Evaluation of mining capacity of mines using the combination weighting approach: A case study in Shenmu Mining Area in Shaanxi Province, China

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Abstract
Aiming at the low mining rate in mines, Xingelao, Dabianyao, and Dongliang Coal Mines in Shenmu Mining Area, Shaanxi Province, China were taken as research objects. Based on this, this study constructed an evaluation index system for the mining capacity of the mines from the perspectives of geological factors, mechanical equipment, humans, and mining design. Moreover, the factors influencing the mining capacity of the mines were evaluated using a combination weighting approach based on an improved analytic hierarchy process and an entropy weight method. A standard cloud was generated based on the mapping standards of each index and a comprehensive cloud was obtained according to comprehensive weight and a backward cloud algorithm. Finally, by combining the comprehensive cloud with local and overall scores of the mines, the mining capacities of the mines were evaluated. The research results demonstrate that the key factor restricting the mining capacity of the mines is the geological environment and five major third-grade indexes affecting mining capacity are igneous rock intrusion, collapse column, scouring zone of the ancient river bed, mechanization level and coal pillar width. In addition, the corresponding suggestions and measures were put forward according to the main factors influencing the mining rate of the mines. In accordance with the weights and scores of each index, the overall scores of the mines were calculated. Dongliang, Dabianyao, and Xingelao Coal Mines were ranked in order based on scores. The research results provide a theoretical basis for improving the mining capacity of the mines under similar geological conditions.

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Keywords
Improved analytic hierarchy process, entropy weight method, combination weighting approach, mining rate, capacity evaluation

Introduction
Coal is the main fossil energy in the world. With the gradual exploitation of resources on the earth, coal resources diminish gradually.1–3 Due to the strong dependence of each country, coal plays the dominant role in the energy structure of each country in the world.4–7 In recent years, to pursue short-term benefits, many coal mining enterprises only mine thick coal seams rather than thin ones, which wastes lots of coal resources and results in a low mining rate on the whole.8–11 It is an inevitable choice to properly reduce the scale of coal development and improve the mining rate under the changing trend of energy consumption and the current situations of coal resources.12–15 Evaluation of the mining capacity of mines using the combination weighting approach can intuitively and clearly reflect the level of mining capacity of mines and improve weak links to raise the mining rate of mines.16–18

Based on the theory of the combination weighting approach, many experts have carried out in-depth studies on factors affecting the mining rate of mines. Qiao et al.19 systematically analyzed various factors influencing the mining rate from the perspectives of hydrogeology, characteristics of coal seams, technical process, and basic work before mining and proposed corresponding measures to improve the mining rate. To solve the problems of a low mining rate and a serious waste of resources at the current stage, Wu et al.20 revealed the primary causes for the low mining rate, including cutthroat competition, giving up the high mining rate, insufficient inspection and supervision, poor geographical location, and backward technical conditions. Moreover, they put forward corresponding suggestions and measures to control the low mining rate. Zhang et al.21 applied short-wall backfill mining with tailing paste into Zhangzhao Coal Mine (Zibo City, Shandong Province, China), which allows the mining rate of the mine to reach above 85%, thus achieving goals of releasing coal resources, controlling surface subsidence, and effectively disposing of solid wastes. Yavue et al.22 studied the optimum support design for the main haulage road in deep coal seams by using an analytic hierarchy process (AHP) method and finally selected a better supporting mode. Bogdanovic23 and Ataei et al.24 analyzed geological, geotechnical, safety, and economic factors by utilizing the AHP method and finally selected a method most suitable for mining the Jajarm Mine in Iran. Charya et al.25 ranked and analyzed the relative importance of artificial intelligence factors in the manufacturing industry based on the AHP method and improved relatively important factors to increase efficiency in industrial automation. Sun et al.26 evaluated agricultural water management in irrigation districts of north China through an improved AHP and classified the evaluation system into five second-grade and 14 third-grade indexes. The evaluation results show that the engineering index and management index are two important factors affecting agricultural water use in irrigation districts.

