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Risk hierarchical management and control model based on AHP-DEMATEL-cloud model

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Abstract: In this paper, for the risk grading evaluation of China's coal mining enterprises, there are problems such as imperfect risk indicator system and subjectivity of evaluation results, etc. From the four elements of "human-machine-environment-pipe" safety production management, we construct a risk evaluation indicator system that meets the characteristics of mine safety production and construct a risk grading evaluation model based on AHP-DEMATEL-Cloud model. Based on AHP-DEMATEL-Cloud model, we construct a risk grading evaluation model. Taking a coal mining enterprise as the research object, the comprehensive risk assessment and grading application is carried out to obtain the risk level of the enterprise and the corresponding improvement opinions.

1. Introduction

Coal, as China's most important energy resource, is reflected in all walks of life in China, and it is expected that its share of primary energy in the middle of the 21st century is still unlikely to be less than 50% [1], and its position as China's top energy source will remain unshakeable for a long time.

The implementation of mine safety management plays a pivotal role in the day-to-day management of mining enterprises, which is directly related to the coal industry's safe production and the overall image, but also related to the national energy reserves, property safety, employee safety and their own interests [2,3]. For this reason, our country puts forward the concept of "double prevention system" with "risk classification and control" and "hidden danger investigation and management" as the core, in order to promote the smooth progress of production safety management.

"Risk classification and control" is the premise and foundation for the smooth promotion of the "dual prevention" system, and risk assessment and classification is the most important part of this process [4]. However, China's risk grading evaluation still exists in the risk indicator system is not perfect [5,6], the evaluation results of serious subjectivity and other problems.

2. Constructing a Risk Indicator Evaluation System Based on AHP-DEMATEL-Cloud Model

2.1. Construction of risk indicator evaluation system

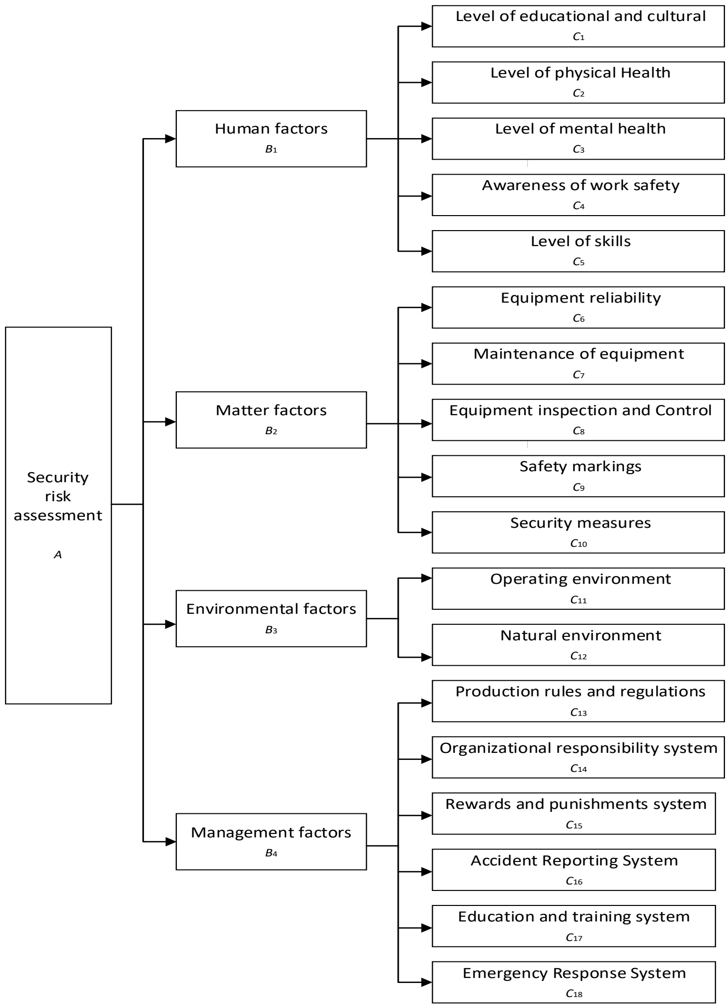

Figure 1: System of security risk evaluation indicators

Based on the four elements of "human-machine-environment-management" safety production, we construct a safety risk evaluation index system with safety risk evaluation as the target layer, "human-machine-environment-management" as the criterion layer, and 18 specific indicators as the program layer, as shown in *Figure 1*.

