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Evaluation Method of Coal Mine Mode Gas Control Mode Based on Analytic Hierarchy Process

Jiaxin Dong[a,b], Lei Cheng[a,b,c,*]

[a] State Key Laboratory Cultivation Base for Gas Geology and Gas Control, Jiaozuo 454000, China
[b] School of Safety Science and Engineering, Henan Polytechnic University, Jiaozuo 454000, China
[c] Coal Production Safety Collaborative Innovation Center in Henan Province, Jiaozuo 454000, China
chengl@hpu.edu.cn

This paper takes the comprehensive evaluation of coal mine gas control mode as the research target to construct a multi-factor and multi-index gas control mode evaluation system with 4 factors and 16 evaluation indices. The analytic hierarchy process (AHP) is used to determine the weight of gas control evaluation indices, and to construct a fuzzy comprehensive assessment model (FCAM). The study finds that the total ranking of various factors in the gas control mode can basically meet the consistency requirement; it should ensure that the wind flow in the mine roadway is sufficient and stable, the professional quality of the operators is excellent, and the production system is perfect, so as to achieve comprehensive improvement of gas control effect; when evaluating the gas control mode, the evaluation factor set and the result evaluation set are combined, the evaluation results are represented by a fuzzy set, and the evaluation matrix T is obtained. Finally, a corresponding evaluation model is established combining the weight vector W.

1. Introduction

Coal is one of China's pillar industries, which has greatly promoted the rapid development of economy and provided a large amount of energy security for the society. Due to the deep exploitation of coal resources, the industry is facing lots of problems such as resource depletion and increased mining difficulty (Li and Cheng, 2014, Yang et al., 2012, Li and Chen, 2016). In addition, frequent coal accidents caused by natural environment, mining mode or human factors have caused serious casualties (Cheng et al., 2014). The outburst of coal and gas is a potential risk in the gas control of coal seam mining (Muramatsu and Iijima, 2003; Xiao and Tian, 2011). Exploring effective gas control mode evaluation methods has significant social (Cheng et al., 2011; Obdam et al., 2003).

In China, the coal mine exploration is extending to the depths of the mine at a mining speed of 20-50 m/year, and a large number of mines have entered the deep mining stage (Jin et al., 2016, Li, 2014, Wan and Song, 2013). With the increase deepening of coal mining, the geological structure of the underground is becoming more complex, and the difficulty of gas control in the mine is gradually increasing (Zhang, 2011, Zhu et al., 2014; Du, 2012). So this paper first constructs a gas control evaluation index system, uses AHP to determine the weight coefficient of the gas control evaluation index, and then establishes a fuzzy comprehensive evaluation model, which can achieve the standard evaluation of gas safety control. (Wu et al., 2018)

2. AHP

2.1 Principle of AHP

This paper introduces AHP into the evaluation system of coal mine gas control mode. Analytic hierarchy process (AHP), also known as the judgment matrix method, was proposed by American operations researcher Saaty T.L. in the 1970s. The analytical principle of AHP is to divide the factors in the complex system into hierarchical structures according to the association and the membership relationship, the hierarchical structures successively are the goal, the criteria and alternatives, then judge the relative importance of each factor in the same hierarchy and establish a hierarchical mathematical model to calculate the relative

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importance weight of each factor in each hierarchy, and use the consistency criterion to test the accuracy of the analysis, finally, the judgment results of each hierarchy are summed up in the hierarchical structure, so as to obtain the total ranking of importance of each factor, and based on this to carry out planning decisions and select optimal solutions from the methods.

2.2 Steps of AHP

Figure 1 shows the basic steps of AHP. The specific process is as follows: first, comprehensively analyze problems of various aspects, establish a structural model to form a hierarchical structure (Figure 2), then construct a judgment matrix, calculate the maximum eigenvalue and eigenvector, obtain relative weight of each factor through consistency test, and perform hierarchical ranking according to the relative importance.

