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Coal Mine Safety Comprehensive Evaluation Based on Extension Theory

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Abstract

This paper indicates that Extenics theory can be used to solve the problem of mine safety. The method includes 4 steps: building the evaluation indexes system and matter-element model, determining the classical field and controlled field of the matter-element model of the coal mine safety comprehensive evaluation, determining the connection function of each index on every safety level and determining the evaluation grade. This paper builds up a coal mine safety comprehensive evaluation indexes system and a matter-element model of coal mine based on extension theory, and then illustrates.the model using a case of Bei-zao Mine and its data.

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*Keywords:*coal mine safety, extension theory, evaluation model;

1 Introduction of the Matter-element Model

1.1 Definition of Matter Element

Matter-element, an essential concept of the extension theory, joins a matter's quantity with its quality reasonably. Defining the name of a matter by N, one of the characteristics of the matter by c, and the value of c of N by v, a matter-element in extension theory can be described as follows:

$$R = (N, c, v) \quad (1)$$

where N, c and v are called the three fundamental elements of the matter element.

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1.2 Multidimensional Matter Element

Assuming R = (N, c, v) is a multidimensional matter element, $c_1, c_2, ...c_n$ is a characteristic vector , and $v_1, v_2, ...v_n$ is a value vector of $c_1, c_2, ...c_n$, then a multidimensional matter element is

$$R = \begin{bmatrix} N & c_1 & v_1 \\ & c_2 & v_2 \\ & \cdots & \cdots \\ & c_n & v_n \end{bmatrix} = (N, c, v) \qquad (2)$$

where $R_i = (N, c_i, v_i)(i = 1,2...n)$ is defined as the submatter element of R.

1.3 Matter Element Model of a Comprehensive Evaluation Issue

Assuming a comprehensive evaluation issue named N and has n number of impact factors, then the matter element Model is:

$$R = (N, c_j, v_j) = \begin{bmatrix} N & c_1 & v_1 \\ & c_2 & v_2 \\ & \cdots & \cdots \\ & c_n & v_n \end{bmatrix} \quad (j=1,2\cdots n) \qquad (3)$$

Assuming there are m indexes and the matter element's divergence rule $c_j = \{c_{j1}, c_{j2}, ...c_{jm}\}$ then $R = (N, c_{jk}, v_{jk})$ (k=1，2，…m，m changes with j) which can be simplified as follows:

$$R = (N, c_j, v_j) = \begin{bmatrix} N & c_1 & v_1 \\ & c_2 & v_2 \\ & \cdots & \cdots \\ & c_l & v_l \end{bmatrix} (j = 1,2...l; l = n \times m) \qquad (4)$$

2 Building Coal Mine Safety Comprehensive Evaluation Indexes System

Coal mine safety is a complex system in which the factors of time and space make influence each other. How to find the fit indexes to evaluate coal mine safety is a thoughtful problem. In 1994 the National Labor Department put forward to some principles to select the evaluation indexes of coal mine safety according to the result of a research project named "Building Coal Mine Safety Evaluation System". Those principles are: purposive, scientific, systematization, operability, independence, directivity, prominence and comparability.

Following the principles a coal mine safety evaluation indexes system was built after selecting representative evaluation indexes (See Fig.1).

Fig.1 shows 7 different index parts each of which contain a few of practical indexes. The contents of these practical indexes are:

1) Production Management indexes includes the efficiency of the safety management department, safety examination, culling density, safety rules and regulations, work regulations.

2) Workers Management indexes evaluate workers in the aspects of qualifications, skill level, proficiency, safety awareness and safety training.
3) Information Management indexes consists of the integral performance of the mine accident monitor system and safety information management.
4) Factory Operating indexes include mining activities of opencast and underground coal mine.
5) **Performance Appraisal** indexes include reward or punishment measure and its strength, the degree and used time to fulfill task.
6) **Factory Circumstance** indexes include production capacity input, safety input, industry challenge level, sale price, enterprise profit and profit rate, and production efficiency and daily output of the working face.
7) **Insurance property** indexes include insurance indemnification, industrial injury insurance funds and its rate, industrial injury insurance funds of profession.
To be more precise , some of the first class indexes should set the second class indexes. Factory operating is one of the first class indexes. Its indexes of mining activities of opencast coal mine include detail indexes as follows: drilling auxiliary operation, demolition auxiliary operation, mining and loading auxiliary operation, transportation and unloading auxiliary operation, field management, dust and poison control, drainage and fire protection. As well underground coal mine indexes include: mine gas, fire and water protection ,dust protection, demolition, mechanical and electrical equipment, transportation and uploading system.

