



# Study on Safety Management Assessment of Coal Mine Roofs Based on the DEMATEL-ANP Method

Lei Li<sup>1,2\*</sup> and Youpeng Ouyang<sup>1,2</sup>

<sup>1</sup>College of Safety Science and Engineering, Xi'an University of Science and Technology, Xi'an, China, <sup>2</sup>Key Laboratory of Western Mine Exploration and Hazard Prevention, Ministry of Education, Xi'an, China

Coal mine roof accidents are one of the main single risks faced by coal miners. According to the statistical data of coal mine accidents in China, there were 40 roof accidents and 55 deaths in 2020 alone, accounting for 32.8 and 24.4% of the total, respectively. Therefore, we can see its danger. To realize the comprehensive scientific assessment of coal mine roof accidents, first, through the collation and analysis of relevant literature reviews and accident investigation reports, combined with the expert investigation method, an assessment index system of coal mine roof accidents is constructed. Then, based on the analysis of the characteristics of the influencing factors of coal mine roof accidents, the assessment model of coal mine roof accidents is established by using the DEMATEL-ANP method. Finally, the established assessment model is applied to a coal mine to verify the rationality of the model.

## OPEN ACCESS

### Edited by:

Shibing Huang,  
Wuhan University of Science and  
Technology, China

### Reviewed by:

Ionut Cristi Nicu,  
Norwegian Institute for Cultural  
Heritage Research, Norway  
Hao-sen Guo,  
East China Jiaotong University, China

### \*Correspondence:

Lei Li  
lilei\_safety@xust.edu.cn

### Specialty section:

This article was submitted to  
Geohazards and Georisks,  
a section of the journal  
Frontiers in Earth Science

Received: 07 March 2022

Accepted: 19 April 2022

Published: 31 May 2022

### Citation:

Li L. and Ouyang Y (2022) Study on  
Safety Management Assessment of  
Coal Mine Roofs Based on the  
DEMATEL-ANP Method.  
Front. Earth Sci. 10:891289.  
doi: 10.3389/feart.2022.891289

**Keywords:** roof accident, index system, DEMATEL method, ANP method, assessment model

## 1 INTRODUCTION

Roof accident is the type of coal mine accident with the largest number of occurrences and deaths. No matter what the scale of the coal mine is, there will be a certain degree of roof safety hazards in the mining process (Zhu et al., 2018; Xu et al., 2021; Zhang et al., 2021). However, because the occurrence of roof accidents is affected by many factors, it is difficult to prevent and control them, which seriously restricts the safe production of coal enterprises. Therefore, analyzing the causes of roof accidents and determining the influence degree of various factors to formulate effective prevention and control measures is still an important work content of the coal industry.

Roof fall refers to the sudden and violent collapse of the roadway roof, resulting in the collapse of roof rock. Roof fall is different from the rockburst disaster in deep engineering (Feng et al., 2015; Feng et al., 2022; Yu et al., 2022a; Yu et al., 2022b). However, it is also very dangerous and causes serious economic losses. Early studies were mostly considered from the perspective of geology and considered that weak and defective roofs, changes in stress conditions, and bedding plane faults and folds were the main reasons for roof collapse (Molinda, 2003; Phillipson, 2003; Düzgün, 2005). In recent years, with the deepening of research, the vibration, humidity in the air, coal pillar stability, and roof rock hanging length after the use of explosives have also been found to have an obvious correlation with roof falling (Yasidu et al., 2019; Liu et al., 2018). Because of the obvious differences in geological conditions in different regions, some scholars have carried out research on the causes of roof accidents under specific geological conditions. For example, Wang et al. (2018) analyzed a roof fall accident in the Huangyanhui coal mine in the Taihang Mountain area of Shanxi Province, China, and found that tectonic stress and fault sliding caused by mining activities are the driving forces of roof fall; Fei et al. (2020) found that under the condition of a thin bedrock and clay roof, the

movement of post-mining overburden is complex. The analysis of the causes of roof falls has laid a certain foundation for evaluating roof safety and putting forward control methods, and relevant research has also been carried out. Oraee et al. (2016) believed that the discontinuity of geological structures would lead to large-area roof collapse, and proposed a roof fall risk assessment method based on structural data and analysis of wedge geometry and stability in coal mines. Bai et al. (2021) took the roof separation and horizontal displacement as the key factors leading to roof falling and proposed that the horizontal displacement can be reduced by increasing the bolt pretension load. Xiong et al. (2021) combined the analytic hierarchy process and fuzzy comprehensive evaluation method and established the cloud model of roof fall risk evaluation by constructing a quantitative grade interval and calculating the weight of each index.

To sum up, the research on the causes of roof falls, roof evaluation, and control is very rich, and the relevant achievements have also played an important role in reducing roof accidents and realizing the scientific management of roofs. However, after further analysis, it is found that the existing research is mainly carried out from geological or closely related factors, and the occurrence of coal mine roof accidents is the result of the coupling of geological uncertainty, stress change, mining conditions, surrounding environments, and safety management (Shen et al., 2017; Tubis et al., 2020; Njock et al., 2021). There is a certain one-sidedness in analyzing only from the geological aspect, and in terms of safety management, because of China's unique coal enterprise management mode and national policies, a roof safety management evaluation method based on China's national conditions is needed.

The Decision Making Trial and Assessment Laboratory (DEMATEL) is a method to solve complex and difficult problems in the real world by using the graph theory and matrix tools. The Analytic Network Process (ANP) method is a decision-making method based on the Analytic Hierarchy Process (AHP), which is suitable for non-independent hierarchical structures. The combination of DEMATEL and ANP can effectively reduce the inconsistency and uncertainty caused by people's subjective judgment in the evaluation of roof safety management. Therefore, first, through literature sorting and the collection and analysis of roof accident investigation reports in China in the past 5 years, find out the influencing factors involved in the coal mine roof accident, classify the influencing factors through expert interviews, establish the coal mine roof safety management evaluation index system, and then use the DEMATEL-ANP to establish the coal mine roof safety management evaluation model for empirical applications.

## 2 ESTABLISHMENT OF THE EVALUATION INDEX SYSTEM OF COAL MINE ROOF SAFETY MANAGEMENT

### 2.1 Identification of the Influencing Factors of Coal Mine Roof Safety Management

Identifying the influencing factors of coal mine roof safety management is an important step in establishing the

evaluation index system. To achieve this goal, the following databases were searched: *Elsevier Science Direct*, *CNKI*, *Google academic*, and *SpringerLink*. The combination of search terms used is roof accident or event and influencing factors, roof accident or event and evaluation, and DEMATEL-ANP. References cited in the article are also used as additional sources for our search.

In addition, to make the research conform to the actual situation of China's coal mine production and national supervision, the coal mine roof accident reports published in China in the past 5 years (2016–2021) were sorted and analyzed to determine the factors not mentioned in the literature. There are 96 accident reports in total, and each report is proposed by the official investigation team formed in accordance with the requirements of laws and regulations and includes the analysis of the influencing factors leading to the accident. Since the accident investigation report comes from different accident investigation teams, there may be inconsistencies in the description of the same influencing factor. Therefore, integrate the different descriptions of the same influencing factor. For example, the safety education and training work are not solid, the safety education and training are not effective, and the safety education and training are not in-depth unified into safety education and training. To sum up, through the literature review and sorting of accident investigation reports, representative evaluation indexes of coal mine roof accidents are obtained, as shown in **Table 1**.

