THE APPLICATION OF THE QUANTIFICATION THEORY IN THE DANGER ASSESSMENT OF THE MINE FLOODING

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ABSTRACT

The mine flooding is one of the three dangerous factors which influence the coal mines in safety production. Only when assessing the danger of the mine flooding reasonably, we can take appropriate steps according to the existing circumstances and can avoid the accidents of the flooding. So, in order to research the danger assessment problem about the mine flooding by the quantification theory, we set up a practical assessing model in the mine flooding and developed a new way to the safety assessment of the coal mine.

Key words: flooding, quantification(II), model, item.

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INTRODUCTION

The problem about the mine flooding is a serious problem which is troubling the coal mine in production all the time. Hundreds of mine flooding accidents have happened since 1950 in our country. Especially the accident, which happened on June 2nd, 1984, in the Gezhuang Mine, in Kailuan, brought a 2053m3/min and caused the economic losses over 0.5 billion yuan. The mine flooding problem has been one of the most serious problems that influence the coal mine in safe production. So it is very important to assess the mine flooding danger reasonably in the coal mine production. Recently, with the application and the development of the safety systems engineering in coal mine departments, people take more and more attentions on the research of the coal mine safety assessment and have obtained lots of valuable results[2-9].The three steps of the safety assessment method of coal mine accidents is supported in Reference Two. The method of index numequation of the safety assessment in coal mine is supported in Reference Three to Five. By introducing the theory of the grey system and the fuzzy mathematics into the safety assessment, Reference Six to Nine also respectively support methods of their own. But most of the quantitative data in the safety assessment are qualitative. This causes lots of inconvenience in the assessment. At present, the method about dealing with the qualitative quantification is the mark method or the index numequation method. The shorting of these methods is that the standard of the quantification is made by the man who marks and the quantification also is done by experience. As a result, it is very hard to reach the quantification results objectively, accurately, and reliably. As an important branch of the method of the multiple factor analysis, the theory of quantification is a powerful tool which can specially process the qualitative data. It uses 0 and 1 to mark the responses. By using the application of the theory of the multiple factor analysis and the method, it also reveals the inner laws of the objects. The problems which are solved by this theory are of high precision and achieve good application results. The theory overcomes the shortcoming of the mark method or the index method. This paper used this theory to research the assessment model of the danger of the coal mine flooding for the first time and successfully solved the quantification problems about the qualitative data. This developed a new way to the safety assessment of the coal mine flooding.

THE ASSESSMENT ITEM AND THE CATEGORY'S BUILDING

The mine flooding is one of the great disasters which are threatening the whole mines. The danger of the mine flooding is decided by lots of qualitative variable numbers. In the theory of the quantification the qualitative illustrating variable is called item and the all kinds of the possible situation of the item are called categories.

The reasonable building of the assessment item is the work of first importance for the building of the assessment model. It influences the precision of the building model directly. In order to choose the assessment item well, the author referred lots of analysis materials about the mine flooding accidents and also carefully investigated the conditions relating to about seven mines such as Taoyang Mine, in Feicheng and so on. According to the main factors of the mine flooding dangerous degree and the bases of the safety supervisor's advice and the engineering geology on the spot, the eight assessment items were determined at last. And each item was classified into four groups' category. There were 32 categories in all. X_1, X_2… X_8 were used to express each assessment item. C_{ij} was used to express each category.(i=1,2,…,8; j=1,2,3,4).

THE DANGEROUS ASSESSMENT MODEL

The Date of the Building Model

The dangerous degree of the mine flooding is classified into 4 grades (grows):

1 - extremely dangerous; 2 - very dangerous; 3 - more dangerous; 4 - a little dangerous

In order to obtain the date of the building model, the author had investigated the hydrogeology structural state, the mine water prospecting, and the preventing plan of the mine water disaster and so on in every mine field of Feicheng Mining Administration. According to specific circumstances of different periods in every mine field, 38 building model samples are determined at last. Among them, there are 10 first grade (extremely dangerous) samples (n_1 =10); 9 second grade (very dangerous) samples (n_2 = 9); 9 third grade (more dangerous) samples (n_3= 9). They are shown in Table 1. If a sample has reactions to the C_{ij} Category (this sample suits the situation of C_{ij}), we would choose 1 as its value. Otherwise, we would choose 0 as its value (i = 1, 2, …, 8; j =1, 2, 3, 4).

