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Research on Assessment of Risk of Gas Disaster in Mine Based on Monte Carlo - AHP Method

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Abstract. The traditional assessment of risk of gas disaster in mine rely on experience of experts to determine weights. And human factors frequently lead to greater errors. In order to overcome these shortcomings, we used Monte Carlo method to improve analytic hierarchy process (AHP) method. We used a large number of random number simulation to replace experts judgment. It can avoid the interference of human factors. The new weights were used to assess the risk of gas disaster, and the fuzziness of traditional fuzzy comprehensive evaluation was eliminated. We used Monte Carlo-AHP Method to assess the risk of gas disaster in Gaoping mine in Shanxi Province, China, and got score of assessment of risk of gas disaster in the study area. The results show that assessment method based on Monte Carlo-AHP has better correlation and lesser error than traditional assessment method.

1. Introduction

Gas disaster has always been one of the main hazards in coal mine production. There are many scientific techniques and methods to assess the risk of gas disaster. The fuzzy neural network was applied to the safety assessment of mine [1].And the gas disaster was evaluated by using AHP-GT model [2]. Using analytic hierarchy process and fuzzy comprehensive evaluation to evaluate the risk of gas disaster quantitatively [3]. The above researchers all directly used the analytic hierarchy process, which did not exclude the human factors of the individual subjectivity when determining the weight in analytic hierarchy process. And this process relied on experts judgment. This paper used Monte Carlo method to obtain weights of indexes to avoid artificial factors interference, so as to make up for the inadequacy of previous evaluation method, and connecting with the formulation, using comprehensive evaluation method to assess the risk of gas disaster in mine.

2. Theory

2.1. Assessment based on Monte Carlo-AHP method

Analytic hierarchy process (AHP) is a process, which includes experts to obtain judgment matrix based on experience, and calculate the weight of all levels and consistency test [4]. The experts concluded that there was a deficiency in the two processes of judging matrices and weights, which could be used to make up for it by using Monte Carlo method. Monte Carlo method uses random simulation to simulate the things that cannot be simulated in reality (e.g., the simulation test of the atomic bomb) [5]. We applied Monte Carlo method to analytic hierarchy process for avoiding the interference of human factors. We constructed the system of risk of gas disaster evaluation [6, 7], which can be shown in Figure 1.

