

# Occupational hazard evaluation model underground coal mine based on unascertained measurement theory

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**Abstract.** In order to study how to comprehensively evaluate the influence of several occupational hazard on miners' physical and mental health, based on unascertained measurement theory, occupational hazard evaluation indicator system was established to make quantitative and qualitative analysis. Determining every indicator weight by information entropy and estimating the occupational hazard level by credible degree recognition criteria, the evaluation model was programmed by Visual Basic, applying the evaluation model to occupational hazard comprehensive evaluation of six posts under a coal mine, and the occupational hazard degree was graded, the evaluation results are consistent with actual situation. The results show that dust and noise is most obvious among the coal mine occupational hazard factors. Excavation face support workers are most affected, secondly, heading machine drivers, coal cutter drivers, coalface move support workers, the occupational hazard degree of these four types workers is II mild level. The occupational hazard degree of ventilation workers and safety inspection workers is I level. The evaluation model could evaluate underground coal mine objectively and accurately, and can be employed to the actual engineering.

## 1. Introduction

Coal mine occupational hazards have always been the focus of occupational disease prevention and control<sup>[1]</sup>, underground coal mining with limited space, narrow vision, long air replacement cycle characteristics, there are a variety of occupational hazards<sup>[2,3]</sup> that will bring serious harm to miners' health. The study of how to evaluate the occupational hazards is the primary work of occupational hazards control. Many scholars have done some research on mine occupational hazards assessment. For example, Guo J.P. et al <sup>[4]</sup> combined the binary semantics and analytic hierarchy process (AHP), and applied it to the mine occupational hazards risk assessment. Based on Fuzzy Mathematics Method, Wang X.N. et al <sup>[5]</sup> constructed multi-level evaluation model for underground mine occupational hazards. Li H. et al <sup>[6]</sup> combined the analytic hierarchy process with the set pair analysis to conduct a comprehensive evaluation of coal mine occupational hazards. Based on fuzzy hierarchy method combining with the TOPSIS method, Xiong L.X. et al <sup>[7]</sup> proposed an identification method of occupational hazard degree in deep well. How to scientifically qualitatively and quantitatively analyze the uncertainties of occupational hazard in coal mine is the focus of evaluation, unascertained measurement theory provides the appropriate approach. Unascertained measurement theory has been



widely developed in the last decade, especially in the field of risk assessment, such as coal mine safety<sup>[8]</sup>, dumping landslides<sup>[9]</sup>, gob collapse<sup>[10]</sup>, sulfide spontaneous combustion<sup>[11]</sup> and so on. Based on the unascertained measurement theory and the coal mine actual situation, this paper establishes the evaluation model of occupational hazards, and implements the proceduralization through programming technology, and finally applies it to the occupational hazards evaluation of six posts in the actual coal mine.

## 2. Unascertained Measurement Theory

Set the number of evaluation object  $X$  to  $m$  and use  $X_1, X_2, \dots, X_m$  to represent them, so the evaluation object space  $X=\{X_1, X_2, \dots, X_m\}$ . Each Evaluation object  $X_i(i=1, 2, 3, \dots, m)$  all has  $n$  single evaluation index and  $I_1, I_2, \dots, I_n$  are used to represent them, so the evaluation index space  $I_j=\{I_1, I_2, \dots, I_n\}$ . Suppose  $x_{ij}$  represent the measured value of the  $i$ th evaluation object  $X_i(i=1, 2, \dots, m)$  about the  $j$ th evaluation index  $I_j(j=1, 2, \dots, n)$ , so  $X_i=\{x_{i1}, x_{i2}, x_{i3}, \dots, x_{in}\}$ . If  $x_{ij}$  has  $p$  evaluation levels  $C_1, C_2, \dots, C_p$ , use  $U$  to represent evaluation space, so  $U=\{C_1, C_2, \dots, C_p\}$ . Set the harm degree of  $k$  lower than  $k+1$  which is recorded as  $C_k < C_{k+1}$ , so  $C_1 < C_2 < \dots < C_p$ .  $\{C_1, C_2, \dots, C_p\}$  is an ordered partition on the evaluation space  $U$ <sup>[12,13]</sup>.

