Study on fuzzy decision-making in production safety management for metal ore drilling

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Abstract. This paper studied a series of main and objective factors that affect production safety in the process of mining for metal ore, analyzed all kinds of safety factors and their sets, levels and weights, established the corresponding expert system, and the fuzzy mathematics model of the safety evaluation of the metal mining process was established, and it is applied to the safety evaluation of the Maoping lead zinc ore in Yunnan province. The practice shows that the model is a feasible, objective, fair, comprehensive and quantifiable safety assessment method, which realizes the quantitative assessment of metal ore production process and has good application value for the safety assessment of metal ore mining.

1. Introduction

Metal mining is the key work in China's resource exploitation engineering. However, the rapid development of geological exploration industry makes it face an unprecedented challenge: production safety. As is known to all, once any safety problem occurs in the construction, on the one hand, it will increase the construction cost, on the other hand, relevant supervision departments will also intervene in the investigation, such as the occurrence of major safety accidents may even cause fines, work stoppage phenomenon; which has a huge impact on productivity and economic benefits. Therefore, safety management work is particularly important. Doing a good job in safety evaluation and conducting a scientific and reasonable quantitative analysis of the safety production level are the basic condition for ensuring the smooth development of project.

At present, the research on the risk of metal mine drilling has the following aspects.

Production risk. The risk coefficient of underground drilling in metal mines is relatively high. On the one hand, the stability of the rock and soil layer will have a great impact on the safety of drilling work; on the other hand, the safety of the work management process will also affect the overall quality of safe production. Problems in drilling work usually cause a comprehensive impact, coupled with the uncertainty of influencing factors, so it is difficult to accurately predict the production risk, there are large safety technical hidden dangers in the work.

Consciousness risk. Production safety plays an important role in drilling work. Every mine unit should vigorously publicize the idea of production safety. But in the actual work, many workers often ignore the safety management work, think that drilling and mining accidents will not happen to their own, there is a fluke psychology. Therefore, underground drilling units should pay attention to the implementation of my management work into the daily education and training, to avoid the situation of safety work not in place, improve the safety risk awareness of mine workers and safety management awareness, reduce the incidence of safety risk in the mine.
management risk. In the process of drilling, people mostly pay attention to the schedule and output, but pay insufficient attention to the safety of downhole working environment, which is mainly reflected in the following aspects. First of all, the personnel management is not in place, many people in the actual drilling work do not pay attention to the drilling work related norms and regulations, according to their own experience, the use of some technology is not in line with the relevant provisions, which has brought greater safety and technical risks to drilling work. Secondly, the environmental management is not in place, and the underground drilling in metal mines is prone to production safety hazards, such as the electrical equipment used for drilling, ventilation conditions, etc., which will lead to larger safety accidents.

Take drapery grouting drilling for example, there are two safety schemes for construction as follows.

**Having a comprehensive understanding of drilling work.** The purpose of curtain grouting in metal mines is to form waterproof curtain in the form of drilling grouting in mining areas to ensure environmental safety in mining operations in the future. A comprehensive understanding of the local geological conditions and hydrological engineering shall be obtained prior to construction. Conduct standard planning for the operation process and formulate a series of safety production technical standards to ensure the safety of mine production and the stability and safety of later production. Secondly, in mine drilling, want to notice to staff the organization work, called the staff technical meeting, clear the application of the mine production equipment, in a timely manner to introduce staff to the use of mechanical production equipment scheme, structure performance and risk problem, the hidden trouble in security technology of operating instructions. Finally, the potential safety hazards were timely predicted, and the drilling plan was adjusted according to the actual geological conditions of the local area, so as to avoid the potential safety technical hazards in the construction. Strict control of safety and quality.

**Strict control of safety and quality.** In order to ensure drilling safety, the following aspects should be taken into consideration. First of all, we should increase the investment in the preliminary investigation work, and make a reasonable fund allocation plan in terms of capital and talent training, pay attention to the management of equipment safety and quality in the capital investment, and guarantee the capital of technical equipment and safety technical equipment. Secondly, in order to further control the quality of safe production, we should pay attention to the formulation of scientific and reasonable safety programs, and make clear plans for specific drilling programs and later mining programs. Finally, adequate attention should be paid to the problems in drilling work to ensure that all information can be summarized in a timely manner to avoid omissions and to do a good job in archiving.