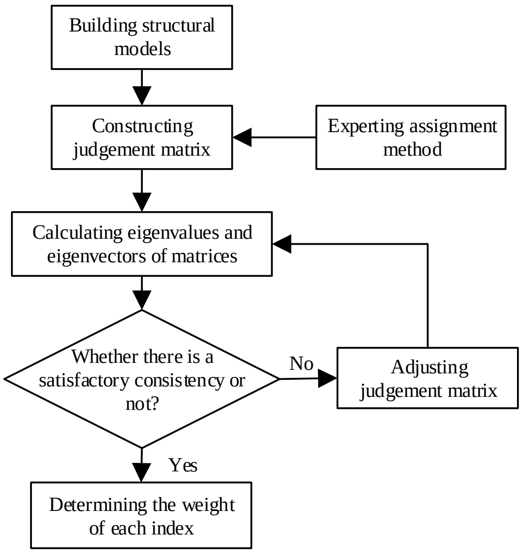

Figure 1: Steps of AHP

For the AHP, the first step is to clarify the interrelationship of the problems and establish a hierarchical structure of the system. The second step is to construct a two-two comparison judgment matrix. Use the Starr relative importance level to perform the two-two comparisons and judge the importance of the factors in each hierarchy. The obtained judgment matrix R is shown as Equation 1.

$$R=\left(r_{ij}\right)_{n\times n} \qquad r_{ij}>0; r_{ij}=1/r_{ji}; r_{ij}=1, i=j \tag{1}$$

The third step is matrix consistency check, judge whether matrix S satisfies equation 2. In the consistency test, the Consistency Index (C.I.) is first calculated according to equation 3, the smaller the C.I. value, the more consistent the judgment matrix is, otherwise, the more obvious the deviation of the judgment matrix from the complete consistency is; according to equation 4, use the mean random consistency index (R.I.) and the Consistency Index (C.I.) to calculate the consistency ratio (C.R.). If the C.R. value is less than 0.1, the judgment matrix has acceptable consistency, otherwise, it needs to be adjusted to achieve good consistency. The fourth step is to calculate the eigenvalue and eigenvector according to equation 5~8, and perform hierarchical single ranking and consistency check.

$$s_{ij}=1;\ s_{ij}=1/s_{ji};\ s_{ij}=s_{ik}/s_{jk}\ \left(i,j,k=1,2,\ldots,n\right) \tag{2}$$

$$\text{C.I.}=\frac{\lambda_{\max}-n}{n-1}=-\sum_{\substack{i=1\\ i\neq k}}^{n}\lambda_i/\left(n-1\right) \tag{3}$$

$$\text{C.R.}=\text{C.I.}/\text{R.I.} \tag{4}$$

$$\prod_{j=1}^{n} r_{ij}=r_{i1}\times r_{i2}\times\ldots\times r_{in}\ \left(i=1,2,\ldots,n\right) \tag{5}$$

$$\overline{w_i} = \sqrt[n]{\prod_{j=1}^{n} r_{ij}} \qquad \overline{w_i} = \left(r_{i1} \times r_{i2} \times \ldots r_{in}\right)^{1/n} \tag{6}$$

Rank the weight vector:

$$W_i = \overline{w_i} \Big/ \sum_{i=1}^{n} \overline{w_i} \qquad W = \left(W_1, W_2, \ldots, W_n\right)^T \tag{7}$$

Maximum eigenvalue:

$$\lambda_{\max} = \sum_{i=1}^{n} \left(RW\right)_i \Big/ nW_i \quad (RW)_i \text{ is the i-th element in } (RW) \tag{8}$$