### 2.2 Selection of Evaluation Indexes for Coal Mine Roof Safety Management

For the identified 26 evaluation indicators, five experts were invited to interview and classify the indicators, including three scholars who have long studied coal mine safety management and two managers engaged in coal mine safety management. During the interview, the experts defined the meaning of each index in detail and classified the index on the basis of fully understanding the connotation and value of the index. Finally, according to expert opinions, 26 coal mine roof accident evaluation indexes were established and divided into five dimensions: principal responsibility, site management, technical management, individual factors, and environmental change, as shown in Appendix 1.

### 2.3 Establishment of the Evaluation Index System of Coal Mine Roof Safety Management

To further determine the effectiveness of the selected indicators and the accuracy of classification, the expert investigation method is used to analyze the rationality of the evaluation indicators. When using the expert survey method, the number of members of the expert group is generally not less than 10, but not more than 20, because when the number is more than 20, it has little impact on the accuracy of the evaluation results (Lin, 2017). Therefore, a total of 15 questionnaires were distributed and recovered, with a questionnaire recovery rate of 100%.

**TABLE 1** | Coal mine roof safety management assessment index.

Number	Index	Number	Index
1	Risk management	14	Break regulations to direct
2	Safety education and training	15	Break regulations to work
3	Leadership lead work groups system	16	Risk Identification ability
4	Safety investment	17	Self-mutual protection awareness
5	Legal mining	18	Working skill
6	Territorial supervision	19	Operation regulation
7	Supervision of the superior company	20	Technical measures
8	Responsibility system for safety in production	21	Roadway layout
9	Timber setting	22	Safety monitoring system
10	Arranging construction	23	Geologic structure
11	Knock ring and roof testing	24	Stress concentration
12	Organizing workers	25	Roof pressurized
13	Emergency disposal	26	Surrounding rock deformation

**TABLE 2** | Results of expert survey indicators.

Dimension	Index	min	max	$\mu$	$\delta$	CV	S	R.
Principal responsibility	Risk management	5	5	5.00	0.00	0.00	100.0%	√
	Safety education and training	4	5	4.93	0.26	0.05	93.8%	√
	Leadership lead work groups system	4	5	4.20	0.41	0.10	100.0%	√
	Safety investment	5	5	5.00	0.00	0.00	93.8%	√
	Legal mining	4	5	4.87	0.35	0.07	100.0%	√
	Territorial supervision	4	5	4.20	0.41	0.10	93.8%	√
	Supervision of superior company	4	5	4.20	0.41	0.10	93.8%	√
Site management	Responsibility system for safety in production	4	5	4.80	0.41	0.09	100.0%	√
	Timber setting	4	5	4.87	0.35	0.07	93.8%	√
	Arranging construction	4	5	4.20	0.41	0.10	100.0%	√
	Knock ring and roof testing	4	5	4.87	0.35	0.07	93.8%	√
	Organizing workers	4	5	4.87	0.35	0.07	100.0%	√
Individual factors	Emergency disposal	4	5	4.87	0.35	0.07	87.5%	√
	Break regulations to direct	4	5	4.87	0.35	0.07	87.5%	√
	Break regulations to work	4	5	4.87	0.35	0.07	100.0%	√
	Risk Identification ability	4	5	4.87	0.35	0.07	100.0%	√
	Self-mutual protection awareness	4	5	4.87	0.35	0.07	100.0%	√
Technology management	Working skill	4	5	4.20	0.41	0.10	100.0%	√
	Operation regulation	4	5	4.93	0.26	0.05	100.0%	√
	Technical measures	4	5	4.93	0.23	0.05	100.0%	√
	Roadway layout	4	5	4.20	0.41	0.10	100.0%	√
Environmental change	Safety monitoring system	4	5	4.20	0.41	0.10	87.5%	√
	Geologic structure	5	5	5.00	0.00	0.00	100.0%	√
	Stress concentration	5	5	5.00	0.00	0.00	100.0%	√
	Roof pressurized	5	5	5.00	0.00	0.00	100.0%	√
	Surrounding rock deformation	5	5	5.00	0.00	0.00	100.0%	√

R stands for rationality.

Using a Likert scale to measure and count the importance of preselected indicators, they is divided into five levels: 1 indicates very unimportant, 2 indicates unimportant, 3 indicates average, 4 indicates important, and 5 indicates very important. The maximum and minimum values of each index score are counted and recorded as max and min, respectively. The mean value, standard deviation, and coefficient of variation of each index score are calculated and recorded as  $\mu$ ,  $\delta$ , and CV, respectively. The index meeting  $\mu \geq 3.5$  and  $0.1 < CV < 0.2$  is regarded as meeting the important requirements. At the same time, according to Wang et al. (2019), 2 subscale is used to measure the rationality of

index classification. Unreasonable classification is represented by 0, 1 represents reasonable classification, and S is the proportion of the number of experts with 1 score in the total number of replies. When S-7, it is considered that the classification of the index is reasonable, which is expressed by  $\sqrt{\quad}$  and vice versa  $\times$  express. Through the statistics of the questionnaire results, the index score results are obtained, as shown in **Table 2**.

It can be seen from **Table 5** that the coefficient of variation of all indicators is less than 0.2, and the s value is greater than 80%, that is, the classification of all indicators is reasonable and does not need to be modified. To verify the rationality of expert

**TABLE 3** | Expert synergy coefficient test.

Project	W value	P value
Expert estimation	0.621	***

\*\*\* indicates  $P < 0.001$ .

**TABLE 4** | Relationship strength metric table.

Point	Implication
4	Very high influence
3	High influence
2	Low influence
1	Very low influence
0	No impact

opinions, the Kendall  $W$  synergy coefficient is used for the consistency test, and its calculation formula is as follows:

$$W = \frac{12}{m^2(n^3 - n)} \sum_{i=1}^n \left( R_i - \frac{m(n+1)}{2} \right)^2, \quad (1)$$

where  $m$  is the number of experts,  $n$  is the number of indicators, and  $R_i$  is the sum of the ranks of the  $i$  th indicator. The value of  $W$  is between 0–1. The larger the value is, the more consistent the expert opinion is, and the evaluation result is reasonable; otherwise, it means that the

