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Pre-evaluation method of coal mine safety based on continental distance model with varying weight

Qi Qing-jie, Zhao Xiao-liang*, Song Bai-chao

College of Resource and Environment Engineering, Liaoning Technical University, FuXin 123000, China

Abstract

At present, the methods of coal mine safety pre-evaluation are Fuzzy comprehensive evaluation, gray cluster analysis, matter-element analysis, BP artificial neural network, and so on. Pre-evaluation of coal mine safety is an effective method to ensure the safe operation of the mine production. Evaluation factors’ weight of every object related to coal mine safety is calculated according to these genes’ safety contribution rates, which would be put forward as a new method in this paper. After evaluation factor’s grade standards of the coal mine are treated properly, the continental distance model with varying weight, which would be capable to make a pre-evaluation of the mine, is established. After the application of this model to Huangling No.2 coal mine, the results of this model and unascertained measure model are compared and analyzed, which are excellently consistent.

Keywords: continental distance model with varying weight; mine safety; pre-evaluation; safety contribution rates

1. Instruction

The coal mine safety is affected by a number of unknown factors\textsuperscript{[1]}. Pre-evaluation of coal mine safety is an effective measure to ensure the safe operation of the mine production. At present, the methods of coal mine safety pre-evaluation are Fuzzy comprehensive evaluation, gray cluster analysis, matter-element analysis, BP artificial neural network, and so on\textsuperscript{[2]}. However, in their own respective ways, they all more or less have the shortcomings that they can not sufficiently reflect the impact of weight. That is because a large number of original information is lost during the adoption of the largest - the smallest operation or the use of the same weight to deal with all the correlation\textsuperscript{[3]}. Therefore, it is particularly necessary to do some effective and further researches on the existing method of the Pre-evaluation. In this paper, on the basis of the weighted distance model\textsuperscript{[4]}, the author put forward the concept of safety contribution rates. After the quantitative analysis of grading standards of safety, the new scale criteria for pre-evaluation was established, and the continental distance model with varying weight was built. The pre-evaluation based on new model was carried out for nature safety of Huangling No.2 coal mine, which reflected splendid results.

2. Continental distance model with varying weight in Mine nature safety pre-evaluation

* Corresponding author. Tel.: +86-13941892426.
E-mail address: zhaoxiaoliang2008@126.com.

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2. Continental distance model with varying weight in Mine nature safety pre-evaluation

2.1. Model initialization

The samples of pre-evaluation are set up:

\[ C = (C_1, C_2, \ldots, C_n). \]  

(1)

Each of \( C_i (i = 1, 2, \ldots, n) \) is the estimate of the No. \( i \) factor. And the Matrix which contains all the standards of every factor is:

\[
S = \begin{bmatrix}
S_{11} & S_{12} & \cdots & S_{1m} \\
S_{21} & S_{22} & \cdots & S_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
S_{n1} & S_{n2} & \cdots & S_{nm}
\end{bmatrix}
\]  

(2)

\( S_{ik} (i = 1, 2, \ldots, n; k = 1, 2, \ldots, m) \) is the No. \( k \) standard limit for the No. \( i \) factor.

2.2. Data standardization

Make relative distance of every standard grade of all factors to be standardization and standardized formula is as follows:

\[
S'_{ik} = \frac{S_{ik} - P_{il}^*}{S_{im} - P_{il}^*}
\]  

(3)

\( S_{ik} (i = 1, 2, \ldots, n; k = 1, 2, \ldots, m) \) is the No. \( k \) standard limit for the No. \( i \) factor . 
\( S_{im}, P_{il}^* \) are respectively the No. \( m \) grade and the first grade standard limit of the No. \( i \) factor. The evaluation criteria matrix after norms is as follows:

\[
S' = \begin{bmatrix}
S'_{11} & S'_{12} & \cdots & S'_{1m} \\
S'_{21} & S'_{22} & \cdots & S'_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
S'_{n1} & S'_{n2} & \cdots & S'_{nm}
\end{bmatrix}
\]  

(4)

The elements are standard coordinates of each factor at different grades, obviously all of the \( S'_{il} (i = 1, 2, \ldots, n) \) are 0, and all \( S'_{im} (i = 1, 2, \ldots, n) \) are 1, and the other elements of the standard coordinates are between 0 and 1.

2.3. Determination of rate of safety contribution

The contribution of each factor to mine safety determines the factor’s weight coefficient in pre-evaluation and estimated numerical value, namely the rate of contribution to the safety:
\[ W_i = \frac{x_i / X_i^*}{\sum_{i=1}^{n} x_i / X_i^*} \]  \hspace{2cm} (5)

\(W_i, X_i\) are respectively the No. \(i\) factor contributions to the safety and the estimated value in pre-evaluation object. \(X_i^*\) is the No. \(i\) factor standard value (in the general, grade II is the standard).