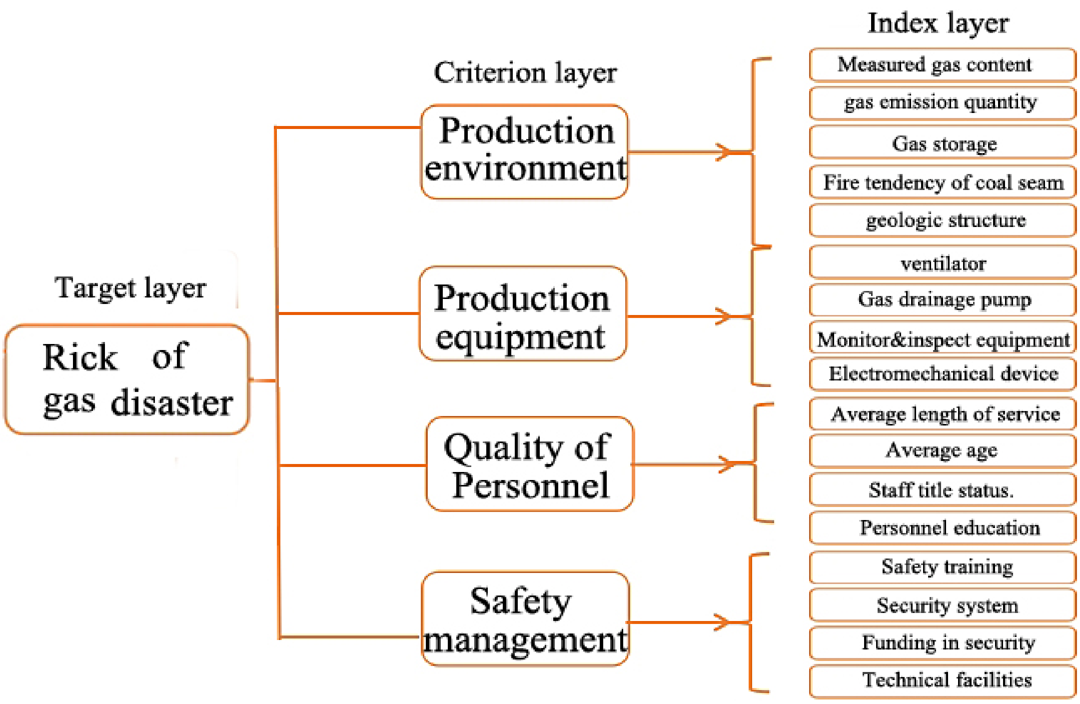

Figure 1. The system of risk of gas disaster evaluation.

We used MATLAB software to simulate random experiment according to Monte Carlo principle. The corresponding occurrence range interval was defined, and the random experiment was conducted with 10 million simulations. The weights of the criterion layer indexes were $R_{\text{production environment}}$: $R_{\text{production equipment}}$: $R_{\text{quality of personnel}}$: R_{safety} management= 0.442:0.385:0.105:0.068. And the consistency test showed that CI=0.085, CR=0.0944, with good consistency.

2.2. Establish relational matrix and comprehensive evaluation

The assessment of risk of gas disaster is divided into five grades, subordinating degree function of 1, 2, 3, 4 and 5 grade was $F_1(x), F_2(x), F_3(x), F_4(x), F_5(x)$. The eigenvalue of each judgment matrix λ is the variance, and the membership function normally chooses normal distribution function, whose probability density function is expressed as

$$f(x) = \frac{1}{\sqrt{2\pi\lambda}} e^{-\frac{x^2}{2\lambda^2}} \tag{1}$$

Then we construct membership matrix by using membership function, whose the expression can be expressed as

$$w_i = \begin{pmatrix} F_1(u_{i1}) & F_2(u_{i1}) & F_3(u_{i1}) & F_4(u_{i1}) & F_5(u_{i1}) \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ F_1(u_{in}) & F_2(u_{in}) & F_3(u_{in}) & F_4(u_{in}) & F_5(u_{in}) \end{pmatrix} \quad (2)$$

Among them, w_1 is production environment-index; w_2 is production equipment-index; w_3 is quality of personnel index; w_4 is safety management index.

Next, using the fuzzy comprehensive evaluation method, the expression is

$$R_i^T = X_i^T * w_i = \begin{pmatrix} x_i & \cdots & x_n \end{pmatrix} \begin{pmatrix} F_1(u_{i1}) & F_2(u_{i1}) & F_3(u_{i1}) & F_4(u_{i1}) & F_5(u_{i1}) \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ F_1(u_{in}) & F_2(u_{in}) & F_3(u_{in}) & F_4(u_{in}) & F_5(u_{in}) \end{pmatrix} = \begin{pmatrix} r_1 & r_2 & r_3 & r_4 & r_5 \end{pmatrix} \quad (3)$$

And doing this equation:

$$\begin{pmatrix} 0.442 \\ 0.385 \\ 0.105 \\ 0.068 \end{pmatrix} * \begin{pmatrix} R_1^T \\ R_2^T \\ R_3^T \\ R_4^T \end{pmatrix} = \begin{pmatrix} a & b & c & d & e \end{pmatrix}$$ .The final score is S=a×5+b×4+c×3+d×2+e.

3. Application and results

The research area is in Gaoping coal mine in Shanxi Province, and its geographical coordinates are 112°47′20″ E ～ 112°50′19″E, 35°49′ 22″ N ～ 35°53′07″N. In the process of mining, gas explosion and gas outburst accidents have not occurred. According to the measured data in the exploration and production stage, the maximum content of CH_4 is 7.36m^3/t. The schematic diagram of this mine is shown as Figure 2.