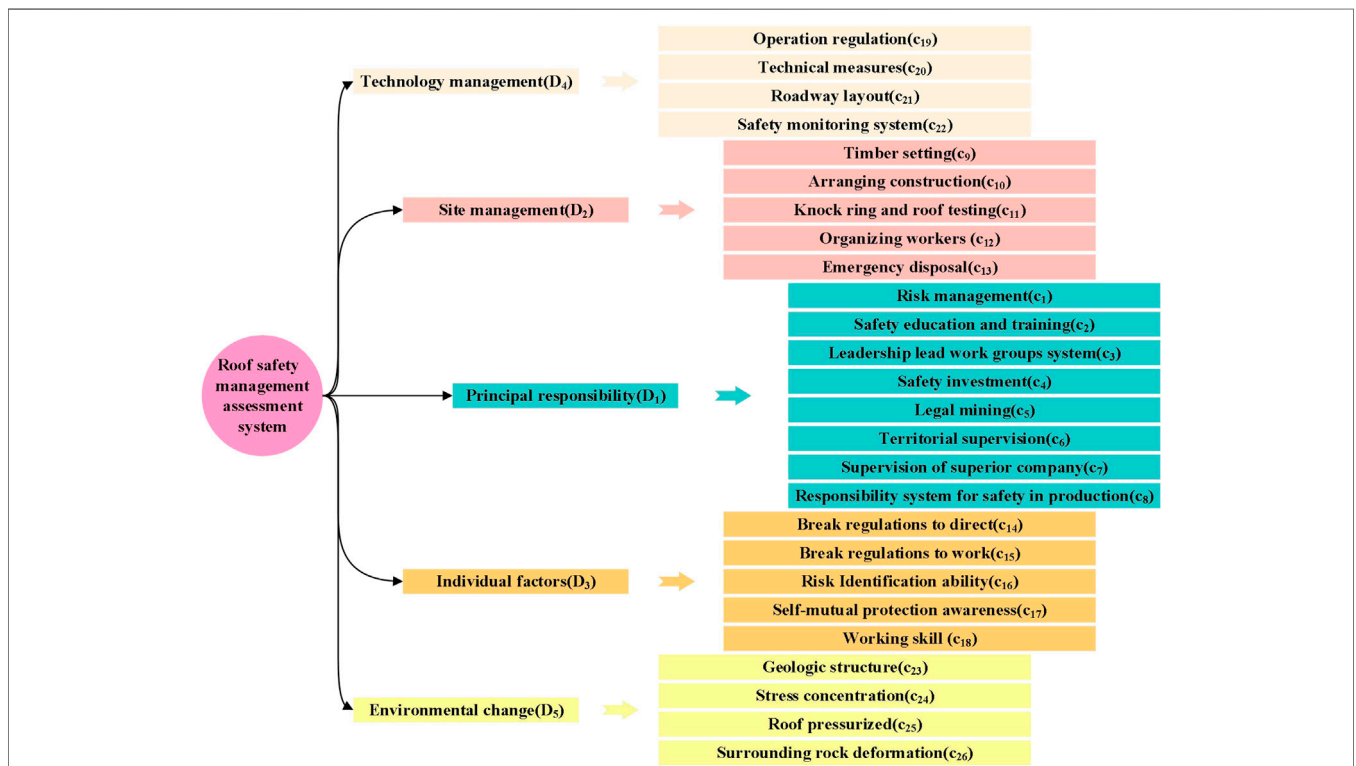
expert opinion is random and the evaluation result is unreasonable. Through spss25 0, calculate the  $W$  synergy coefficient of expert opinions, as shown in **Table 3**.

It can be seen from **Table 4** that the synergy coefficient of expert scoring is 0.621, indicating that the consensus of expert group members is strong, and the significance level  $P$  value of the synergy coefficient is less than 0.001, indicating that the synergy coefficient is significant. Therefore, the evaluation results are consistent. To sum up, the coal mine roof accident evaluation system is shown in **Figure 1**.

### 3 CONSTRUCTION OF THE COAL MINE ROOF SAFETY MANAGEMENT EVALUATION MODEL

#### 3.1 Applicability Analysis of DEMATEL-ANP

The evaluation indexes of coal mine roof accidents affect each other, and the weight of each index is different. Enterprise managers need to not only know the evaluation results but also to clarify the influence relationship between various indicators and identify key factors, to take targeted measures for control and treatment. Using traditional evaluation and analysis methods, it is difficult to determine the complex relationship between indicators in a real situation, and the DEMATEL-ANP rule solves this defect well (Dehdasht et al., 2017). The DEMATEL has the advantages of not relying on big data samples and simplifying the factor correlation analysis. It



**FIGURE 1** | Coal mine roof safety management assessment system.

can build a mapping structure with clear relationships between sub criteria for each criterion and establish a cause and effect diagram that can visualize the cause and effect relationship. In a network with relevant standards, the ANP can make the prediction more accurate through better priority calculation. At present, this method has been applied in many fields and received positive feedback (Chukwuma et al., 2021; Osintsev et al., 2021; Mubarik et al., 2021). Therefore, the application of the DEMATEL-ANP method for coal mine roof accident evaluation has the following applicability:

- 1) DEMATEL can clarify the relationship between evaluation indicators.

First, through the steps of determining the direct influence matrix, standardizing the direct influence matrix, and determining the comprehensive influence matrix, the influence diagram of coal mine roof accident evaluation indexes is drawn to intuitively show the interaction relationship between each index. Second, the ANP model of coal mine roof accidents is established by using the drawn influence relationship network diagram, to avoid the problem of being too subjective in determining the influence relationship of indicators. Finally, by calculating the influence intensity of the relationship between the indicators, the cause degree and centrality are determined. On this basis, the indicators are arranged according to the influence to identify the key factors affecting coal mine roof accidents and lay a foundation for formulating targeted control measures.

- 2) ANP determines the relative importance of the criterion layer and index layer of the index system.

After the DEMATEL identifies the relationship between coal mine roof accident indicators, the ANP can capture the interdependence between decision attributes to realize a more systematic analysis. First, compared with the AHP, which assumes that the relationship between indicators is independent, the ANP provides a more general decision-making model without assuming the independence between indicators at the same level and different levels. Second, by determining the index weight, enterprise managers can pay more balanced attention to the overall influence of various dimensions on roof accidents. Finally, when constructing the judgment matrix, the nine-level scaling method is used to assign the value, which greatly reduces the subjective influence caused by human reasons.

### 3.2 Evaluation Index Influence Relationship and Weight Establishment

#### 3.2.1 Identifying the Impact Relationship Between Indicators

- 1) Determining the Direct Impact Matrix

To construct the network diagram of roof safety management evaluation, first, experts need to judge the influence relationship and degree of all indicators and form an influence relationship matrix. Among them, indicators  $S_i$  and  $S_j$  should be compared twice, which

**TABLE 5 |** Direct impact matrix.

M	D <sub>1</sub>	D <sub>2</sub>	D <sub>3</sub>	D <sub>4</sub>	D <sub>5</sub>
D <sub>1</sub>	0	$m_{1,2}$	$m_{1,3}$	$m_{1,4}$	$m_{1,5}$
D <sub>2</sub>	$m_{2,1}$	0	$m_{2,3}$	$m_{2,4}$	$m_{2,5}$
D <sub>3</sub>	$m_{3,1}$	$m_{3,2}$	0	$m_{3,4}$	$m_{3,5}$
D <sub>4</sub>	$m_{4,1}$	$m_{4,2}$	$m_{4,3}$	0	$m_{4,5}$
D <sub>5</sub>	$m_{5,1}$	$m_{5,2}$	$m_{5,3}$	$m_{5,4}$	0

are the direct impacts of indicator  $S_i$  on  $S_j$  and the direct influence of index  $S_j$  on  $S_i$ . For the whole system, if there are  $n$  indicators, it needs to be compared  $n(n - 1)$  times. The index itself does not need to be compared, that is, the value on the diagonal of the matrix is usually represented by 0. The 5-point scale is adopted in the process of expert scoring, as shown in **Table 4**.