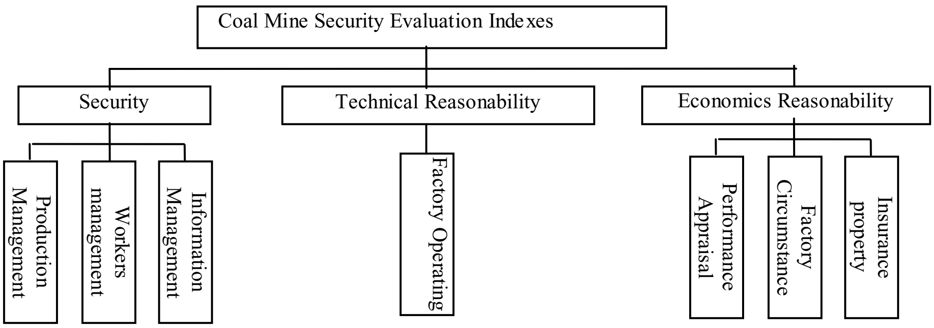

Fig.1 Layer Structure of Coal Mine Security Evaluation Indexes

3 Using Extension Theory in Coal Mine Safety Comprehensive Evaluation

3.1 Coal Mine Safety Comprehensive Evaluation Method based on Extension Theory

The method includes 4 steps. First is building the evaluation indexes system and matter-element model which has been finished with the result of formula (4). Second step is determining the classical field and controlled field of the matter-element model of the coal mine safety comprehensive evaluation. Third step is determining the connection function of each index on every safety level. The last step is determining the evaluation grade.

3.2 Determining the classical field and controlled field of the matter-element model

Dividing coal mine safety system’s impact factors into separated grades according to certain standard, then the formula (5) can be defined as classical field matter-element model.

$$R_t = (N_t, C_j, v_{tj}) = \begin{bmatrix} N_t & c_1 & v_{t1} \\ & c_2 & v_{t2} \\ & \cdots & \cdots \\ & c_l & v_{tl} \end{bmatrix} = \begin{bmatrix} N_t & c_1 & <a_{t1}, b_{t1}> \\ & c_2 & <a_{t2}, b_{t2}> \\ & \cdots & \cdots \\ & c_l & <a_{tl}, b_{tl}> \end{bmatrix} \text{(t=1,2....}\mathbf{S}\text{, j=1,2...l)} \quad (5)$$

where **S** is the number of the grades, N_t is the grade t of evaluation, C_j is the index of evaluation, $v_{tj} = (a_{tj}, b_{tj})$ is the value of C_j on one of the grades. Afterwards the formula (6) can be defined as controlled field matter-element model.

$$R_p = (p, C_j, v_{pj}) = \begin{bmatrix} p & c_1 & v_{p1} \\ & c_2 & v_{p2} \\ & \cdots & \cdots \\ & c_l & v_{pl} \end{bmatrix} = \begin{bmatrix} N_t & c_1 & <a_{p1}, b_{p1}> \\ & c_2 & <a_{p2}, b_{p2}> \\ & \cdots & \cdots \\ & c_l & <a_{pl}, b_{pl}> \end{bmatrix} (j = 1,2....l) \quad (6)$$

Where P is the number of the grades, C_j is the index of evaluation, $v_{pj} = (a_{pj}, b_{pj})$ is the value range of C_j on all grades which is the controlled field of **P**.

3.3 Determining the Connection Function of Each Index on Every Safety Level

Connection Function $k_{tj}(v_j)$ indicates the safety degree of the index. The formula (7) is the connection Function $k_{tj}(v_j)$ on v

$$\begin{cases} k_{tj}(v_j) = -\dfrac{p(v_j, v_{tj})}{\left|v_{tj}\right|} & (v_j \in v_{tj}) \\ k_{tj}(v_j) = -\dfrac{p(v_j, v_{tj})}{p(v_j, v_{tj}) - p(v_j, v_{tj})} & (v_j \notin v_{tj}) \end{cases} \quad (7)$$

Where $p\ (v_j, v_{pj}) = \left| v_j - \dfrac{a_{pj} + b_{pj}}{2} \right| - \dfrac{1}{2}(b_{pj} - a_{pj})$ is the distance between v_j and controlled field v_{pj} while $p\ (v_j, v_{tj}) = \left| v_j - \dfrac{a_{tj} + b_{tj}}{2} \right| - \dfrac{1}{2}(b_{tj} - a_{tj})$ is the distance between v_j and classical field v_{tj}.

3.4 Determining evaluation grades

Formula (8) calculates the connection degree of an evaluated matter on grade t using the connection Function $k_{tj}(v_j)$.

$$k_t(N) = \sum_{j=1}^{l} A_j \cdot k_{tj}(v_j) \quad (8)$$

where A_j is the weight coefficient of the indexes. Then $\max\{k_t(N)\}(t = 1, 2, ...s)$ is the final evaluation value which presents the grade of the evaluated matter.