In conclusion, the main factors affecting the mining capacity of mines include mine geology, hydrogeological characteristics, technical process, management, and
mechanical equipment. These studies provide ideas, methods, and theoretical bases for this research. On this basis, this study improved the selection of scales for the traditional AHP method\textsuperscript{27–31} and showed that the improved scales could more accurately express scores. By using a combination weighting approach based on the improved AHP and entropy weight method (EWM), this research analyzed weights of factors influencing the mining rate of Xingelao, Dabianyao, and Dongliang Coal Mines in Shenmu Mining Area, Yulin City, Shaanxi Province, China, and evaluated mining capacity.

**Evaluation index system for mining capacity of the mines**

The selection of evaluation indexes for factors affecting the mining capacity of the mines should follow five principles: scientficity, comprehensiveness, operability, timeliness, and standardability.\textsuperscript{32,33} Based on the above five principles, by referring to existing studies\textsuperscript{34,35} it can be concluded that geological environment, mechanical equipment, humans, and mining design are factors influencing the mining rate of the mines. Therefore, a target layer, a rule layer, and an index layer were comprehensively and reasonably constructed, in which the evaluation index system including four second-grade indexes and 16 third-grade indexes is shown in Figure 1.

**Evaluation of the mining capacity of mines**

The basic idea for evaluating the mining capacity of the mines using the combination weighting approach based on the improved AHP and EWM is shown as follows: Firstly, the mapping standard and the score matrix are determined. Secondly, the weight of each index is determined by combining it with subjective and objective methods. Finally, the local and overall scores are calculated, and the evaluation grades are determined according to scores. The specific steps are displayed in Figure 2. Note
that the cloud model is based on probability theory and fuzzy set theory, and forms a model of conversion between qualitative concept and quantitative representation through specific algorithms. The cloud model can take into account the randomness and fuzziness of the real world, and organically combine the two. After the construction of the mapping standard, to convert the actual conditions of the mine into corresponding scores and then calculate, the target layer and the criterion layer of the mine are evaluated later. Mine total score and local score is a form of expression, which can quantitatively analyze the situation of the mine target layer and criterion layer.

**Establishment of cloud model**

Based on probability theory and fuzzy set theory, a bidirectional cognitive model, namely a cloud model to solve the problem of uncertainty was proposed, realizing interconversion between qualitative concepts and quantitative data. C is a qualitative concept in the universe X. The distribution of mapping from the universe X to the interval [0, 1] in the universe space is called a membership cloud (a cloud for short). Each x is known as a cloud droplet.36 As shown in Figure 3, the abscissa represents the scope of qualitative concepts, and the ordinate denotes the degree of membership. The digital features of Ex, En, and He reflect the overall characteristics of the cloud model, which are expressed as expectation, entropy, and superentropy, respectively.37–39

Weights of each index are determined by using the combination weighting approach combining the improved AHP with EWM, which can not only learn theories and experience from senior experts but also reduce subjective arbitrariness of
weighting so that evaluation results are more authentic and reliable. Note that senior experts come from coal mines or government departments. We sent evaluation forms to these experts and obtained evaluation results through an anonymous questionnaire.

Selection of scales for improving the traditional AHP

The scales of 1–9 of the traditional AHP are not in harmony with the habit of language judgment. Moreover, the scores of grades of the importance of factors generally do not reach 7 or 9, and there are often scores at grades of 2, 4, and 6. This may lead to some errors in evaluation conclusions and consistency tests. The improved AHP method plays a role to reasonably improve the scales of evaluation indexes. The specific method for establishing scales is shown as follows: if the relative importance of a for b as well as of b for c are known, then the relative importance of a for c is transitive. It is supposed that the scores of equal importance, slight importance, obvious importance, strong importance, and extreme importance are 1, $a^2$, $a^3$, $a^4$ and $a^5$, and $a:c = (a:b)/(b:c)$. The limit of the judgment of Saaty in a numerical value is 9 and $a^5 = 9$, that is, $a = 1.5518$ (values above $a^5$ are all recorded as 9). Therefore, the scales of indexes can be presented and the indexes can be scored by taking the scale of exponent indexes and their reciprocal as scales, as displayed in Table 1.

