Study on Optimum Design of Outburst Prevention Measures in Weijiadi Coal Mine

Jufeng Zhang1, *, Fengfeng Yang1, Ruiyun Wang2, Chao Zheng1, Ning Sun1, Wulin Lei1, Tai Xu1, Jianjiang Zhang2 and Zaiquan Miao2

1School of Energy Engineering, Longdong University, Qingyang 745000, China
2Weijiadi Coal Mine, Jingyuan Coal Mine Industry Group, Baiyin 730913, China

*Corresponding author e-mail: jufeng6100229@126.com

Abstract. Aiming at the problems of large amount of engineering, long construction period and high economic cost of regional outburst prevention measures in Dongyi Mining Area of Weijiadi Coal Mine, the grey clustering fuzzy evaluation method is used to investigate four regional outburst prevention measures from five indicators of Engineering quantity, construction period, capital input, cost of gas control and prevention of secondary disasters, and the best regional outburst prevention measures are selected. The results show that the best regional outburst prevention measures are drilling strips through strata and pre-draining coal seam gas by drilling along strata in floor rock roadway, with a quantified score of 0.9179, which is greater than the quantified results of the other three regional outburst prevention measures.

1. Introduction
With the extension of coal mining to depth, coal and gas outburst disasters become more and more serious. In order to ensure the safety, high efficiency and sustainable development of outburst mines, regional outburst prevention has become an important measure for the safe mining of outburst coal seams. At present, regional outburst prevention measures mainly include protective seam mining, pre-drainage of coal seam gas from surface wells, underground cross-seam and pre-drainage of coal seam gas along seams [1]. Du Zesheng, Qin Botao, etc. [2] put forward the reliability evaluation model of protective layer mining effect; Liu Yanwei [3] proposed a reliability evaluation system consisting of target layer, criterion layer and sub-criterion layer for the reliability of protective layer mining and pressure relief gas extraction technology. Wang Zhiliang [4] Based on the theory of pressure relief and deformation of coal and rock and the characteristics of gas migration, established a protective layer mining evaluation system including protection scope and protection effect. Liu Mingju [5] tracked the protective seam mining in Jinling Coal Mine, and determined the effect of protective seam mining according to the changes of some basic parameters of coal seam. However, the specific application conditions of these regional outburst prevention measures for some mines need to be investigated, and the existing regional outburst prevention measures need to be comprehensively analyzed according to the characteristics of coal seams, and the most suitable regional outburst prevention measures should be selected. Aiming at the problems of large amount of engineering, long construction period and high economic cost in the implementation of regional outburst prevention measures in Dongyi mining area of Weijiadi Coal Mine, based on the fuzzy evaluation method, the author investigates the five indexes...
of Engineering quantity, construction period, safety and reliability, technical feasibility and economic rationality respectively, and optimizes the best regional outburst prevention measures.

2. Basic Principles of Optimizing

In order to solve the unscientific evaluation results caused by different quantities and dimensions in the evaluation index, the grey fixed weight theory evaluation model was used to optimize the evaluation of the outburst prevention scheme in the No. 1 mining area.

2.1. Clustering Theory Definition

When the meaning and dimension of clustering indicators are different and the number of them varies greatly, the use of grey variable weight clustering may lead to the weak role of some indicators in clustering. There are two ways to solve this problem: first, initial or mean operators are used to convert the sample values of each index into dimensionless data, and then clustering. Secondly, each clustering index is empowered beforehand.

Definition 1: Let $x_{ij}(i=1,2,...,n; j=1,2,...,m)$ is the observed value of index $j$ for object $i$, and $f_j^k(i)(j=1,2,...,m; k=1,2,...,s)$ is the whitening weight function of subclass $k$ of index $j$. If the weight $f_j^k(i)(j=1,2,...,m; k=1,2,...,s)$ of subclass $k$ of $j$ index is independent of $k$, that is to say, for any $k_1,k_2 \in \{1,2,...,s\}$, there is always $\eta_j^{k_1} = \eta_j^{k_2}$. In this case, The superscript $k$ of $\eta_j^k$ can be omitted, and recorded as $\eta_j^k$. Also called

$$\sigma_i^k = \sum_{j=1}^{m} f_j^k(x_{ij})\eta_j$$  \hspace{1cm} (1)

For object $i$, the grey fixed weight clustering coefficient belongs to $k$-grey class.

Definition 2: Let $x_{ij}(i=1,2,...,n; j=1,2,...,m)$ for object $i$, the observed value of index $j$, and $f_j^k(i)(j=1,2,...,m; k=1,2,...,s)$ is the whitening weight function of subclass $k$ of index $j$. If for any $j=1,2,...,m$ always has $\eta_j = 1/m$. Also called

$$\sigma_i^k = \sum_{j=1}^{m} f_j^k(x_{ij})\eta_j = \frac{1}{m} \sum_{j=1}^{m} f_j^k(x_{ij})$$  \hspace{1cm} (2)

For object $i$, the grey equal weight clustering coefficient belongs to $k$-grey class.