In actual decision-making, there will also be interactions between different dimensions and different indicators. It can be assumed that there is relationship between all indicators, but this assumption will lead to more complex problems. Therefore, this study assumes that the interaction relationship of 26 indicators is the same as that of five dimensions. The scoring results of each expert's influence relationship are expressed in the matrix  $X^k = [x_{ij}^k]_{5 \times 5}$ , where  $x_{ij}^k$  represents the influence degree of dimension  $B_i$  on  $B_j$  considered by the  $k$  expert, and  $k$  experts form the 5-order matrix  $X^1, X^2, X^3, X^4, X^5$ . Treat the evaluation matrix of  $k$  experts according to the following equation:

$$m_{ij} = \frac{1}{k} \sum_{k=1}^k x_{ij}^k, i, j = 1, 2, \dots, 5. \tag{2}$$

The initial direct influence matrix  $M = [m_{ij}]_{5 \times 5}$  is obtained. The direct influence matrix represents the influence relationship and degree between the performance evaluation dimensions obtained by the arithmetic averaging of the opinions of each expert, as shown in **Table 5**.

- 2) Normalized Direct Impact Matrix

The normalized influence matrix can be obtained by standardizing the direct influence matrix  $M$  with **Eqs (3), (4)**, as shown in **Table 6**.

$$\lambda = \min \left( \frac{1}{\max_{1 \leq i \leq n} \sum_{j=1}^n a_{ij}}, \frac{1}{\max_{1 \leq j \leq n} \sum_{i=1}^n a_{ij}} \right), \tag{3}$$

$$N = \lambda \times M. \tag{4}$$

- 3) Determining the Comprehensive Impact Matrix

The comprehensive influence matrix  $T$  can be obtained by calculating the limit of the specification influence matrix  $N$  in **Equation (5)**, as shown in **Table 7**. The comprehensive impact matrix shows all the direct and indirect impact relationships between the dimensions of the index system.



**TABLE 6 |** Norm influence matrix.

N	D <sub>1</sub>	D <sub>2</sub>	D <sub>3</sub>	D <sub>4</sub>	D <sub>5</sub>
D <sub>1</sub>	0	$\lambda m_{1,2}$	$\lambda m_{1,3}$	$\lambda m_{1,4}$	$\lambda m_{1,5}$
D <sub>2</sub>	$\lambda m_{2,1}$	0	$\lambda m_{2,3}$	$\lambda m_{2,4}$	$\lambda m_{2,5}$
D <sub>3</sub>	$\lambda m_{3,1}$	$\lambda m_{3,2}$	0	$\lambda m_{3,4}$	$\lambda m_{3,5}$
D <sub>4</sub>	$\lambda m_{4,1}$	$\lambda m_{4,2}$	$\lambda m_{4,3}$	0	$\lambda m_{4,5}$
D <sub>5</sub>	$\lambda m_{5,1}$	$\lambda m_{5,2}$	$\lambda m_{5,3}$	$\lambda m_{5,4}$	0

$$T = \lim_{k \rightarrow \infty} (N + N^2 + \dots + N^5) = N(I - N)^{-1} = [t_{ij}]_{5 \times 5}, \quad (5)$$

where  $T$  is the comprehensive influence matrix; the influence matrix is normalized into  $N$ ;  $I$  is the identity matrix; and  $(I - N)^{-1}$  is the inverse matrix of  $(I - N)$ .

4) Calculating the Center Degree and Cause Degree of Each Index

The sum of the values of each row and column of the comprehensive influence matrix  $T$  is calculated through **Equations (6), (7)** to represent the comprehensive influence value of the corresponding indicators of each row and column on all other indicators, that is, the influence degree and the affected degree, which are recorded as sets  $R$  and  $C$ , respectively.

$$R_i = \sum_{j=1}^5 t_{ij}, \quad (i = 1, 2, \dots, 5), \quad (6)$$

$$C_i = \sum_{j=1}^5 t_{ij}, \quad (j = 1, 2, \dots, 5). \quad (7)$$

Based on the calculation of centrality and cause degree, using **Equation (8)**, add the influence degree and affected degree of index  $i$  to obtain the centrality of the index, which is recorded as  $Z_i$ , indicating the position of the index in the evaluation index system and its role. Use **Equation 9** to subtract the influence degree and affected degree of index  $i$  to obtain the cause degree of this element, which is recorded as  $Y_i$ . If it is greater than 0, it indicates that this index has a great impact on other indexes, which is called cause element, otherwise, it is the result factor.

$$Z_i = R_i + C_i, \quad (8)$$

$$Y_i = R_i - C_i. \quad (9)$$

5) Drawing the Network Diagram

To more clearly describe the relationship between indicators, an impact relationship diagram with a threshold is established, which is used to deal with the impact value in the overall relationship comprehensive impact matrix  $T$ . The impact graph only describes the impact beyond the threshold, which simplifies the decision-maker's identification of important information. The drawing of the influence relation diagram can be used as the basis of the ANP analysis. The indexes have mutual influence, one-way influence, and no influence, which are represented by a two-way arrow, one-way arrow, and no arrow, respectively.

**TABLE 7 |** Comprehensive influence matrix.

T	D <sub>1</sub>	D <sub>2</sub>	D <sub>3</sub>	D <sub>4</sub>	D <sub>5</sub>
D <sub>1</sub>	0	$t_{1,2}$	$t_{1,3}$	$t_{1,4}$	$t_{1,5}$
D <sub>2</sub>	$t_{2,1}$	0	$t_{2,3}$	$t_{2,4}$	$t_{2,5}$
D <sub>3</sub>	$t_{3,1}$	$t_{3,2}$	0	$t_{3,4}$	$t_{3,5}$
D <sub>4</sub>	$t_{4,1}$	$t_{4,2}$	$t_{4,3}$	0	$t_{4,5}$
D <sub>5</sub>	$t_{5,1}$	$t_{5,2}$	$t_{5,3}$	$t_{5,4}$	0

**3.2.2 Determining the Index Weight**

By determining the relationship between the criterion layers of the coal mine roof safety management evaluation index system, we can identify the criteria that have great influence or are easily affected. According to the DEMATEL analysis results, we can put forward scientific and reasonable improvement measures, but we should also clearly realize that the criteria closely related to other criteria are not necessarily the most important in the evaluation index system, and the weight of each index needs to be identified to determine the real key factors of roof safety management. Therefore, the ANP method is applied to further clarify the weight of each index.