### 2.1. Single parameter unascertained measure and its matrix

If  $u_{ijk}=u$  is the measured value which represents the  $k$ th evaluation level of  $x_{ij}$  and  $u$  conforms to formula (1)~(3), then  $u$  is called single unascertained measure, namely, single index measure.

$$0 \leq u(x_{ij} \in C_k) \leq 1 \quad (1)$$

$$u(x_{ij} \in U) = 1 \quad (2)$$

$$u \left| x_{ij} \in \bigcup_{l=1}^k C_l \right| = \sum_{l=1}^k u(x_{ij} \in C_l) \quad (3)$$

Among them: the formula (1) indicates that index measure is non-negative bounded, the formula (2) indicates that the index measure has the normalization in the rank space and the formula (3) is the accumulation of the level space of  $u$  and in the formula  $i=1, 2, \dots, m; j=1, 2, \dots, n; k=1, 2, \dots, p$ . A certain index measure value of  $X_i$  is  $u_{ijk}$  and the matrix  $(u_{ijk})_{n \times p}$  is composed of all measure values  $u_{ijk}$ , which is called single index measure matrix. The matrix is shown as formula (4).

$$(u_{ijk})_{n \times p} = \begin{bmatrix} u_{i11} & u_{i12} & \cdots & u_{i1p} \\ u_{i21} & u_{i22} & \cdots & u_{i2p} \\ \vdots & \vdots & \ddots & \vdots \\ u_{in1} & u_{in2} & \cdots & u_{inp} \end{bmatrix} \quad (4)$$

### 2.2. Unascertained measure function

In order to get unascertained measure accurately and rapidly, the concrete expression of the measure function needs to be constructed and the measure value can be calculated by this function. The constructed function must follow the principle of “non-boundedness”, “normalization”, “accumulation”, otherwise the result is wrong. The classical methods of constructing the measure function include the straight line method, the quadratic curve method and the exponential curve method etc. the straight line method is widely used, practical and acceptable and the expressions are shown in formula (5). In the formula,  $x$  is the index measure value,  $u_k(x)$  and  $u_{k+1}(x)$  are the measured values of  $x$  in the  $C_k, C_{k+1}$  states.  $a_k$  and  $a_{k+1}$  respectively represents the intermediate value of the measured value  $x$  in the  $C_k$  and  $C_{k+1}$  state.

$$\left\{ \begin{array}{l} u_k(x) = \begin{cases} \frac{-x}{a_{k+1} - a_k} + \frac{a_{k+1}}{a_{k+1} - a_k}, a_k < x \leq a_{k+1} \\ 0, x > a_{k+1} \end{cases} \\ u_{k+1}(x) = \begin{cases} 0, x \leq a_k \\ \frac{x}{a_{k+1} - a_k} - \frac{a_k}{a_{k+1} - a_k}, a_k < x \leq a_{k+1} \end{cases} \end{array} \right. \quad (5)$$

### 2.3. Information entropy index weight

If  $w_{ij}$  represents the importance of evaluation index  $I_j$  of object  $X_i$  compared with other index, namely,  $w_{ij}$  is the weights of evaluation index  $I_j$  of  $X_i$  and it should be consistent with  $0 \leq w_{ij} \leq 1$ ,  $\sum_{j=1}^n w_{ij} = 1$ . The index weight is determined by the information entropy theory. According to the formula (6) and (7) into the known index measure value is  $u_{ijk}$ , we can calculate the index weight  $w_{ij}$ . For an evaluation object, the index weight vector of evaluation object  $X_i$  is recorded as  $W_i = \{w_{i1}, w_{i2}, \dots, w_{in}\}$ .

$$v_{ij} = 1 + \frac{1}{\lg p} \sum_{j=1}^n (u_{ijk} \times \lg u_{ijk}) \quad (6)$$

$$w_{ij} = v_{ij} / \sum_{j=1}^n v_{ij} \quad (7)$$

### 2.4. Multi index unascertained measure

If  $u_{ik} = u(u_i \in C_k)$  is the measured value which represents the  $k$ th evaluation level of  $X_i$ ,  $w_{ij}$  is the weights of evaluation index  $I_j$  of object  $X_i$  and it conforms to non-boundedness:  $0 \leq u_{ij} \leq 1$ , normalization:  $\sum_{k=1}^p u_{ik} = 1$ , accumulation:  $u(u_i \in U) = \sum_{k=1}^p u_{ik}$ , then  $u_{ik}$  is the multi index unascertained measure of evaluation object  $X_i$  and the calculation formula is shown as formula (8).  $u_i = \{u_{i1}, u_{i2}, \dots, u_{ip}\}$  is used to represent the multi index unascertained measure of a certain object.

