

The Application of Fuzzy Mathematics on Classification of Producing Dust Condition in Mining Working Face Different Processes and Selection of Nozzles with Dust Removal Function

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Abstract. Aiming at the problem of large water consumption of the coal mine dust suppression by atomized water, this article based on the fuzzy mathematics theory, to realize the classification of dust condition that different processes of mining coal face produced and the scientific choice of dust nozzle, application of fuzzy clustering analysis method to classify dust condition that different processes of mining coal face produced, and this article uses the fuzzy similarity measure for the process to select the most appropriate a classified nozzles with dust removal function, the multi-target quantitative analysis method makes the choice of the nozzles to have the scientific nature, there is an important guiding significance on water saving which dust suppression by atomized water use, the reliability of this method was verified through the actual example analysis.

1. Classification of dust conditions in different processes of mining face based on fuzzy cluster analysis

1.1. Establish the set dust characteristics of different processes in the mining face

According to the current research status of domestic scholars for the nozzle performance of dust, we can draw a conclusion that affecting spray dust efficiency is closely related to the particle diameter, and droplets are dust catcher minimum size is proportional to the particle diameter [1]. In the case that other parameters are the same, the smaller the particle size is the higher the efficiency of dust is [2]. There are many characteristic indexes of dust particle size, and many kinds of characteristic indexes are defined.

$$M = \{m_1, m_2, \dots, m_m\}$$

In order to describe relationship between the particle diameter and dust particle size on improving the efficiency of the spray dust we select the characteristic parameters of dust particle size concentration elements which have concentration, D_{10} 、 D_{50} 、 D_{90} 、 D_{av} , D is dust diameter, D_{50} is particle size, particle cumulative distribution of 50% D which is smaller than the size of grain quality accounted for 50% of total particle. D_{av} is volume weighted average particle size, particle diameter feature index set their composition. The dust classification of different positions in the known mining face is selected and the sample set is selected as:



$$X = \{x_1, x_2, \dots, x_n\}$$

Each sample x_i has m dimension characteristic index vector to represent:

$$x_i = \{x_{i1}, x_{i2}, \dots, x_{im}\}, i = 1, 2, \dots, n$$

x_{ij} represents the i th characteristic index of the i th sample. All the characteristics of the object index of n target constitute a matrix, denoted by $X^* = (x_{ij})_{n \times m}$, It is called that X^* is the property index matrix for X .

$$X^* = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix}$$

1.2. Data normalization

Due to the dimension of m characteristic parameters and order of magnitude is not necessarily the same, so it may be especially big highlight one order of magnitude in the process of computing the characteristic parameters of classification and reduce or even eliminate the effect of the characteristic parameters of some orders of magnitude is small. Normalization enables of data each index value to be unified in a common numerical range. There are four major data normalization method, including the mean normalization method, center standardization method, maximum standardization method. The article adopts the method of maximum standardization, and the specific calculation method is: The j th column of the characteristic index matrix X^* , the maximum value $M_j = \max\{x_{1j}, x_{2j}, \dots, x_{nj}\}$, $j = 1, 2, \dots, m$, and then the transformation

$$x'_{ij} = x_{ij}/M_j, i = 1, 2, \dots, n, j = 1, 2, \dots, m \quad (1)$$

After data normalization, a new matrix is constituted:

$$X' = \begin{bmatrix} x'_{11} & x'_{12} & \dots & x'_{1m} \\ x'_{21} & x'_{22} & \dots & x'_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x'_{n1} & x'_{n2} & \dots & x'_{nm} \end{bmatrix}$$

1.3. Construct fuzzy similarity matrix.

Clustering is to identify the proximity of elements in X by some criteria and classify each other as a class. As a result, the number r_{ij} in $[0, 1]$ represents the approximate or similar degree of x_i and x_j in X . The similarity coefficient in classical cluster analysis and the closeness degree between fuzzy sets can be used as similarity coefficient. There are many methods for determining the degree of similarity, such as quantitative product method, Angle cosine method, correlation coefficient method, proximity method, distance method and absolute value reciprocal method. In this paper, the maximum and minimum method are adopted to determine the degree of closeness, and the calculation formula is

$$r_{ij} = \frac{\sum_{k=1}^m (x_{ik} \cap x_{jk})}{\sum_{k=1}^m (x_{ik} \cup x_{jk})} \quad (2)$$

1.4. Fuzzy classification

The fuzzy relation matrix between object and object constructed by the above methods is generally a fuzzy similarity matrix $R = (r_{ij})_{n \times n}$, but not necessarily transitive. Therefore, R is constructed into a new fuzzy equivalent matrix, and the equivalent matrix has both reflexivity, symmetry and transference, and then a dynamic clustering is performed based on the fuzzy equivalence matrix.