The fifth step is to perform hierarchical total ranking and consistency check according to equation 9~12. In which, the value of the total ranking weight WR_i of the R hierarchy is shown in Table 1.
The combined ranking weight vector of the k-1th hierarchical element is:

$$r^{k-1} = \left(r_1^{k-1}, r_2^{k-1}, \ldots, r_m^{k-1}\right)^T \tag{9}$$

The three ranking weight vectors of the k-th hierarchical elements are:

$$S^k = \left(s_1^k, s_2^k, \ldots, s_m^k\right) \tag{10}$$

Then the ranking combined weight is:

$$r^k = S^k * S^{k-1} \ldots S^3 a^3 \quad (3 \le k \le L, \;\; L \text{ is the number of hierarchies}) \tag{11}$$

Finally, the random consistency ratio of the total ranking of the S hierarchies is:

$$\text{C.R.} = \left(\sum_{j=1}^{m} WA_j * \text{C.I.}_j\right) \Big/ \left(\sum_{j=1}^{m} WA_j * \text{R.I.}_j\right) \tag{12}$$

Table 1: Computation matrix of total ranking

	Level *R*						
	R_1	R2	…	R_j	…	R_m	
Level *S*	WR_1	WR_2	…	WR_j	…	WR_m	WR_i
S_1	s_{11}	s_{12}		s_{1i}		s_{2m}	$\sum_{j=1}^{m} WR_j \times s_{1j}$
S_2	s_{21}	s_{22}		s_{2i}		s_{2m}	$\sum_{j=1}^{m} WR_j \times s_{2j}$
	…		…		…		…
S_i	s_{i1}	s_{i2}		s_{ij}		s_{im}	$\sum_{j=1}^{m} WR_j \times s_{ij}$
	…		…		…		…
S_n	s_{n1}	s_{n2}		s_{ni}		s_{nm}	$\sum_{j=1}^{m} WR_j \times s_{nj}$

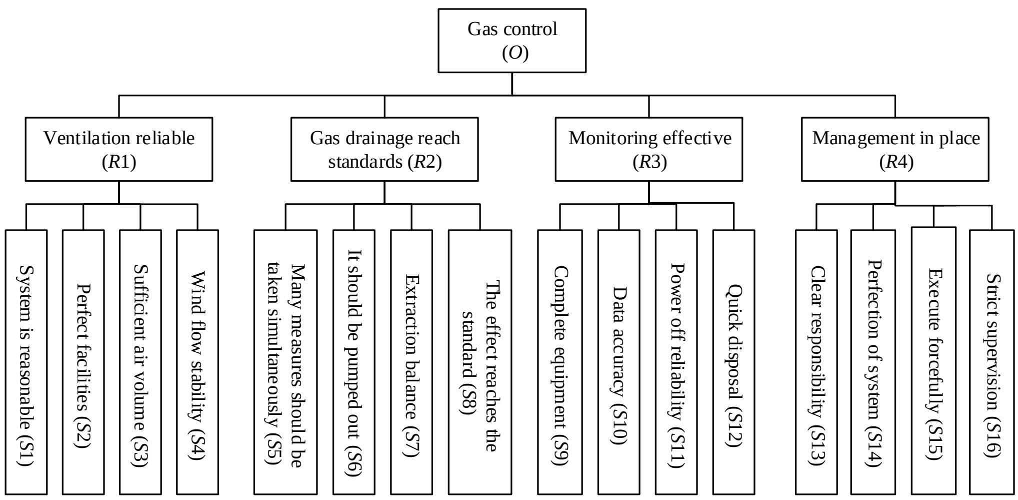

Figure 2: Safety index system for gas control in coal mines

3. Gas control mode evaluation system

3.1 Hierarchical structure model

According to the hierarchical structure model, the coal mine gas control evaluation is divided into several hierarchies of goal, criteria and alternatives, as shown in Figure 2. For specific hierarchies see the following figure.

