Research on Risk Assessment of Coalbed Methane Development Project Based on SEWM-GCA

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Abstract. Coalbed Methane development is a complex system project with complex technology, many links and long cycle. It is highly susceptible to risks such as legal, technical and management during the development process. In order to scientifically measure the overall risk of CBM development projects, reduce resource waste and property losses caused by risk management failure. This paper constructs a risk assessment index system for CBM development projects consisting of six first-level indicators and 28 second-level indicators. The weight of each indicator is calculated by the structural entropy weight method. Secondly, based on the grey clustering analysis method, the theoretical model of risk assessment for coalbed methane development projects is established. Finally, an empirical study on a coalbed methane development project in Qinshui County, Shanxi Province was carried out using the evaluation system. After calculation, the overall risk level of the project is Grade II. The evaluation results are consistent with the actual situation of the enterprise, indicating that the established evaluation system has certain effectiveness and feasibility.

1. Introduction
Coalbed methane (CBM) is a companion mineral resource of coal and a clean energy with high calorific value, commonly known as “gas” [1]. China is a big coal producer, but it is also a country with high gas explosion accidents. According to incomplete statistics, there were 45 gas explosion accidents in China from 2014 to 2017, resulting in 365 deaths [2]. Such accidents are not only easy to cause death and mass injury, but also lead to a series of secondary disasters, which seriously affect the harmonious and stable development of society. The development of coalbed methane can not only mitigate environmental pollution, but also effectively prevent gas explosion accidents [3]. Under this background, China's coalbed methane industry has shown a trend of rapid development. However, CBM development is a complex system project with complex technology, many links and long cycle. It is highly susceptible to risks such as legal, technical and management during the development process [4]. In order to scientifically measure the risk of CBM development, it is necessary to construct a complete CBM development risk assessment system. Researchers at home and abroad have also achieved some success in the risk of coalbed methane development. For example, Roadifer [5] evaluated the future trends and development risks of coalbed methane development, and combined the experimental and mathematical statistics methods to identify the key factors affecting CBM reserves and production capacity. Senthi et al. [6] used Monte Carlo simulation and hypercube model to evaluate the economic risks faced by the CBM industry. Zhang et al [7] determined the optimal index weights by using the optimized combination...
entropy method and the triangular fuzzy number method, and established a coalbed methane development potential evaluation model.

Although there have been some achievements in the field of coalbed methane risk at home and abroad, there are still some shortcomings. Firstly, most of research were qualitative analysis and lacks a quantitative measure of the overall risk of the CBM project. Secondly, the establishment of the indicator system was incomplete and does not include the entire life cycle of the CBM project. Finally, the research dimension of most studies were limited to the national macro level and cannot meet the actual needs of investors, insurance companies and CBM development companies. Based on the above deficiencies, this paper intends to construct a complete theoretical model of risk assessment for coalbed methane development projects based on structural entropy weighting (SEWM) and grey clustering analysis (GCA), and scientifically measure the overall risk level of the project for investors.

2. Construction of Risk Assessment Index System

2.1. Construction of Index System

Based on the results of life cycle risk identification of exploration, exploitation and operation of CBM project development, the key risk factors of CBM development are obtained as risk evaluation indexes. These indexes fully draw on the research results of domestic and foreign literature [8-10], the characteristics of CBM risk and the results of expert interviews. A risk evaluation index system for CBM development projects with six first-level indicators and 28 second-level indexes, including laws and policies, resource characteristics, engineering technology, economic operation, organization and management, and safety assurance, has been formed, as shown in Table 1.