2.2. Calculation of composite indicator weights based on AHP-DEMATEL

On the basis of using AHP to calculate the weights of the initial indicators, DEMATEL is introduced to calculate the centrality between the evaluation indicators and calculate the weights of the comprehensive indicators, to make up for the shortcomings of the AHP method of calculating the weights that cannot take into account the mutual influence of the indicators.

2.2.1. Calculate initial weights based on AHP

A two-by-two comparison of relative importance between indicators at the same level based on the evaluation criteria is performed to obtain the judgment matrix A. Assume that the initial judgment matrix $\boldsymbol{A}=(a_{ij})_{n\times n}$.

$$A=\left(a_{ij}\right)_{n\times n}=\begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix}$$

Regularizing the judgment matrix $\boldsymbol{A}$, see *Equation 1*,

$$b_{ij}=\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}\left(i,\, j=1,2\cdots\cdots n\right) \tag{1}$$

Yields the regularized judgment matrix $\boldsymbol{B}=(b_{ij})_{n\times n}$.

In order to avoid logical errors in the indicators at all levels, it is necessary to carry out a reliability analysis of the judgment matrix A that has been established, which yields the consistency ratio

$$C_{\mathrm{R}}=\frac{C_{\mathrm{I}}}{R_{\mathrm{I}}} \tag{2}$$

Of these, the consistency indicator

$$C_{\mathrm{I}}=\frac{\lambda_{\max}-n}{(n-1)}$$

Formula **n** - the matrix order;

$\lambda_{\max}$ - Determining the largest eigenvalue of a matrix;

R_{I} - Stochastic Consistency Indicators, a constant, commonly used **R_{I}** values are shown in the *Table 1*.

Table 1: R_{I} values

n	1	2	3	4	5	6	7	8	9	10
***R*I**	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

When **C_{R}** < 0.1, reliability analysis was passed.

After passing the reliability analysis, the regularized judgment matrix $\boldsymbol{B}$, with the column vectors as the base data, was normalized by the sum method, in order to obtain the initial weights of each indicator.

$$X_i=\frac{\overline{X}_i}{\sum_{j=1}^{n}\overline{X}_i}(i,\, j=1,2\cdots\cdots n) \tag{3}$$

Of these $\overline{X}_i=\sum_{j=1}^{n} b_{ij}\left(i,\, j=1,2\cdots\cdots n\right)$

2.2.2. Calculation of centrality weights based on DEMATEL

Assuming that the influence relationship between each factor is categorized into five influence levels, namely, no influence, weak influence, general influence, strong influence and strong influence, with corresponding scores of 0, 1, 2, 3 and 4, respectively, experts in the relevant fields will form a direct influence matrix ***N*** by evaluating and scoring the influence relationship existing between each indicator. $\boldsymbol{N}=(n_{ij})_{n\times n}$.

$$N=\left(n_{ij}\right)_{n\times n}=\begin{pmatrix} 0 & n_{12} & \cdots & n_{1n} \\ n_{21} & 0 & \cdots & n_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ n_{n1} & n_{n2} & \cdots & 0 \end{pmatrix}$$

The judgment matrix ***N*** is normalized to obtain its canonical direct impact matrix ***O***, which is further processed to obtain the integrated impact matrix $\boldsymbol{T}=(t_{ij})_{n\times n}$.

$$\boldsymbol{T}=\boldsymbol{O}\bullet(\boldsymbol{I}-\boldsymbol{O})^{-1} \tag{4}$$

Formula ***O*** - The norm of the matrix ***N*** directly affects the matrix;

I - Unit matrix.