Table 1.: Response matrix of samples.

Grade (t)	order	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
		$C_{11}C_{12}$ $C_{13}C_{14}$	$C_{21}C_{22}$ $C_{23}C_{24}$	$C_{31}C_{32}$ $C_{33}C_{34}$	$C_{41}C_{42}$ $C_{43}C_{44}$	$C_{51}C_{52}$ $C_{53}C_{54}$	$C_{61}C_{62}$ $C_{63}C_{64}$	$C_{71}C_{72}$ $C_{73}C_{74}$	$C_{81}C_{82}$ $C_{83}C_{84}$
1 n_1=10	1	0 1 0 0	1 0 0 0	1 0 0 0	1 0 0 0	1 0 0 0	1 0 0 0	1 0 0 0	1 0 0 0
	2	0 1 0 0	0 1 0 0	0 1 0 0	1 0 0 0	1 0 0 0	1 0 0 0	0 1 0 0	0 1 0 0
	3	1 0 0 0	0 1 0 0	0 0 1 0	0 1 0 0	0 1 0 0	0 0 1 0	0 1 0 0	0 1 0 0
	4	1 0 0 0	1 0 0 0	1 0 0 0	1 0 0 0	1 0 0 0	1 0 0 0	1 0 0 0	1 0 0 0
	5	1 0 0 0	0 1 0 0	0 1 0 0	0 1 0 0	0 1 0 0	0 1 0 0	0 1 0 0	0 1 0 0
	6	1 0 0 0	1 0 0 0	1 0 0 0	0 1 0 0	0 0 1 0	0 1 0 0	1 0 0 0	0 1 0 0
	7	0 1 0 0	1 0 0 0	0 1 0 0	1 0 0 0	0 1 0 0	0 1 0 0	0 1 0 0	0 1 0 0
	8	1 0 0 0	0 1 0 0	0 1 0 0	1 0 0 0	1 0 0 0	0 0 0 1	0 0 0 1	0 0 0 1
	9	0 1 0 0	0 1 0 0	0 1 0 0	1 0 0 0	0 1 0 0	0 1 0 0	0 1 0 1	0 1 0 0
	10	0 1 0 0	0 1 0 0	0 1 0 0	1 0 0 0	1 0 0 0	0 1 0 0	0 1 0 0	0 1 0 0
2 n_2=9	1	0 1 0 0	0 1 0 0	0 1 0 0	0 1 0 0	0 1 0 0	0 1 0 0	0 1 0 0	0 1 0 0
	2	0 1 0 0	0 1 0 0	0 0 1 0	0 0 1 0	0 1 0 0	1 0 0 0	0 1 0 0	0 1 0 0
	3	1 0 0 0	0 1 0 0	0 0 1 0	0 0 1 0	0 0 1 0	0 0 1 0	0 1 0 0	0 1 0 0
	4	1 0 0 0	0 0 1 0	0 0 1 0	0 0 1 0	0 0 1 0	0 0 1 0	0 0 1 0	0 0 1 0
	5	1 0 0 0	1 0 0 0	1 0 0 0	0 1 0 0	0 0 1 0	0 0 0 1	0 0 0 1	0 0 0 1
	6	1 0 0 0	0 0 0 1	0 0 1 0	1 0 0 0	1 0 0 0	0 0 0 1	0 0 1 0	0 0 1 0
	7	1 0 0	0 0 0	1 0 0	0 1 0	0 0 1	0 0 0	0 1 0	0 0 0
	8								
	9								