Definition 3: (1) Classify the clustering objects according to the value of grey constant weight clustering coefficient, which is called grey fixed weight clustering; (2) Classify the clustering objects according to the value of grey equal weight clustering coefficient, which is called grey equal weight clustering.

2.2. Optimizing calculation steps

There are $n$ clustering objects, $m$ different clustering indicators and $s$ different grey classes. The sample observation value $x_{ij}(i=1,2,...,n; j=1,2,...,m)$ of the object about index $j$ is evaluated according to the value of $x_{ij}$.

(1) According to the number of grey classes $s$ required for evaluation, the range of values of each index is also divided into $s$ Grey classes. For example, the range of values of $k$ grey class of $j$ index is marked as $[x_j^k(l), x_j^k(u)]$, and the upper and lower limits of values of the grey classes can be determined according to the actual situation or qualitative research results.
(2) Give the whitening weight function of subclass $k$ of $j$ index: $f_{ij}^k(j = 1, \ldots, m; k = 1,2,\ldots, n)$. Typical whitening weight function is $f_j^k(x) = [x_j^k(1), x_j^k(2), x_j^k(3), x_j^k(4)]$, where $x_j^k(1), x_j^k(2), x_j^k(3)$ and $x_j^k(4)$ are the turning points of $f_j^k(x)$. As shown in Figure 1. According to the turning points, the whitening weight piecewise function is obtained.

$$f_{ij}^k(x) = \begin{cases} 0 & x \in [x_j^k(1), x_j^k(4)] \\ \frac{x - x_j^k(1)}{x_j^k(2) - x_j^k(1)} & x \in [x_j^k(1), x_j^k(2)] \\ 1 & x \in [x_j^k(2), x_j^k(4)] \\ \frac{x_j^k(4) - x}{x_j^k(4) - x_j^k(3)} & x \in [x_j^k(3), x_j^k(4)] \end{cases}$$

(3) Determining Clustering Weight of Indicators

Let $\lambda_j^k$ be the critical value of subclass $k$ of $j$ index, then $\eta_j^k = \lambda_j^k / \sum_{j=1}^{m} \lambda_j^k$ is called the weight of subclass $k$ of $j$ index. If $f_j^k(x)$ is the observed value of index $j$ of object $i$, $\eta_j^k$ is the whitening weight function of subclass $k$ of index $j$. $\eta_j^k$ is the weight of $k$ subclass of $j$ index, and $\sigma_j^k = \sum_{j=1}^{m} f_j^k(x_j) \eta_j = \frac{1}{m} \sum_{j=1}^{m} f_j^k(x_j)$ is the grey equal weight clustering coefficient of $k$ grey class of object $i$.

In the formula, $f_j^k(x_j)$ is the whitening weight function of grey $k$ under index $j$, and $\eta_j(j = 1,2,\ldots,m)$ determines the clustering weight of index $j$ according to the conclusion or qualitative analysis.

(4) According to $\max_{i\in k<s} \{\sigma_j^k\} = \sigma_j^k$, judging that object $j$ belongs to grey class $k^*$; when multiple objects belong to the same class $k^*$, the relative advantages and disadvantages of objects belonging to the same class $k^*$ are further determined according to the size of the comprehensive clustering coefficient.
3. Outburst Prevention Technical Scheme of Dongyi Mining Area

3.1. Scheme I: Pre-drainage of coal seam gas by large-area cross-layer boreholes in floor rock roadway

Every certain distance (50m-80m) of 1050 middle roadway is used to construct a drilling ground, and several grid-type upward drilling holes are constructed into the coal seam inside the drilling ground.

Borehole drilling parameters: borehole diameter is 90-120 mm, borehole shield strip is 6-7 m, the rest is 10-15 m, borehole spacing is based on the coal seam medium thickness line; borehole penetrates the coal seam and enters the coal seam roof 0.5 m; boreholes are evenly arranged in the coal seam, after construction, boreholes should be evenly and regularly arranged in the coal seam inclination section.

3.2. Scheme II: Pre-drainage of coal seam gas by drilling strips through strata and along strata in floor rock roadway

The drilling field is constructed in 1050 rock roadway, and then the grid-type dense drilling holes are constructed at the first working face of the east-facing mining area in the middle of the drilling field, at the coal roadway position of the cutting hole and the air roadway, and the coal seam gas is pre-pumped, so as to eliminate the danger of the coal roadway and surrounding coal body regionally in a relatively short time.