| Primary index          | Secondary index             | Weight  | Primary index          | Weight  |
|------------------------|-----------------------------|---------|------------------------|---------|
| Law and policy $B_1$ 0.2022 | Mineral rights and air rights conflict $B_{11}$ | 0.3661 | Coal seam thickness $B_{35}$ | 0.0635 |
|                        | Major licenses and approvals $B_{12}$                | 0.3665 | Buried depth $B_{46}$    | 0.0908 |
|                        | National policy $B_{13}$                             | 0.2674 | Hydrogeological conditions $B_{47}$ | 0.1164 |
| Engineering technology $B_2$ 0.2019 | Drilling technology $B_{21}$ | 0.1856 | Engineering Geology $B_{48}$ | 0.1050 |
|                        | Mining technology $B_{22}$                            | 0.2137 | Gas content $B_{49}$     | 0.1428 |
|                        | Resource exploration technology $B_{23}$             | 0.2958 | Organization structure $B_{51}$ | 0.247 |
|                        | Drainage system $B_{24}$                             | 0.3049 | Coordination and communication $B_{52}$ | 0.183 |
| Economic operation $B_3$ 0.1355 | Project cost $B_{31}$ | 0.3661 | Process management $B_{53}$ | 0.155 |
|                        | Market demand $B_{32}$                                | 0.3665 | Fineness of Management $B_{54}$ | 0.168 |
|                        | Coal bed gas price fluctuation $B_{33}$              | 0.2674 | Resource allocation $B_{55}$ | 0.247 |
| Resource characteristics $B_4$ 0.1956 | Coal seam area $B_{41}$ | 0.0708 | Safety management system $B_{61}$ | 0.2297 |
|                        | Porosity $B_{42}$                                     | 0.135  | Safety culture $B_{62}$ | 0.1503 |
|                        | Reservoir pressure $B_{43}$                           | 0.137  | Safety input $B_{63}$ | 0.3053 |
|                        | Permeability $B_{44}$                                 | 0.139  | Emergency rescue capability $B_{64}$ | 0.3148 |

2.2. Weight Determination Based on Structural Entropy Weight Method

2.2.1. Basic Principles of Structural Entropy Weight Method

Under the premise of definite index hierarchy, the first and second indexes of this evaluation index system have been listed in Section 2.1. Then, the expert scoring method is used to get the "structural ranking", and the corresponding entropy value is obtained by substituting it into the formula of the
entropy weight method. Finally, the average of the entropy value is calculated to "cognitive exclusion blind", so as to reduce the influence of abnormal data on the calculation of the index weight. The specific steps are as follows [11-12]:

1) Collection of expert opinions

Several experts who are representative, authoritative and fair in the industry are invited to fill in the questionnaire (Table 2). Experts need to fill in forms according to the importance of indexes, and rank indexes according to their importance, such as "1" for "the most important", "2" for "the most important", "3" for "the important". Some indexes can be considered equally important, and experts can discuss the final ranking of these indexes.

2) Computation of membership function and analysis of “eliminating blindness”

The corresponding index set of each questionnaire is $V=\{v_1,v_2,v_3,\ldots,v_n\}$, the "structure sort" is $d=\{d_1,d_2,d_3,\ldots,d_m\}$, then the structural ranking matrix $D=(d_i)_{m \times n}$ formed by k-sheets of questionnaires.

Quantitative transformation of "structural ranking" is carried out, and expert ranking is transformed into quantitative membership function. The transformation formula is as follows:

$$X(I) = -\lambda P(I) \ln P(I)$$  \hspace{1cm} (1)

Let $P_n(I) = \frac{m-I}{m-1}$ take $\lambda = \frac{1}{\ln(m-1)}$, bring in:

$$X(I) = -\frac{1}{\ln(m-1)} \left( \frac{m-I}{m-1} \right) \ln \left( \frac{m-I}{m-1} \right)$$ \hspace{1cm} (2)

Among them, $\ln \left( \frac{m-I}{m-1} \right) = \ln(m-I) - \ln(m-1)$, brought into simplification to get:

$$X(I) = -\frac{(m-I)\ln(m-I)}{m-1} + \frac{m-I}{m-1}$$ \hspace{1cm} (3)