3.2 Hierarchical single ranking and consistency check

According to the above hierarchies and weight calculation method, the matrix, weight and consistency test results of various factors in gas control are obtained, as shown in Table 2~Table 6. From Table 2 we can calculate to get that, the eigenvalue $\lambda_{\max} = 4.001$, the corresponding eigenvector value is $W^T = (w_1, w_2, w_3, w_4) = (0.473, 0.165, 0.108, 0.255)$, $\text{C.I.} = \frac{\lambda_{\max} - n}{n-1} = 0.0006$, as R.I.=0.89, then C.R.=C.I./R.I.=0.00067<0.1, it can be seen that the judgment matrix R generally satisfies the consistency. Similarly, the judgment matrices between R1, R2, R3, R4 and S are obtained, as shown in Table 4~Table 7.

Table 2: The judgement matrix between goal (O) and criteria (R)

O	R_1	R_2	R_3	R_4
R_1	1	3	4	2
R_2	1/3	1	2	1/2
R_3	1/4	1/2	1	1/2
R_4	1/2	2	2	1

Table 3: The judgement matrix between criterion (R_1) and alternatives (S)

R_1	S_1	S_2	S_3	S_4	*w*	
S_1	1	4	2	1/2	0.264	$\lambda_{\max} = 4.003$ C.I.=0.001 C.R.=0.0011 < 0.1 (General agreement)
S_2	1/4	1	1/3	1/8	0.06	
S_3	1/2	3	1	1/4	0.146	
S_4	2	8	4	1	0.528	

Table 4: The judgement matrix between criterion (R_2) and alternatives (S)

R_2	S_5	S_6	S_7	S_8	*w*	
S_5	1	5	4	2	0.468	$\lambda_{\max} = 4.014$ C.I.=0.0047 C.R.=0.0052 <0.1 (General agreement)
S_6	1/4	1	1/2	1/3	0.092	
S_7	1/3	2	1	1	0.186	
S_8	1/2	3	4	1	0.232	

Table 5 The judgement matrix between criterion (R_3) and alternatives (S)

R_3	S_9	S_{10}	S_{11}	S_{12}	*w*	
S_9	1	3	3	2	0.460	$\lambda_{\max} = 4.001$ C.I.=0.0004 C.R.=0.0005 < 0.1 (General agreement)
S_{10}	1/3	1	1	1/2	0.142	
S_{11}	1/3	1	1	1	0.172	
S_{12}	1/2	2	1	1	0.226	

Table 6 The judgement matrix between criterion (R_4) and alternatives (S)

R_4	S_{13}	S_{14}	S_{15}	S_{16}	*w*	
S_{13}	1	3	1/2	25	0.314	$\lambda_{\max} = 4.004$ C.I.=0.0013 C.R.=0.0015 <0.1 (General agreement)
S_{14}	1/3	1	1/4	1	0.122	
S_{15}	1/2	4	1	2	0.498	
S_{16}	1/5	1/2	1/6	1	0.068	

3.3 Hierarchical total ranking and consistency check

Set the hierarchical single ranking consistency index and the random consistency index of each index in the alternatives S for each factor R_i in the criterion R as C.I._i and R.I._j, respectively, then the consistency ratio of the hierarchical total ranking is shown as equation 9, it can be seen that the total ranking meets the consistency requirement, which indicates that in the process of gas control, the wind flow in the mine roadway should be sufficient and stable, the professional quality of the workers should be excellent, and the production system should be perfect, so as to comprehensively improve the gas control effect.

$$\text{C.R.}=\frac{s_1\text{C.I.}_1+s_2\text{C.I.}_2+s_3\text{C.I.}_3+s_4\text{C.I.}_4}{s_1\text{R.I.}_1+s_2\text{R.I.}_2+s_3\text{R.I.}_3+s_4\text{R.I.}_4}=\frac{\mathbf{0.0016}}{\mathbf{0.89}}=\mathbf{0.002}<\mathbf{0.1} \tag{13}$$

3.4 Fuzzy comprehensive evaluation model

This paper uses the principle of maximum membership of the Fuzzy Comprehensive Assessment Model (FCAM) to determine the application effect of the gas control mode. The FCAM applies the principle of synthesis of fuzzy relations, effectively combines the advantages of qualitative description and quantitative analysis, and comprehensively evaluates the grade status and relevance of the events to be evaluated. Based on FCAM and the above analysis, the weights of each evaluation index in the gas control mode evaluation system are calculated, as shown in Table 7.