		0 1 0 0 0 0 1 0 0	1 0 1 0 0 0 0 1 0	0 0 1 0 0 0 0 0 1	0 1 0 0 0 0 0 1 0	0 0 0 0 1 1 0 0 0	1 0 0 0 1 0 1 0 0	0 0 0 1 0 0 0 1 0	1 0 0 1 0 0 0 1 0
3 n_3=9	1 2 3 4 5 6 7 8 9	0 0 1 0 0 0 1 0 0 0 1 0 0 1 0 0 0 1 0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 0 1	0 1 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 1 0 0 0 0 1 10 0 0	1 0 0 0 1 0 0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 0 1 0 0 1 0 0 0 0 1 1 0 0 0	0 1 0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 1 0 0 0 0 1 0 1 0 0 0 0 0 1 0 1 0 0 0	0 0 0 1 0 1 0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 0 1 0 1 0 0 0 1 0 0 1 0 0 0	0 1 0 0 0 1 0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 0 1 0 1 0 0 1 0 0 0	0 1 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 1 0 0 0 0 0 1 0 0 1 0 0 1 0 0 1 0 0 0	0 0 1 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 1 0 0 0 1 0 1 0 0 0
4 n_4=10	1 2 3 4 5 6 7 8 9 10	0 0 0 1 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 1 0 0 1 0 0 1 0 0 0 0 0 1 0 0 0 1	1 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 1 0 0 1 0 1 0 0 0	0 1 0 0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 1 1 0 0 0 0 1 0 0	0 0 1 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 1 1 0 0 0 0 0 1 0	0 0 1 0 0 1 0 0 0 0 1 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 1 1 0 0 0	1 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0 0 1 1 0 0 0 0 1 0 0	0 0 0 1 0 0 0 1 0 0 1 0 0 0 0 1 1 0 0 0 0 0 0 1 0 0 0 1 0 1 0 0 1 0 0 0	0 1 0 0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 1 1 0 0 0

		0 0 1 0	0 0 0 1	0 0 0 1	0 0 0 1	0 0 0 1	0 1 0 0	0 1 0 0	0 0 1 0

The Dangerous Mark Model

According to the quantification theory, consider this linear model as follows:

$$y_i^{(t)} = \sum \sum \delta_i^{(t)}(j, k)\, b_{jk} \qquad (1)$$

Among them, $y_i^{(t)}$ is the dangerous score of *i* sample in the t dangerous grade; $\delta_i^{(t)}(j, k)$ is the response of the *i* sample of the C_{jk} category in the *t* dangerous grade. $\delta_i^{(t)}(j, k) = 0$ or 1 (shown in Table 2). b_{jk} is the score of the C_{jk} category, and it is a undetermined constant, $t = 1, 2, 3, 4$; $j = 1, 2, \ldots, 8$; $k = 1, 2, 3, 4$.

We can arrange the response date of Table 2 in original order, and obtain the response matrix. It is expressed as: $X = (\delta_i^{(t)}(j, k))_{38\times 32}$ (2)

Mark $\boldsymbol{b} = [b_{11} \ldots b_{14,} b_{21} \ldots b_{24} \ldots\, b_{81} \ldots, b_{84}]^{\mathrm{T}}$ (3)

$$Y = [\, y_1^{(1)}, \ldots, y_{10}^{(1)}, y_1^{(2)}, \ldots, y_9^{(2)}, \ldots, y_1^{(4)}, \ldots, y_{10}^{(4)}\,] \qquad (4)$$

Then the (1) formula can be changed into

$$Y = X\, b \qquad (5)$$

According to the Fisher Law[1], the problem about determining category score of vector b can be turned into solving the characteristic vector *b* suiting with the max characteristic root λ,which must be satisfied with the (7) equation, of the (6) characteristic equation.

$$C\, b = \lambda D\, b \qquad (6)$$

$$b^T D\, b = 1 \qquad (7)$$

Among them,

$$C = (\bar{X} - \bar{\bar{X}})^{\mathrm{T}} (\bar{X} - \bar{\bar{X}}) \qquad (8)$$

$$D = (\bar{X} - \bar{\bar{X}})^{\mathrm{T}} (\bar{X} - \bar{\bar{X}}) \qquad (9)$$