The transfer closure $t(R)$ of fuzzy similarity matrix R is a fuzzy equivalence matrix. The specific steps of classification based on $t(R)$ are as follows:

(1) The transfer closure $t(R)$ of the fuzzy similarity matrix R is obtained by the square self - synthesis method.

(2) Select appropriate confidence level $\lambda \in [0,1]$, and solve for the λ th order matrix $t(R)_\lambda$ of $t(R)$., it is an equivalent of X on Boole matrix. Then, the classification is made according to $t(R)_\lambda$, and the classification obtained is the equivalence classification at the level of λ .

$$\text{Let } t(R) = (r_{ij}')_{n \times n}, t(R)_\lambda = (r_{ij}'(\lambda))_{n \times n}, \text{ So } r_{ij}'(\lambda) = \begin{cases} 1, & r_{ij}' \geq \lambda \\ 0, & r_{ij}' < \lambda \end{cases} \quad (3)$$

2. Selection of dust removal nozzle based on fuzzy similarity measurement

The similarity between two fuzzy sets can be measured by the distance between them. The distance is indicated by the symbol d or D . The smaller the distance between the two fuzzy sets, the larger the similarity is, and vice versa. Calculation methods of "distance" which is usually used include hamming distance, weighted hamming distance, distance etc., The article is based on hamming distance for the mining face to choose suitable nozzle and improve the efficiency of the spray dust. The specific calculation formula is.

$$d(A, B) = \sum_{i=1}^n |u_A(x_i) - u_B(x_i)| \quad (4)$$

3. Case analysis

The particle size distribution of the dust particles produced by different production processes in the 1303 working face of dongtan coal mine is an example [3], and eight process samples are selected. The data are shown in table 1.

Table 1. Results of particle size determination of dust particles in different processes.

Sampling locations	The sample proportion(kg/m3)	The concentration	D10 (μm)	D50 (μm)	D90 (μm)	Dav (μm)
Cable tray X1	1.35×10^3	1.1	3.40	6.45	13.71	7.57
Transportation belt X2	1.35×10^3	1.6	4.01	9.61	41.23	19.26
Reproduced machine X3	1.35×10^3	1.2	4.55	13.03	31.82	16.45
Crusher X4	1.35×10^3	1.4	5.08	19.22	86.22	33.56
The back chute X5	1.35×10^3	1.3	5.54	24.88	128.59	50.64
A slip of the front X6	1.35×10^3	1.2	5.52	28.10	143.19	54.18
Hydraulic support X7	1.35×10^3	1.6	5.64	29.92	150.34	56.81
Coal winning machine X8	1.35×10^3	1.3	7.54	33.99	119.90	52.01

The characteristic index matrix is sorted out according to table 1.

$$X^* = \begin{bmatrix} 1.1 & 3.40 & 6.45 & 13.71 & 7.57 \\ 1.6 & 4.01 & 9.61 & 41.23 & 19.26 \\ 1.2 & 4.55 & 13.03 & 31.82 & 16.45 \\ 1.4 & 5.08 & 19.22 & 86.22 & 33.56 \\ 1.3 & 5.54 & 24.88 & 128.59 & 50.64 \\ 1.2 & 5.52 & 28.10 & 143.19 & 54.18 \\ 1.6 & 5.64 & 29.92 & 150.34 & 56.81 \\ 1.3 & 7.54 & 33.99 & 119.90 & 52.01 \end{bmatrix}$$

According to the formula (1), we normalize the data and get the normalized matrix.

