Application of Entropy-weight Fuzzy Comprehensive Evaluation Method in Post Safety Competency Appraisal of Special Operation Staff in Coal Enterprises

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***Abstract*—For individual miners with the phenomenon of accident proneness, this study proposes to establish a competency model of miner safety management. On this basis, entropy-weight method is used to determine the weights of competency indexes at all levels, and fuzzy comprehensive evaluation is applied to score security competency. The computerized solving is realized with the help of Matlab programming. The results show that the entropy-weight fuzzy comprehensive evaluation method of the post safety competence of coal mine special operations personnel is feasible.**

***Index Terms*—special operation staff, security competent feature, entropy-weight, fuzzy comprehensive evaluation**

I. INTRODUCTION

China's coal output increases annually, but the death tolls of coal industry remain high. For example, the world's coal production in 2003 was about 5 billion tons, with 8,000 deaths in mining accidents. China's coal output in that year accounted for about 35% of the world, while the 6,385 deaths accounted for more than 80% of the world, which was far more than the sum of coal mining accidents' deaths in other coal-producing countries. In 2004, China had 3639 coal mining accidents, with 6027 deaths. The mortality rate in per million tons was 3.08%, which was the lowest in history. But it is still 100 times that of the United States, 30 times South Africa and 10 times India. [1] From 2002 to 2007, China's coal mining accident deaths decreased by 45.9%, from 6597 in 2002 to 3786 in 2007. The mortality rates in per million tons decreased by 69.94%, from 4.94 to 1.485. But extra serious accidents have repeatedly occurred and the safety situation is still grim. Statistics analysis show that majority of mining accidents are caused by human factors. Based on theory of human resource management and organizational psychology, this study uses techniques like questionnaires, behavioral event interviews and statistical analysis to build the post safety competency model of special operation staff in coal enterprises. And the entropy weight of fuzzy comprehensive evaluation method is used to apply this model to the identification, selection and assessment of special workers. This method has a strong realistic pertinence for forming a good employment mechanism and strengthening the safety construction of coal mining enterprises.

Special operation personnel are operators who are vulnerable to fatal accidents, causing significant harm to the safety of the operator himself, other personnel and the surrounding facilities. Special operation personnel in coal enterprises include gas inspectors, underground rock blasters, safety inspectors, main hoist operators, underground electrical fitters, shearer drivers and ventilation safety monitors, etc.

II. THE BASIC STEPS OF ENTROPY-BASED FUZZY COMPREHENSIVE EVALUATION METHOD

The basic idea of fuzzy comprehensive evaluation is to provide quantitative characterization and description of

doi:10.4304/jsw.7.10.2217-2222

the constituents of the object to be evaluated according to the double-sided property of the inherent behavior and components of the object, applying the principle of synthesis of fuzzy relations. Due to fuzzy characteristic of the concept of security, the concepts and methods of fuzzy mathematics could be used to establish the theories and models of the fuzzy evaluation of safety competency of the special operation personnel in coal mines. This method conforms better than the traditional evaluation method to the actual situation of the phenomenon. In addition, the designing of weights in fuzzy evaluation is a key element, which has a major impact to the results of evaluation. Because of its objective rationality, entropy weight method is now widely used in engineering technology, socio-economy, environmental science and other fields. [2]

（1）Establish an evaluation index set（Factor set U）[3]

Evaluation factor set U is a collection of comprehensive evaluation indexes which has hierarchy.

The primary grade index is：

$$U = \{U_1, U_2, U_3, U_4\}$$

The secondary grade index is $U_i = \{U_{i1}, U_{i2}, \cdots, U_{ij}\}$

In this formula，U_{ij} ——The indicator j of the criteria level i.

（2）Establish comment set

Assume comment set: $V = (V_1, V_2, V_3, V_4, V_5)$ .where V_1 represents excellent, scoring (90-100)；V_2 represents good, scoring (70-90); V_3 represents general, scoring (60-70); V_4 represents poor, scoring (40-60); V_5 represents very poor, scoring (0 -40).