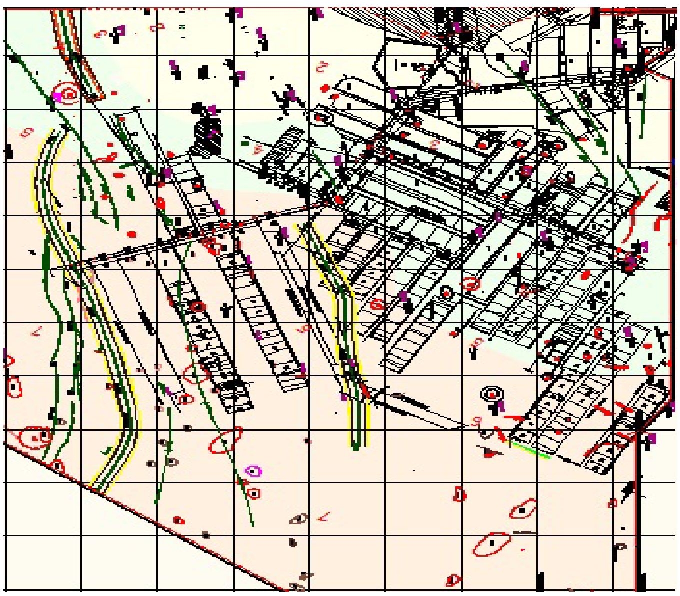

Figure 2. Schematic diagram of coal mine operation.

Then, we assessed the risk of gas disaster in this mine based on Monte Carlo-AHP method. Categorizing final score according to 5 S statement 4 - 5 grade can be divided into 1 (good), divided into 3 - 4 2 level (better), 2-3 are rated 3 (general), 1 - 2 are rated 4 (poor), 0 and 1 are rated 5 (poor). In this paper, the risk of gas disaster in Gaoping mine was evaluated safely, and the results can be shown in figure 3.

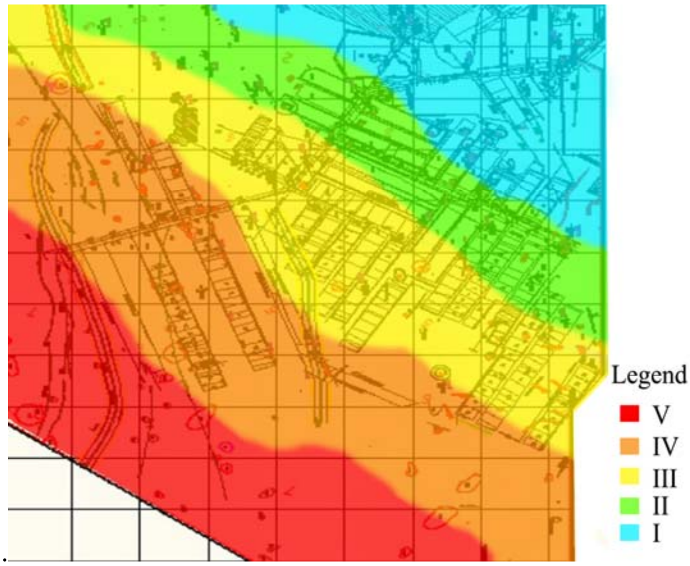

Figure 3. Safety evaluation degrees of risk of gas disaster in the mine

Therefore, results of assessment of risk of gas disaster in the mine were from southeast to northwest gradually becoming poor, also were in the process of production in the future need to attach great importance to its score into 4 and 5 area.

4. Compare the results with traditional fuzzy evaluation results

According to the data of absolute methane emission measured in the heading face, the correlation analysis of the results of the study and the fuzzy comprehensive evaluation results was conducted respectively, as shown in Figure 4.

From Figure 4, the measured absolute gas emission and the results based on the Monte Carlo - AHP method have good correlation, the correlation coefficient $R_1^2 = 0.9918$, while correlation coefficient of the traditional fuzzy comprehensive evaluation method is $R_2^2 = 0.9456$. Therefore, the results based on Monte Carlo method are more relevant than the traditional fuzzy comprehensive evaluation method, and the error is smaller, which can reflect the real risk of gas disaster in the coal mine.