1) Constructing the judgment matrix

According to the internal correlation of risk evaluation indexes in the DEMATEL model, the network hierarchy diagram of roof safety management evaluation is formed. For all indicators with a mutual influence relationship, the importance judgment is carried out by using the 1-9 scale method (**Table 8**), to construct the pairwise judgment matrix of the relative importance of indicators in a certain dimension with different indicators as the sub-criteria. Each group of judgment matrix is summarized to form the initial relative importance judgment matrix after checking the consistency through the consistency index  $CI$  and consistency ratio  $CR$ .

$$B_c = \begin{matrix} & & & D_1 & & & & D_j & & & D_5 \\ & & & c_{1,1} & \dots & c_{1,m_1} & \dots & c_{j,1} & \dots & c_{j,m_j} & \dots & c_{5,1} & \dots & c_{5,m_5} \\ D_1 & & & \vdots & & & & \vdots & & & & & & \\ & & & c_{1,m_1} & & & & \vdots & & & & & & \\ & & & \vdots & & & & \vdots & & & & & & \\ & & & c_{i,1} & & & & \vdots & & & & & & \\ D_i & & & \vdots & & & & \vdots & & & & & & \\ & & & c_{i,m_i} & & & & \vdots & & & & & & \\ & & & c_{5,1} & & & & \vdots & & & & & & \\ & & & \vdots & & & & \vdots & & & & & & \\ D_5 & & & c_{5,m_5} & & & & \vdots & & & & & & \\ & & & & & & & & & & & & & \end{matrix} \quad (10)$$

2) Getting the unweighted super matrix

Each group of pairwise comparison matrices is standardized and transposed to obtain the eigenvalue vector  $W_{ij}$ . The matrix obtained by summarizing the eigenvalue vectors of all pairwise comparison matrices is the unweighted super matrix  $W$ , as shown in Equation (11). If the index in  $D_j$  and the index  $c_{i,1}, c_{i,2}, \dots, c_{i,m_i}$  in  $D_i$  are independent of each other, then  $W_{i,j} = 0$ . Each set of eigenvalue vectors of the unweighted super matrix represents the weight of each index in a certain dimension under a certain criterion. The unweighted super matrix can select the criteria of the judgment

**TABLE 8** | Reference table for assignment.

Scores	Implication
1	Indicator $i$ and indicator $j$ are equally important
3	Indicator $i$ is slightly more important than indicator $j$
5	Indicator $i$ is significantly more important than indicator $j$
7	Indicator $i$ is much more important than indicator $j$
9	Index $i$ is more important than index $j$ at the extreme
2, 4, 6, 8	Between two adjacent judgment levels

matrix and the element set of the judgment matrix. The correlation of all elements in all element sets will be quantitatively reflected in the way of this judgment matrix.

$$W = \begin{matrix} & \begin{matrix} D_1 & \dots & D_j & \dots & D_5 \end{matrix} \\ \begin{matrix} D_1 \\ \vdots \\ D_i \\ \vdots \\ D_5 \end{matrix} & \begin{bmatrix} c_{1,1} & \dots & c_{j,1} & \dots & c_{5,1} \\ \vdots & & \vdots & & \vdots \\ c_{i,1} & \dots & c_{i,j} & \dots & c_{i,5} \\ \vdots & & \vdots & & \vdots \\ c_{5,1} & \dots & c_{5,j} & \dots & c_{5,5} \end{bmatrix} \end{matrix} \quad (11)$$

3) Getting the weighted super matrix

Although each of the unweighted hypermatrices is normalized, the overall unweighted hypermatrix is not normalized. Therefore, by multiplying the standardized importance judgment matrix of each dimension with the unweighted super matrix, the standardization of the super matrix is realized, that is, the weighted super matrix is obtained.

Taking the safety evaluation of coal mine roof construction as the criterion and dimension  $D_j (j = 1, 2, 3, 4, 5)$  as the sub-criterion, the relative importance of the dimensions with an influence relationship with  $D_j$  is compared in pairs. After traversing all dimensions, the judgment matrix  $B_D$  of each dimension is obtained, as shown in the following equation:

$$B_D = \begin{bmatrix} b_D^{1,1} & \dots & b_D^{1,j} & \dots & b_D^{1,5} \\ \vdots & & \vdots & & \vdots \\ b_D^{i,1} & \dots & b_D^{i,j} & \dots & b_D^{i,5} \\ \vdots & & \vdots & & \vdots \\ b_D^{5,1} & \dots & b_D^{5,j} & \dots & b_D^{5,5} \end{bmatrix} \quad (12)$$

The matrix  $B_D$  is standardized to obtain  $B_D^\alpha$ , and the weighted super matrix  $W^\alpha$  is obtained by multiplying  $B_D^\alpha$  with the unweighted super matrix  $W$ . As shown in **Equation (13)**, the weighted super matrix constitutes the weight of the normalized coal mine roof safety management evaluation index, but the super matrix is unstable and needs further limit treatment.

$$W^\alpha = B_D^\alpha \times W = \begin{bmatrix} B_D^{\alpha_{1,1}} \times W_{1,1} & \dots & B_D^{\alpha_{i,1}} \times W_{i,1} & \dots & B_D^{\alpha_{5,1}} \times W_{5,1} \\ \vdots & & \vdots & & \vdots \\ B_D^{\alpha_{1,j}} \times W_{1,j} & \dots & B_D^{\alpha_{i,j}} \times W_{i,j} & \dots & B_D^{\alpha_{5,j}} \times W_{5,j} \\ \vdots & & \vdots & & \vdots \\ B_D^{\alpha_{1,5}} \times W_{1,5} & \dots & B_D^{\alpha_{i,5}} \times W_{i,5} & \dots & B_D^{\alpha_{5,5}} \times W_{5,5} \end{bmatrix} \quad (13)$$

4) Calculating local and global weights

To reflect the dependency between elements, it is necessary to stabilize the weighted hypermatrix, that is, calculate the limit matrix of the matrix. Calculate the multiple power of the weighted hypermatrix, and note that the  $t$  power of  $W^\alpha$  is  $W^{\alpha t} = (W^{\alpha t})_{i,j}$ . When  $W^\alpha$  is in  $t \rightarrow \infty$ , the limit exists, that is,  $W^\infty = \lim_{n \rightarrow \infty} W^{\alpha n}$ .

5) Determining the comprehensive weight

When the column vectors are equal, the hypermatrix converges to stability to obtain the limit relative ranking of the indicators in each dimension, that is, the weight of each indicator. The weight determined by the DEMATEL-ANP considers the relative importance determined by the influence relationship between indicators, so it can better adapt to the characteristics of mutual influence among coal mine roof safety management evaluation indicators.

4 CASE ANALYSIS

4.1 Data Collection

Based on the established risk evaluation index system and the DEMATEL-ANP risk evaluation model, 12 of the 15 experts were organized to conduct a five-day field investigation in the SL coal mine during the construction of the index system, meeting the requirements of 8–15 experts for the DEMATEL method (Mavi and Standing, 2018). Then, according to the present situation of

**TABLE 9** | Overview of the members of the group of experts.

Category	Research/professional experience		Proportion/%
	≤ 10 years	> 10 years	
Coal mine safety scholars	2	4	50
Coal mine safety management practitioners	1	3	33.3
Safety assessment organization practitioners	1	1	16.7

roof management in the coal mine, a questionnaire survey was carried out among experts. The details of the members of the expert group are shown in **Table 9**.

### 4.2 Establishment and Analysis of Influence Relationships Among Indicators

According to the data collected by the questionnaire, first calculate the arithmetic average value from **Equation 2** to form the initial direct influence matrix. Second, standardize the direct influence matrix according to **Eqs (3), (4)** to form a standardized direct influence matrix. Finally, calculate the comprehensive influence matrix *T* according to **Equation (5)**, as shown in **Table 10**. After many expert discussions, it is agreed that the comprehensive impact matrix  $t_{i,j} \leq 0.2$  indicates that *D<sub>j</sub>* indicates that *D<sub>i</sub>* has no impact relationship; 0.2–0.4 indicates that the influence of *D<sub>i</sub>* on *D<sub>j</sub>* is weak; 0.4–0.6 indicates that the influence of *D<sub>i</sub>* on *D<sub>j</sub>* is general; 0.6–0.8 indicates that *D<sub>i</sub>* has a strong influence on *D<sub>j</sub>*; and 0.8–1 indicates that the influence of *D<sub>i</sub>* on *D<sub>j</sub>* is very strong.

