SAFETY EVALUATION OF COAL MINES USING *R*-NORM ENTROPY

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ABSTRACT

In this paper, we have established the evaluation index system of coal mines by using R-norm entropy. The method is explained by using 'A Case Study' on the evaluation of safety conditions of coal mines. Entropy weight method is used to determine the weights of indices. TOPSIS method is used to evaluate the safety conditions in coal mines. A comparison of the proposed method with other existing methods is also given.

Keywords: Entropy, Hamming Distance Measure, R-norm Entropy, Safety Evaluation, TOPSIS, Weight.

I. INTRODUCTION

The safety of coal mines is an important issue which needs an immediate attention. So many people have lost their lives in the accidents occurred in coal mines. Safety evaluation of coal mines is the evaluation of risk factors and consequences due to installation of the project by using the theories and methods available to us and then to develop a system or mechanism which can reduce the fatal accidents or incidents and improve the safety conditions in coal mines. Safety in coal mines depend on many factors. So, we need to choose a method which takes all the factors into account. The safety evaluation methods used all over the world can be broadly classified into two categories, one is qualitative method and other is quantitative method. In qualitative methods there are expert evaluation methods, safety checklist methods and fault hypothesis analysis methods etc. whereas quantitative methods involve exponential methods, probability methods etc. These methods have their own benefits and drawbacks. Therefore, it is necessary to develop more comprehensive methods to meet the requirements. In this paper, we have tried to develop a more comprehensive and reliable method by using TOPSIS and an extended entropy weight method. This rest of the paper is organized as follows:

After the introductory section, we have explained the method of determining the evaluation index system and index's weights in section 2. Section 3 is devoted to the TOPSIS (Technique of Order Preference by Similarity to Ideal Solution) method and its structure. In section 4, a case study on evaluation of coal mines is given. Section 5, is devoted to ranking of alternatives. At last the paper is concluded with the 'Concluding Remarks' in section 6.

II. EVALUATION OF INDICES AND THEIR WEIGHTS

2.1 Principles

To evaluate the safety conditions of coal mines is complicated issue. Depending upon the evaluation indices used, evaluation results also vary. To achieve the target of safety conditions in coal mine, a comprehensive and object oriented approach is needed which coincides with the SMART principles laid down by the World Bank and adopted by many countries. These principles are Specific, Measurable, Achievable, Relevant and Time bound in nature.

2.2 Evaluation Index System

Compiled data of evaluation indices of coal mines are given in the following table 1:

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

Target	Indices	Symbols of Indices
Evaluation index system of safety conditions of coal mines	Average amount gas emitting	O_1
	The rate at which gas is draining	O_2
	The amount of gas overrunning	O_3
	The amount of gas accumulation	O_4
	The amount of gas outburst	O_5
	Air supply and demand ratio	O_6
	The safety management score	O_7
	Perfectness ratio of ventilation equipment	O_8
	Concentration of dust	O_9
	Spontaneous combustion period	O_{10}

2.2 Weights of Indices

To determine the index weights, generally, two methods are used; Subjective Fixed Weight Method and Objective Fixed Weight Method. Expert Survey Method and Delphi Method are the examples of Subjective Fixed Weight Method. In these methods, chances of manmade occurrences are more which can deviate the results and therefore are not preferred. Whereas, in Objective Fixed Weighted Method inherent information of indices is used to determine the weights of indices and this reduces the effects of external disturbances and gives more accurate results. In this paper, we have used the Objective Fixed Weight Method in which we use entropy value to determine the weights of indices. The weights of indices are determined as:

2.3.1 Standardization of indices

For benefit indices, the transformation equation is:

$$\dot{r}_{ij} = \frac{x_{ij}}{\max\limits_{j} x_{ij}}, (i = 1,\ldots,m;\ j = 1,\ldots,n). \quad (1)$$

For cost indices equation of transformation is:

$$\dot{r}_{ij} = \frac{\min\limits_{j} x_{ij}}{x_{ij}}, \ \min_{j} x_{ij} \neq 0, \quad (i = 1,\ldots,m;\ j = 1,\ldots,n) \quad (2)$$

where x_{ij} is the attribute value of j^{th} index on i^{th} coal mine.

Standardized index matrix so obtained is $R' = [r_{ij}]_{m \times n}$.