### 2.4. Determination of relative grade of distance standards

Using the continental formula combined with safety contribution rates, we calculate the relative distance from coordinate standards at all grades to coordinate the original point, \(D_k (k=1, 2, \ldots, m)\).

\[ D_k = \sqrt{\sum_{i=1}^{n} \left( W_i S_i \right)^2} \]  \hspace{2cm} (6)

\(D_k (k = 1, 2, \ldots, m)\) is the relative standard distance from coordinate standards of the No. \(k\) grade to the original point, so \(0 \leq D_k \leq 1\).

### 2.5. Standardization of estimate coordinates of each factor in pre-evaluation

\[ C_i' = \begin{cases} 0 & , C_i \leq P_i^* \\ \frac{C_i - P_i^*}{S_{ii} - P_i^*} & , C_i \geq P_i^* \end{cases} \]  \hspace{2cm} (7)

\(C_i' = (C_1', C_2', \ldots, C_n')\) is the measurement estimate data of the No. \(i\) factor of the pre-evaluation object after standardized treatment.

### 2.6. Determination of relative distance from estimate coordinates to the origin point

\[ d = \sqrt{\sum_{i=1}^{n} \left( W_i C_i' \right)^2} \]  \hspace{2cm} (8)

Where \(d\) is the relative distance from coordinates point of the pre-evaluation object to the origin point.

### 2.7. Determination of evaluation grade

If \(D_k \leq d \leq D_{k-1} \) (\(k=1, 2, \ldots, m-1\)), the concrete grade results of the pre-evaluation:

\[ R = k + \frac{d - D_k}{D_{k+1} - D_k} \]  \hspace{2cm} (Grade)

Where \(k\) is the number of standard grade corresponding to \(D_k\).
3. Pre-evaluation procedures of the continental distance model with varying weight in Coal Mine Safety

Take the geological structure (relative index), the roof (relative index), gas emission, coal seam dip angle, coal seam thickness, depth of exploration, average water yield, the volatile coal, spontaneous combustion stage and the depth for rock-burst in coal mines as main factors in Coal Mine Safety pre-evaluation \[5\]. The value of geological structure and the roof are obtained by the qualitative index method, shown in Table 1.

Table 1. The gratification standard of indicators in mine natural disaster

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Grade</th>
<th>Grade</th>
<th>Grade</th>
<th>Grade</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_1 地质结构</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>C_2 天井</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>C_3 煤气排放 / (m^3 / t)</td>
<td>0~5</td>
<td>5~10</td>
<td>10~15</td>
<td>15~25</td>
<td>&gt;25</td>
</tr>
<tr>
<td>C_4 煤层倾角</td>
<td>≤10</td>
<td>12~18</td>
<td>25~35</td>
<td>40~50</td>
<td>≥55</td>
</tr>
<tr>
<td>C_5 床高 / m</td>
<td>1.8~2.5</td>
<td>2.5~3.5</td>
<td>4.5~6.0</td>
<td>6.0~12</td>
<td>≥12</td>
</tr>
<tr>
<td>C_6 采煤深度 / m</td>
<td>≤100</td>
<td>110~200</td>
<td>250~300</td>
<td>350~400</td>
<td>≥500</td>
</tr>
<tr>
<td>C_7 坑内水流量 / (m^3/h)</td>
<td>&lt;180</td>
<td>180~300</td>
<td>300~600</td>
<td>600~900</td>
<td>≥1000</td>
</tr>
<tr>
<td>C_8 煤的挥发分 / %</td>
<td>&lt;10</td>
<td>10~15</td>
<td>15~28</td>
<td>28~40</td>
<td>≥40</td>
</tr>
<tr>
<td>C_9 自燃期 / 月</td>
<td>≥12</td>
<td>8~10</td>
<td>6~7</td>
<td>5~6</td>
<td>&lt;3</td>
</tr>
<tr>
<td>C_10 岩爆深度 / m</td>
<td>&lt;200</td>
<td>300~400</td>
<td>450~500</td>
<td>550~600</td>
<td>&gt;650</td>
</tr>
</tbody>
</table>

According to the "mine safety", combined with the historical experience data, it is divided into 5 grades, which are I, II, III, IV and V. Respectively, they are named respectively very secure, relatively secure, general secure, insecure and very insecure, shown in Table 2.

Table 2. The relative risk index

<table>
<thead>
<tr>
<th>The safety degree</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative index</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

The measurement data are estimated in Huangling No. 2 coal mine\[6\] shown in Table 3.