Table 7: The weight of each evaluation index in the gas control evaluation system

O	R_1	R_2	R_3	R_4	Weight
	0.473	0.165	0.108	0.255	
S_1	0.264	0	0	0	0.124
S_2	0.06	0	0	0	0.027
S_3	0.146	0	0	0	0.071
S_4	0.528	0	0	0	0.250
S_5	0	0.468	0	0	0.079
S_6	0	0.092	0	0	0.016
S_7	0	0.186	0	0	0.030
S_8	0	0.232	0	0	0.037
S_9	0	0	0.468	0	0.051
S_{10}	0	0	0.092	0	0.016
S_{11}	0	0	0.186	0	0.018
S_{12}	0	0	0.232	0	0.024
S_{13}	0	0	0	0.314	0.081
S_{14}	0	0	0	0.122	0.031
S_{15}	0	0	0	0.498	0.127
S_{16}	0	0	0	0.068	0.018

In the evaluation of coal mine gas control mode, the various factors affecting the evaluation index are composed into a set, that is, the evaluation factor set, shown as equation 10; the gas control evaluation results are generally divided into five levels (quite safe, safe, general, dangerous, quite dangerous), that is, the evaluation set can be represented as equation 11.

$$U=\{u_1,u_2,...,u_n,\}\ \ (i=\mathbf{1},\mathbf{2},...,n) \tag{14}$$

$$V=\{quite\ safe,\ safe,\ general,\ dangerous,\ quite\ dangerous\}\ \ (i=\mathbf{1},\mathbf{2},\mathbf{3},\mathbf{4},\mathbf{5}) \tag{15}$$

$$T=\begin{bmatrix} t_{11} & t_{12} & \cdots & t_{1m} \\ t_{21} & t_{22} & \cdots & t_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ t_{n1} & t_{n2} & \cdots & t_{nm} \end{bmatrix} \tag{16}$$

Where, t_i is the evaluation result of the i-th factor, t_{ij} is the membership degree of the factor u_i to the evaluation result v_j, and m and n are the number of evaluation factors and evaluation grades, respectively.

$$H=WoT \tag{17}$$

Based on the above evaluation factor set and the result evaluation set, the evaluation result is represented by a fuzzy set, and the evaluation matrix T is obtained, then, the corresponding evaluation model is established in combination with above-mentioned weight vector W, as shown in equation 13, where "o" is a fuzzy synthesis operator.

4. Conclusion

This paper takes the comprehensive evaluation of coal mine gas control mode as the research target. A gas control evaluation index system is constructed, and a fuzzy comprehensive evaluation model is established to perform standard evaluation of the gas safety control. The main research results are as follows:

(1) According to the hierarchical structure model, the matrix, weight and consistency test results of various factors in gas control are obtained. It is found that the total ranking meets the consistency requirement.

(2) The wind flow in the mine roadway should be sufficient and stable, the professional quality of the workers should be excellent, and the production system should be perfect, so as to comprehensively improve the gas control effect.

(3) In the evaluation of coal mine gas control mode, the various factors affecting the evaluation index are composed into an evaluation factor set, combined with the result evaluation set, the evaluation results are represented by a fuzzy set, and the evaluation matrix T is obtained, and at last, a corresponding evaluation model is established combining the weight vector W.