$$X' = \begin{bmatrix} 0.69 & 0.45 & 0.19 & 0.09 & 0.13 \\ 1.00 & 0.53 & 0.28 & 0.27 & 0.34 \\ 0.75 & 0.60 & 0.38 & 0.21 & 0.28 \\ 0.88 & 0.67 & 0.57 & 0.57 & 0.59 \\ 0.81 & 0.73 & 0.73 & 0.86 & 0.89 \\ 0.75 & 0.73 & 0.83 & 0.95 & 0.95 \\ 1.00 & 0.75 & 0.88 & 1.00 & 1.00 \\ 0.81 & 1.00 & 1.00 & 0.80 & 0.92 \end{bmatrix}$$

According to formula (2), we get the X' structure as the fuzzy similar matrix

$$R = \begin{bmatrix} 1.00 & 0.64 & 0.69 & 0.47 & 0.39 & 0.37 & 0.34 & 0.34 \\ 0.64 & 1.00 & 0.79 & 0.68 & 0.53 & 0.49 & 0.52 & 0.48 \\ 0.69 & 0.79 & 1.00 & 0.68 & 0.56 & 0.53 & 0.48 & 0.49 \\ 0.47 & 0.68 & 0.68 & 1.00 & 0.79 & 0.73 & 0.71 & 0.70 \\ 0.39 & 0.53 & 0.56 & 0.79 & 1.00 & 0.93 & 0.87 & 0.85 \\ 0.37 & 0.49 & 0.53 & 0.73 & 0.93 & 1.00 & 0.91 & 0.85 \\ 0.34 & 0.52 & 0.48 & 0.71 & 0.87 & 0.91 & 1.00 & 0.83 \\ 0.34 & 0.48 & 0.49 & 0.70 & 0.85 & 0.85 & 0.83 & 1.00 \end{bmatrix}$$

The fuzzy equivalent matrix $t(R)$ is obtained according to the square self - synthesis method.

$$R^2 = \begin{bmatrix} 1.00 & 0.69 & 0.69 & 0.68 & 0.56 & 0.53 & 0.52 & 0.49 \\ 0.69 & 1.00 & 0.79 & 0.68 & 0.68 & 0.68 & 0.68 & 0.68 \\ 0.69 & 0.79 & 1.00 & 0.68 & 0.68 & 0.68 & 0.68 & 0.68 \\ 0.68 & 0.68 & 0.68 & 1.00 & 0.79 & 0.79 & 0.79 & 0.79 \\ 0.56 & 0.68 & 0.68 & 0.79 & 1.00 & 0.93 & 0.91 & 0.85 \\ 0.53 & 0.68 & 0.68 & 0.79 & 0.93 & 1.00 & 0.91 & 0.85 \\ 0.52 & 0.68 & 0.68 & 0.79 & 0.91 & 0.91 & 1.00 & 0.85 \\ 0.49 & 0.68 & 0.68 & 0.79 & 0.85 & 0.85 & 0.85 & 1.00 \end{bmatrix}$$

$$R^4 = \begin{bmatrix} 1.00 & 0.69 & 0.69 & 0.68 & 0.68 & 0.68 & 0.68 & 0.68 \\ 0.69 & 1.00 & 0.79 & 0.68 & 0.68 & 0.68 & 0.68 & 0.68 \\ 0.69 & 0.79 & 1.00 & 0.68 & 0.68 & 0.68 & 0.68 & 0.68 \\ 0.68 & 0.68 & 0.68 & 1.00 & 0.79 & 0.79 & 0.79 & 0.79 \\ 0.68 & 0.68 & 0.68 & 0.79 & 1.00 & 0.93 & 0.91 & 0.85 \\ 0.68 & 0.68 & 0.68 & 0.79 & 0.93 & 1.00 & 0.91 & 0.85 \\ 0.68 & 0.68 & 0.68 & 0.79 & 0.91 & 0.91 & 1.00 & 0.85 \\ 0.68 & 0.68 & 0.68 & 0.79 & 0.85 & 0.85 & 0.85 & 1.00 \end{bmatrix}$$

$$R^8 = \begin{bmatrix} 1.00 & 0.69 & 0.69 & 0.68 & 0.68 & 0.68 & 0.68 & 0.68 \\ 0.69 & 1.00 & 0.79 & 0.68 & 0.68 & 0.68 & 0.68 & 0.68 \\ 0.69 & 0.79 & 1.00 & 0.68 & 0.68 & 0.68 & 0.68 & 0.68 \\ 0.68 & 0.68 & 0.68 & 1.00 & 0.79 & 0.79 & 0.79 & 0.79 \\ 0.68 & 0.68 & 0.68 & 0.79 & 1.00 & 0.93 & 0.91 & 0.85 \\ 0.68 & 0.68 & 0.68 & 0.79 & 0.93 & 1.00 & 0.91 & 0.85 \\ 0.68 & 0.68 & 0.68 & 0.79 & 0.91 & 0.91 & 1.00 & 0.85 \\ 0.68 & 0.68 & 0.68 & 0.79 & 0.85 & 0.85 & 0.85 & 1.00 \end{bmatrix} = R^4$$