The values of the influencing factors are calculated according to the comprehensive influence matrix ***T*** and normalized to obtain the influence weights of each indicator

$$Y_i=\frac{U_i}{\sum_{i=1}^{n}U_i}(i=1,2\cdots\cdots n) \tag{5}$$

Of these, the centrality

$$\boldsymbol{U}=\boldsymbol{D}+\boldsymbol{C}$$

Formula $D=\sum_{j=1}^{n}t_{ij}$;

$$C=\sum_{i=1}^{n}t_{ij}.$$

2.2.3. Calculation of weights for composite indicators based on AHP-DEMATEL

$$Z_i=\frac{X_i\cdot Y_i}{\sum_{i=1}^{n}X_i\cdot Y_i}(i=1,2\cdots\cdots n) \tag{6}$$

2.3. Security Risk Evaluation Cloud Model

The cloud model theory is used to carry out fuzzy comprehensive evaluation, and the comprehensive assessment of security risks is carried out through the method of presenting comprehensive cloud diagrams, in which the necessary similarity analysis is introduced to distinguish the risk level of each secondary indicator, so as to reduce the bias brought about by the evaluator's subjectivity, and thus improve the reliability of the evaluation results to realize a more accurate analysis and evaluation.

2.3.1. Cloud Model Generator

Cloud model theory mainly realizes the interconversion of qualitative concepts and quantitative values through two major cloud model numerical generators, namely the forward cloud generator and the inverse cloud generator[9-11].

1) Reverse cloud generator

The inverse cloud generator is able to transform specific quantitative values into qualitative concepts with easy-to-understand, starting from statistically measurable "cloud droplets" and calculating numerical characteristics (*Ex, En, He*) of the cloud model, realizing the qualitative presentation of specific data, as shown in *Figure 2*.

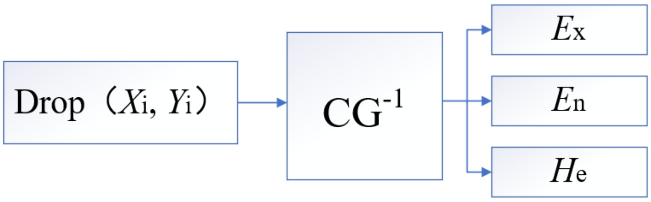

Figure 2: Reverse cloud generator.

2) Forward cloud generator

The forward cloud generator is capable of transforming fuzzy qualitative concepts into precise quantitative values by generating "cloud droplets" based on the numerical characteristics of the cloud model (*Ex, En, He*), each of which is a concrete manifestation of the fuzzy qualitative concepts, as shown in *Figure 3*.

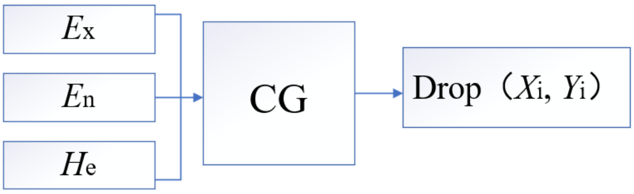

Figure 3: Forward cloud generator.

2.3.2. Establish Standardized Evaluation Cloud Map

In the process of security risk assessment, risks are classified into four levels - major risk, greater risk, general risk and low risk - according to the risk level, which are scaled by the color of "red, orange, yellow and blue", and the numerical characteristics corresponding to each evaluation level (*Ex, En, He*) are obtained through calculation[].

$$E_x = \frac{x_{max} + x_{min}}{2} \tag{7}$$

$$E_n = \frac{x_{max} - x_{min}}{6} \tag{8}$$

$$H_e = i \cdot E_n \tag{9}$$

Formula x_{max} - Maximum of the evaluation set

x_{min} - Minimum of the evaluation set

i - a constant, reflecting the randomness of the evaluation.

With this, the evaluation level values are set, as shown in *Table 2*.