References

Cheng G.Y., Feng S., Cheng Y., 2014, Assessment system of coal seam gas distribution state based ahp, Applied Mechanics & Materials, 577, 1087-1092, DOI: 10.4028/www.scientific.net/amm.577.1087

Cheng Y.P., Wang L., Zhang X.L., 2011, Environmental impact of coal mine methane emissions and responding strategies in china, International Journal of Greenhouse Gas Control, 5(1), 157-166, DOI: 10.1016/j.ijggc.2010.07.007

Du X.Z., 2012, Optimization for prediction indexes of coal and gas outburst in coal roadway excavation working face based on grey synthetically relational degree, Advanced Materials Research, 524-527, 647-652, DOI: 10.4028/www.scientific.net/amr.524-527.647

Jin K., Cheng Y., Wang W., Liu H., Liu Z., Zhang H., 2016, Evaluation of the remote lower protective seam mining for coal mine gas control: a typical case study from the zhuxianzhuang coal mine, huaibei coalfield, China, Journal of Natural Gas Science & Engineering, 33, 44-55, DOI: 10.1016/j.jngse.2016.05.004

Li B., Chen Y., 2016, Risk assessment of coal floor water inrush from underlying aquifers based on gra–ahp and its application, Geotechnical & Geological Engineering, 34(1), 143-154, DOI: 10.1007/s10706-015-9935-z

Li D., 2014, Evaluation for the reduction and utilisation of coal mine methane emission with ahp method and decision tree, International Journal of Oil Gas & Coal Technology, 7(4), 431-449, DOI: 10.1504/ijogct.2014.062166

Li D., Cheng Y., 2014, Evaluation of gas control ability of a coal and gas outburst mine, Energy Sources, 36(21), 2401-2409, DOI: 10.1080/15567036.2011.567241

Li J.T., Wang S.C., 2013, Analysis and measure of coal and gas outburst based on matter element model, Applied Mechanics & Materials, 329, 79-86, DOI: 10.4028/www.scientific.net/amm.329.79

Muramatsu E., Iijima M., 2003, Life Cycle Assessment for CO_2 Capture Technology from Exhaust gas of Coal Power Plant, Greenhouse Gas Control Technologies-6th International Conference, ELSEVIER, 57–62, DOI: 10.1016/b978-008044276-1/50010-6

Obdam A., Meer L.V.D., May F., Kervevan C., Bech N., Wildenborg A., 2003, Effective CO_2 Storage Capacity in Aquifers, Gas Fields, Oil Fields and Coal Fields, Greenhouse Gas Control Technologies-6th International Conference, ELSEVIER, 339–344, DOI: 10.1016/b978-008044276-1/50055-6

Wan J.J., Song Y.H., 2013, Applied technology and evaluation on emergency management capability of coal mine accidents based on ahp and the fuzzy comprehensive evaluation method, Advanced Materials Research, 859, 511-514, DOI: 10.4028/www.scientific.net/amr.859.511

Wu Q., Shi Y., Lu X., 2018, Odor identification and data transmission method of harmful gas in chemical environment, Chemical Engineering Transactions, 68, 181-186, DOI: 10.3303/CET1868031 Xiao H., Tian Y., 2011, Prediction of mine coal layer spontaneous combustion danger based on genetic algorithm and bp neural networks, Procedia Engineering, 26(1), 139-146, DOI: 10.1016/j.proeng.2011.11.2151

Yang W., Lin B., Cheng Z., Li X., Sun X., Zhang C., 2012, A new technology for coal and gas control based on the in situ stress distribution and the roadway layout, International Journal of Mining Science and Technology, 22(2), 145-149, DOI: 10.1016/j.ijmst.2011.08.002

Zhang J., 2011, The application of analytic hierarchy process in mine gas prevention system, Procedia Engineering, 26(C), 1576-1584, DOI: 10.1016/j.proeng.2011.11.2341

Zhu S., Jiang Z., Zhou K., Peng G., Yang C., 2014, The characteristics of deformation and failure of coal seam floor due to mining in xinmi coal field in china, Bulletin of Engineering Geology & the Environment, 73(4), 1151-1163, DOI: 10.1007/s10064-014-0612-x