The above researches on this issue are qualitative. However, quantitative researches should be made on the safety level of exploration and production, that is, specific classification of production safety should be made and quantitative evaluation of the safety of exploration and production process should be made by using fuzzy mathematical methods. Therefore, in order to ensure the safety of mine production and establish a safe and orderly mining operation environment, we take curtain grouting drilling as an example, use the fuzzy mathematical model, study the scientific safety level discrimination method, guide the production work, and further improve the safety of curtain grouting drilling project, so as to improve economic benefits.

2. Methodology
The fuzzy decision should first determine the target layer, the criterion layer and the index layer of the evaluated object. Then, the weight of the criterion layer on the target layer and the factors of the corresponding criterion layer is determined to obtain a fuzzy evaluation matrix. The matrix and the weight vector of the factors are fuzzy operation and the fuzzy comprehensive evaluation result is obtained finally. The purpose of fuzzy decision making is to sort the evaluation objects and select the relatively optimal one from the evaluation objects according to the highest membership degree.
2.1. Determine the Layer of Criterion and the Layer of Index Factor Set for Comprehensive Evaluation

For example, the evaluation standard of integrated safety level comes from Production, consciousness, and management, and each aspect can be divided into several sub-factors (that is the indicator layer of factors), each sub-factor has the corresponding scoring criteria. The factors set out in the criteria layer and the indicator layer is as follows:

\[ U = \{ U_1, U_2, U_3 \cdots U_n \} \]
\[ U_1 = \{ U_{11}, U_{12}, U_{13} \cdots U_{1m} \} \]
\[ U_2 = \{ U_{21}, U_{22}, U_{23} \cdots U_{2n} \} \]
\[ U_3 = \{ U_{31}, U_{32}, U_{33} \cdots U_{3n} \} \]

Determining the domain of engineering safety evaluation grade, assume that the grade of engineering safety evaluation has five levels: excellent, good, medium, passing and failed, the established ranking is: = (excellent, good, medium, passing and failed).

2.2. Weight Set for Determining Evaluation Factors

In fuzzy decision-making, the weight set of evaluation factors is determined: \( A = (a_1, a_2, \ldots, a_n) \). The element \( a_i \) in weight set \( A \) is essentially the membership of the factor \( U_i \) to the target layer factor \( U \), \( B_i \) is the degree to which the metrics layer factors are subordinate to the corresponding \( U_i \). The common methods to determine the weight set are: analytic hierarchy process, Delphi method, etc.

Analytic hierarchy process (AHP) is used to determine the relative importance order of each evaluation index. Thus, the weight coefficient is determined and normalized before synthesis. That is

\[ \sum_{i=1}^{n} a_i = 1 \quad \sigma_i \geq 0 \quad i = 1, 2, \ldots, n \]

The Delphi method communicates back to back with the panel members. After several rounds of consultation, it usually focuses on the panel's prediction and finally makes a reasonable prediction. Method is based on the system application, using anonymous expression point of view, experts questions through questionnaire for many times, after repeated negotiation, conclude and modification, the last meeting conference of experts basically consistent view of the result of forecast. This method is widely representative and reliable.

2.3. Establishing the Fuzzy Relation Matrix \( R \)

After constructing the domain of engineering safety evaluation grade, we should evaluate the criteria layer from the index layer, which is the organization expert quantifying the evaluated factors \( U_1, U_2, U_3 \ldots U_n \), that is, to determine the membership degree of the graded fuzzy subsets from the single factor, and then get the fuzzy relation vector \( B_i \).

\[ B_i = A \circ R_i = (b_{i1}, b_{i2}, b_{i3}, \ldots, b_{in}) \quad i = 1, 2, 3, 4 \]

That is the number of \( (U_1, U_2, U_3, U_4) \). \( A_i \) is the weight sets of \( (U_{11}, U_{12}, U_{13}, U_{14}) \) to \( U_1 \), \( (U_{21}, U_{22}, U_{23}, U_{24}) \) to \( U_2 \), \( (U_{31}, U_{32}, U_{33}, U_{34}) \) to \( U_3 \), \( (U_{41}, U_{42}, U_{43}, U_{44}) \) to \( U_4 \). \( R_i \) is the evaluation matrix of each sub-factor in \( (U_1, U_2, U_3, U_4) \) to the evaluation of hierarchical domain \( V \).