After the construction of coal seam roadway is completed under the cover of cross-layer boreholes, the gas in the mining area can be extracted from the air roadway and the machine roadway by the construction of boreholes along the seam. The spacing of boreholes along the seam is related to the extraction radius of boreholes. The length of boreholes is designed according to the inclination length of the working face, and there is no less than 10 m stubble in the middle of the inclination of the working face.

3.3. Program III: Pre-drainage of coal seam gas by "drilling through seams in strips of floor rock roadway + drilling along seams + high-level drilling"

If the scheme 2 is adopted, the gas extraction method of high borehole should be added. The main function of high-level boreholes is to use roof fissures formed by mining influence as a channel to extract gas from goaf and upper corner roof, reduce gas influx into goaf, and thus reduce gas emission from working face. At the same time, it can pull the gas in the lower part of the goaf, change the distribution of gas flow direction in the goaf, solve the problems of gas gushing from the upper corner, causing gas accumulation in the upper corner and gas exceeding the limit of return air flow, so as to ensure the safe and efficient production of the coal face.

3.4. Plan IV: Pre-drainage of coal seam gas by drilling through seam+drilling along seam+high-level drilling+buried pipe in Goaf

If scheme 3 still can not solve the problem of gas exceeding limit in the production process of Dong102 working face in Dongyi mining area, gas drainage measures of semi-closed buried pipe in goaf are added on the basis of scheme 3, so that gas control will become a mode of "drilling through layer + drilling along layer + drilling at high position + buried pipe in goaf". A bend pipe is set at the end of the extraction pipe in the return air roadway of Dong102 working face in Dongyi mining area to raise the extraction pipe mouth to the top of the return air roadway, and a stack is set to protect the pipe mouth, so as to form a buried pipe mouth.

4. Optimizing the Comprehensive Control Scheme of No.3 North-1 Gas

4.1. Drawing up 4 Optimum Schemes

According to the four schemes of gas extraction mode proposed by Beiyi Mining Area for outburst prevention, according to the fixed weight clustering rule in grey theory, the preliminary schemes I, II, III and IV are clustered objects; drilling volume (m), construction time (day), total capital investment
10,000 yuan), gas control cost (yuan/t) and secondary disasters are selected as clustering evaluation index $j$; and they are classified as good, better and worse. Classification $k$ is used to carry out grey clustering analysis of outburst prevention extraction schemes. The performance parameters of each scheme are shown in Table 1.

**Table 1.** The performance parameters of each scheme

| Outburst prevention technical scheme | Drilling volume ($10^3$ m) | Construction time ($10^3$ days) | Capital investment ($10^3$ yuan) | Gas control cost (yuan/t) | Prevention and Control of Secondary Disasters (%) |
|-------------------------------------|-----------------------------|---------------------------------|---------------------------------|--------------------------|-----------------------------------------------|
| I                                   | 779.19                      | 6.72                            | 11.93                           | 78.15                    | poor (70)                                     |
| II                                  | 805.68                      | 8.04                            | 17.70                           | 53.29                    | better (80)                                   |
| III                                 | 889.72                      | 7.45                            | 19.06                           | 53.39                    | medium (75)                                   |
| IV                                  | 902.13                      | 10.36                           | 20.10                           | 82.56                    | good (95)                                     |

According to the observation value $x_{ij}$ of each clustering object about each clustering index, the matrix $A$ can be constructed.

$$
A = \begin{pmatrix}
779.19 & 6.72 & 11.93 & 78.15 & 70 \\
805.68 & 8.04 & 17.70 & 53.29 & 80 \\
889.72 & 7.45 & 19.06 & 53.39 & 75 \\
902.13 & 10.36 & 20.10 & 82.56 & 95 \\
\end{pmatrix}
$$

4.2. Clustering Sample Indicators and the Determination of Whitening Number

In grey clustering, clustering objects (schemes 1, 2, 3) are called samples, and clustering factors are called indicators. The measured data of each sample about each clustering factor is called whitening number. From Table 1, it can be seen that there are 4 gas extraction schemes in the 31 mining area, which are the technical measures for outburst prevention. Five indicators are given according to the quantity of borehole drainage, the time of borehole construction, the investment of outburst prevention funds, the cost of gas control and the advantages and disadvantages of preventing secondary disasters. $X_{ij}$ is used to represent the whitening number of index $J$ of the first sample ($i = 1, 2, 3, 4; j = 1, 2, 3$).

4.3. Grey Classification

The gas extraction scheme is divided into three grades: good, good and bad, that is to say, three ash classes are determined as shown in Table 2.