2.3.2 Entropy of j^{th} index is calculated by using R-norm entropy formula [1] given by:

$$H_R(p_{ij}) = \frac{R}{R-1}\sum_{i=1}^{m}\left[1-\left(\sum_{i=1}^{m}(p_{ij})^R\right)^{\frac{1}{R}}\right](i=1,2,\ldots,m;\ j=1,2,\ldots,n), R>0(\neq 1) \tag{3}$$

where $p_{ij} = \frac{\dot{r}_{ij}}{\sum_{i=1}^{m}\dot{r}_{ij}}(i=1,2,\ldots,m;\ j=1,2,\ldots,n).$ (4)

2.3.3 Entropy weight of j^{th} index is calculated as:

$$w_j = \frac{1-H_R(p_{ij})}{n-\sum_{j=1}^{n}H_j},\ \sum_{j=1}^{n}w_j = 1,\ (j=1,2,\ldots,n). \tag{5}$$

III. TOPSIS METHOD

TOPSIS stands for 'Technique for Order Preference by Similarity to Ideal Solution'. In this method, we calculate the positive ideal solution and negative ideal solution and find the distances of all feasible solutions from these ideal solutions. Then we calculate the relative closeness coefficients and rank the options according to the closeness coefficients in decreasing order. The procedural steps are:

3.1 Let $M=(M_1, M_2, \ldots, M_m)$ be the evaluation set and $O=(O_1, O_2, \ldots, O_n)$ be the index set of a multiple attribute decision making problem. Construct the decision matrix as $R' = [x_{ij}]_{mxn}$ *where* x_{ij} is the value of j^{th} index in i^{th} coal mine.

3.2 To ensure equal weightage to all the attributes and to treat them at par, we normalize the decision matrix as $R'' = [r_{ij}]_{mxn}$ where:

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

3.3 Construct the weighted decision matrix by multiplying equations (5) and (6) as:

$$V = \left[v_{ij}\right] = w_i .r_{ij},(i=1,2,\ldots,m;\ j=1,2,\ldots,n) \tag{7}$$

3.4 Define positive ideal solution (V^+) and negative ideal solution (V^-) as:

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

where

$$V_j^+ = \begin{cases} \max v_{ij}, the\ benefit\ \ indexes \\ \min v_{ij}, the\ \cos t\ \ indexes \end{cases} \tag{9}$$

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$$V_j^- = \begin{cases} \max v_{ij}, \text{the cost indexes} \\ \min v_{ij}, \text{the benefit indexes} \end{cases} \qquad (10)$$

3.5 Determination of Distance Measures

The distance measures of all possible solutions from V^+ and V^- by using **Hamming distance measure** are defined as follows:

$$D_i^+ = \frac{1}{2}\sum_{j=1}^{n}\left(\left|v_{ij} - V_j^+\right|\right)(i = 1,2,\ldots,m;\ j = 1,2,\ldots,n), \qquad (11)$$

and

$$D_i^- = \frac{1}{2}\sum_{j=1}^{n}\left(\left|v_{ij} - V_j^-\right|\right)(i = 1,2,\ldots,m;\ j = 1,2,\ldots,n). \qquad (12)$$

3.6 Determination of Closeness Coefficients

The closeness coefficients are calculated as:

$$C_i = \frac{D_i^-}{\left(D_i^+ + D_i^-\right)}, \left(0 \le C_i \le 1; i = 1,2,\ldots,m\right). \qquad (13)$$

The ranking of alternatives is done according to the values of the closeness coefficients. The alternative with highest value will be the best alternative.

IV. A CASE STUDY ON COAL MINES

This example is adopted from LI *et al.* [2]. In this case study, the safety conditions of coal mines are studied. The compiled data is given in the following Table 2.

Table 2: The Compiled Data of Evaluation Indices.

Index	Coal Mine A_1	Coal Mine A_2	Coal Mine A_3	Coal Mine A_4
O_1 (m^3/h)	10.5	5	13	11
O_2 (%)	65	70	45	60
O_3	0.20	0.10	0.19	0.26
O_4	0.18	0.12	0.21	0.19
O_5	0.0055	0.0045	0.010	0.014
O_6 (%)	88	86	83	82
O_7	90	84	60	55
O_8 (%)	85	90	79	86
O_9(mg/m^3)	8.5	6.5	10	9
O_{10}(month)	6	6.4	3.5	4

The computational steps are as follows:

4.1 Construction of Decision Matrix

Construct the decision matrix $R'=[x_{ij}]$ where x_{ij} is calculated by using (1) and (2) according to the evaluation indices;

$$R' = \begin{bmatrix} .4762 & .9286 & .5 & .6667 & .1818 & 1 & 1 & .9444 & .7647 & .9375 \\ 1 & 1 & 1 & 1 & .2222 & .9773 & .9333 & 1 & 1 & 1 \\ .3846 & .6429 & .5263 & .5714 & 1 & .9432 & .6667 & .8778 & .6500 & .5469 \\ .4545 & .8571 & .3846 & .6316 & .7143 & .9318 & .6111 & .9556 & .7222 & .6250 \end{bmatrix}$$

Weights of ten indices are calculated by using equations (3), (4) and (5) as:

Table 3: Weights of Indices.