Table 2: Table of evaluation level values

	Major risk	***Greater risk***	***General risk***	***Low risk***
Interval	0~60	60~80	80~90	90~100
E_x	30	70	85	95
E_n	10.000	3.333	1.666	1.666
H_e	1.000	0.333	0.167	0.167

using this data to generate a cloud map of mine safety risk evaluation criteria, like *Figure 4.*

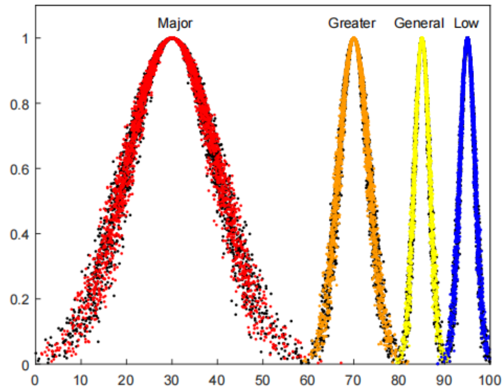

Figure 4: Standardized Evaluation Cloud

2.3.3. Establish Integrated Evaluation Cloud Map

By inviting experts to score and evaluate each indicator, the inverse cloud generator based on the ***SBCT-1stM*** algorithm is used to calculate and obtain the digital characteristics of each program layer indicator.

$$E_{x_i} = \bar{X} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{10}$$

$$E_{n_i} = \sqrt{\frac{\pi}{2}} \times \frac{1}{n}\sum_{i=1}^{n} |x_i - Ex| \tag{11}$$

$$H_{e_i} = \sqrt{S_i^2 - En_i^2} \tag{12}$$

Of these, S_i^2 – Variance, $S_i^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{X})^2$

Due to the uncertainty between the indicators, the cloud model eigenvalues (Ex, En, He) of each criterion layer and decision layer indicator are calculated by combining the weights of each indicator calculated by AHP - DEMATEL with the eigenvalues (Ex_i , En_i , He_i) of each indicator at the program layer and the corresponding evaluation cloud maps are generated by using this with the forward cloud generator. And the corresponding evaluation cloud map is combined with the standard cloud map to generate a comprehensive evaluation cloud map.

2.3.4. Similarity analysis

By comparing the output composite cloud map with the standard cloud map, although the safety level of the composite cloud map can be derived more intuitively, however, there will still be an error, so similarity analysis is introduced[12].

$$\lambda_i = e^{-\frac{(x_i - Ex_i)^2}{2(3He_i + En_i)^2}} \tag{13}$$

Comprehensively analyze the similarity λi between the evaluation cloud map and the standard cloud map, and determine the evaluation interval of the standard cloud corresponding to the maximum of λ_i according to the principle of maximum affiliation, which is the final comprehensive evaluation result.

3. Example Applications

3.1. Calculation of weights for composite indicators

According to the established mine emergency response capacity assessment index system, a number of experts were invited to assess and score the mine's emergency response capacity with four first-level indexes and 18 second-level indexes of preventive capacity, preparedness capacity, response capacity and restoration capacity, and the comprehensive index weights between each factor can be obtained by combining AHP and DEMATEL. The combined AHP-DEMATEL method was used to calculate the comprehensive weights of indicators at all levels, as shown in *Table 3*.

Table 3: Weights for composite indicators

Target layer	*Initial weight*	*Center weight*	*Combined weight*	*Program layer*	*Initial weight*	*Center weight*	*Combined weight*
B_1	0.227	0.266	0.236	C_1	0.020	0.044	0.016
				C_2	0.036	0.044	0.028
				C_3	0.036	0.049	0.032
				C_4	0.077	0.068	0.092
				C_5	0.059	0.061	0.063
B_2	0.227	0.266	0.236	C_6	0.088	0.049	0.075
				C_7	0.038	0.057	0.038
				C_8	0.025	0.060	0.026
				C_9	0.015	0.059	0.015
				C_{10}	0.061	0.071	0.076
B_3	0.123	0.209	0.145	C_{11}	0.061	0.037	0.039
				C_{12}	0.061	0.037	0.039
				C_{13}	0.052	0.060	0.054
				C_{14}	0.038	0.056	0.037
				C_{15}	0.073	0.048	0.061
B_4	0.423	0.259	0.383	C_{16}	0.027	0.059	0.028
				C_{17}	0.123	0.061	0.151
				C_{18}	0.110	0.079	0.131

3.2. Cloud Model Digital Feature Computing

Using the expert scoring method, 10 experts in the fields of safety production, equipment testing, geological exploration, emergency rescue and other related areas were invited to score and evaluate the evaluation indicators of the 18 program layers, and then using an inverse cloud generator based on the SBCT-1stM algorithm for calculations to obtain the numerical characteristics of the cloud model for each metric, the digital features of the cloud model for the program layer were computed

(*Ex*, *En*, *He*), as shown in *Table 4*.