C is called the discrete difference matrix; *D* is called the total discrete difference matrix.Here:

$$\bar{X} = \begin{bmatrix} \left.\begin{matrix} \bar{\delta}^{(1)}(1,1) & \cdots & \bar{\delta}^{(1)}(1,4) & \bar{\delta}^{(1)}(2,1) & \cdots & \bar{\delta}^{(1)}(8,1) & \cdots & \bar{\delta}^{(1)}(8,4) \\ \cdots & & \cdots & \cdots & & \cdots & & \cdots \\ \bar{\delta}^{(1)}(1,1) & \cdots & \bar{\delta}^{(1)}(1,4) & \bar{\delta}^{(1)}(2,1) & \cdots & \bar{\delta}^{(1)}(8,1) & \cdots & \bar{\delta}^{(1)}(8,4) \end{matrix}\right\}_{n1} \\ \left.\begin{matrix} \bar{\delta}^{(4)}(1,1) & \cdots & \bar{\delta}^{(4)}(1,4) & \bar{\delta}^{(4)}(2,1) & \cdots & \bar{\delta}^{(4)}(8,1) & \cdots & \bar{\delta}^{(1)}(8,4) \\ \cdots & & \cdots & \cdots & & \cdots & & \cdots \\ \bar{\delta}^{(4)}(1,1) & \cdots & \bar{\delta}^{(4)}(1,4) & \bar{\delta}^{(4)}(2,1) & \cdots & \bar{\delta}^{(4)}(8,1) & \cdots & \bar{\delta}^{(1)}(8,4) \end{matrix}\right\}_{n2} \end{bmatrix}_{38\times 32} \qquad (10)$$

$$\bar{\bar{X}} = \begin{bmatrix} \bar{\bar{\delta}}(1,1) & \cdots & \bar{\bar{\delta}}(1,4) & \bar{\bar{\delta}}(2,1) & \cdots & \bar{\bar{\delta}}(8,1) & \cdots & \bar{\bar{\delta}}(8,4) \\ \bar{\bar{\delta}}(1,1) & \cdots & \bar{\bar{\delta}}(1,4) & \bar{\bar{\delta}}(2,1) & \cdots & \bar{\bar{\delta}}(8,1) & \cdots & \bar{\bar{\delta}}(8,4) \\ \cdots & & \cdots & \cdots & & \cdots & & \cdots \\ \bar{\bar{\delta}}(1,1) & \cdots & \bar{\bar{\delta}}(1,4) & \bar{\bar{\delta}}(2,1) & \cdots & \bar{\bar{\delta}}(8,1) & \cdots & \bar{\bar{\delta}}(8,4) \end{bmatrix}_{38\times 32} \qquad (11)$$

$$\bar{\delta}^{(i)}(j,k) = \frac{1}{n_i}\sum_{i=j}^{n_i} \delta_i^{(1)}(j,k) \qquad (12)$$

$$\bar{\bar{\delta}}(j,k) = \frac{1}{38}\sum_{t=1}^{4}\sum_{i=1}^{n_t} \delta_i^{(1)}(j,k) \qquad (13)$$

$t = 1, 2, 3, 4$; $j = 1, 2 \ldots 8$; $k = 1, 2, 3, 4$

Because C and D matrixes are singular matrixes, it needs a suit of special solving method when solving the characteristic equation (6) – (7). We use *the Applied Software of the Quantification Theory* written by the author to calculate the building model, and obtain this result: This problem has 3 determining functions (score models) in total, and the corresponding correlation coefficients (characteristic roots) are 0.97, 0.75, and 0.68 respectively. Here δ (j, k) shows the responses of any sample in C_{jk} category, j = 1, 2… 8; k = 1, 2, 3, 4. The three determining functions are shown as:

