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Research and application of safety assessment method of gas explosion accident in coal mine based on GRA-ANP-FCE*

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Abstract

According to the complexity and nonlinear interaction between influencing factors of gas explosion in coal mine, this paper analyzed the main influencing factors of coal mine gas explosion accident with Grey Relational Analysis, and built the risk assessment index system of coal mine gas explosion based on four factors of “man-machine-environment- management”. This paper built the multi-criterion and multi-level network calculation model for the index system and got the weight sets by using Analytic Network Process. Multi-level fuzzy comprehensive evaluation determined the risk of gas explosion level. A coal mine in the South, for example, its gas explosion risk assessment, results showed that the method could find the main key risk factors and deal effectively the complex influence relationship among them, and provide an important reference to coal mine gas accident risk control and management.

Keywords: coal mine; gas explosion; risk assessment; grey relational analysis; analytic network process; fuzzy comprehensive evaluation

Nomenclature

γ	grey relational grade
$\overline{W}$	weighted super matrix
W^{∞}	limit matrix

1. Introduction

Gas explosion is the main hazard in the safety production activity of our country coal mine. It always threatened to our country mine industry of healthy development because of its characteristics such as heavy damage, more casualty, serious economic losses and so on. According to the latest statistics of State Administration of Work Safety, gas accidents accounted for more than 80% of our country gas accidents, and fatalities accounted for 90% of most serious accidents. To strengthen hazard risk assessment of mine gas explosion which is an important method to prevent and control accident happen, and it has great significance to provide great guarantee for rising safety production of coal mine, and to strengthen the prevention for gas explosion and for reducing the losses by accidents.

There exists many method for analysis and assessment on gas explosion hazard of coal mine, such as Analytic Hierarchy Process(AHP), Fuzzy Analysis Method, Grey Assessment Method, Artificial Neural Network Assessment Method and so on [4-9]. SHI [4] established the non-linear multilevel gray evaluation model of risk assessment of gas explosion accident

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evolution in coal mine based on AHP and gray clustering method. CAO [5] established the risk assessment model of gas explosion in coal mine based on the hazard theory and fuzzy mathematics. Among them, AHP gets the most extensive application in the system decision-making analysis, but the premise of AHP application is that each level or its elements are mutually independent. Because of this, AHP suffers limitation in being used for assessment of complex nonlinear system. Coal mine production is a multi-factor, multivariable and multi-level complex nonlinear system [1-3]. There are many influencing factors to induce mine coal gas explosion in the course of coal mine underground production, and they are interaction and inter-influence. Those uncertain factors can't be quantized by using traditional mathematical model or science computation. Analytic Network Process (ANP) [10] solved the dependent and feedback between factors and it has been used in selecting scheme and assessing indexes of complex system [11-12].

This paper analyzed the main influencing factors of coal mine gas explosion accident, and built the risk assessment index system of coal mine gas explosion on the basis of four aspects: "man-machine- environment- management", and built ANP-Fuzzy risk assessment model for coal mine gas explosion by using grey relational analysis (GRA). We built the network model for this assessment indexes to compute the weights distribution by using ANP. At last, we assess the risk of gas explosion in coal mine by using fuzzy comprehensive evaluation (FCE). The result of assessment was in agreement with actual situation and showed that the method would provide an important reference for controlling this risk.

2. GRA of the control factors of gas explosion in coal mine

2.1. Model of GRA

GRA is one of core content of grey theory [14]. Let the index of gas explosion in coal mine was parent factor $x_0(i)$ and each of influence factors was sub-factor $x_j(i)$, where $i=1,2,...,m,\ j=1,2,...,n$, and m and n denoted the number of observed values and the number of sub-factors respectively. So, the original data matrix $X^0=\left|x_0(i) \quad x_1(i) \quad x_2(i) \quad \ldots \quad x_n(i)\right|^T$ was composed of the observed values of parent factor and sub-factors. Dimensionless of original data matrix X_0 was done by using equation (1) and we got the dimensionless data X which was comparable.

$$x_j(i)=\frac{y_j(i)}{\frac{1}{m}\sum_{i=1}^{m} y_j(i)} \tag{1}$$

So, the grey relational coefficient of parent factor x_0 and sub-factor x_j in the ith position:

$$\gamma(x_0(i),x_j(i))=\frac{\min_j \min_i \left|x_0(i)-x_j(i)\right|+\zeta \max_j \max_i \left|x_0(i)-x_j(i)\right|}{\left|x_0(i)-x_j(i)\right|+\zeta \max_j \max_i \left|x_0(i)-x_j(i)\right|} \tag{2}$$

where, $\min_j \min_i \left|x_0(i)-x_j(i)\right|$ is called lower environment parameter, $\max_j \max_i \left|x_0(i)-x_j(i)\right|$ is called super environment parameter and $\zeta\in[0,1]$ is distinguishing coefficient, usually, $\zeta=0.5$.

By focusing the $\gamma(x_0(i),x_j(i))$ at utter points the algorithm on grey relational grade is as follows equation:

$$\gamma(x_0,x_j)=\frac{1}{m}\sum_{i=1}^{m}\gamma(x_0(i),x_j(i)) \tag{3}$$

2.2. Main controlling factors of gas explosion in coal mine

Gas explosion in coal mine would happen in microscopic scales only when the three conditions possess simultaneously that include gas accumulation, fire source and oxygen concentration, and was caused by human production activity in macroscopic view. We analysis the main influence factors of gas explosion in coal mine on basis of four factors of "man-machine-environment- management" combined with gas explosion data in coal mine in south china, and selected 20 qualitative and quantitative indexes, where "non-existence" and "existence" of the qualitative indexes was denoted with 0.5 and 1 respectively. Dimensionless of original data matrix was done by using formula (1) and we calculate the grey relational coefficient using formula (2) and calculate the grey relational grade of each controlling factors by using formula (3). The greater grey relational grade is, the greater influence degree the sub-factors impact on the parent factors and vice versa. The order from big to small of grey relational grade showed as follow: safety investment X_5, safety education X_3, ratio of technical staff X_{15}, safety system X_{14}, staff education standard X_1, safety culture X_{12}, ventilation facilities situation $X6$, monitoring facilities situation X_7, distribution of age and seniority X_{10}, air volume supply ratio X_2, mechanization standard