After establishing an AHP model for the consistency test, experts in the field are asked to make a pairwise comparison and score the importance of each factor. The importance of $m$ factors to a certain factor A in the upper layer is compared. Two factors $B_i$ and $B_j$ are set for comparison and the comparison results are $b_{ij}$. Based on the scoring results, the comparison value $b_{ij}$ and the judgment matrix $A$ are separately obtained.
The largest characteristic root and weight of AHP

1. The $m$ root of square $k_i$ of the product of elements in each row of the judgment matrix $A$ is calculated.

$$ k_i = \sqrt[m]{\prod_{j=1}^{m} b_{ij} (i = 1, 2, \ldots m; j = 1, 2, \ldots, m)} \quad (1) $$

2. $Q_i$ after normalization of $K_i$ is calculated.

$$ Q_i = K_i / \prod_{i=1}^{m} K_i \quad (2) $$

where, $Q_i = [Q_1, Q_2, \ldots, Q_m]^T$. The normalized components indicate the relative importance of the elements, that is, weights.

3. The largest characteristic root $\lambda_{\text{max}}$ is obtained.

$$ \lambda_{\text{max}} = \sum_{i=1}^{m} (B_i / m Q_i) (i = 1, 2, \ldots m; j = 1, 2, \ldots, m) \quad (3) $$

where $B_i$ represents the $i$th element in the hierarchical single ranking (namely a superiority and inferiority ranking $B$) of the largest characteristic root $\lambda_{\text{max}}$ calculated by vectors and $B = AQ$. The relatively rigorous ranking method is the largest characteristic root method, which can obtain the largest characteristic root and its eigenvector.

Finally, the consistency test is carried out. $RI$ is the average random consistency index of the judgment matrix. When $CR < 0.1$, it meets the consistency requirements.

Table 1. Scale definition.

| Grade of importance                                      | Score $b_{ij}$ | Description                                                                 |
|----------------------------------------------------------|----------------|-----------------------------------------------------------------------------|
| Factor i is extremely important compared with factor j   | 9              | Maximum difference in judgment between the two indexes in the allowable range. |
| Factor i is strongly important compared with factor j    | 5.799          | Strong difference in judgment between the two indexes.                      |
| Factor i is obviously important compared with factor j   | 3.737          | Obvious difference in judgment between the two indexes.                     |
| Factor i is slightly important compared with factor j    | 2.408          | Slight difference in judgment between the two indexes.                      |
| Factor i is equally important compared with factor j     | 1              | No difference in judgment between the two indexes.                          |

Table 1. Scale definition.
To reduce the impact of subjective factors, questionnaires were used in this study. To be specific, a total of 20 questionnaires were issued to mine professionals and teaching and research staff and the weight of each index in each questionnaire was calculated by using Yaahp software. Yaahp is a comprehensive evaluation auxiliary software based on the AHP and fuzzy comprehensive evaluation method, which provides help in model construction, calculation and analysis for the decision-making process using the AHP and fuzzy comprehensive evaluation method. According to weight vectors, clustering analysis was performed by utilizing SPSS software to cluster 20 questionnaires into several categories. The weight coefficient of each category is calculated based on formula (4) and finally, the weight of each index is determined by formula (5).28

\[ \lambda_i = \frac{\phi_i^2}{\sum_{i=1}^{n} \phi_i^2} \]  
\[ \alpha = \sum_{i=1}^{n} \lambda_i \sigma \]  

where, \( \lambda_i \), \( \phi_i \) and \( \sigma \) separately indicate the weight coefficient, bulk weight and average weight, of each category.

**Concept of EWM**

EWM is used to determine the objective weight according to the variability of indexes. The smaller the entropy of an index, the more information the index has, the greater the role it plays in the evaluation, and the greater the weight it has.29 The steps for determining weights using the EWM are shown as follows:

1. Constructing the evaluation index matrix

Assuming that there are \( m \) objects and \( n \) indexes for evaluation, the evaluation index matrix is constructed.