There are $t(R) = R^4$, $t(R)$ elements in order from large to small as follows:

$$1 > 0.93 > 0.91 > 0.85 > 0.79 > 0.69 > 0.68$$

According to the formula (3), the number of values is

$$\lambda = 1, 0.93, 0.91, 0.85, 0.79, 0.69, 0.68.$$

$$t(R)_1 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

At this time, the dust conditions of different processes are classified into 8 categories: $\{x_1\}$, $\{x_2\}$, $\{x_3\}$, $\{x_4\}$, $\{x_5\}$, $\{x_6\}$, $\{x_7\}$, $\{x_8\}$.

$$t(R)_2 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

At this time, the dust conditions of different processes are classified into 7 categories:

$\{x_1\}$, $\{x_2\}$, $\{x_3\}$, $\{x_4\}$, $\{x_5, x_6\}$, $\{x_7\}$, $\{x_8\}$.

$$t(R)_3 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

At this time, the dust conditions of different processes are divided into 6 categories: $\{x_1\}$, $\{x_2\}$, $\{x_3\}$, $\{x_4\}$, $\{x_5, x_6, x_7\}$, $\{x_8\}$.

$$t(R)_4 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \end{bmatrix}$$

At this time, the dust conditions of different processes are classified into 5 categories: $\{x_1\}$, $\{x_2\}$, $\{x_3\}$, $\{x_4\}$, $\{x_5, x_6, x_7, x_8\}$.

$$t(R)_5 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

At this time, the dust conditions of different processes are divided into 3 categories: $\{x_1\}$, $\{x_2, x_3\}$, $\{x_4, x_5, x_6, x_7, x_8\}$.

$$t(R)_6 = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

At this time, the dust conditions of different processes are divided into two categories: $\{x_1, x_2, x_3\}$, $\{x_4, x_5, x_6, x_7, x_8\}$.

$$t(R)_7 = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

At this time, the dust conditions of different processes are classified into 1 category: $\{x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8\}$.

If we choose the confidence level as $\lambda = 0.79$, then the dust conditions of different processes are divided into three categories: $\{x_1\}$, $\{x_2, x_3\}$, $\{x_4, x_5, x_6, x_7, x_8\}$. The selected nozzle is shown in table 2.

Table 2. spray characteristics of dust removal nozzle

The dust nozzle	The concentration	D10 (μm)	D50 (μm)	D90 (μm)	Dav (μm)
Y1	1.5	5.55	6.75	110	50
Y2	1.2	5	5.0	50	20
Note: the above non-real experimental data is only used as an interpretation algorithm.					

According to formula (4),

$d(X1, Y1) = 141.57$, $d(X2, Y1) = 104.01$, $d(X4, Y1) = 53.26$; $d(X1, Y2) = 51.87$, $d(X2, Y2) = 15.51$, $d(X4, Y2) = 64.28$, then it is indicated that the process X1 is suitable for selecting the dust removal nozzle Y2, and the process X2 and X3 are suitable for the use of dust removal nozzle Y2, the process X4, X5, X6, X7 and X8 are suitable for selecting the nozzle Y1.

4. Conclusion

According to the close relationship between the particle size, one of the important factors of dust suppression by atomized water, and improvement of efficiency of dust suppression by atomized water. This article applies the fuzzy cluster analysis method in fuzzy mathematics method to classify dust condition of different and uses the fuzzy similarity measure for the classification of the process from known dust removal nozzle to select the most suitable one. Based on the fuzzy clustering analysis and fuzzy similarity measure, for classification of producing dust condition in mining working face different processes and selection of nozzles with dust removal function, considering the dust particle size multielement index, is a kind of new try of the application of fuzzy mathematics which has an important significance for saving water, and guiding significance for the different processes for mining working face dust pollution assessment.

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