（3）Determine weight set

The set of primary grade indexes：

$$W = \{W_1, W_2, W_3, W_4\}$$

The set of secondary grade indexes：

$$W_i = \{W_{i1}, W_{i2}, \cdots, W_{ij}\}$$

The importance of the same or different indicators reflects different function of special operation staff in mine safety job competency, so it is needed to weight the indicators. The weights must be taken seriously for they affect the objectivity and rationality of the evaluation results directly; there are many ways to weight the indicators, such as the survey method, Delphi method, AHP method, etc. [4]

Determination of weights：according to current status and the feature of the special operator's post safety competency in a large stated-owned coal mining enterprises, this study scores from four aspects, the knowledge and skills of safe operation, emotional stability, emergency response capacity, and environmental adaptability based on the safety competency model, in order to make it conform to the actual working requirement to the greatest extent. Entropy technology evaluation is applied in order to get a weight which can better reflect the objective requirements on basis of subjective weighting. [5] The objective analysis and processing of the result of subjective weighting is to calculate the weight of each index relative to the weight of the upper indicator. This method combines the subjective judgments with the objective calculation and thus enhances the credibility of the weight.

We assume that there are m scorers and n evaluation indexes, X_{ij} stands for the score that scorer i gives to index j, X_j^* is the highest score for index j. X_j^* varies according to the feature of index. For a profitability index, X_j^* is the bigger the better; for a loss index, the smaller the better. So d_{ij}, which stands for the proximity between X_{ij} and X_j^*, can be expressed as:

$$d_{ij} = \begin{cases} X_{ij} / X_j^* \\ X_j^* / X_{ij} \end{cases}$$

According to the definition of entropy, the entropy of m scorers to n indexes is：

$$E = -\sum_{j=1,\cdots,n} \sum_{i=1,\cdots,m} d_{ij} \ln d_{ij} \qquad (1)$$

$$d_j = \sum_{i=1,\cdots,m} d_{ij} \qquad (2)$$

When d_{ij} / d_j equal, conditional entropy is the largest, i.e., $E_{\max} = \ln m$,

Using $E_{\max}$ to normalize the conditional entropy, the entropy to the evaluating and decision-making importance of j is:

$$e(d_j) = 1/\ln mE'$$

（3）

the weight of evaluation index weights can be expressed as：

$$W_j = 1/n - E_e[1 - e(d_j)]$$

（4）

In this formula,

$$E_e = \sum_{j=1,\cdots,n} e(d_j) \qquad 0 < W_j < 1 且 \sum_{j=1,\cdots,n} W_j = 1$$

The experiments are conducted using MATLAB. The main program of entropy technology evaluation in MATLAB is following as

```
clear;
clc;
x=[    ];
y=[    ]
```

```
[m,n]=size(x);
for i=1:n
       y(:,i)=x(:,i)/sum([x(:,i)])
end
for l=1:n
       s(1,l)=0;
       for j=1: m
              p(1,l)=y(j,l)*log(y(j,l))
              s(1,l)=s(1,l)+p(1,l)
       end
end
k=(log(m))^(-1)
e=-k*s
h=ones(1,n)-e
w=h/sum(h)
sum(w)
g=y*w'
```

（4）Establish a judging membership matrix R

$$R=\begin{Bmatrix} R_1 \\ R_2 \\ \vdots \\ R_m \end{Bmatrix}=\begin{Bmatrix} R_{11} & R_{12} & \cdots & R_{1n} \\ R_{21} & R_{22} & \cdots & R_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ R_{m1} & R_{m2} & \cdots & R_{mn} \end{Bmatrix}$$

（5）Where R_i is the evaluation of i; R_{ij} is the membership of evaluation factor i to evaluation level j, which reflects the fuzzy relations expressed by a membership between the evaluation factors and evaluation level; n is the number of evaluation level in rating set; m is the number of factors being evaluated.

（5）Secondary fuzzy comprehensive evaluation

First, we conduct the first comprehensive evaluation. Based on the weight W which is calculated by entropy evaluation method and the established judging attached matrix R, using fuzzy operational rule, we conduct integrated operations and normalize the result, then we get the membership vector Si standing for factor U_i to comment set V .

$$S_i=W_i\bullet R_i=\left(W_{i1},W_{i2},\cdots,W_{ij}\right)\begin{pmatrix} R_{11} & R_{12} & \cdots & R_{1n} \\ R_{21} & R_{22} & \cdots & R_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ R_{m1} & R_{m2} & \cdots & R_{mn} \end{pmatrix}$$