1. Data processing

Very large and very small data are obtained, and the data are normalized.

\[ l_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} (j = 1, 2, \ldots, n) \]  

1. Calculating the entropy of the \( n \)th index

\[ e_j = -\kappa \sum_{j=1}^{m} l_{ij} \ln l_{ij} (j = 1, 2, \ldots, n) \]  

Chen et al. 7
where, $\kappa = 1/\ln m$.

$$e_j = -\sum_{j=1}^{m} l_{ij} \ln l_{ij} / \ln m \ (j = 1, 2, \ldots, n) \tag{7}$$

1. Determining weights of indexes

The coefficient of variability $g_j$ of the $n$th index is $g_j = 1 - e_j$ and the weight of the index is $\beta_j = g_j / \sum_{j=1}^{n} g_j$.

**Determining weights of indexes using the combination weighting approach**

The combination weighting approach is to use the geometric average method to combine subjective weight vector $\alpha = (\alpha_1, \alpha_2, \ldots, \alpha_j)$ with objective weight vector $\beta = (\beta_1, \beta_2, \ldots, \beta_j)$ determined by the EWM, which is calculated as follows:

$$w_j = \sqrt{\alpha_j \beta_j} / \sum_{j=1}^{n} \sqrt{\alpha_j \beta_j} \tag{8}$$

**Determination of mapping standard and standard cloud**

In the evaluation index system for the mining capacity of mines, the third-grade indexes include three qualitative indexes and 13 quantitative indexes. During the evaluation, the qualitative indexes are quantified by field professionals with specific scores following the actual situations. In the meanwhile, the quantitative indexes are also mapped as specific scores according to measured values. Mapping standards are displayed in Table 2. According to the score matrix $R_{ij}$ of each index, the local score is calculated by combining with weights of each index determined by the combination weighting approach, as shown below:

$$c_i = \sum_{j=1}^{n} w_{ij} R_{ij} \tag{9}$$

Based on the local score, the calculation formula for the overall evaluation score of the mining capacity of the mines is

$$c = \sum_{i=1}^{4} w_i c_i \tag{10}$$

According to the above cloud model theory and basic mapping standards, the corresponding cloud model of evaluation grade in the model for the mining capacity of the mines is generated by using Matlab software, as shown in Figure 4. In the figure, the ordinate represents the degree of membership of cloud droplets to different evaluation grades, while the abscissa indicates the quantitative value of the index at different grades. Different colors are used to distinguish the degree of membership of the same variable at different grades. From left to right, blue, red, yellow, purple and green represent
grade I (weaker capacity), grade II (weak capacity), grade III (medium capacity), grade IV (strong capacity) and grade V (stronger capacity), respectively.

Table 2. Mapping standards of each index.

| Evaluation grade | [0, 40) weaker capacity | [40, 55) weak capacity | [55, 70) medium capacity | [70, 85) strong capacity | [85, 100] stronger capacity |
|------------------|-------------------------|------------------------|-------------------------|-------------------------|--------------------------|
| Thickness of coal seam (m) | ≤0.8 | [0.8, 1.5) | [1.5, 2) | [2, 4) | [4, 6) |
| Number of fault fracture zones | ≥16 | [12, 16) | [8, 12) | [4, 8) | [0, 4) |
| Area of igneous rock intrusion (m$^2$) | ≥5000 | [2500, 5000) | [1000, 2500) | [500, 1000) | [0, 500) |
| Area affected by collapse column (m$^2$) | ≥4000 | [2000, 4000) | [800, 2000) | [300, 800) | [0, 300) |
| Area affected by scouring zone of ancient river bed (m$^2$) | ≥3000 | [1500, 3000) | [800, 1500) | [400, 800) | [0, 400) |
| Qualified rate of maintenance (%) | [50, 60) | [60, 70) | [70, 80) | [80, 90) | [90, 100) |
| Serviceability rate of equipment (%) | [50, 60) | [60, 70) | [70, 80) | [80, 90) | [90, 100) |
| Mechanization level | [0, 40) | [40, 55) | [55, 70) | [70, 85) | [85, 100) |
| Equipment failure rate (%) | [60, 100) | [45, 60) | [30, 45) | [15, 30) | [0, 15) |
| Matching degree of height of a coal mining machine with coal thickness (%) | [50, 60) | [60, 70) | [70, 80) | [80, 90) | [90, 100) |
| Cultural competence of staffs (average education years per person) | [0, 6) | [6, 12) | [12, 16) | [16, 19) | [19, 23) |
| Technical quality of staffs (working years per person) | [0, 3) | [3, 6) | [6, 9) | [9, 12) | [12, 30) |
| Staff training rate (%) | [50, 60) | [60, 70) | [70, 80) | [80, 90) | [90, 100) |
| Layout of working face | [0, 40) | [40, 55) | [55, 70) | [70, 85) | [85, 100) |
| Coal pillar width (m) | [16, 20) | [12, 16) | [8, 12) | [4, 8) | [0, 4) |
| Coal mining method | [0, 40) | [40, 55) | [55, 70) | [70, 85) | [85, 100) |