Table 3. The estimated data of pre-evaluation factors in natural conditions in Huangling II

<table>
<thead>
<tr>
<th>Factors</th>
<th>Geological structure</th>
<th>Roof</th>
<th>Gas emission (m^3/t)</th>
<th>Seam dip / (°)</th>
<th>Bed height / m</th>
<th>The exploitation depth / m</th>
<th>Average water inflow (m^3/h)</th>
<th>Coal Volatile / %</th>
<th>Spontaneous combustion stage / month</th>
<th>Depth of rock burst occurred in / m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>1</td>
<td>4</td>
<td>6.33</td>
<td>3</td>
<td>2.67</td>
<td>450</td>
<td>160</td>
<td>30</td>
<td>15</td>
<td>550</td>
</tr>
</tbody>
</table>

First of all, we need to deal with some data of Table 1. Introduction is as follows: count down the line data; name spontaneous combustion stage in Table 1; take the upper limit of the range as C_1-grade factors of characteristics; take the lower limit of range as C_5-grade factors of characteristics; take the mid-value of the gratification as standard C_2, C_3, C_4 grade.

According to the formula (3), dealt with gratification standards into standardization in Table 1, so $S'$ matrix:

$$S' = \begin{bmatrix}
0 & 0.25 & 0.5 & 0.75 & 1 \\
0 & 0.25 & 0.5 & 0.75 & 1 \\
0 & 0.125 & 0.375 & 0.75 & 1 \\
0 & 0.111 & 0.444 & 0.778 & 1 \\
0 & 0.053 & 0.289 & 0.684 & 1 \\
0 & 0.138 & 0.438 & 0.688 & 1 \\
0 & 0.073 & 0.329 & 0.695 & 1 \\
0 & 0.083 & 0.383 & 0.800 & 1 \\
0 & 0.112 & 0.284 & 0.396 & 1 \\
0 & 0.333 & 0.611 & 0.833 & 1
\end{bmatrix}$$
According to the formula (5), the contribution rate of every indicator of coal factor related to mine safety is calculated.

Table 4. Contribution rates of Safety factor in Huangling II

<table>
<thead>
<tr>
<th>Index factor</th>
<th>W_1</th>
<th>W_2</th>
<th>W_3</th>
<th>W_4</th>
<th>W_5</th>
<th>W_6</th>
<th>W_7</th>
<th>W_8</th>
<th>W_9</th>
<th>W_10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>0.028</td>
<td>0.114</td>
<td>0.072</td>
<td>0.017</td>
<td>0.076</td>
<td>0.247</td>
<td>0.057</td>
<td>0.204</td>
<td>0.051</td>
<td>0.134</td>
</tr>
</tbody>
</table>

According to the formula (6), calculate the relative distance named \( D_k \) from standard at all points \( k = 1, 2, ..., m \) coordinates to the origin, shown in Table 5.

Table 5. Safety grade standards of coal mine based on this new model

<table>
<thead>
<tr>
<th>Grade</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Distance</td>
<td>0 ≤ D₁ ≤ 0.067</td>
<td>0.067 ≤ D₂ ≤ 0.173</td>
<td>0.173 ≤ D₃ ≤ 0.289</td>
<td>0.289 ≤ D₄ ≤ 0.389</td>
<td>≥ 0.389</td>
</tr>
</tbody>
</table>

According to the formula (7), make standardization treatment to the measuring estimates of safety indicators \( C_i \) \( (i = 1, 2, ..., n) \), the coordinates after treatment are \( C = (0, 0.375, 0.067, 0, 0.018, 0.875, 0, 0.667, 0, 0.778) \). By the formula (8), (9), calculate the relative distances from the location of estimates to the origin. The concrete grade of refinement is shown in Table 6.

Table 6. The pre-evaluation results of the natural safety in Huangling

<table>
<thead>
<tr>
<th>The object of pre-evaluation</th>
<th>Distance(d)</th>
<th>Grade</th>
<th>Result of this new method</th>
<th>Result of unascertained measure model</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.078</td>
<td>2.100</td>
<td>II</td>
<td>II</td>
</tr>
</tbody>
</table>

Through the calculation of the continental distance model with varying weight, the result of the pre-evaluation of natural safety is grade II, which is a match with the result of pre-evaluation of unascertained measure model[6]. By applying this pre-evaluation model, we could determine the safety type of object concrete safety of mine as well as Huangling II was grade 2.100, and could also reflect the trend of mine safety state, which is beneficial to make the necessary precautionary measures for mine safety management decision-makers in advance.

4. Conclusions

(1) According to the contribution of the various factors in mine measurement estimate data to the mine safety, the concept of the contribution rate is put forward. In order to achieve the improvement of the continental distance model with the same weight despite of giving weight to the factors, the continental distance model with varying weight of the mine safety pre-evaluation is established. The results show that the natural safety pre-evaluation is grade II in Huangling, which is relatively secure. Forecasting results coupled with the actual situation prove the scientific rationality of the continental distance model with varying weight.

(2) The continental distance model with varying weight in mine safety pre-evaluation could not only determine the safety type to which natural conditions of the mine belong, but also work out concrete numerical grade which reflects the safety trends of mine state. So a scientific basis is provided for the mine safety management. At the same time, a new model is established for the safety pre-evaluation of coal mine construction projects.

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References