It can be seen from **Table 10** that each dimension of coal mine roof safety management evaluation has an impact on the five dimensions (including itself) and is also affected by the five dimensions (including itself). But the degree of mutual influence is different.

Based on the comprehensive influence matrix *T*, the influence degree *R* and affected degree *C* are calculated according to **Equations (6), (7)**, and the centrality and cause degree of each dimension of coal mine roof accident evaluation are formed, as shown in **Table 11**. By analyzing the centrality and cause degree, we can identify the key factors affecting the safety management of coal mine roofs, and each key factor will form its own influence relationship network through the influence relationship.

Finally, according to the results of **Table 10** and **Table 11**, the network relationship model between each dimension is obtained, as shown in **Figure 2**. To show the strength of the influence relationship between different dimensions, **Figure 2** is distinguished by the color and thickness of the line. The drawing of this model can lay a foundation for the drawing of the network structure in the ANP analysis.

### 4.3 Calculation and Analysis of the Evaluation Index Weight

Based on the final influence matrix and network relationship model determined by the DEMATEL, the ANP network structure diagram of coal mine roof safety management evaluation is constructed by using super decisions software, as shown in **Figure 3**. A loop indicates that there is an interactive relationship within each dimension.

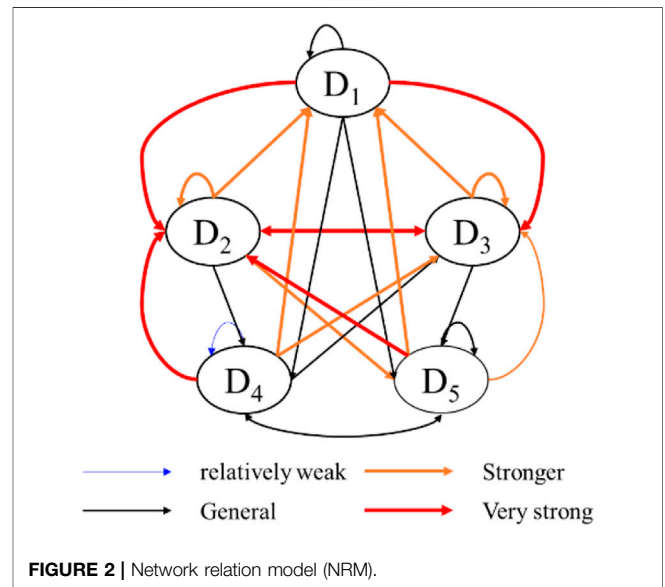
After determining the structural relationship of the ANP network, the 19-scale method (**Table 9**) is used to compare the relative importance of two risk factors to obtain the judgment matrix at the dimension level and the unweighted super matrix at the index level to further obtain the weighted super matrix and limit super matrix. Finally, the local and global weights of

**TABLE 10 |** Comprehensive impact matrix of dimensions.

T	D <sub>1</sub>	D <sub>2</sub>	D <sub>3</sub>	D <sub>4</sub>	D <sub>5</sub>
D <sub>1</sub>	0.517	0.886	0.842	0.460	0.585
D <sub>2</sub>	0.704	0.688	0.866	0.501	0.675
D <sub>3</sub>	0.676	0.845	0.628	0.539	0.583
D <sub>4</sub>	0.636	0.813	0.773	0.289	0.598
D <sub>5</sub>	0.644	0.841	0.782	0.499	0.463

**TABLE 11 |** Importance and causes of dimensions.

Dimension	R	C	R + C	R - C
Principal responsibility	3.291	3.178	6.469	0.113
Site management	3.435	4.073	7.508	-0.638
Individual factors	3.271	3.892	7.163	-0.621
Technology management	3.109	2.288	5.397	0.821
Environmental change	3.229	2.904	6.133	0.325



each dimension and each index are shown in **Table 12**. In the whole calculation process, the software will conduct a consistency inspection. The consistency ratio *CR* is a measure of consistency. When  $CR < 0.1$ , it shows strong consistency. In this study, *CR* is less than 0.1, which meets the research requirements.

## 5 DISCUSSION

Through sorting out and analyzing the influencing factors of coal mine roof accidents, this study puts forward a coal mine roof safety management evaluation model based on the DEMATEL-ANP method. The model evaluates the overall risk of coal mine roof management by determining the main aspects and key factors. According to the analysis of literature reviews and



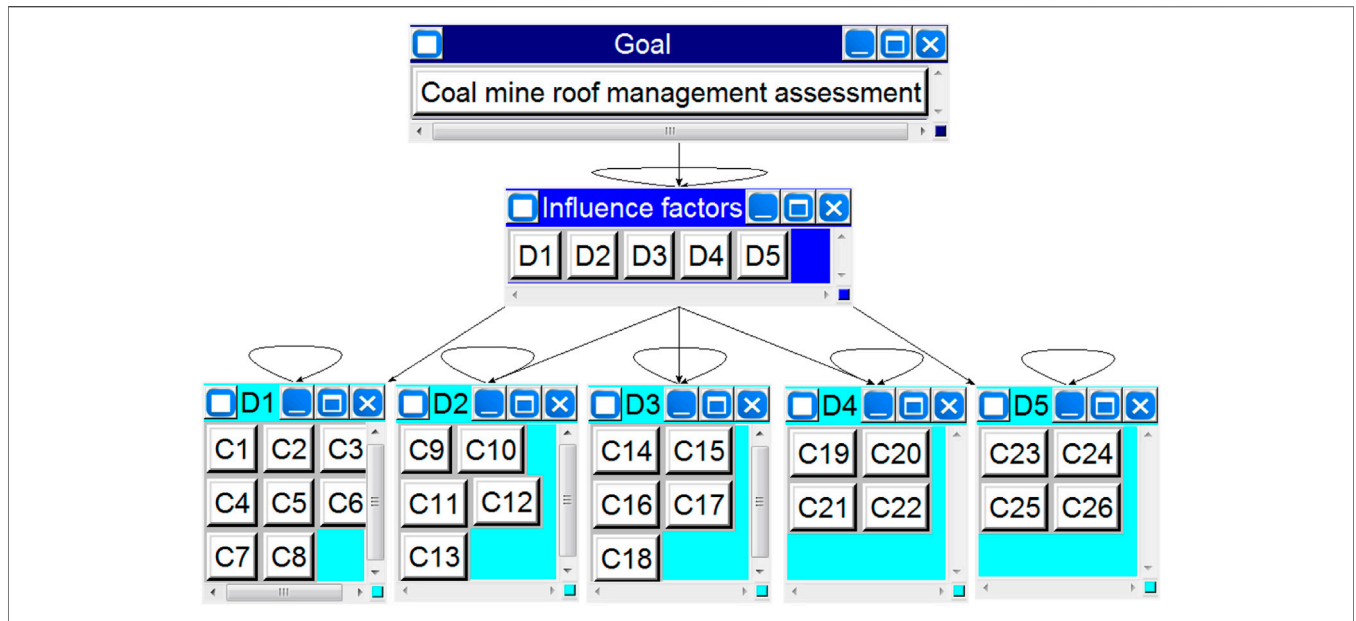


FIGURE 3 | ANP decision network model.

roof accident investigation reports and through expert interviews, 26 risk factors related to coal mine roof accidents in five categories are determined.