**Table 2.** Experts on the Whitening Weight Function $f_j^k (\cdot)$

| Evaluating indicator                                      | $f_j^1 (\cdot)$ | $f_j^2 (\bullet)$ | $f_j^3 (\bullet)$ |
|-----------------------------------------------------------|-----------------|-------------------|-------------------|
| Drilling volume ($10^3$ m)                                | $f_j^1 (-, -420.840)$ | $f_j^2 (420.840, -1260)$ | $f_j^3 (840.1260, -, -)$ |
| Construction time ($10^3$ days)                           | $f_j^1 (-, -4.10.8.20)$ | $f_j^2 (4.10.8.20, -12.30)$ | $f_j^3 (8.20.12.30, -, -)$ |
| Total capital input ($10^3$ yuan)                         | $f_j^1 (17.20.25.80, -, -)$ | $f_j^2 (8.60.17.20, -25.80)$ | $f_j^3 (-, -8.60.17.20)$ |
| Governance cost (yuan/t)                                  | $f_j^1 (-, -33.66)$ | $f_j^2 (33.66, -99)$ | $f_j^3 (66.99, -, -)$ |
| Prevention and Control of Secondary Disasters (%)         | $f_j^1 (80.120, -, -)$ | $f_j^2 (40.80, -120)$ | $f_j^3 (-, -40.80)$ |

According to the investigation, the drilling quantity, construction time, capital input, gas control cost and the weight of prevention and control of secondary disasters are respectively:
\[ \delta_1 = 0.1512; \delta_2 = 0.1441; \delta_3 = 0.1512; \delta_4 = 0.1441; \delta_5 = 4094 \]

### 4.4. Index Fixed Weight Clustering Coefficient

From \( \sigma_i^k = \sum_{j=1}^{m} f_i^k (x_j) \eta_j \), when \( i = 1 \):

\[
\sigma_1 = \sum_{j=1}^{m} f_1^1 (x_j) \eta_j = f_1^1 (779.19) \times 0.1512 + f_1^2 (6.72) \times 0.1512 + f_1^3 (11.93) \times 0.1441 + f_1^4 (78.15) \times 0.1441 + f_1^5 (0.4094) = 0.2206
\]

Similarly, it can be calculated that: \( \sigma_1^2 = 0.6798, \sigma_1^3 = 0.2431 \).

\[
\sigma_1 = (\sigma_1^1, \sigma_1^2, \sigma_1^3) = (0.2206, 0.6798, 0.2431)
\]

Similarly, it can be calculated.

\[
\begin{align*}
\sigma_2 &= (\sigma_2^1, \sigma_2^2, \sigma_2^3) = (0.4915, 0.9179, 0.0000) \\
\sigma_3 &= (\sigma_3^1, \sigma_3^2, \sigma_3^3) = (0.1139, 0.8170, 0.2132) \\
\sigma_4 &= (\sigma_4^1, \sigma_4^2, \sigma_4^3) = (0.2021, 0.6235, 0.1743)
\end{align*}
\]

By synthesizing the above results, the grey fixed weight clustering coefficient \( \sum \) can be obtained as follows:

\[
\sum = (\sigma_i^k) = \begin{bmatrix}
0.2206 & 0.6798 & 0.2431 \\
0.4915 & 0.9179 & 0.0000 \\
0.1139 & 0.8170 & 0.2132 \\
0.2021 & 0.6235 & 0.1743
\end{bmatrix}
\]

### 4.5. Program Optimization Results

It can be seen from the grey fixed weight clustering coefficient matrix that:

\[
\begin{align*}
\max_{1 \leq k \leq 3} \{ \sigma_1^k \} = \sigma_1^2 = 0.6798; \quad \max_{1 \leq k \leq 3} \{ \sigma_2^k \} = \sigma_2^2 = 0.9179; \quad \max_{1 \leq k \leq 3} \{ \sigma_3^k \} = \sigma_3^2 = 0.8170; \quad \max_{1 \leq k \leq 3} \{ \sigma_4^k \} = \sigma_4^2 = 0.6235
\end{align*}
\]

Among the four gas extraction modes mentioned above, the "bottom rock strip drilling + bedding drilling" extraction mode (scheme II) has the best comprehensive effect, followed by scheme III, scheme I, scheme IV, and scheme IV. Therefore, it is suggested to give priority to the proposed scheme II and implement the gas extraction mode in the East-First mining area of Weijiadi Coal Mine.

### 5. Conclusions

Four kinds of regional outburst prevention measures were investigated by using grey clustering fuzzy evaluation method from five indexes of engineering quantity, construction period, capital investment, gas control cost and secondary disaster prevention. It was concluded that the best regional outburst prevention measures were drilling strips through floor rock roadway and pre-draining coal seam gas along seam boreholes, with a quantified score of 0.9179, which was greater than the quantified values of the other three regional outburst prevention measures.
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