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Application of the Entropy Weight and TOPSIS Method in Safety Evaluation of Coal Mines

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Abstract

In this paper, evaluation index system of coal mine safety is established on the basis of the SMART principles. Weights of indexes are determined by means of entropy weight method. Safety conditions in four coal mines are applied by used of TOPSIS and the method is compared with other evaluation methods. The case study shows that the method is simple and clear, the evaluation results are reliable which are more coincident with the reality. So the method should be promoted widely in safety evaluation of coal mines.

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1. Introduction

Recently, coal mine safety is an important issue that we need to solve immediately. Safety evaluation of coal mines is to evaluate comprehensively risks and the possible consequences of the proposed or existing projects and the system by used of theories and methods of safety system engineering, then put forward to corresponding security reform measures according to the risks of accidents in order to ensure security of the engineering and system [1]. So safety evaluation of coal mines is an effective means to

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ensure the safe operation of coal mines. Coal mine safety should consider many factors, so choosing an appropriate method is important. At present, the safety evaluation methods used commonly at home and abroad can be divided into two kinds of qualitative and quantitative evaluation methods. Wherein, qualitative evaluation methods have expert evaluation method, safety check list method, fault hypothesis analysis method, ect. Quantitative evaluation methods have exponential method, probability method, fuzzy synthetic evaluation method, BP artificial neural network method, ect. Those methods not only have their own characteristics and feasibility, but also have some drawbacks in the process of disposal [2]. Therefore, it is important that the existing safety evaluation methods are complemented and further researched. In this paper, a comprehensive evaluation model of coal mine safety is established by used of the entropy weight and TOPSIS, then applied to evaluate safety conditions of four coal mines in order to improve the level of safety management and ensure safe production of coal mines.

2. Determination of evaluation index system and indexes' weights

2.1. Principles

Safety evaluation of coal mines is complex. Evaluation indexes are different, evaluation results are different too. In order to comprehensively and objectively reflect safety conditions of coal mines, evaluation index system of coal mine safety is established on the basis of the SMART principles that the World Bank and many national government departments and organizations usually follow in the assessment work [3]. The SMART principles are specific, measurable, attainable, relevant and trackable.

2.2. Evaluation index system

On the basis of "Safety in Production Law of the People's Republic of China", " Safety in Production Law in coal Mine ", " Safety Regulations in Coal Mine " and other relevant laws and regulations of China, as well as spot studies and relevant references combining with experts' opinion and questionnaire, evaluation index system of safety conditions of coal mines is established and shown in the table 1.

Table 1. Evaluation index system of safety conditions of coal mines

Target	Indexes	Symbols of indexes
Evaluation index system of safety conditions of coal mines	Mean quantity of emission gas	C_1
	Drainage rate of gas	C_2
	The times of ten thousand tons of gas overrunning	C_3
	The times of ten thousand tons of gas accumulation	C_4
	The times of ten thousand tons of gas outburst	C_5
	The ratio of air volume's supply and demand	C_6
	The score of safety management	C_7
	Perfectness ratio of ventilation equipment	C_8
	Dust concentration	C_9
	Spontaneous combustion period	C_{10}

2.3. Weights of indexes

When determining weights of indexes, subjective fixed weight methods such as the Delphi method, expert survey method, the analytic hierarchy process method (AHP), ect., are usually used. They could lead to deviations of indexes' weights due to subjective factors. While objective fixed weight methods are based on the inherent information of indexes to determine weights of indexes, which could eliminate man-made disturbances and make results in more accord with facts. In information theory, the entropy by Shannon can be used to determine the disorder degree and its utility in system information. The smaller the entropy value is, the smaller the disorder degree of the system is. Entropy weight method is based on amount of information to determine the index's weight, which is one of objective fixed weight methods. In this paper, the entropy weight method is adopted to determine the weight of the index, which is calculated as follows.