The DEMATEL can be used to determine the interdependence between influence dimensions and the results are shown in Tables 10, 11. The centrality of site management ( $D_2$ ) is the highest, which is 7.508, while the individual factor ( $D_3$ ) is not different from it, which also reaches 7.163, followed by the principal responsibility ( $D_1$ ), environmental change ( $D_5$ ), and technology management ( $D_4$ ). Because of the complex underground environment of coal mines, the site management involves the technology, individual, environment, and other aspects, which makes the underground site management closely related to other dimensions. Statistics show that the deviation of human behavior is the main cause of coal mine

accidents (Chang, 2016), and people are very vulnerable to the influence of surrounding factors in the process of work, so the relationship between individual factors ( $D_3$ ) and other dimensions is also very close. Although the centrality of principal responsibility ( $D_1$ ), environmental change ( $D_5$ ), and technology management ( $D_4$ ) is slightly lower than that of the site management ( $D_2$ ) and individual factors ( $D_3$ ), because coal mine safety management is a systematic project, involving many factors and will have a certain impact on each other, the relationship between these three dimensions and other dimensions is also very close.

In terms of the cause degree, the order from large to small is the principal responsibility ( $D_1$ ), environmental change ( $D_5$ ), technology management ( $D_4$ ), individual factors ( $D_3$ ), and site management ( $D_2$ ). The first three dimensions are positive, which

TABLE 12 | Weight of the roof safety management assessment index in coal mines.

Dimension	Dimension weight	Indicators	Local weight	Global weight
Principal responsibility	0.619	Risk management	0.284	0.176
		Safety education and training	0.038	0.023
		Leadership shift system	0.009	0.006
		Safety investment	0.277	0.172
		Legal mining	0.286	0.177
		Territorial supervision	0.003	0.002
		Supervision of superior company	0.003	0.002
		Responsibility system for safety in production	0.099	0.061
		Site management	0.047	Timber setting
Arranging construction	0.238	0.011		
Knock on top	0.185	0.009		
Work organization	0.194	0.009		
Emergency disposal	0.103	0.005		
Individual factors	0.094	Violate commanding	0.171	0.016
		Work performed against regulation	0.156	0.015
		Risk Identification ability	0.238	0.022

means they have a strong impact on the other dimensions. The latter two dimensions are negative, indicating that they are easily affected by the other dimensions, which is also consistent with the aforementioned analysis. Taking the principal responsibility ( $D_1$ ) as an example, the reason degree is as high as 0.821, which is related to China's national policy. China has attached great importance to safety production for a long time and has written the implementation of enterprise principal responsibility into the work safety law of the People's Republic of China, which has formed a consensus that China's government and enterprises attach great importance to the implementation of principal responsibility.

According to table 13, the order of the weight of the five dimensions is principal responsibility, technology management, site management, individual factors, and environmental impact. Among the 26 indicators, three indicators have relatively large weights, exceeding 0.1, including hidden danger investigation and treatment (0.165), safety investment (0.160), and legal mining (0.148), indicating that key attention should be paid to coal mine management. However, other influencing factors should not be ignored, such as the safety production responsibility system, operation procedures, and technical measures, which are more than 0.05, and can be used as the next level of concern. Other indicators are directly related to roof accidents, such as support setting, knocking on the top, construction arrangement, labor organization, and monitoring system, which also exceed 0.01, so the management should be strengthened. Although the weight of other factors is small, no more than 0.01, sometimes roof accidents will occur due to improper control. Therefore, these factors should be properly managed.

To sum up, the DEMATEL-ANP method can directly reflect the causal relationship between the influencing factors of coal mine roof safety management, and clarify the weight of each index. The determination of the influence relationship between factors can help coal mine managers accurately find out the root causes affecting coal mine roof safety management, and the determination of the index weight is conducive to coal mine managers quickly identifying the key factors affecting coal mine roof safety management. The combination of the two can effectively guide coal mine supervision and managers to improve the level of roof safety management.

## 6 CONCLUSION

Roof fall is one of the important dangers faced by workers during underground coal mining. To realize the comprehensive and

scientific evaluation of roof safety management of coal enterprises, first, the evaluation index system of coal mine roof safety management is constructed by combining literature reviews, accident investigation report analyses, and expert interviews. The system includes five dimensions and 26 indexes. Second, to determine the relationship and action degree between the influencing factors of roof management, a coal mine roof safety management evaluation model is constructed based on the DEMATEL-ANP. The application of this method can effectively reduce the inconsistency in the judgment process and make the evaluation results more objective. Finally, the empirical application of the model shows that the influence degree of the dimensions on roof safety management from high to low is principal responsibility, technical management, individual factors, site management, and environmental impact, while in terms of specific indicators, it is proposed that hierarchical control should be given according to the degree of influence.

## DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

## AUTHOR CONTRIBUTIONS

LL, resources, writing—original draft preparation, and validation; OY, writing—review and editing, and supervision. All authors have read and agreed to the published version of the manuscript.

## FUNDING

This work was supported by grants from the National Natural Science Foundation of China (52074214), the Social Science Foundation of Shaanxi Province (2020M010), and Xi'an Science and Technology Program Project (21SFSF0010).

## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feart.2022.891289/full#supplementary-material>

## REFERENCES

- Bai, J., Feng, G., and Wang, X. (2021). Investigation on the Mechanism and Control Methods for Roof Collapse Caused by Cable Bolt Shear Rupture[J]. *Eng. Fail. Anal.* 130, 105724. doi:10.1016/j.engfailanal.2021.105724
- Chang, F. (2016). Investigation on the Coal Mine Workers' Unsafe Behavior Management[J]. *Energy Energy Conservation* 1, 9–10. doi:10.16643/j.cnki.14-1360/td.2016.01.005
- Chukwuma, E. C., Okonkwo, C. C., Ojediran, J. O., Anizoba, D. C., Ubah, J. I., and Nwachukwu, C. P. (2021). A GIS Based Flood Vulnerability Modelling of Anambra State Using an Integrated IVFRN-DEMATEL-ANP Model. *Heliyon* 7 (9), e08048. doi:10.1016/j.heliyon.2021.e08048
- Dehdasht, G., Mohamad Zin, R., Ferwati, M., Mohammed Abdullahi, M. a., Keyvanfar, A., and McCaffer, R. (2017). DEMATEL-ANP Risk Assessment in Oil and Gas Construction Projects. *Sustainability* 9 (8), 1420. doi:10.3390/su9081420