$$u_{ik} = \sum_{j=1}^n w_{ij} u_{ijk} \quad (8)$$

### 2.5. Confidence criterion

If  $\{C_1, C_2, \dots, C_p\}$  is an ordered partition of the evaluation space and satisfies  $C_1 < C_2 < \dots < C_p$ , then  $\lambda$  is set as the confidence according to confidence criterion, the range of  $\lambda$  is  $\lambda \geq 0.5$ . The evaluation object  $X_i$  belongs to the  $k_0$ th rating, namely  $C_{k_0}$ .

$$k_0 = \min \left| k : \sum_{i=1}^k u_i > \lambda, k = 1, 2, \dots, p \right| \quad (9)$$

### 2.6. Sorting

If the evaluation results of multiple objects are sorted by the degree of occupational hazard, then the  $q$  value of the relative degree of occupational hazard is defined as the comparison parameter. If

$C_1 < C_2 < \dots < C_p$ , let the score of  $C_i$  be  $I_i$ , there are  $I_i < I_{i+1}$  and  $q = \sum_{i=1}^p I_i u_i$ . In the formula  $u_i$  is the unascertained measure belongs to the  $i$ th level of evaluation object,  $q$  represents the parameter of occupational hazard degree and different objects can be sorted according to the value of  $q$ .

### 3. Occupational Hazards Evaluation Model of Coal Mine

#### 3.1. Evaluation index system of occupational hazards in coal mine

Through the coal mine underground workplace occupational hazards on-site research, based on the relevant research standards<sup>[14,15]</sup> and the relevant literature research<sup>[4,5]</sup>, eight indicators were selected to establish the evaluation index system of occupational hazards in coal mine. Quantitative and quantitative indicators were quantified, as shown in Table 1 and Table 2.

**Table 1.** The quantitative indicators' grading standards of occupational hazard evaluation

Indicator	I level, relatively harmless	II level, slight harm	III level, moderate harm	IV level, Serious harm
Respirable dust, $I_1$ (mg/m <sup>3</sup> )	<3.5	3.5-7	7-16	>16
Hazardous gas index, $I_2$	<1.0	1.0-1.5	1.5-3.0	>3.0
Noise, $I_3$ (dB)	<85	85-90	90-95	>95
Temperature, $I_4$ (°C)	15-25	25-28 or 10-15	28-34 or 5-10	>34 or <5
Humidity, $I_5$ (%)	40-60	30-40 or 60-75	20-30 or 75-85	<20 or >85
Wind speed, $I_6$ (m/s)	0.5-1.5	0.35-0.5 or 1.5-3.0	0.25-0.35 or 3-4	<0.25 or >4

**Table 2.** The qualitative indicators' classification and assignment about occupational hazard evaluation

Indicators	I level, relatively harmless	II level, slight harm	III level, moderate harm	IV level, serious harm
Value	1	2	3	4
Work space, $I_7$	Spacious	Limited	Narrow	Extremely narrow
Labour intensity, $I_8$	Light	Medium	Heavy	Extremely heavy

#### 3.2. The solution process of coal mine occupational hazard evaluation model

(1) Construct the occupational hazard evaluation index system. Eight occupational hazards were selected as the discriminant indexes, and the occupational hazard evaluation index system was constructed and classified.

(2) Quantify the evaluation index of each object. Through the measurement of the evaluation indexes of the coal mine, the evaluation index of the occupational hazards in the mine is quantified.