Case study and analysis

Determination of measured value and mapping score of each mine

Against the engineering backgrounds of Xingelao, Dabianyao, and Dongliang Coal Mines in Shenmu City of Shaanxi Province, the mining capacities of the three mines were evaluated. The three mines all had shallow-buried nearly horizontal coal seams with a mining depth of about 110 m. The three mines were mined with the longwall retreat full-seam mining along the strike and belonged to mines with low gas content, in which coal dust was explosive. The coal seams under mining were combustion spontaneous ones in class I and Xingelao Coal Mine was adjacent to Dabianyao Coal Mine.
Protective coal pillars with a width of 30 m were reserved on both sides and there were no facilitates, such as buildings, rivers, and roads on the surface. The measured values and mapping scores of each index of the three mines are demonstrated in Table 3.

Table 3. Measured values and mapping scores of each index.

| Evaluation index                                           | Xingelao Coal Mine | Dabianyao Coal Mine | Dongliang Coal Mine |
|------------------------------------------------------------|--------------------|---------------------|---------------------|
| Thickness of coal seam (m)                                 | 1.6 (58)           | 1.7 (61)            | 2.7 (75)            |
| Number of fault fracture zones                             | 8 (70)             | 6 (78)              | 3 (90)              |
| Area of igneous rock intrusion (m²)                        | 0 (100)            | 0 (100)             | 0 (100)             |
| Area affected by collapse column (m²)                      | 0 (100)            | 0 (100)             | 0 (100)             |
| Area affected by scouring zone of ancient river bed (m²)   | 0 (100)            | 0 (100)             | 0 (100)             |
| Qualified rate of maintenance (%)                          | 85 (78)            | 80 (70)             | 85 (78)             |
| Serviceability rate of equipment (%)                       | 86 (79)            | 83 (75)             | 90 (85)             |
| Mechanization level                                        | 80                 | 85                  | 85                  |
| Equipment failure rate (%)                                 | 18 (82)            | 16 (84)             | 12 (88)             |
| Matching degree of the height of a coal mining machine with coal thickness (%) | 93 (90)            | 96 (94)             | 92 (88)             |
| Cultural competence of staffs (average education years per person) | 13 (58)            | 12 (55)             | 13 (58)             |
| Technical quality of staffs (working years per person)     | 6 (55)             | 7 (60)              | 6 (55)              |
| Staff training rate (%)                                    | 92 (88)            | 94 (91)             | 95 (93)             |
| Layout of working face                                     | 80                 | 85                  | 85                  |
| Coal pillar width (m)                                      | 12 (55)            | 10 (63)             | 10 (63)             |
| Coal mining method                                         | 75                 | 80                  | 80                  |

Figure 4. Standard cloud model of evaluation grades.
Calculation of combined weights

The 20 questionnaires were numbered as 1–20, and then the weights of each index in each questionnaire were calculated by Yaahp software. Finally, clustering analysis on weight vectors was performed by using SPSS software. The 20 questionnaires were clustered into four categories. Based on formula (6), the weight coefficients of the rule layer in the index system were calculated as 0.4679, 0.2157, 0.1007, and 0.2157 and then weights of each index were calculated through formula (7). Furthermore, according to the measured values of each index in the field, the weights were calculated using the EWM. Finally, by virtue of formula (8), the weights determined by AHP were combined with those determined by the EWM to calculate the final weight. The calculation results of weights are shown in Table 4.

By finding the index of maximum weight subordinating to the rule layer, a strategic quadrilateral with A3, B4, C2, and D2 for mining capacity of the mines was constructed based on four-quadrant analysis, as displayed in Figure 5.