\[ R_i = \begin{bmatrix} B_{i1} \\ B_{i2} \\ \vdots \\ B_{in} \end{bmatrix} = \begin{bmatrix} b_{i11} & b_{i12} & \cdots & b_{i1n} \\ b_{i21} & b_{i22} & \cdots & b_{i2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{im1} & b_{im2} & \cdots & b_{imn} \end{bmatrix} \]

Where \( m \) is the number of neuron factors \( (U_1, U_2, U_3, U_4) \).
After determining the fuzzy relation vector of each criterion layer subfactor, the target level fuzzy relation vector $B$ can be obtained according to the following formula.

$$
B = A^o R = (b_1, b_2, b_3, b_4, b_5),
$$

where $A$ is the weight set of the criterion layer factor set to the target layer factor $U$, that is, $A = (a_1, a_2, a_3, a_4)$, $R$ is the evaluation matrix of the criterion layer factor set for $U$.

$$
R = \begin{bmatrix}
    b_1 \\
    b_2 \\
    b_3 \\
    b_4
\end{bmatrix} = \begin{bmatrix}
    b_{11} & b_{12} & b_{13} & b_{14} & b_{15} \\
    b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \\
    b_{31} & b_{32} & b_{33} & b_{34} & b_{35} \\
    b_{41} & b_{42} & b_{43} & b_{44} & b_{45}
\end{bmatrix}
$$

$B = (b_1, b_2, b_3, b_4, b_5)$ is the subordinate degree of the fuzzy subset $V = (excellent, good, medium, passing, failed)$ of the evaluation grade $U$ of accounting practice. According to the principle of maximum membership, we can evaluate the grade of a project.

3. Experiment
An empirical Study on safety evaluation of the Curtain grouting drilling project for Maoping lead zinc ore in Yunnan province.

Take the Curtain grouting drilling project for Maoping lead zinc ore as an example to analyze the above evaluation methods. The purpose is to establish waterproof curtain for the mine to ensure the safety of subsequent production. The experts of this system are composed of project manager, front-line safety management personnel and front-line staff, striving to be fair, objective and comprehensive.

Considering the particularity of underground construction, specific target layer, standard layer and index layer are established according to local construction conditions. Evaluation Set $V = (excellent, good, medium, passing, failed)$. Take the Curtain grouting drilling project for Maoping lead zinc ore as an example, using the Delphi method, the weights of the indicators are as follows, shown in Table 1.

Table 1. Application of Delphi method to the evaluation of each factor set weight of construction safety

| Target layer | Assessment | $A$ |
|--------------|------------|-----|
| Criterion layer | Geological condition (0.40) | | |
| | Staff training (0.22) | | |
| | Working strength (0.17) | | |
| | Equipment situation (0.30) | | |
| | Management attaches to safety (0.44) | | |
| | The average education level of front-line personnel (0.17) | | |
| | Special operations (0.48) | | |
| | The implementation of rewards and punishments (0.31) | | |
| Indicator layer | If there is a rush hour situation (0.29) | | |
| | Transportation conditions (0.18) | | |
| | The noise (0.06) | | |
| | The temperature of the construction site (0.19) | | |
| | Safety inspection frequency (0.41) | | |
| | Labor protection measures (0.32) | | |
| | Electric power safety (0.31) | | |
| | The ventilation condition (0.33) | | |

The calculation results are as follows,

$$
B = (0.2278, 0.33750, 0.30875, 0.0497)
$$
Based on the above data, Curtain grouting drilling project for Maoping lead zinc ore meets the construction conditions.

4. Conclusion
For safety management in metal ore drilling, it is necessary to establish an effective and scientific comprehensive evaluation system. This study provides an effective and convenient evaluation method for the management of production safety. According to the above fuzzy mathematical calculation method, Curtain grouting drilling project for Maoping lead zinc ore meets the construction conditions, and makes the productive process stable and safe. From 2017 to now, the Maoping lead zinc ore projects have run efficiently with no accidents. Therefore, this fuzzy mathematical algorithm is scientifically feasible.

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