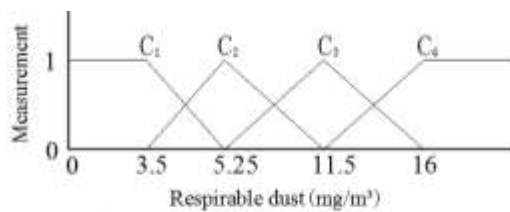
(3) Establish an unascertained measure function. This paper use the straightness measure function, according to the index classification criteria of Table 1 and Table 2, the indicators measurement function was created, as shown from Figure 1 to Figure 8.

(4) Solve the index unascertained measurement matrix. According to the results of step (2) and step (3), the unascertained measurement of each index could be solved and the unascertained measure matrix was composed.

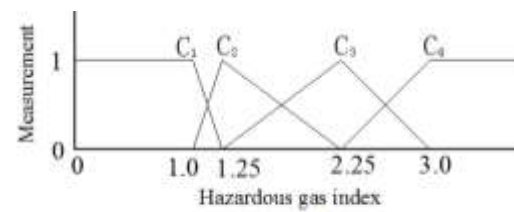
(5) According to the information entropy theory to calculate the weight coefficient of each index.

(6) Calculate the multi-index measure vector. The formula is shown in (8).

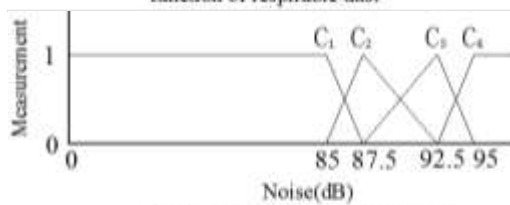
(7) According to the confidence degree identification criteria, the evaluation results were obtained.



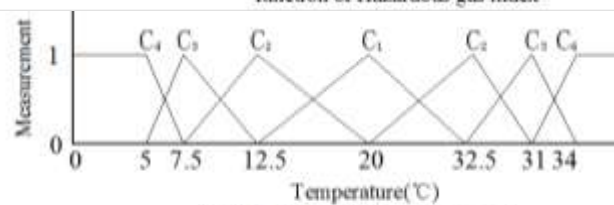
**Figure 1.** Uncertainty measurement function of respirable dust



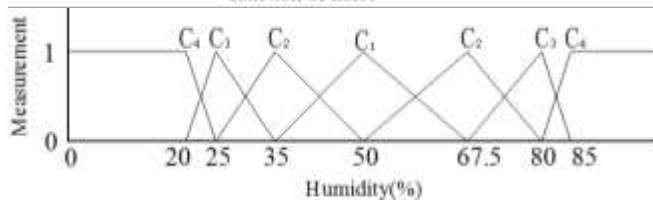
**Figure 2.** Uncertainty measurement function of Hazardous gas index



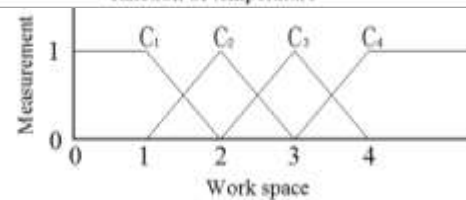
**Figure 3.** Uncertainty measurement function of noise



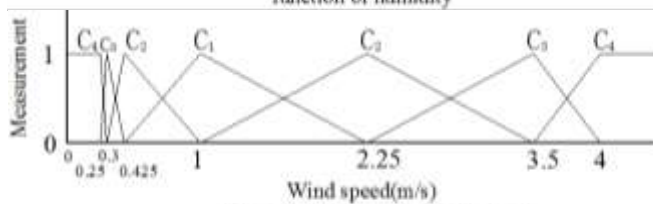
**Figure 4.** Uncertainty measurement function of temperature



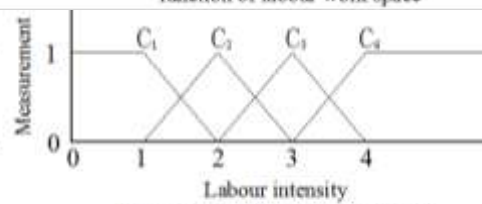
**Figure 5.** Uncertainty measurement function of humidity



**Figure 7.** Uncertainty measurement function of labour work space



**Figure 6.** Uncertainty measurement function of wind speed



**Figure 8.** Uncertainty measurement function of labour intensity

### 3.3. Programming of occupational hazard evaluation model for coal mine

In order to realize the programming of the evaluation model, the Visual Basic language is used to program, and the VB good visual interface is used to link the Access database, and the application software of coal mine occupational hazard evaluation was compiled, as shown in Figure 9.