The mining rate of the mines was mainly evaluated from the geological environment, mechanical equipment, humans, and mining design. Although the geological environment exerts great influences on the mining rate of the mines, it is formed under natural conditions and is an inherent influence factor. The mechanical equipment and mining design are assigned with the same weight, but the weight on the human factor is small. By analyzing the overall ranking of weights, it is obtained that the area of igneous rock intrusion, area affected by collapse column, area affected by scouring zone of the ancient river bed and mechanization level occupy larger proportions in the total weight, which have large effects on mining capacity of the mines.

| Index | Weight | Index | Weightαj determined by the AHP | Weightβj determined by the EWM | Combined weightwj | Total ranking weight |
|-------|--------|-------|-------------------------------|-------------------------------|-------------------|---------------------|
| A 0.4679 | A1 0.0666 | 0.0086 | 0.0248 | 0.0116 |
| A2 0.1234 | 0.026 | 0.0587 | 0.0275 |
| A3 0.2699 | 0.3217 | 0.3055 | 0.1429 |
| A4 0.2699 | 0.3217 | 0.3055 | 0.1429 |
| A5 0.2699 | 0.3217 | 0.3055 | 0.1429 |
| B 0.2157 | B1 0.0789 | 0.0241 | 0.0522 | 0.0112 |
| B2 0.1341 | 0.0340 | 0.0808 | 0.0174 |
| B3 0.1695 | 0.0241 | 0.0764 | 0.0164 |
| B4 0.4117 | 0.9063 | 0.7306 | 0.1576 |
| B5 0.2064 | 0.0122 | 0.0600 | 0.0129 |
| C 0.1007 | C1 0.1743 | 0.1656 | 0.1700 | 0.0176 |
| C2 0.6513 | 0.6460 | 0.6489 | 0.0653 |
| C3 0.1743 | 0.1882 | 0.1812 | 0.0182 |
| D 0.2157 | D1 0.5693 | 0.0916 | 0.3208 | 0.0691 |
| D2 0.1136 | 0.8045 | 0.4246 | 0.0916 |
| D3 0.3169 | 0.1037 | 0.2545 | 0.0549 |
According to Figure 5, the area of triangles in each quadrant of the strategic quadrilateral can be calculated. Since the area is relatively small, the area of each triangle is multiplied by 100 for comparison. Therefore, the areas of triangles $A_3OD_2$, $A_3OB_4$, $C_2OB_4$ and, $C_2OD_2$ are 1.3090, 2.2564, 1.0291, and 0.5981, respectively. Through analysis, the factors mainly affecting the mining capacity of the mines are $AB$, $CB$, $DA$, and $CD$, ranking in descending order. The triangle $A_3OB_4$ has the largest area; so, $AB$ should be improved to raise the mining rate of the mines.

Based on the combined weight of each index in Table 4 and specific values mapped by measured values, local and overall scores of mining capacity of the mines are separately calculated using formulas (9) and (10). Evaluation grades are determined in accordance with scores and Table 2 and the calculation results and corresponding evaluation grades are demonstrated in Table 5. Dongliang Coal Mine, Dabianyao Coal Mine, and Xingelao Coal Mine are ranked in order according to the scores of mining capacity thereof. In the rule layer “mechanical equipment” and “mining design” evaluation grade evaluation is good, stope capacity evaluation level and the total score is relatively good, big span kiln and east beam coal mining recovery rate to meet the demand, as the “mechanical equipment” and “mining design” rating for strong and moderate, Xingelao coal mining power rating is “strong”, but there is relatively low score evaluation. These two weaknesses need to be addressed further.