At this time, both sides of the formula are divided by $\frac{m-I}{m-1}$, then $X(I) = -\frac{\ln(m-I)}{\ln(m-1)} + 1$;

$$\frac{X(I)}{m-I} = \frac{1}{\mu(I)} \mu(I) = \frac{\ln(m-I)}{\ln(m-1)}$$ \hspace{1cm} (4)

In formula (4), I is a "structural ordering" given qualitative ranking according to the questionnaires filled out by experts. $\mu(I)$ is a membership function of "Structure Sorting" I, and its value interval is [0,1]. I=1, 2, 3, j, j+1, where j is the maximum ordinal order of the expert, as shown in Table 2 at j=5. m is the conversion parameter, m=j+2, and j=7 when m=5.

When I=1, $P_n(I)$=1, when I=j+1 (where j+1 is the maximum ordinal number), then $P_n(j+1)=1/(j+1)>0, I= d_i$ is brought into formula (4), $\mu(d_i)=b_{ij}$, and $b_{ij}$ is the membership degree of I. It is assumed that each expert has the same "speaking power" for the weight of the evaluation index, $b_{ij} = b_{ij} + b_{2j} + b_{3j} + \ldots + b_{kj}$, is the average sorting intention of k experts for an indicator $V_i$.

At this time, $H_j$ is "cognitive literacy", that is, $H_j = [\max(b_{ij}, b_{2j}, b_{3j}, \ldots, b_{kj}) - b_{ij}] + [\min(b_{ij}, b_{2j}, b_{3j}, \ldots, b_{kj}) - b_{ij}]$]. At this point $H_j=0$. Define that all experts who fill in questionnaires have always ranked an index $V_i$ with the intention of $X_j$, $X_j = b_{ij}(1-H_j)$, $X_j > 0$. $X_j$ is the evaluation vector of index $V_j$ after expert investigation and membership calculation, $X=(x_1,x_2,\ldots,x_6)$.

3) Calculating Index Weight

$$\eta_j = X_j / \sum_{i=1}^{m} X_j, \text{among} \eta_j > 0, \text{and} \sum_{i=1}^{m} \eta_j = 1 \cdot (\eta_1, \eta_2, \ldots, \eta_n).$$ is a set of K experts on indicators $V=\{v_1,v_2,v_3,\ldots,v_n\}$. The unified ranking judgment of the importance degree of represents the judgment policy of experts. $W=(\eta_1, \eta_2, \ldots, \eta_n)$ is the weight vector of $V=\{v_1,v_2,v_3,\ldots,v_n\}$.
2.2.2. Determination of weights

This evaluation invited five experts from the field of coalbed methane development to score the indicator system. Taking the first-level index as an example, this paper uses the structural entropy weight method to calculate the weight. The detailed calculation process is shown in Table 3. Due to space limitations, the calculation process of the weights of the secondary indicators will not be repeated here. The weights of the indicators are shown in Table 1.

### Table 3: Weight calculation process of first-level indicators

| Expert | B1 | B2 | B3 | B4 | B5 | B6 |
|---|---|---|---|---|---|---|
| A   | 2  | 1  | 4  | 3  | 6  | 5  |
| B   | 3  | 2  | 5  | 1  | 6  | 4  |
| C   | 1  | 3  | 5  | 2  | 4  | 6  |
| D   | 1  | 1  | 4  | 2  | 3  | 4  |
| E   | 1  | 2  | 5  | 3  | 4  | 3  |

| bj | 0.950 | 0.934 | 0.624 | 0.899 | 0.593 | 0.635 |
| hj max | 1.000 | 1.000 | 0.712 | 1.000 | 0.827 | 0.827 |
| hj min-bj | -0.122 | -0.107 | -0.059 | -0.072 | -0.237 | -0.278 |
| Hj | 0.036 | 0.020 | 0.015 | 0.014 | 0.001 | 0.0429 |
| Xj | 0.964 | 0.980 | 0.985 | 0.986 | 0.999 | 0.957 |
| ηj | 0.2022 | 0.2019 | 0.1355 | 0.1956 | 0.1307 | 0.1339 |

3. Assessment Model Construction

3.1. Division of Risk Levels

Based on the relevant literature review, the risk characteristics of coalbed methane and the actual situation of production and operation enterprises, this paper divides the risk of coalbed methane industry into five grades as shown in Table 4.