**Figure 9.** The software of coal mine occupational hazard evaluation

#### 4. Example Application

By investigating the occupational hazards of coal mine operators, combined with the relevant drawings and materials of the mine, a total of six posts, including heading machine drivers, coal cutter drivers, coalface move support workers, ventilation workers, excavation face supporting workers and safety inspection workers. The eight occupational hazards indicators were measured and analysed during these six posts work period respectively, the occupational hazard indicators of the measured results shown in Table 3.

**Table 3.** The occupational hazard evaluation indicators' value of operation posts underground coal mine

Posts	Respirable dust, $I_1$ (mg/m <sup>3</sup> )	Hazardous gas index, $I_2$	Noise, $I_3$ (dB)	Temperature, $I_4$ (°C)	Humidity, $I_5$ (%)	Wind speed, $I_6$ (m/s)	Work space, $I_7$	Labour intensity, $I_8$
Heading machine drivers	59.70	0.32	93.1	27.8	68.2	2.31	3	2
Coal cutter drivers	49.50	0.34	92.0	28.5	63.0	1.54	3	2
Coalface move support workers	37.40	0.20	88.4	28.3	64.5	1.30	3	3
Ventilation workers	10.80	0.07	90.1	23.1	62.4	2.25	2	2
Excavation face supporting workers	27.10	0.16	94.3	27.4	65.2	2.14	3	3
Safety inspection workers	11.50	0.03	83.5	24.5	61.1	0.86	2	1



In Table 3, the measured data of the occupational hazards indicators of the six posts are input into the unascertained measure evaluation software for occupational hazards in coal mine. The selection method is linear method and the confidence degree is 0.5. The evaluation result can be obtained, as shown in Table 4. The results of the evaluation model are consistent with the present situation of the coal mine.

**Table 4.** The evaluation results of occupational hazard underground coal mine

Results	Heading machine drivers	Coal cutter drivers	Coalface move support workers	Ventilation workers	Excavation face supporting workers	Safety inspection workers
Evaluation results	II level, slight harm	II level, slight harm	II level, slight harm	I level, relatively harmless	II level, slight harm	I level, relatively harmless

Ranking the occupational hazards degree of the six posts. Due to  $C_1 < C_2 < C_3 < C_4$ , the scores of  $C_1$ ,  $C_2$ ,  $C_3$  and  $C_4$  are 1, 2, 3 and 4 respectively. According to the formula (10), The relative degree of occupational hazards of each post calculated,  $\{q_1, q_2, q_3, q_4, q_5, q_6\} = \{2.531, 2.447, 2.324, 2.302, 2.587, 1.479\}$ . According to the post by the severity of occupational hazards, the results are: excavation face supporting workers > heading machine drivers > coal cutter drivers > coalface move support workers > ventilation workers > safety inspection workers.

## 5. Conclusion

(1) Based on the comprehensive consideration of coal mine occupational hazards, eight occupational hazard evaluation indexes were selected and the evaluation index system was established. The unascertained measure theory was introduced, the information entropy was applied to determine the index weight, and the coal mine occupational hazard evaluation model was established, which provides a new method for coal mine occupational hazard evaluation.

(2) Based on the theoretical basis of the unascertained measure evaluation model of occupational hazards in coal mine, Visual Basic language is used to design and visualize the interface design, link the Access database, compile the mine occupational hazard evaluation software, and facilitate the mine occupational hazard evaluation model Promotion and application.

(3) Taking the actual situation of a coal mine as an example, through the investigation of six posts underground coal mine, the self-compiled evaluation software was applied to measure the evaluation index, the results of the evaluation model are consistent with the present situation of the coal mine.

(4) In order to further improve the universality of coal mine underground occupational hazard evaluation model based on unascertained theory, it is necessary to carry out research on different coal mine and establish a more widely applicable measure function, so that the model could be maturely applied in practice.

## Acknowledgments

This work was supported by the National Natural Science Foundation of China (No. 51574016).

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