2.3.1. Standardization of indexes

Supposing there are m coal mines and n pieces of indexes in the index system, x_{ij} is the jth index's value in the ith coal mine. In order to eliminate the influence of index dimension on incommensurability, it is necessary to standardize indexes using the equations of relative optimum membership degree.

To the benefit indexes, the attribute value of the jth index in the ith coal mine can be transformed by (1).

$$r_{ij}^{'} = \frac{x_{ij}}{\max_{j} x_{ij}}, (i = 1,..., m; j = 1,..., n) \quad (1)$$

To the cost indexes, the attribute value of the jth index in the ith coal mine can be transformed by (2).

$$r_{ij}^{'} = \frac{\min_{j} x_{ij}}{x_{ij}}, \min_{j} x_{ij} \neq 0, (i = 1,..., m; j = 1,..., n) \quad (2)$$

After standardization of indexes, the standardized index matrix is $R' = [r_{ij}]_{m \times n}$.

2.3.2. Calculation of the index's entropy

According to the definition of entropy, entropy of the jth index is determined by (3).

$$H_j = -\frac{\sum_{i=1}^{m} f_{ij} \ln f_{ij}}{\ln m}, (i = 1,..., m; j = 1,..., n) \quad (3)$$

Wherein:

$$f_{ij} = \frac{r_{ij}^{'}}{\sum_{i=1}^{m} r_{ij}}, (i = 1,..., m; j = 1,..., n) \quad (4)$$

2.3.3. Calculation of the index's entropy weight

Entropy weight of the jth index is determined by (5).

$$w_j = \frac{1 - H_j}{n - \sum_{j=1}^{n} H_j}, \sum_{j=1}^{n} w_j = 1, (j = 1,..., n) \quad (5)$$

In information theory, the entropy weight represents useful information of the evaluation index. Therefore, the bigger the entropy weight of the index is, the more useful information of the index is. It's the same in reverse.

3. TOPSIS method

The full name of TOPSIS is Technique for Order Preference by Similarity to Ideal Solution and it is called Ideal Solution for short. The basic thought is to define the ideal solution and negative ideal solution for decision making problem firstly, then find a feasible solution and rank the coal mine according to the closeness between the feasible solution and the ideal solution, which is made the nearest from the ideal solution and farthest from the negative ideal solution. The solution steps are as follows.

3.1. Structure of the decision matrix

Supposing evaluation set of multi-attribute decision making problem is $M=(M_1,M_2,\ldots,M_m)$, index set is $C=(C_1,C_2,\ldots,C_n)$, the jth index's value in the ith coal mine is x_{ij}, then the decision matrix is $X=[x_{ij}]_{m\times n}$.

3.2. Normalization of the decision matrix

In order to eliminate the influence of index dimension and its variation range on evaluation results, it is necessary to normalize the original matrix to ensure that all the attributes are equivalent and the same format, then the normalized decision matrix is $R=[r_{ij}]_{m\times n}$, which is calculated by (6).

$$r_{ij} = x_{ij} \Big/ \sqrt{\sum_{j=1}^{m} x_{ij}^2}, (i = 1,\ldots, m; j = 1,\ldots, n) \quad (6)$$

3.3. Determination of the weighted decision matrix

The weighted decision matrix is determined by the normalized decision matrix multiplication with weights of indexes and shown by (7).

$$v_{ij} = w_i r_{ij}, (i = 1,\ldots, m; j = 1,\ldots, n) \quad (7)$$

3.4. Determination of the ideal solution

The ideal solution is composed of the optimal value of every attribute from the weighted decision matrix and shown by (8), and the negative ideal solution is composed of the worst value of every attribute from the weighted decision matrix and shown by (9).

$$V^+ = \left(V_1^+, V_2^+, \ldots, V_m^+\right) \quad (8)$$

$$V^- = \left(V_1^-, V_2^-, \ldots, V_m^-\right) \quad (9)$$

Wherein, the ideal value and negative ideal value are determined by (10) ~ (11).

