32| -0.37| -0.30| -0.30| -0.37| -0.37| 0   | -0.33| -0.32| -0.33| -0.24| 0 |
| B   | 0   | -0.37| 1   | -0.32| -0.37| -0.30| -0.27| -0.36| -0.37| -0.35| -0.31| -0.35| -0.37| -0.31| -0.23| -0.35| 0   | -0.37| 0 |
| C   | -0.36| 0.00| 2   | -0.37| -0.32| 0   | -0.13| -0.28| -0.35| 0   | -0.35| -0.37| -0.36| -0.33| -0.37| -0.30| -0.36| -0.37| -0.37 |
| D   | -0.37| -0.21| 3   | 0.00| 0.54| 0.69| 0.78| 0.73| 0.69| 0.79| 0.70| 0.67| 0.77| 0.70| 0.77| -1.94| -1.97| 3.30| 3.46 |

(3) Calculate the information entropy value of the JTH index according to formula (4).

Table 7. The entropy of information of the index

| X11 | X12 | X13 | X14 | X21 | X22 | X23 | X24 | X31 | X32 | X33 | X34 | X35 | X41 | X42 | X43 | X44 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| e_j | 0.79| 0.65| -4.3| 0.76| 0.76| 0.52| 0.54| 0.69| 0.78| 0.73| 0.69| 0.79| 0.79| 0.70| 0.70| 0.77| -1.94| -1.97|

(4) Calculate the entropy weight according to formula (5)

Table 8. The entropy weight

| X11 | X12 | X13 | X14 | X21 | X22 | X23 | X24 | X31 | X32 | X33 | X34 | X35 | X41 | X42 | X43 | X44 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| w_j | 0.03| 0.06| 0.87| 0.04| 0.16| 0.32| 0.31| 0.21| 0.12| 0.14| 0.17| 0.12| 0.11| 0.16| 0.18| 0.05| 0.04| 0.46| 0.46|

(5) Calculate the comprehensive evaluation value of each evaluation object according to formula (6).

And we can do the same thing:

$$w = (0.211, 0.384, 0.075, 0.302)^T$$

$$w = (0.280, 0.397, 0.242, 0.081)^T$$

$$w = (0.085, 0.175, 0.680, 2.789)^T$$

4.2. Fuzzy comprehensive evaluation method

(1) Determine the judgment matrix according to the 1-9 scale method

$$A = \begin{bmatrix}
1 & 1 & 1 & 1 \\
5 & 5 & 5 & 5 \\
3 & 1 & 1 & 3 \\
3 & 1 & 3 & 1 
\end{bmatrix}$$

(2) Use "normalization" to calculate the weight vector
(3) Conduct consistency test

Calculate the maximum characteristic root: 
\[ \lambda_{\text{max}} = \sum_{i=1}^{n} \frac{|W_{ii}|}{n(W_{ii})} = 4.204 \]

Test for consistency: 
\[ C.I. = \frac{\lambda_{\text{max}} - n}{n-1} = \frac{4.204 - 4}{4} = 0.068 \leq 0.1 \]

Look at the consistency index value, RI=0.89 when n=4
\[ C.R. = \frac{C.I.}{RI} = \frac{0.068}{0.89} = 0.076 \leq 0.1 \]

Therefore, the result of the judgment matrix is acceptable and the weights obtained can be used.

4.3. Comprehensive evaluation of coal mine production system

\[
\begin{pmatrix}
0.061 & 0.406 & 0.290 & 0.243 \\
0.211 & 0.384 & 0.075 & 0.302 \\
0.280 & 0.397 & 0.242 & 0.081 \\
0.085 & 0.175 & 0.680 & 2.789
\end{pmatrix} \times \begin{pmatrix}
0.076 \\
0.543 \\
0.245 \\
0.136
\end{pmatrix} = \begin{pmatrix}
0.329 \\
0.284 \\
0.307 \\
0.647
\end{pmatrix}
\]

5. Conclusion

The above calculation results show that the production safety of coal mine D is the highest, while that of coal mine B is the worst. Among the four first-level indicators in the risk assessment of coal mine safety production, the level of management factors has the greatest impact on the safety of coal production system. Among the four secondary indicators corresponding to management factors, the employee's monthly training time (X_{22}) and safety management system and implementation degree (X_{23}) play the most significant roles.

The safety of coal mine production system can be improved obviously by determining the appropriate monthly training time. According to the characteristics of multi-links and high requirements of the coal mine system, when formulating the work plan of safety education and training, it is necessary to make clear the training objectives and requirements and strengthen the pertinence of the plan. The organization mode of production, the work of the position and the level of personal quality should be taken into account so that the actual needs of employees can be reflected in the feedback enthusiasm of employees for safety education [4].

The implementation of the safety management system can be divided into different stages, such as the implementation of the safety management system, problem management and operational supervision [5]. After formulating a clear safety management system, relevant departments should organize employees to study, to ensure that every cadre and workers understand the requirements of the system and the system of work tasks, work procedures, work requirements. During the implementation of the system, managers should pay attention to the dynamic nature of the actual production process to ensure the effectiveness of the safety management system.

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