IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

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

To cite this article: Quanlong Deng *et al* 2017 *IOP Conf. Ser.: Earth Environ. Sci.* **64** 012039

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

Quanlong Deng, Zhongan Jiang*, Yaru Sun and Ya Peng

School of Civil and Resource Engineering, University of Science and Technology Beijing, Beijing 100083, China

*Corresponding author e-mail: jza1963@263.net

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[1], underground coal mining with limited space, narrow vision, long air replacement cycle characteristics, there are a variety of occupational hazards[2,3] 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 [4] 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 [5] constructed multi-level evaluation model for underground mine occupational hazards. Li H. et al [6] 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 [7] 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 [8], dumping landslides [9], gob collapse [10], sulfide spontaneous combustion [11] 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 $X_1, X_2, \ldots, X_m$ to represent them, so the evaluation object space $X=\{X_1, X_2, \ldots, X_m\}$. Each Evaluation object $X_i(i=1, 2, 3, \ldots, m)$ all has n single evaluation index and $I_1, I_2, \ldots, I_n$ are used to represent them, so the evaluation index space $I_j=\{I_1, I_2, \ldots, I_n\}$. Suppose x_{ij} represent the measured value of the ith evaluation object $X_i(i=1, 2, \ldots, m)$ about the jth evaluation index I_j $(j=1, 2, \ldots, n)$, so $X_i=\{x_{i1}, x_{i2}, x_{i3}, \ldots, x_{in}\}$. If x_{ij} has p evaluation levels $C_1, C_2, \ldots, C_p$, use U to represent evaluation space, so $U=\{C_1, C_2, \ldots, C_p\}$. Set the harm degree of k lower than $k+1$ which is recorded as $C_k<C_{k+1}$, so $C_1<C_2<\ldots<C_p$. $\{C_1, C_2, \ldots, C_p\}$ is an ordered partition on the evaluation space U[12,13].

2.1. *Single parameter unascertained measure and its matrix*

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

$$0 \le u(x_{ij} \in C_k) \le 1 \tag{1}$$

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

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

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 $i=1, 2, \ldots, m;$ $j=1, 2, \ldots, n;$ $k=1, 2, \ldots, p$. 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).

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

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.

$$\begin{cases} u_k(x)=\begin{cases}\dfrac{-x}{a_{k+1}-a_k}+\dfrac{a_{k+1}}{a_{k+1}-a_k}, a_k < x \le a_{k+1} \\ 0, x > a_{k+1}\end{cases} \\ u_{k+1}(x)=\begin{cases} 0, x \le a_k \\ \dfrac{x}{a_{k+1}-a_k}-\dfrac{a_k}{a_{k+1}-a_k}, a_k < x \le a_{k+1}\end{cases}\end{cases} \tag{5}$$

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 $0 \le w_{ij} \le 1$, $\sum_{j=1}^{n} w_{ij} = 1$. 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 $W_i=\{w_{i1}, w_{i2}, \ldots, w_{in}\}$.

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

$$w_{ij} = v_{ij} / \sum_{j=1}^{n} v_{ij} \tag{7}$$

2.4. *Multi index unascertained measure*

If $u_{ik}=u(u_i \in C_k)$ is the measured value which represents the kth 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: $0 \le u_{ij} \le 1$, 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). $u_i=\{u_{i1}, u_{i2}, \ldots, u_{ip}\}$ is used to represent the multi index unascertained measure of a certain object.

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

2.5. *Confidence criterion*

If $\{C_1, C_2, \ldots, C_p\}$ is an ordered partition of the evaluation space and satisfies $C_1 < C_2 < \ldots < C_p$, then λ is set as the confidence according to confidence criterion, the range of λ is $\lambda \ge 0.5$. The evaluation object X_i belongs to the k_0th rating, namely C_{k0}.

$$k_0 = min\left| k : \sum_{i=1}^{k} u_i > \lambda, k = 1,2,\ldots,p \right| \tag{9}$$

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

$C_1 < C_2 < \ldots < C_p$, 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 ith 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[14,15] and the relevant literature research[4,5], 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^3)	<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 (℃)	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.