4 A Case of the Bei-zao Mine of Long-kou Mine Corporation

4.1 Determining Bei-zao's safety evaluation indexes and their values

Dividing the evaluation into 3 levels in which level Ⅰ is defined the best safety level, level Ⅱ is moderate and level Ⅲ is the worst safety level. The Bei-zao's safety evaluation indexes and their values were made and listed in table1 with reference of the research result of the project named "Bei-zao Mine Operation System Evaluation of Long-kou Mine Corporation". Table 2 lists the indexes and investigation data in 2007.

Table.1 Bei-zao Mine's Safety Evaluation Indexes and Their Values

Evaluation factor	Evaluation index		Safety Level		
			I	II	III
Worker	C_1	Average age/y	30-35	25-30	35-45
	C_2	Average training time a year/h	150-180	80-150	0-80
	C_3	Average working years/y	10-15	15-20	0-10
	C_4	Average education/y	6-9	3-6	0-3
Management	C_5	professional managers/%	0.75-1	0.4-0.75	0-0.4
	C_6	Rule and regulation /%	0.75-1	0.4-0.75	0-0.4
	C_7	Violation rate /%	0.75-1	0.4-0.75	0-0.4
	C_8	Coordination /%	0.9-1	0.6-0.9	0-0.9
Equipment	C_9	Rate of repair waiting/%	0-0.05	0．05-0.4	0.4-1
	C_{10}	Failure rate /%	0-0.2	0．2-0.4	0.4-1
	C_{11}	Maintenance&Qualify rate/%	0.9-1	0.6-0.9	0-0.9
	C_{12}	Protective equipment qualify /%	0.9-1	0.6-0.9	0-0.9

Table.2 Initial data of Bei-zao Mine's Safety Evaluation Indexes (2007）

	Worker				Management				Equipment		
Evaluation Indexes	Average age/y	Average training time a year/h	Average working years/y	Average education/y	professional managers/%	Rule and regulation /%	Violation rate /%	Coordination /%	Rate of repair waiting/%	Failure rate /%	Maintenance & Qualify rate/%
Value	30.2	109	13.1	7.5	2	85.4	32.1	91.2	2.1	7.6	92.6

4.2 Building classical and controlled field and matter-element model of the worker's indexes

According to Table1 and Table2, the classical field R_t of the worker's indexes can be written as

$$R_t = \begin{bmatrix} & & \text{I} & \text{II} & \text{III} \\ & C_1 & [30,35] & [25,30] & [35,45] \\ N_t & C_2 & [150,180] & [80,150] & [0,80] \\ & C_3 & [10,15] & [15,20] & [0,10] \\ & C_4 & [6,9] & [3,6] & [0,3] \end{bmatrix} \tag{9}$$

while the controlled field R_p can be written as

$$R_p = \begin{bmatrix} & C_1 & [25,45] \\ P & C_2 & [0,180 \\ & C_3 & [0,20] \\ & C_4 & [0,9] \end{bmatrix} \tag{10}$$

Then the evaluated matter-element model R will be:

$$R = \begin{bmatrix} N & C_1 & 30.2 \\ & C_2 & 109 \\ & C_3 & 13.1 \\ & C_4 & 7.5 \end{bmatrix}. \tag{11}$$

4.3 Determining the weight coefficient of the indexes using the Layer Analysis method

Defining C_1=0.075, C_2=0.525, C_3=0.363 and C_4=0.038 then A_1=[0.075,0.525,0.363,0.038].

4.4 Determining the connection degree between indexes and safety levels of the worker

According formula (7) the connection function as follows:

$K_{11}(v_1)$=0.184 $K_{21}(v_1)$=-0.1 $K_{31}(v_1)$=-1;

$K_{12}(v_2)$=0.203 $K_{22}(v_2)$=-0.217 $K_{32}(v_2)$=-0.554;

$K_{13}(v_3)$=0.752 $K_{23}(v_3)$=0.474 $K_{33}(v_3)$=-1;

$K_{14}(v_4)$=-0.004 $K_{24}(v_4)$=0.02 $K_{34}(v_4)$=-0.536.

Then the connection degree can be calculated as follows using formula (8): $K_t(N)$=(0.114,-0.094,-0.596) .
Using the same method the connection degree of management and equipment can be calculated also as follows: $K_t(N$ =(-0.632,0.217,-0.121) and $K_t(N$ =(-0.046,0.198,-0.326).

4.5 Evaluation result calculation and analysis

Take above 3 extension evaluation results $K_t(N$ as a mine safety evaluation matrix, and their weight coefficient A=（0.403,0.382,0.215）calculated according to worker, management and equipment by layer analysis method. Using formula $K = A \times K_i^{'}(N$ .Thus the connection degree of Bei-zao Mine's safety with the safety levels K =（-0.186，-0.143，-0.316). This mine's safety level is Ⅱ(moderate). This result indicates the factory should decrease its equipment failure rate and repairing latency time .

Improvement of its environment of operating is also very important for the mine. Other measures are providing more train to decrease violation rate and strengthening its management.

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