$$V_j^+ = \left| \begin{array}{l} \max v_{ij}, \textit{the benifit indexes} \\ \min v_{ij}, \textit{the cost indedxes} \end{array} \right. \quad (10)$$

$$V_j^- = \left| \begin{array}{l} \max v_{ij}, \textit{the cost indexes} \\ \min v_{ij}, \textit{the benifit indexes} \end{array} \right. \quad (11)$$

3.5. Calculation of the distance

The distance of every feasible solution from the ideal solution and the negative ideal solution is calculated respectively by (12) ~ (13).

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2}, (i = 1,\ldots, m; j = 1,\ldots, n) \quad (12)$$

$$s_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2}, (i = 1,..., m; j = 1,..., n) \quad (13)$$

3.6. Calculation of the relative degree of approximation

The relative degree of approximation is determined by (14).

$$C_i = s_i^- \Big/ (s_i^+ + s_i^-), (0 \le C_i \le 1; i = 1,2,...m) \quad (14)$$

The evaluation object is ranked according to the value of the relative degree of approximation. The bigger the value is, the better the evaluation object is.

4. Case study

Some Mining Bureau examined safety conditions of four coal mines in accordance with relevant production regulations in coal mine and evaluation methods in the process of safe production examination and the surveyed data of evaluation indexes of four coal mines are shown in the table 2. Please evaluate safety conditions of four coal mines.

Table 2. The surveyed data of evaluation index of the four coal mines

Indexes	C_1(m^3/h)	C_2(%)	C_3	C_4	C_5	C_6(%)	C_7	C_8(%)	C_9(mg/m^3)	C_{10}(month)
Coal mine A	10.5	65	0.20	0.18	0.0055	88	90	85	8.5	6
Coal mine B	5	70	0.10	0.12	0.0045	86	84	90	6.5	6.4
Coal mine C	13	45	0.19	0.21	0.010	83	60	79	10	3.5
Coal mine D	11	60	0.26	0.19	0.014	82	55	86	9	4

4.1. Calculation of the entropy weight

According to evaluation indexes which are the benefit indexes or the cost indexes, standardization of indexes is calculated by (1) ~ (2) and shown as follows.

$$R' = \begin{bmatrix} 0.3125 & 0.8000 & 0.3750 & 0.3333 & 0.8947 & 1.000 & 1.0000 & 0.5455 & 0.4286 & 0.8621 \\ 1.0000 & 1.0000 & 1.0000 & 1.0000 & 1.0000 & 0.6667 & 0.8286 & 1.0000 & 1.0000 & 1.0000 \\ 0.0000 & 0.0000 & 0.4375 & 0.0000 & 0.4211 & 0.1667 & 0.1429 & 0.0000 & 0.0000 & 0.0000 \\ 0.2500 & 0.6000 & 0.0000 & 0.2222 & 0.0000 & 0.0000 & 0.0000 & 0.6364 & 0.2857 & 0.1724 \end{bmatrix}$$

Weighs of ten indexes are calculated by (3) ~ (5) and shown in the table 3.

Table 3. Weights of indexes

Indexes	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
H	0.8723	0.9865	0.9377	0.8662	0.9607	0.8792	0.8642	0.9797	0.9122	0.8800
w	0.1483	0.0157	0.0723	0.1554	0.0456	0.1403	0.1577	0.0235	0.1019	0.1393

4.2. Determination of evaluation ranks

The decision matrix of four coal mines decision-making and ten evaluation indexes are established according to the data in the table 2. The normalized decision matrix is established by (7) and shown as follows.