$$Y_1 = 0.0\delta(1,1) + 0.07\delta(1,2) + 0.23\delta(1,3) + 0.34\delta(1,4) + 0.0\delta(2,1) - 0.03\delta(2,2) + 0.0\delta(2,3) + 0.06\delta(2,4) + 0.0\delta(3,1) + 0.02\delta(3,2) + 0.0\delta(3,3) - 0.07\delta(3,4) + 0.0\delta(4,1) + 0.05\delta(4,2) + 0.09\delta(4,3) + 0.15\delta(4,4) + 0.0\delta(5,1) + 0.02\delta(5,2) + 0.01\delta(5,3) + 0.1\delta(5,4) + 0.0\delta(6,1) - 0.02\delta(6,2) + 0.03\delta(6,3) - 0.04\delta(6,4) + 0.0\delta(7,1) - 0.07\delta(7,2) + 0.02\delta(7,3) - 0.05\delta(7,4) + 0.0\delta(8,1) + 0.06\delta(8,2) + 0.07\delta(8,3) + 0.16\delta(8,4) \qquad (14)$$

$$Y_2 = 0.0\delta(1,1) + 0.1\delta(1,2) - 0.04\delta(1,3) + 0.16\delta(1,4) + 0.0\delta(2,1) - 0.13\delta(2,2) - 0.41\delta(2,3) + 0.0\delta(2,4) + 0.0\delta(3,1) - 0.40\delta(3,2) - 0.28\delta(3,3) - 0.19\delta(3,4) + 0.0\delta(4,1) + 0.02\delta(4,2) + 0.29\delta(4,3) - 0.03\delta(4,4) + 0.0\delta(5,1) + 0.19\delta(5,2) + 0.04\delta(5,3) - 0.06\delta(5,4) + 0.0\delta(6,1) - 0.03\delta(6,2) - 0.02\delta(6,3) + 0.1\delta(6,4) + 0.0\delta(7,1) + 0.19\delta(7,2) + 0.45\delta(7,3) + 0.12\delta(7,4) + 0.0\delta(8,1) + 0.06\delta(8,2) + 0.2\delta(8,3) + 0.07\delta(8,4) \qquad (15)$$

$$Y_3 = 0.0\delta(1,1) + 0.13\delta(1,2) + 0.28\delta(1,3) - 0.01\delta(1,4) + 0.0\delta(2,1) + 0.08\delta(2,2) + 0.03\delta(2,3) + 0.15\delta(2,4) + 0.0\delta(3,1) - 0.2\delta(3,2) + 0.03\delta(3,3) - 0.27\delta(3,4) + 0.0\delta(4,1) - 0.15\delta(4,2) - 0.08\delta(4,3) - 0.34\delta(4,4) + 0.0\delta(5,1) + 0.06\delta(5,2) - 0.09\delta(5,3) + 0.14\delta(5,4) + 0.0\delta(6,1) + 0.05\delta(6,2) + 0.01\delta(6,3) - 0.21\delta(6,4) + 0.0\delta(7,1) + 0.01\delta(7,2) + 0.1\delta(7,3) + 0.25\delta(7,4) + 0.0\delta(8,1) - 0.10\delta(8,2) - 0.26\delta(8,3) - 0.11\delta(8,4) \qquad (16)$$

The Central Coordinates of each Danger Grade and the Determining Law

Substitute the response vector (17) in the t (t = 1, 2, 3, 4) grade into the (14) – (16) equations.

$$[\ \delta^{(t)}(1,1)\ \ldots\ \delta^{(t)}(1,4)\ \ \delta^{(t)}(2,1)\ \ldots\ \delta^{(t)}(8,1)\ \ldots\ \delta^{(t)}(8,4)\ ] \qquad (17)$$

Then we can obtain three scores, marked as $Y_1^{(t)}$, $Y_2^{(t)}$, $Y_3^{(t)}$.