- Düzgün, H. S. B. (2005). Analysis of Roof Fall Hazards and Risk Assessment for Zonguldak Coal Basin Underground Mines[J]. *Int. J. Coal Geol.* 64 (1-2), 104–115. doi:10.1016/j.coal.2005.03.008
- Fei, Y., Liu, S., Xu, Y., and Zhao, L. (2020). Failure Analysis of Thin Bedrock and Clay Roof in Underground Coal Mining: Case Study in Longdong Coal Mine. *Int. J. Geomech.* 20 (10), 04020187. doi:10.1061/(asce)gm.1943-5622.0001839
- Feng, G. L., Bing-Rui, C., Ya-Xun, X., Jiang, Q., Li, P. X., and Zhang, W. (2022). Microseismic Characteristics of Rockburst Development in Deep TBM Tunnels with Alternating Soft–Hard Strata and Application to Rockburst Warning: A Case Study of the Neelum–Jhelum Hydropower Project[J]. *Tunn. Undergr. Space Technol.* 122, 104398. doi:10.1016/j.tust.2022.104398
- Feng, G. L., Xia-Ting, F., Bing-Rui, C., and Yaxun, X. (2015). A Microseismic Method for Dynamic Warning of Rockburst Development Processes in Tunnels [J]. *Rock Mech. Rock Eng.* 48 (5), 2061–2076. doi:10.1007/s00603-014-0689-3
- Kiani Mavi, R., and Standing, C. (2018). Critical Success Factors of Sustainable Project Management in Construction: A Fuzzy DEMATEL-ANP Approach. *J. Clean. Prod.* 194, 751–765. doi:10.1016/j.jclepro.2018.05.120
- Lin, C. (2017). *Research on the Performance Assessment System of Policy-Based Financing Institutions in China*[D]. Shenyang: Liaoning University. (in Chinese).
- Liu, C., Yang, Z., Gong, P., Wang, K., Zhang, X., Zhang, J., et al. (2018). Accident Analysis in Relation to Main Roof Structure when Longwall Face Advances toward a Roadway: a Case Study[J]. *Adv. Civ. Eng.*, 2018, 3810315. doi:10.1155/2018/3810315
- Molinda, G. M. (2003). “Geologic Hazards and Roof Stability in Coal Mines[M],” in *US Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Pittsburgh Res. Laboratory* (Washington, DC: National Institute for Occupational Safety and Health).
- Nilashi, M., Zakaria, R., Ibrahim, O., Majid, M. Z. A., Zin, R. M., and Farahmand, M. (2015). MCPDM: A DEMATEL-ANP-Based Multi-Criteria Decision-Making Approach to Evaluate the Critical Success Factors in Construction Projects. *Arab. J. Sci. Eng.* 40 (2), 343–361. doi:10.1007/s13369-014-1529-1
- Njock, P. G. A., Shen, S.-L., Zhou, A., and Modoni, G. (2021). Artificial Neural Network Optimized by Differential Evolution for Predicting Diameters of Jet Grouted Columns. *J. Rock Mech. Geotechnical Eng.* 13 (6), 1500–1512. doi:10.1016/j.jrmge.2021.05.009
- Oraee, K., Oraee, N., Goodarzi, A., and Khajepour, P. (2016). Effect of Discontinuities Characteristics on Coal Mine Stability and Sustainability: A Rock Fall Prediction Approach. *Int. J. Min. Sci. Technol.* 26 (1), 65–70. doi:10.1016/j.ijmst.2015.11.012
- Osintsev, N., Rakhmangulov, A., and Baginova, V. (2021). Evaluation of Logistic Flows in Green Supply Chains Based on the Combined Dematel-Anp Method. *FU Mech. Eng.* 19 (3), 473–498. doi:10.22190/fume2105050610
- Phillipson, S. E. (2003). The Control of Coal Bed Decollement-Related Slickensides on Roof Falls in North American Late Paleozoic Coal Basins. *Int. J. Coal Geol.* 53 (3), 181–195. doi:10.1016/s0166-5162(02)00196-9
- Shen, S. L., Wang, Z. F., and Cheng, W. C. (2017). Estimation of Lateral Displacement Induced by Jet Grouting in Clayey Soils. *Géotechnique* 67 (7), 621–630. doi:10.1680/jgeot.16.p.159
- Tubis, A., Werbińska-Wojciechowska, S., and Wroblewski, A. (2020). Risk Assessment Methods in Mining Industry-A Systematic Review. *Appl. Sci.* 10 (15), 5172. doi:10.3390/app10155172
- Wang, H., Xue, S., Jiang, Y., and Deng, D. (2018). Field Investigation of a Roof Fall Accident and Large Roadway Deformation under Geologically Complex Conditions in an Underground Coal Mine[J]. *Rock Mech. Rock Eng.* 51 (17). doi:10.1007/s00603-018-1425-1
- Wang, N., Ma, M., Wu, G., Liu, Y., Gong, Z., and Chen, X. (2019). Conflicts Concerning Construction Projects under the Challenge of Cleaner Production - Case Study on Government Funded Projects. *J. Clean. Prod.* 225, 664–674. doi:10.1016/j.jclepro.2019.03.315
- Xiong, Y., Kong, D., Cheng, Z., Wu, G., and Zhang, Q. (2021). The Comprehensive Identification of Roof Risk in a Fully Mechanized Working Face Using the Cloud Model. *Mathematics* 9 (17), 2072. doi:10.3390/math9172072
- Xu, G., Huang, Z., Fan, Z., Lu, Z., Zhang, Z., Xue, J., et al. (2021). Types, Monitoring and Prevention Technology System of Roof Disasters in Mining Face[J]. *Coal Sci. Technol.*, 49 (02), 1–11. doi:10.13199/j.cnki.cst.2021.02.001
- Yu, Y., Guang-Liang, F., Chang-Jie, X., Bing-Rui, C., and Bi-Tang, Z. (2022a). Quantitative Threshold of Energy Fractal Dimension for Immediate Rock-Burst Warning in Deep Tunnel: a Case Study[J]. *Lithosphere* 2022, 1699273. doi:10.2113/2022/1699273
- Yu, Y., Zhao, D. C., Guang-Liang, F., Geng, D. X., and Guo, H. S. (2022b). Energy Evolution and Acoustic Emission Characteristics of Uniaxial Compression Failure of Anchored Layered Sandstone. *Front. Earth Sci.* 10, 841598. doi:10.3389/feart.2022.841598
- Yasidu, U. M., Fujii, Y., Kodama, J., Fukuda, D., Maneya, G. J., Dandadzi, J., et al. (2019). Influences of Water Vapor on Roof Fall Accidents in Selected Underground Coal Mines in Malawi[J]. *Adv. Civ. Eng.*, 2019, 5350686. doi:10.1155/2019/5350686
- Zhang, P., Niu, H., Zhu, H., and Li, F. (2021). Analysis of Coal Mine Safety Production Situation in China from 2019 to 2020[J]. *Saf. Coal Mines*, 52 (11), 245–249. doi:10.13347/j.cnki.mkaq.2021.11.039
- Zhu, L., Lv, W., Yang, P., et al. (2018). Statistical Analysis and Occurrence Laws of Coal Mine Accidents of China from 2007 to 2016[J]. *Saf. Coal Mines*, 49 (07), 237–240. doi:10.13347/j.cnki.mkaq.2018.07.061

**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

**Publisher's Note:** All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Copyright © 2022 Li and Ouyang. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.