### Table 4: Risk level interval table

| Risk level | Scoring range | Basic features |
|---|---|---|
| I | (8,10] | Risk is very low |
| II | (6,8] | Lower risk |
| III | (4,6] | Moderate risk |
| IV | (2,4] | High risk |
| V | [0,2] | Extremely high risk |

3.2. Construction of Grey Clustering Evaluation Model

3.2.1. Determination of Gray Class and Gray Whitening Weight Function

The rationality of the determination of the gray center point will affect the accuracy of the evaluation results. With reference to past experience, the point with the highest degree of gray is selected as the central point. Combined with the range of risk factors for CBM development, the center point vector U=(9,7,5,3,1) is selected as the gray center point. This paper draws on the central point triangle whitening weight function proposed in the literature [13-14], and combines the characteristics of coalbed methane industry risk to construct the gray matter and gray whitening weight function of coalbed methane industry risk assessment (Table 5).

### Table 5: Grey whitening weight function

| Gray (e) | Grey number (⊗e) | Whitening weight function f[e[dijk]] |
|---|---|---|
| e=1 | ⊗e ∈ [0,9,∞] | f[e[dijk]] = \begin{cases} \frac{d_{ijk}}{9}, & d_{ijk} \in [0,9] \\ 0, & d_{ijk} \in [9,∞] \end{cases} |

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3.2.2. Construction of Grey Cluster Evaluation Model

1) Establishment of evaluation matrix: According to the scope of risk grade of CBM industry, the evaluation matrix $D_i = [d_{ijk}]_{s \times p}$ is established by subjective rating of index $A_j$ by $p$ experts, in which $d_{ijk}$ refers to the subjective rating of index $j$ under index $i$ by experts $(k = 1, 2, ..., p)$, $s$ are the number of factors to be evaluated.

2) Constructing grey clustering weight matrix: $X_{i je} = \sum_{n=1}^{p} f_e [d_{ijk}]$ denotes the clustering coefficient of secondary index $A_j$ in grey class $e; X_{ij} = \sum_{e=1}^{E} X_{ije}$ denotes the clustering coefficient of primary index $A_i$. Continue to calculate the grey clustering weight vector $r_{ije} = x_{ije}/x_{ij}$, and finally construct the grey clustering weight matrix [15]:

$$R_i = \begin{bmatrix} r_{i11} & r_{i12} & r_{i13} & r_{i14} & r_{i15} \\ r_{i21} & r_{i22} & r_{i23} & r_{i24} & r_{i25} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ r_{ij1} & r_{ij2} & r_{ij3} & r_{ij4} & r_{ij5} \end{bmatrix} \quad (5)$$

3) Composite clustering evaluation matrix: With the help of formula (6), the primary index clustering evaluation matrix is obtained.

$$Z_i = \eta_i \cdot R_i \quad (6)$$

Suppose that the first-order index evaluation matrix $Z_0 = [Z_1, Z_2, ... Z_n]$. The final grey clustering evaluation matrix is obtained by formula (7):

$$M = \eta_0 \cdot Z_0 = [M_1, M_2, ..., M_n] \quad (7)$$

4) Synthesizing the final evaluation value $Q$: Using the traditional maximum weight to determine the result of grey evaluation may result in loss of index information. To avoid this situation, vector $M$ and threshold $U$ are synthesized by formula (8) to get the risk level of CBM industry.

$$Q = M^T \cdot U \quad (8)$$

4. Case Study

In order to verify the effectiveness and feasibility of the evaluation system, this paper will take a coalbed methane development project in Qinshui County, Shanxi Province as an example to describe how to use the weight value and gray cluster analysis method to measure the specific risk value of coalbed methane development projects.