Table 4: Digital features of the Program Layer

	Ex	***En***	***He***
C_1	80.4	4.81	0.46
C_2	76.7	5.63	1.83
C_3	79.3	5.38	1.12
C_4	80.6	4.11	1.47
C_5	77.4	5.61	2.21
C_6	78.8	3.09	1.36
C_7	79.9	3.65	0.69
C_8	79.7	5.89	2.67
C_9	77.0	5.26	1.98
C_{10}	78.7	5.13	2.34
C_{11}	64.1	7.19	1.45
C_{12}	33.8	7351	1.44
C_{13}	73.6	8.52	3.04
C_{14}	69.2	6.06	1.17
C_{15}	75.3	8.14	3.54
C_{16}	74.9	7.67	2.55
C_{17}	76.8	7.87	1.88
C_{18}	71.3	7.21	0.58

Based on the numerical characteristics of the above table and the combined indicator weights of the indicators in *Table 3*, the numerical characteristics of the layer cloud model for each criterion are obtained by weighting operation, as shown in *Table 5*.

Table 5: Digital features of the Criterion Layer

	Ex	***En***	***He***
B_1	79.0	4.93	1.61
B_2	78.8	4.32	1.76
B_3	65.4	7.35	1.44
B_4	73.8	7.62	1.79

Similarly, the numerical characteristics of the decision level indicator, Security Risk Evaluation ***A***, can be obtained from the integrated cloud weighting calculation as (75.4 6.22 1.72).

3.3. Integrated assessment cloud mapping

Based on the above, the numerical characteristics of safety risk evaluation ***A*** (***Ex***=75.4, ***En***=6.22, ***He***=1.72). *On this basis, A comprehensive evaluation cloud map is obtained by combining the forward cloud generator with the standard evaluation cloud map*, as shown in *Figure 5*.

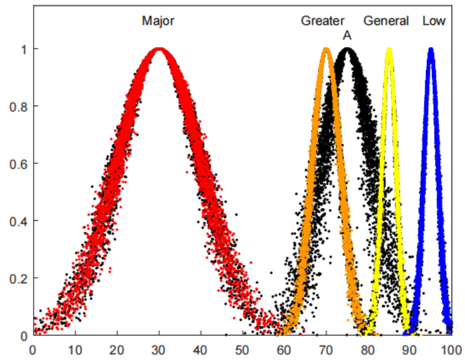

Figure 5: A comprehensive evaluation cloud

Similarly, the comprehensive evaluation cloud diagrams of $\boldsymbol{B_1}$ ($\boldsymbol{Ex_1}$=79.0, $\boldsymbol{En_1}$=4.93, $\boldsymbol{He_1}$=1.61), $\boldsymbol{B_2}$ ($\boldsymbol{Ex_2}$=78.8, $\boldsymbol{En_2}$=4.32, $\boldsymbol{He_2}$=1.76), $\boldsymbol{B_3}$ ($\boldsymbol{Ex_3}$=65.4, $\boldsymbol{En_3}$=7.35, $\boldsymbol{He_3}$=1.44) and $\boldsymbol{B_4}$ ($\boldsymbol{Ex_4}$=73.8, $\boldsymbol{En_4}$=7.62, $\boldsymbol{He_4}$=1.79) are shown in *Figures 6, 7, 8* and *9*.