**Determination of the comprehensive evaluation cloud**

According to the above scores of second-grade indexes and total scores of each mine, the comprehensive cloud maps of Xingelao, Dabianyao, and Dongliang Coal Mines were separately plotted by Matlab software. Cyan represents the standard cloud. From the left to right, dark yellow, purple, brown, dark blue and red separately indicates human, mining design, mechanical equipment, geological environment, and overall evaluation score of the mines, as illustrated in Figures(6) to (8).
Table 5. Evaluation on mining capacity of the mines.

| Coal mine          | Total score | Evaluation grade | Second-grade index | | Local score | Evaluation grade |
|--------------------|-------------|------------------|--------------------| | | |
| Xingelao Coal Mine | 84.02       | Strong           | Geological environment | 97.19 | Strong |
|                    |             |                  | Mechanical equipment | 80.87 | Strong |
|                    |             |                  | Human               | 61.49 | Medium |
|                    |             |                  | Mining design       | 68.10 | Medium |
|                    |             |                  | Geological environment | 97.74 | Strong |
|                    |             |                  | Mechanical equipment | 83.21 | Strong |
|                    |             |                  | Human               | 64.77 | Medium |
|                    |             |                  | Mining design       | 74.37 | Strong |
| Dabianyao Coal Mine| 86.24       | Stronger         | Geological environment | 97.74 | Strong |
|                    |             |                  | Mechanical equipment | 83.21 | Strong |
|                    |             |                  | Human               | 64.77 | Medium |
|                    |             |                  | Mining design       | 74.37 | Strong |
| Dongliang Coal Mine| 87.31       | Stronger         | Geological environment | 98.79 | Strong |
|                    |             |                  | Mechanical equipment | 87.01 | Strong |
|                    |             |                  | Human               | 62.40 | Medium |
|                    |             |                  | Mining design       | 74.38 | Strong |

Figure 6. Comprehensive cloud map of Xingelao Coal Mine.

By analyzing Figures (6) to (8), it can be concluded that the score of the geological environment is high, and it is evaluated to be of stronger mining capacity. Although the geological environment is the main factor affecting the mining rate of the mines,
the three mines have a good geological environment, which slightly influences the mining rate. Low local scores of human factor and mining design indicate the low quality of staff management and staff themselves, and the coal pillar width is relatively large. Therefore, it is necessary to strengthen the training of staff and effectively reduce the width of coal pillars on the premise of guaranteeing safety and rationality.

**Discussion**

The main factors affecting the mining capacity of the mines are the area of igneous rock intrusion, the area affected by collapse column, the area affected by scouring zone of the ancient river bed, mechanization level, and coal pillar width. The mining capacity can be
improved according to these main influence factors by taking the following specific measures. In the process of mining, the principle of “exploration while mining” should be adopted as far as possible, and mining areas of igneous rock intrusion, collapse columns, and scouring zones of ancient river beds should be avoided as far as possible. The mines should be mined by mostly using fully-mechanized mining, rather than blasting mining and conventional mining. The management and training of staff should be strengthened. Coal pillars need to be narrowed within a reasonable range, to improve the mining rate and reduce the waste of resources.

**Conclusions**

Based on the engineering backgrounds of Xingelao, Dabianyao, and Dongliang Coal Mines in Shennu City, Shaanxi Province, the traditional AHP method was improved and weight coefficients of each index were determined by using the combination weighting approach based on the improved AHP and EWM. This not only considers subjectivity of decision makers, but also ensures accuracy of weights, which provides a scientific decision-making model for methods improving the mining rate. Therefore, the model can be widely used in the field relevant to the mining capacity of the mines, and can better guide improvement of the mining rate of the mines.

(1) The evaluation index system and standard cloud model for the mining capacity of the mines were constructed. Based on the principle for constructing the index system, the evaluation index system for mining capacity of the mines was built from the perspectives of geological environment, mechanical equipment, human factor, and mining design by referring to relevant studies and combining with the actual situations in the field.

(2) The selection of scales in the traditional AHP method was improved so that the results calculated using the improved AHP method were more reasonable and reliable. By combining the improved AHP method with the EWM method, the weights of influence factors in the index system for mining capacity of the mines were calculated and analyzed by combining the subjective and objective aspects. By analyzing the weights, the main influence factors were determined and corresponding suggestions were put forward.

(3) Based on the evaluation model and cloud model, the mining capacities of Xingelao, Dabianyao, and Dongliang Coal Mines were evaluated. In accordance with evaluation results, the key factor restricting mining capacity was the geological environment. The mining capacities of the three mines were scored. According to the scores of mining capacity, Dongliang, Dabianyao, and Xingelao Coal Mines were ranked in order.

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