Determination of continuous miner matching property for different geological conditions

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Abstract. In order to find a common method to match different geological conditions for continuous miner, fuzzy synthetic evaluation method is used to find the influence factors of continuous miner matching attribute. A total of twenty-one impact factors were found, and the structures and membership functions of these impact factors were established. The judgment matrix is constructed to determine the weight of each influencing factor based on statistical data, research results, and expert experience. Comprehensive evaluation model is established based on multi-level and multi-factor, then the integrated assessment value for different geological conditions are calculated, it is used to judge how well the continuous miner matches the geological conditions. This method is used in four field examples, compared with experts evaluation results, the two results are basically the same, so this theoretical approach is effective.

1. Introduction
The short-wall mechanized mining technology with continuous miner originated from the United States in 1950s, after nearly 70 years of development, this technology has been applied in many fields. China introduced various types of continuous miner since 1970s. According to the geological characteristics, since 1995, Shendong company has applied the complete set of technology and equipment used for the rapid excavation and short-wall mining in Yujialiang coal mine and Shangwan coal mine, and achieved fruitful results. In recent years, with the development of technology and establishment of provisions in Coal Mine Safety Regulation, continuous miner has been widely used [1]. But the research on continuous miner type selection and matching of geological conditions is in the description stage [2-3]. The theory of continuous miner matching different geological conditions must be established, then quantitative calculation is realized for continuous miner type selection.

2. Evaluation theory of geological condition matching of continuous miner
In order to describe the matching attribute of continuous miner more accurately and quantitatively, the membership function of influence factors was created using fuzzy comprehensive evaluation method based on fuzzy mathematics, then these factors are grouped into different levels use AHP (Analytic Hierarchy Process) [4], the quantitative analysis will be do.

2.1 Influence factor structure
According to the principle of establishing the structure of influencing factors and combining with the actual situation on the site, the structure of influencing factors of geological conditions is shown in FIG. 1, including one special factor, seven primary factors and thirteen secondary factors.
2.2 Influence factors of continuous miner matching attribute to geological conditions

The special influence factor gas grade is that whether the gas pressure \( p \) and absolute gas emission quantity \( q \) in the working face is the prerequisite for choose a continuous miner, which is clearly stipulated in Coal Mine Safety Regulations. The following studies on other influencing factors are all conducted to meet the applicable conditions of gas [5].

2.2.1 Complexity of geological structure

- Fault impact. Based on the experience and data, the main factors that affect the adaptability of continuous miner are fault density \( q_1 \), length coefficient \( q_2 \) and drop coefficient \( q_3 \). Fault density \( q_1 \) is expressed by the quotient of fault lines in the block \( n_1 \) and the block area \( S \). The fault length coefficient \( q_2 \) is expressed by the ratio of the total fault length to the block area \( S \), which reflects the total length of faults per unit area. Fault drop coefficient \( q_3 \) is defined as the ratio between the height of fault drop \( h \) and the mining thickness of coal seam \( m \) in the block. Normally, the logarithmic function of coal seam mining thickness is used to correct the fault drop coefficient: 

\[
q_3 = \frac{1}{n_1} \sum_{i=1}^{n_1} \frac{h_i}{m} \frac{1}{\ln(m + 1)},
\]

where \( h_i \) is the drop of the \( i \) fault, \( m \).

- Collapse column effect. The influence coefficient of collapse column \( k \) is used to describe the influence of collapse column on the matching attribute of continuous miner, \( k = \sum_{i=1}^{n} \frac{s_i}{S} \eta_i \), where \( s_i \) is the influence area of the \( i \)th collapse column, km\(^2\); \( s \) is the area of the block, km\(^2\); \( \eta_i \) is the ratio of the destruction thickness caused by the \( i \)th collapse column to the mining thickness.

2.2.2 Influence of coal seam stability

The stability of coal seam is described by the following three factors: the variation coefficient of coal thickness \( \gamma' \); coal seam workability coefficient \( K_m \); gangue inclusion coefficient is \( G \).

- Coefficient of variation of coal thickness \( \gamma' = \frac{\delta}{H} \); \( \delta \) is mean square error; 

\[
\delta = \frac{1}{n} \sum_{i=1}^{n} (H_i - H)^2, \quad H
\]

is the average thickness of borehole coal, m; \( H_i \) is the thickness of coal detected by drilling hole, m; \( n \) is the total number of coal boreholes.