$$R=\begin{bmatrix} 0.5586 & 3.4577 & 0.0106 & 0.0096 & 0.0003 & 4.6812 & 4.7876 & 4.5216 & 0.4522 & 0.3192 \\ 0.2680 & 3.7517 & 0.0054 & 0.0064 & 0.0002 & 4.6093 & 4.5021 & 4.8236 & 0.3484 & 0.3430 \\ 0.7583 & 2.6249 & 0.0111 & 0.0122 & 0.0006 & 4.8414 & 3.4998 & 4.6081 & 0.5833 & 0.2042 \\ 0.6273 & 3.4218 & 0.0148 & 0.0108 & 0.0008 & 4.6765 & 3.1366 & 4.9046 & 0.5133 & 0.2281 \end{bmatrix}$$

The weighted decision matrix is gotten by (7), and when the ideal value and the negative ideal value are obtained by (10) ~ (11), the ideal solution and the negative ideal solution are obtained by (8) ~ (9). They are shown as follows.

$$V=\begin{bmatrix} 0.1291 & 0.1259 & 0.0021 & 0.0007 & 0.0001 & 0.0053 & 0.2981 & 0.0140 & 0.0175 & 0.0291 \\ 0.0619 & 0.1366 & 0.0011 & 0.0005 & 0.0001 & 0.0052 & 0.2804 & 0.0149 & 0.0135 & 0.0313 \\ 0.1753 & 0.0956 & 0.0022 & 0.0009 & 0.0002 & 0.0055 & 0.2179 & 0.0143 & 0.0225 & 0.0186 \\ 0.1450 & 0.1246 & 0.0030 & 0.0008 & 0.002 & 0.0053 & 0.1953 & 0.0152 & 0.0198 & 0.0208 \end{bmatrix}$$

$$V^{+}=(0.0619,0.1366,0.0011,0.0005,0.0001,0.0055,0.2981,0.0152,0.0135,0.0313)$$

$$V^{-}=(0.1753,0.0956,0.0030,0.0009,0.0002,0.0052,0.1953,0.0140,0.0225,0.0186)$$

The distance of every feasible solution from the ideal solution and the negative ideal solution is obtained according to (12) ~ (13). The relative degree of approximation is determined according to (14). Safety conditions of four coal mines could be ranked by the relative degree of approximation and shown in the table 4.

Table 4. The connection number of four coal mines and evaluation ranks

Four coal mines	S^+	S^-	C	Evaluation ranks	Results of reference [4]	Results of reference [5]	Results of reference [6]
Coal mine A	0.0682	0.1173	0.6323	2	2	2	2
Coal mine B	0.0177	0.1484	0.8932	1	1	1	1
Coal mine C	0.1456	0.0227	0.1347	4	4	4	4
Coal mine D	0.1333	0.0421	0.2399	3	3	3	3

4.3. Evaluation results analysis

As can be seen from the table 4, evaluation ranks of four coal mines are as follows: coal mine B > coal mine A > coal mine D > coal mine C. Evaluation results are accordance with the results of the references [4-6], so the results gotten by this method are reasonable. The entropy weight and TOPSIS method which have high resolution and whose the calculation process is simple could objectively evaluate safety conditions of overall coal mines. According to evaluation results, relevant departments could summarize backward reasons and take relevant effective measures to increase the level of safety production management to ensure the safety and stability of coal mines.

5. Conclusions

For multi-index comprehensive evaluation model, determination of the index's weight is important. In this paper, entropy weight method could not only the full use of the inherent information of indexes, but also avoid effectively the subjectivity using the expert scoring method, so the results are more objective.

In this paper, the ideal solution, the negative ideal solution and the relative degree of approximation are determined and safety conditions of coal mines are evaluated according to the value of the relative degree of approximation by used of TOPSIS. The case study shows that the method is rational, feasible and scientific, so it could be applied to safety evaluation of coal mines.

Comparing with fuzzy synthetic evaluation method, BP artificial neural network and other evaluation methods, the entropy weight and TOPSIS method is simple, clear and reasonable. Therefore, the method should be applied widely to the safety evaluation of coal mines.

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