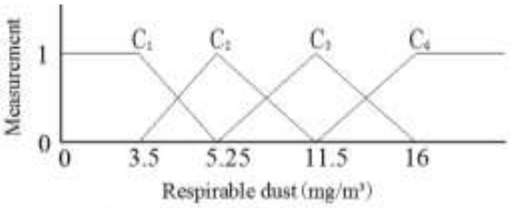

Figure 1. Uncertainty measurement function of respirable dust

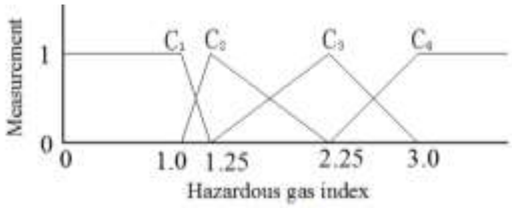

Figure 2. Uncertainty measurement function of Hazardous gas index

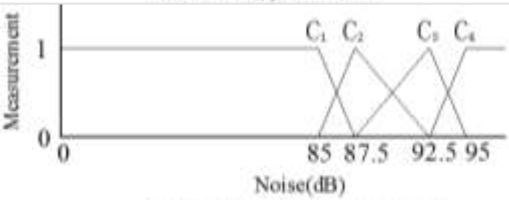

Figure 3. Uncertainty measurement function of noise

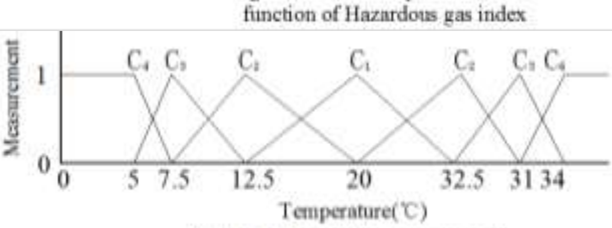

Figure 4. Uncertainty measurement function of temperature

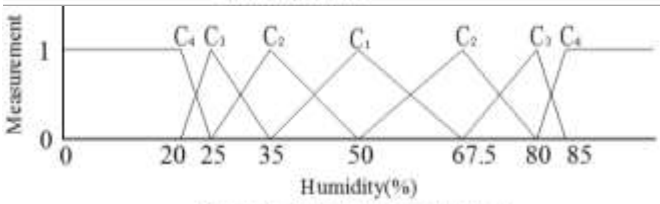

Figure 5. Uncertainty measurement function of humidity

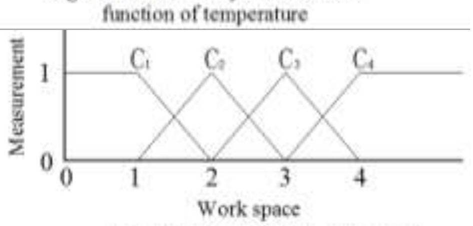

Figure 7. Uncertainty measurement function of labour work space

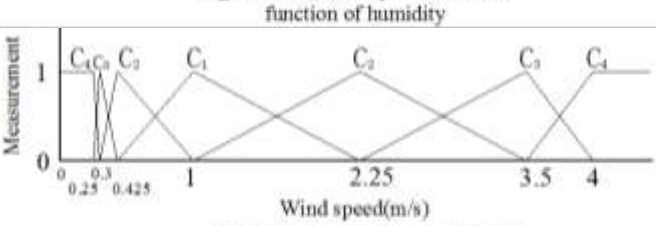

Figure 6. Uncertainty measurement function of wind speed

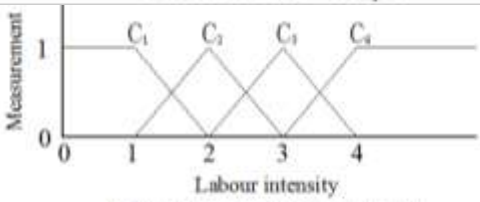

Figure 8. Uncertainty measurement function of labour intensity

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^3)	Hazardous gas index, I_2	Noise, I_3(dB)	Temperature, I_4 (℃)	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).
*Corresponding author. Tel.: +86 010- 62313972; E-mail addresses: jza1963@263.net.

References

[1] Wang Z.X., Qin R.L., Li Y.Z., et al, A study of occupational hazards in 23 coal mine enterprises in China and their protection status. Journal of Environmental & Occupational Medicine, 2009, 26(6): 565−568.
[2] Liao H.J., Sun Q.Y., Zhang Z.B., et al, Analysis for cross-sectional survey data of occupational hazards in coal mine. Journal of Safety Science and Technology, 2009, 5(5): 152−156.

[3] Shen B.H., Lei Y., Guo Y.H, Progress of coal science and technology in China. Journal of China Coal Society, 2011, 36(11): 1779−1783.
[4] Guo J.P, Shang J.Y., Wang X.N., Comprehensive safety evalution method for mine occupational hazards based on two-tuple linguistic information and APH. China Safety Science Journal, 2011, 21(8): 116−122.
[5] Wang X.N., Guo J.P., Study on the occupational hazards evaluation system of underground mine. Metal Mine, 2011 (4): 130−133.
[6] Li H., Tian Y.Q., Zhong X.R., Comprehensive evaluation of the occupational hazards in coal enterprises by using identical discrepancy contrast model. Journal of Safety and Environment, 2012, 12(3): 216−219.
[7] Xiong L.X., Luo Z.Q., Wu C., et al, Evaluation method for occupational hazards of confined space of deep mines. Metal Mine, 2014(11): 132−137.
[8] Cao Q.K., Yang Y.L., Yu R.L., The coal mines safetyappraisal based on unascertained set. Journal of China Coal Society, 2007, 32(2): 181−185.
[9] Luan T.T., Xie Z.H., Wu Z.Z., et al, Risk evaluation model of waste dump landslide based on uncertainty measurement theory. Journal of Central South University (Science and Technology), 2014, 45(5): 1612−1617.
[10] Gong F.Q., Li X.B., Dong R.J., et al, Underground goaf risk evaluation based on uncertainty measurement theory. Chinese Journal of Rock Mechanice and Engingeering, 2008, 27(2): 323−330.
[11] Yang F.Q., Wu C., Risk assessment on spontaneous combustion of sulfide ore dump in stope based on uncertainty measurement theory. Journal of Central South University (Science and Technology), 2010, 41(6): 2373−2380.
[12] Wang G.Y., Uncertainty information and its mathematical treatment. Journal of Harbin Architecture and Engineering Institute, 1990, 23(4):52−58.
[13] Liu K.D., Wu H.Q., Wang N.P., et al, Uncertainty mathematics. Huazhong University of Science and Technology Press, 1997: 199−206.
[14] GBZ 2.1—2007 Occupational exposure limits for hazardous agents in the workplace Part 1: Chemical hazardous agents [S]. People's Medical Publishing House, 2008.
[15] GBZ 2.2—2007 Occupational exposure limits for hazardous agents in the workplace Part 2: Physical hazardous agents [S]. People's Medical Publishing House, 2008.