Mark $\quad V_i = [Y_1^{(t)}, Y_2^{(t)}, Y_3^{(t)}]^T \qquad (18)$

t = 1, 2, 3, 4, V_i is the central coordinate of the t grade. The central coordinates of the four grades are given in Table 2.

Table 2.: The central coordinates of each grade.

grade	the central coordinates (three dimensions)
1	V_1 (0.05, 0.03, -0.06)
2	V_2 (0.14, 0.34, -0.28)
3	V_3 (0.32, 0.31, 0.08)
4	V_4 (0.46, 0.08, -0.20)

The determining law conforms to the minimum distance method. In order to explain the minimum distance method, let's take the three dimensions analysis for example. Assume the responses of a undetermined sample in each category are:

$$[\ \delta(1,1)\ \dots\ \delta(1,4)\ \ \delta(2,1)\ \dots\ \delta(8,1)\ \dots\delta(8,4)\ ] \qquad (19)$$

Substitute the (19) formula into the (14) – (16) equation and can obtain three scores Y_1, Y_2, Y_3.

Mark $\quad V = [Y_1, Y_2, Y_3]^T \qquad (20)$

Order $\quad V - Vt_0 = \min \{V - V_1\} \qquad (21)$

$(1 \le t \le 4)$

Then the undetermined sample is the t_0 danger grade ($1 \le t_0 \le 4$, . is the model value.)

The Analysis of the Models Check-up

There are three score functions in this problem in all. So we can use one dimension, two dimensions, and three dimensions analysis to check up the model. The analysis results of one dimensions (only use the first score function and the first vector of the $V_1 - V_{4)}$, two dimensions (use the first and the second score functions and the first and the second vectors of the $V_1 - V_4$), and three dimensions are shown in Table 3.

Table 3.: The results of models check – up.

grade	sample number	wrong determining number		
		one dimension	two dimensions	three dimensions
1	10	0	0	0
2	9	1	2	1
3	9	0	1	1
4	10	0	0	0
the ratio of right determining		97.37%	92.11%	94.74%

Because the first correlation coefficient (0.97) is very close to 1, the determining capacity of the first determining function is very strong. When using the one dimension analysis, the ratio of the right determining reaches nearly 97.37%. The effect is very ideal. But because the two later correlation coefficients are smaller, the determining effect of the second and the third determining functions is not very good. The enjoinment of them makes the right ratio drop a little. So, we abandoned the second and the third determining functions, and adopted the one dimension model. The one dimension model (14) and the first vector of the V_1- V_4 are used as the determining model at last.

The Examples of the Models Application

Assuming there is a undetermined mine field, first, we inspect its responses in each item and each category. Assume that responses are:

$$(0\ 0\ 1\ 0,\ 0\ 1\ 0\ 0,\ 1\ 0\ 0\ 0,\ 0\ 1\ 0\ 0,\ 0\ 0\ 0\ 1,\ 0\ 1\ 0\ 0,\ 0\ 1\ 0\ 0,\ 0\ 0\ 1\ 0) \qquad (22)$$

Second, substitute the (22) formula into the (14) formula and obtain the danger score of this mine field:

$$Y_1 = 0.33 \qquad (23)$$

Then, evaluate the distance from Y_1 to each one dimension central coordinates (means the first vector 0.05, 0.14, 0.32, 0.46 of the $V_1 - V_4$). According to the minimum distance method, it is very easy to know that the degree of this mine flooding is the third grade (more dangerous).

CONCLUDING REMARKS

(1) This paper used the quantification theory to research the problems about the danger assessment of the mine flooding, built a new method of assessment, and also successfully solved the quantification problems about the safety assessment of the qualitative date, and developed a new way to the safety assessment.

(2) This method has an important useful value. The final model correlation coefficient is 0.97, and the ratio of the right determining reaches 97.37%. The effect is very ideal. So it can be used as the final danger assessment model of the mine flooding.

(3) With the condition of the present mine production, because of the help of the computers in this method, it is quite convenient to be used and it is also very easy to be used practically.

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