- Coal seam workability coefficient \( K_m = \frac{n_i}{n} \); \( n_i \) is the drilling hole with a thickness greater than the minable thickness.
2.2.3 **Influence of Coal Seam Thickness**
Coal seam thickness is evaluated by the average coal thickness $H$ of the coal borehole in this block, 

$$H = \frac{1}{n} \sum_{i=1}^{n} H_i.$$

2.2.4 **Influence of coal seam dip Angle**
Coal seam dip Angle $\alpha$ is: 

$$\alpha = \frac{1}{n} \sum_{i=1}^{n} \alpha_i,$$

where $\alpha_i$ is the dip Angle of coal seam in the $i$th borehole.

2.2.5 **Effect of stiffness of coal seam**
Coal seam strength $R$: 

$$R = (1 - G) \times R_e + G \times R_g,$$  

where $R_e$ is the gangue inclusion unidirectional compressive strength, MPa; $R_g$ is the single compressive strength of coal, MPa.

2.2.6 **Influence of roof and floor conditions**
The roof and floor conditions affects cutting cycle depth and opening probability of continuous miner [6].

- The stability of the direct roof is the unidirectional compressive strength of the direct roof $\sigma$.
- The support of old roof is expressed by multiple ratio of direct roof to mining height $N = \frac{h}{H}$.
- False roof impact, the thickness of false roof $h_0$ is taken as the evaluation index.
- Floor strength is expressed by the unidirectional compressive strength of the direct bottom strata $R_D$.

2.2.7 **Goaf area conditions**
To evaluate the influence of the goaf area, goaf area coefficient $\tau$ is used: 

$$\tau = \frac{L_{KH}}{S} \times 100\%,$$

where $L_{KH}$ is the goaf area, m$^2$; $S$ is the area of the working surface, m$^2$.

2.3 **Influencing factor membership function construction**
To construct membership function, we can use undetermined coefficient method, statistical analysis method, multiphase fuzzy statistical method, etc.

| Influence factor       | membership function |
|------------------------|---------------------|
| gas pressure $p$       | $P_p(p) = \begin{cases} 1 & (p < 0.74) \\ 0 & (p \geq 0.74) \end{cases}$ |
| absolute gas emission $q$ | $Q_q(q) = \begin{cases} 1 & (q \leq 3) \\ 0 & (q > 3) \end{cases}$ |
| coal seam dip angle    | $\mu_{\alpha}(\alpha) = \begin{cases} 0 & (\alpha \leq 8^{\circ}) \\ \frac{17}{9} & (8^{\circ} \leq \alpha < 17^{\circ}) \\ \frac{1}{9} & (17^{\circ} \leq \alpha) \end{cases}$ |
2.4 Weight calculation of influencing factors
The weight of evaluation factors is the quantitative evaluation of the relative importance of each factor to the matching attribute of continuous miner.

2.4.1 Construct judgment matrix
After the summary of field experience, the analysis of statistical data and the consultation and investigation of experts, the judgment matrix is shown in table 2.
Table 2. Judgment matrix between layer A and layer B

|   | A   | B1  | B2  | B3  | B4  | B5  | B6  | B7  |
|---|-----|-----|-----|-----|-----|-----|-----|-----|
| B1| 1   | 1/2 | 1/5 | 1   | 1/6 | 1/8 | 1   |
| B2| 2   | 1   | 1/4 | 2   | 1/5 | 1/7 | 2   |
| B3| 5   | 4   | 1   | 5   | 1   | 1/5 | 5   |
| B4| 1   | 1/2 | 1/5 | 1   | 1/6 | 1/8 | 1   |
| B5| 6   | 5   | 1   | 6   | 1   | 1/5 | 5   |
| B6| 8   | 7   | 5   | 8   | 5   | 1   | 8   |
| B7| 1   | 1/2 | 1/5 | 1   | 1/5 | 1/8 | 1   |

2.4.2 Weight calculation of judgment matrix

Use the product n root method to find the relative weight coefficient, that is

For A to B matrix: \( W_i^B = \sqrt[n]{\prod_{j=1}^{n} W_{ij}} \) i, j = 1,2,3,……n. then Normalization: 
\[
\overline{W_i^B} = \frac{W_i^B}{\sum_{j=1}^{n} W_{ij}} \]

For B~C matrix: \( W_i^C = \sqrt[n]{\prod_{j=1}^{n} W_{ijk}} \) i, j = 1,2,3,……n. then Normalization: 
\[
\overline{W_i^C} = \frac{W_i^C}{\sum_{k=1}^{n} W_{ijk}} \]

Layer base factor relative to A layer weight coefficient: \( W_{ij}^C = \overline{W_i^C} \times \overline{W_j^A} \), i, j = 1,2,3,……n, the calculation results are shown in table 3.