4.1. Establish Initial Evaluation Matrixes

According to the risk level of coalbed methane development and the corresponding gray whitening weight function in Table 5, refer to the scores of the five indicators of the coalbed methane development project by five experts in the industry, and establish a matrix of $i$ rows and 5 columns $D_i = [d_{ijk}]_{s \times p}$, where $d_{ijk}$ refers to the subjective scoring $(k = 1, 2, ..., p)$ of the secondary indicator $a_j$ under the first-level indicator $A_i$, and $s$ is the number of factors to be evaluated.
In order to scientifically measure the overall risk value of coalbed methane development projects, this paper constructs six primary indicators and 28 secondary indicators based on a combination of on-site investigation, literature research, legal and legal inquiry. Risk assessment index system for coalbed methane development projects. The weights of each index are calculated based on the structural entropy weight method.

4.2. Constructing Gray Clustering Weight Matrix
According to formula (5), the grey clustering weight matrix $R_i$ is finally constructed:

$$R_i = \begin{bmatrix}
0.252 & 0.324 & 0.356 & 0.068 & 0 \\
0.429 & 0.320 & 0.352 & 0.080 & 0 \\
0.263 & 0.339 & 0.343 & 0.055 & 0
\end{bmatrix}$$

4.3. Synthetic Cluster Evaluation Matrix and Final Evaluation Value
According to formula (6), the primary index clustering evaluation matrix $Z_0$ is obtained:

$$Z_0 = \eta_i \cdot R_i = \begin{bmatrix}
0.2537 & 0.3264 & 0.3509 & 0.0689 & 0.00 \\
0.2540 & 0.3267 & 0.3539 & 0.0653 & 0.00 \\
0.2097 & 0.2697 & 0.3502 & 0.1691 & 0.00 \\
0.2552 & 0.3281 & 0.3546 & 0.0620 & 0.00 \\
0.2045 & 0.2631 & 0.3571 & 0.1750 & 0.00 \\
0.2021 & 0.2598 & 0.3504 & 0.1877 & 0.00
\end{bmatrix}$$

Assuming the obtained first-level index evaluation matrix $Z_0 = [Z_1, Z_2, ...Z_6]$, the final gray clustering evaluation matrix is obtained by using equation (7): $M = \eta_0 \cdot Z_0 = [0.2320 \ 0.2983 \ 0.3525 \ 0.1166 \ 0.0000]$. The vector $M$ is combined with the threshold $U$ by the formula (8) to obtain the risk level of the coalbed methane industry: $Q = M \cdot U^T = 7.2878$. According to the classification of risk level interval in Table 4, the risk level of the CBM development project is Grade II. The evaluation results are consistent with the actual situation of the enterprise, indicating that the established model has certain validity and feasibility.

5. Conclusion
1) In order to scientifically measure the overall risk value of coalbed methane development projects, this paper constructs six primary indicators and 28 secondary indicators based on a combination of on-site investigation, literature research, legal and legal inquiry. Risk assessment index system for coalbed methane development projects. The weights of each index are calculated based on the structural entropy weight method.
2) According to the actual situation of coalbed methane development, the rules for determining the risk level are determined, and the theoretical model of risk assessment for coalbed methane development projects is established based on the grey cluster analysis method.

3) Using the evaluation system constructed, an empirical study was carried out on a coalbed methane development project in Qinshui County, Shanxi Province. After calculation, the overall risk level of the project is Grade II, indicating that the overall risk is small and only partial improvement is needed. The evaluation results are consistent with the actual situation of the enterprise, indicating that the established model has certain validity and feasibility.

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