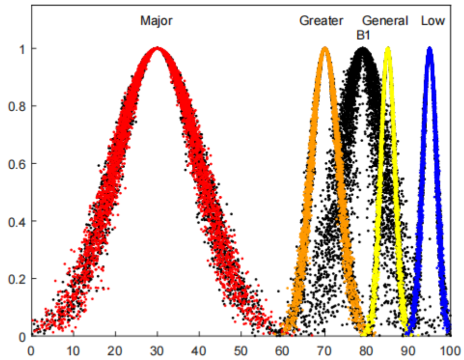

Figure 6: B_1 comprehensive evaluation cloud

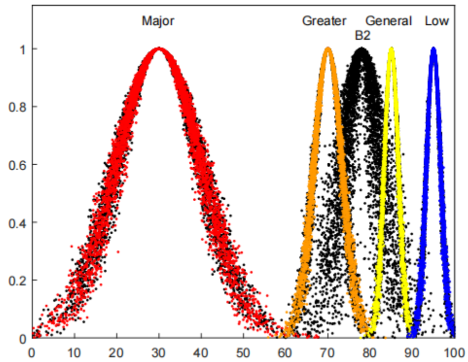

Figure 7: B_2 comprehensive evaluation cloud

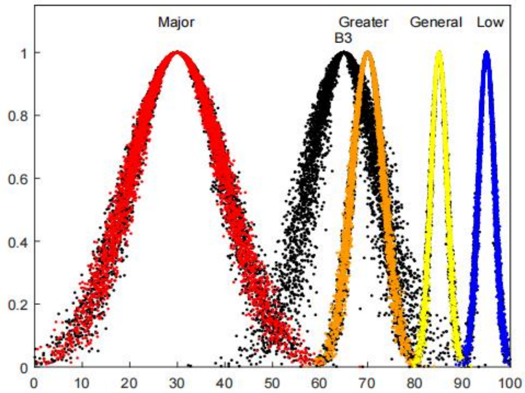

Figure 8: B_3 comprehensive evaluation cloud

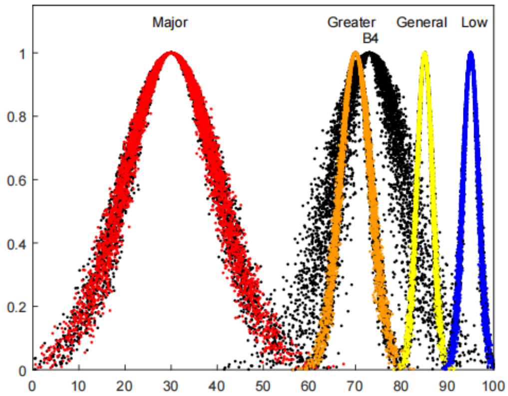

Figure 9: B_4 comprehensive evaluation cloud

3.4. Similarity analysis

Although the safety comprehensive evaluation cloud diagram can be more intuitive to analyse the safety risk level of the decision-making layer and the indicators of each criterion layer, in order to make the safety comprehensive evaluation results more objective, scientific and reasonable, the similarity is introduced here, and the MATLAB software is used to achieve the calculation of the similarity of the analysis of λi, and according to the principle of the maximum degree of subordination, to determine the corresponding standard cloud evaluation interval of the λi when the maximum is the ultimate comprehensive evaluation results.

The results of similarity calculation are shown in *Table 6*.

Table 6: Similarity analysis values

	Major risk	*Greater risk*	*General risk*	*Low risk*
A	0.2844	0.5776	0.5149	0.5082
B_1	0.1049	0.5549	0.5150	0.5113
B_2	0.1021	0.5559	0.5157	0.5147
B_3	0.2037	0.5989	0.5221	0.5119
B_4	0.2141	0.5856	0.5137	0.5124

4. Conclusions

(1) The use of AHP-DEMATEL to calculate the combined weights of the indicators is more objective, scientific and reasonable.

(2) The introduction of cloud modelling can better achieve the conversion of evaluation indicators from qualitative concepts to quantitative indicators, and make the evaluation results more intuitive and reliable.

(3) The results of the real-life application are in line with the actual situation of the company, which proves that it is reliable and feasible to carry out safety risk evaluation for the enterprise by constructing a safety risk assessment system based on the theory of AHP-DEMATEL-Cloud model.

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