Indices	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
H	.5797	.7226	.5971	.6648	.5387	.7537	.7025	.7495	.6951	.6920
w	.1272	.0839	.1219	.1014	.1396	.0745	.0900	.0758	.0923	.0932

4.2 Normalization of Decision Matrix

Construct the normalized decision matrix R'' by using the equation (6) as:

$$R'' = \begin{bmatrix} .0633 & .3919 & .0012 & .0011 & .0000 & .5305 & .5426 & .5125 & .0512 & .0362 \\ .0301 & .4217 & .0006 & .0007 & .0000 & .5180 & .5060 & .5421 & .0392 & .0386 \\ .0942 & .3262 & .0014 & .0015 & .0000 & .6016 & .4349 & .5726 & .0725 & .0254 \\ .0760 & .4144 & .0018 & .0013 & .0000 & .0422 & .0342 & .0450 & .0057 & .0026 \end{bmatrix}$$

4.3 Construction of Weighted Normalized Decision Matrix

Construct the weighted normalized decision matrix by using equation (7) as:

$$V = \begin{bmatrix} .0081 & .0329 & .0001 & .0001 & .0000 & .0395 & .0489 & .0389 & .0047 & .0034 \\ .0038 & .0354 & .0001 & .0001 & .0000 & .0386 & .0456 & .0411 & .0036 & .0036 \\ .0120 & .0274 & .0002 & .0002 & .0000 & .0448 & .0392 & .0434 & .0067 & .0024 \\ .0097 & .0348 & .0002 & .0001 & .0000 & .0422 & .0342 & .0450 & .0057 & .0026 \end{bmatrix}$$

4.4 Determination of Ideal Solutions

The positive ideal solution V^+ and negative ideal solution V^- are calculated by using equations (8), (9) and (10) and are given as:

$$V^+ = (.0038, .0354, .0001, .0001, 0, .0395, .0489, .0450, .0036, .0036)$$

$$V^- = (.0120, .0274, .0002, .0002, 0, .0386, .0342, .0389, .0067, .0024)$$

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4.5 Determination of Distance Measures

The distance measures of all possible solutions from V^+ and V^- are calculated by using equations (11) and (12) as:

$$D_1^+ = .0071,\ D_2^+ = .0040,\ D_3^+ = .0186,\ D_4^+ = .0136$$
$$D_1^- = .0141,\ D_2^- = .0171,\ D_3^- = .0078,\ D_4^- = .0103$$

4.6 Relative Closeness Coefficients

The relative closeness coefficients are calculated by using the equation (13) as:

$$C_1 = .6651,\quad C_2 = .8104,\quad C_3 = .2955,\quad C_4 = .4310$$

Ranking

The ranking of coal mines on the basis of safety conditions is done as in the Table 3.

Table 3: The Ranks of Coal Mines.

Coal Mines	D^+	D^-	C_i	Evaluation Ranks	Results by LI et al. [2]	Results of Ref. [3]	Results of Ref. [4]	Results of Ref. [5]
Coal Mine A_1	.0071	.0141	.6651	2	2	2	2	2
Coal Mine A_2	.0040	.0171	.8104	1	1	1	1	1
Coal Mine A_3	.0186	.0078	.2955	4	4	4	4	4
Coal Mine A_4	.0136	.0103	.4310	3	3	3	3	3

Thus, the ranking of four coal mines in terms of safety conditions is done according to the closeness coefficients. The coal mines are ranked as under:

$$A_2 > A_1 > A_4 > A_3$$

Ranking is in agreement with [2], [3], [4], [5].

V. CONCLUDING REMARKS

In case of multiple attribute decision making problems, weights of attributes play an important role. In this paper, we use an entropy weight method to determine the weights of the attributes. By using this method, we have used the inherent information of indices and eliminated man-made disturbances. In this paper, we have established an evaluation index system of coal mines by using *R*-norm entropy. TOPSIS method is used to rank the coal mines on the basis of safety measures. The method is explained with the help of a case study on coal mines. A comparison of the proposed method is given with other existing methods. This shows that the proposed method is easily applicable, simple and gives reliable output.

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