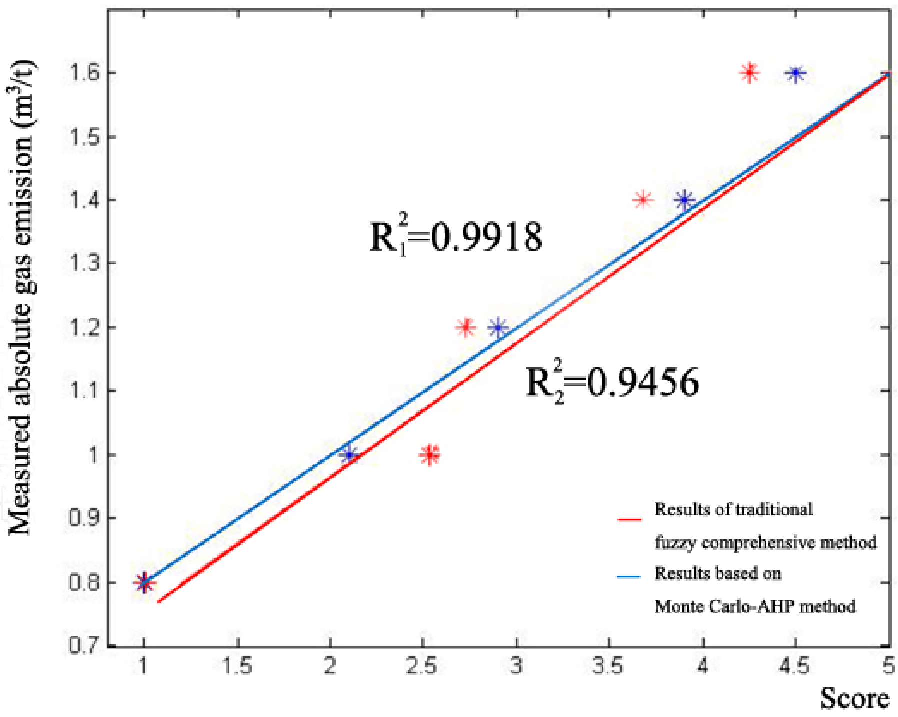

Figure 4. Results of comprehensive evaluation based on Monte Carlo-AHP method and results of traditional fuzzy comprehensive evaluation

5. Conclusion

In this paper, Monte Carlo-AHP method is used to obtain the corresponding weights of all levels of indexes. It avoids the interference of human factors and saves the tedious process of relying on expert judgment. Meanwhile, it reduces the cost of evaluation. This paper optimizes the traditional assessment method of risk of gas disaster.

In quantitative analysis, the results based on Monte Carlo method are more relevant than results of the traditional fuzzy comprehensive evaluation method, which can reflect the real risk of gas disaster in the coal mine with better correlation, less error.

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References

[1] J.L. Wang, B. Jiang, Using Fuzzy Artificial Neural Network to Evaluate the Mine Structure, Journal of China University of Mining &Technology .34 (2005) 609 - 612.
[2] S. L. Shi, R. Q. Li ,Research and application of AHP-GT model of gas explosion accident evolution risk assessment in coal mine, Journal of China Coal Society (in Chinese). 35 (2010) 1137 - 1141.
[3] W. D. Liao, Y. L. Zhong, J. J. Ye, Quantitative evaluation method of mine gas disaster hazard sources based on AHP - FCE Method, Coal Science and Technology (in Chinese).43 (2015) 85 - 89.
[4] T. L. Saaty, Decision making with analytic hierarchy process, Int. J. Services Sciences. 1 (2008)83 - 97.
[5] L. Chen, W. Z. Yao, Q. K. Guo, X. H. Wang, Effectiveness evaluation theory, method and application, Beijing university of posts and telecommunications, Beijing, 2015, pp.37 - 50.
[6] Y. J. Han, J. H. Chen, Z. Y. Zhou, Fuzzy assessment method of interval number for gas explosion coal mines based on index of attitude, Journal of China Safety Science (in

Chinese). 20 (2010) 83 - 88.
[7] R. L. M. Kotze, J.K. Visser, An analysis of maintenance performance systems in the South African mining industry, South African Journal of Industrial Engineering. 3 (2012) 13 - 29.