Table 3. The calculation result of C layer base factor weight relative to the A layer

| NO. | Base factor C          | Relative weight coefficient | Relative weight coefficient of layer A |
|-----|------------------------|----------------------------|----------------------------------------|
| 1   | Fault impact C_{11}    | 0.83                       | 0.0367                                 |
| 2   | Collapse column effect C_{12} | 0.17                 | 0.0073                                 |
| 3   | Coal seam workability C_{21} | 0.54                   | 0.0376                                 |
| 4   | Coal thickness variability C_{22} | 0.30                 | 0.0207                                 |
| 5   | Gangue inclusion coefficient C_{23} | 0.16                 | 0.0114                                 |
| 6   | Seam working thickness C_{31} | 1.00                   | 0.1826                                 |
| 7   | Seam dip Angle C_{41}   | 1.00                       | 0.0440                                 |
| 8   | Coal seam comprehensive strength C_{51} | 1.00               | 0.2083                                 |
| 9   | Direct roof strength C_{61} | 0.55                   | 0.2258                                 |
| 10  | Main roof support C_{62} | 0.10                       | 0.0393                                 |
| 11  | False roof impact C_{63} | 0.10                       | 0.0393                                 |
| 12  | Floor impact C_{64}     | 0.25                       | 0.1024                                 |
| 13  | Goaf area conditions C_{71} | 1.00                 | 0.0446                                 |

2.4.3 Matrix consistency test

Consistency test index CI: \( CI = \frac{\lambda_{max} - n}{n - 1} \), \( \lambda_{max} \) is the maximum eigenvalue of the judgment matrix. Judgment matrix between layer A and layer B: \( \lambda_{max} = 7.2 \), n = 7, CI = 0.033, look up the average random consistency index RI = 1.32, so the random ratio \( CR = \frac{CI}{RI} = 0.025 < 0.1 \) the judgment matrix has satisfactory consistency.

2.4.4 Establishment of comprehensive evaluation model

The matching attribute evaluation of continuous miner is a multi-level and multi-factor evaluation, the evaluation of influencing factors is converted into the comprehensive evaluation value according to a certain algorithm, which will evaluate the matching attribute of continuous miner for different
geological conditions.

Set up the evaluation sample set \( X = \{x_1, x_2, \cdots, x_n\} \) there are \( m \) evaluation factors, its index matrix:

\[
X = \begin{bmatrix}
x_{11} & x_{12} & \cdots & x_{1n} \\
x_{21} & x_{22} & \cdots & x_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
x_{m1} & x_{m2} & \cdots & x_{mn}
\end{bmatrix}
\]

Because each evaluation factor has constructed the evaluation fuzzy membership function, the above index value matrix can be mapped to the index membership matrix, \( \mu: X \rightarrow R \)

\[
R = \begin{bmatrix}
r_{11} & r_{12} & \cdots & r_{1n} \\
r_{21} & r_{22} & \cdots & r_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
r_{m1} & r_{m2} & \cdots & r_{mn}
\end{bmatrix}
\]

\( W(w_1, w_2, \cdots, w_m) \) used for multiple factor weight.

The weighted average type is selected for the comprehensive evaluation model, and the decisive role of \( P_w \) and \( Q_w \) are taken into account, the integrated assessment value \( b_j \):

\[
b_j = P_w \cdot Q_w \cdot \sum_{i=1}^{m} w_i \cdot r_{ij} \quad j = 1, 2, \cdots, m
\]

The \( b_j \) is divided into four ranges to evaluate the application of continuous miner by the experience of more than 100 working surfaces and the opinions of many experts in related fields at home and abroad, as shown in table 4.

| \( b_j \) | Matching degree | Mismatching | Basically matched | Matching | Perfect |
|---|---|---|---|---|---|
| <0.7 | 0.7~0.8 | 0.8~0.9 | \( \geq 0.9 \) |

3. Example verification

In order to verify the feasibility of the above method, the geological conditions of several coal mines were selected for the expert group evaluation and the above evaluation method, and the two results were compared.

The geological parameters and evaluation results of each working face of A~D mine are shown in table 5.

| Geological parameter | Working face gas pressure \( p \) (MPa) | Absolute gas emission from working face \( q \) (m\(^3\)/min) | Fault density \( q_1 \) (quantity per km\(^2\)) | Fault length index \( q_2 \) (m/km\(^2\)) | Fault drop coefficient \( q_3 \) | Impact coefficient of collapse column \( k \) | Unidirectional compressive strength of direct roof strata \( \sigma \) (MPa) |
|---|---|---|---|---|---|---|---|
| 415 working face of mine A | 0 | 0.85 | 0.32 | 0.8 | 0.07 | 0.4 | 25.1 |
| 502 working face of mine B | 0 | 1.13 | 0 | 0.2 | 0.0 | 0.1 | 33 |
| C mine 24206 working face | 1.8 | 1.8 | 0.2 | 0.5 | 0.1 | 0.02 | 47 |
| D mine 15601 working face | 0.19 | 0 | 0 | 0 | 0 | 0 | 80 |
### Conditions of coal seam

| Main roof support N | 0.78 | 0.9 | 1.1 | 1.5 |
|---------------------|------|-----|-----|-----|
| False roof thickness h₀ | 0.36 | 0.51 | 0.3 | 0.1 |

#### Unidirectional compressive strength of direct floor strata \( R_D \) (MPa)

|          | 23   | 21   | 20   | 30.4 |
|----------|------|------|------|------|

Coefficient of variation of coal thickness \( \gamma \)

|          | 0.19 | 0.021 | 0.02 | 0.01 |
|----------|------|--------|------|------|

Coal seam workability \( K_{\text{m}} \)

|          | 0.85 | 0.88 | 0.91 | 0.93 |
|----------|------|------|------|------|

Gangue inclusion coefficient \( G \)

|          | 27%  | 10%  | 6%   | 2%   |
|----------|------|------|------|------|

Average seam thickness \( H \) (m)

|          | 3.8  | 4.53 | 4.6  | 6.5  |
|----------|------|------|------|------|

Seam dip Angle \( \alpha \) (°)

|          | 9.3  | 3.4  | 2.2  | 3    |
|----------|------|------|------|------|

Comprehensive strength of coal seam \( R \) (MPa)

|          | 30.2 | 26.7 | 28   | 25   |
|----------|------|------|------|------|

Goaf area coefficient \( \tau \)

|          | 36.7%| 2.3% | 1.5% | 0.5% |
|----------|------|------|------|------|

### Consistency Result

| \( b_j \) | 0.638694 | 0.704174 | 0.82429 | 0.919325 |
|------------|----------|----------|----------|----------|
| result     | Mismatching | Basically matched | Matching | Perfectly match |

According to the basic geological conditions of the above four mines, the expert group made an evaluation.

The expert review results of A mine 415 working face as follows: the coal thickness, hardness meets the requirements, but the soft and unstable roof and poor main roof supporting, hanging area ratio of goaf reached 36.7%, gas also exist in this working face, therefore this kind of roof is not conducive to the efficiency of the continuous miner, and have the risk of gas leakage, there is the effect of fault and collapse column, the continuous miner is not recommended.

The expert review results of B mine 502 working face as follows: the roof of this working face is soft, the thickness of false roof is more than 0.5 meters and presence of gas , no fault factors, coal thickness, hardness, angle and so on is very suitable for continuous miner, but you need pay attention to roof bolting in time and false roof fall, because of the effect of roof, the continuous miner capacity is not fully exert.

The expert review results of C mine 24206 working face as follows: although there are gas, fault and collapse column on the working face, the influence is small, the roof condition is good, and the coal seam condition is also very conducive to the continuous miner, this working face have a certain empty roof distance, which is conducive to the continuous miner's ability, so it is suitable for continuous miner.

The expert review results of D mine 15601 working face as follows: low gas content, no fault, no collapse column, roof condition is very good, the coal seam thickness is large, the variation is small, the inclination angle is small, the hardness is moderate, the inclusion of gangue is low, very suitable for the application of continuous miner, should choose the continuous miner with large mining height to obtain a high recovery rate of resources.

### 4. Conclusion

By comparing the results of quantitative evaluation and expert group evaluation, it can be known that the quantitative evaluation result is highly consistent with the expert group evaluation result, so the comprehensive evaluation model based on the comprehensive evaluation method of fuzzy
mathematics can realize the quantitative evaluation of the matching attribute of continuous miner.

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