（6）

Then we conduct the secondary fuzzy synthetic evaluation and get the overall evaluation vector A. Finally we get the comprehensive evaluation conclusions according to the principle of fuzzy vector single value：

$$A=W\bullet S \qquad (7)$$

The experiments are conducted using MATLAB. The main program of fuzzy comprehensive evaluation in MATLAB is following as

```
clear;
clc;
a=[ ];
d=[ ];
       [m,n]=size(a);
       [x,y]=size(d);
       TheResultMoHu=[];
for s=1:x
     for p=1:n
          b(p)=d(s,p);
       end
       for i=1:n
          ColAverage(i)=0;
          for j=1:m
             ColAverage(i)=ColAverage(i)+a(j,i);
          End
          ColAverage(i)=ColAverage(i)/m;
       End
       ETotal = 0;
       for j = 1: n
           ETotal = ETotal + (b(j) / ColAverage(j));
       End
       for i = 1: n
          EResult(i) = (b(i) / ColAverage(i)) / ETotal;
               SortedMatrix=a;
       for j=1:n
          for i=1:m
             for k=i:m
                if SortedMatrix(i,j)>SortedMatrix(k,j)
                   tmp=SortedMatrix(i,j);
                   SortedMatrix(i,j)=SortedMatrix(k,j);
                   SortedMatrix(k,j)=tmp;
                End
             End
          End
       End
        c=SortedMatrix;
        for j = 1 : n
                for i = 1 : m
                     for k = 1 : m
                        if a(i, j) == c(k, j)
                           if k == 1
                              if b(j) < c(k, j)
                                 LSDResult(j, i) = 1;
                              End
                              if b(j) >= c(k, j) & b(j) < c(k + 1, j)
                                LSDResult(j, i) = ((c(k + 1, j) - b(j)) / (c(k + 1, j) - c(k, j)));
                              End
                              if b(j) >= c(k + 1, j)
                                 LSDResult(j, i) = 0;
                              End
                           End
                           if k > 1 & k < m
                              if b(j) < c(k - 1, j)
                                 LSDResult(j, i) = 0;
                              End
                              if b(j) >= c(k - 1, j) & b(j) < c(k, j)
```

```
                    LSDResult(j, i) = ((b(j) - c(k - 1, j)) / (c(k, j) - c(k - 1, j)));
                  End
                  if b(j) >= c(k, j) & b(j) < c(k + 1, j)
                    LSDResult(j, i) = ((c(k + 1, j) - b(j)) / (c(k + 1, j) - c(k, j)));
                  End
                  if b(j) >= c(k + 1, j)
                    LSDResult(j, i) = 0;
                  End
                End
                if k == m
                  if b(j) < c(k - 1, j)
                    LSDResult(j, i) = 0;
                  End
                  if b(j) >= c(k - 1, j) & b(j) < c(k, j)
                    LSDResult(j, i) = ((b(j) - c(k - 1, j)) / (c(k, j) - c(k - 1, j)));
                  End
                  if b(j) >= c(k, j)
                    LSDResult(j, i) = 1;
                  End
                End
              End
            End
          End
      End
        R=LSDResult;
       E=EResult;
      FuzzyEvalution=E*R;
      TheResultMoHu=[TheResultMoHu;FuzzyEvalution];
   end
```

III. THE APPLICATION OF ENTROPY FUZZY COMPREHENSIVE EVALUATION

A. Establish Comprehensive Evaluation Set

The assessment on special operations personnel in the coal mining enterprises should commence on two aspects, general index and specific index. We have not developed the specific indicators because its establishment should be combined with specific business need or job background and it has great variability. However, due to the basic consistent assessment ideas, we choose the universal measure index of the security competency model established on basis of the previous research as a standard to fuzzy assess/evaluate the operator's security competency feature. And organizations can be interpreted accordingly. The competency security model based universal measure index for special operation personnel evaluation of coal enterprises is shown in table Ⅰ.

TABLE Ⅰ.
SPECIAL OPERATIONS PERSONNEL MINE SAFETY JOB COMPETENCY ASSESSMENT INDEX SYSTEM OF UNIVERSAL MEASURE

Post safety competency features of special operations personnel in coal mines（U）

Knowledge and skills of safe operation（U1）	Emotional Stability（U2）	Emergency response capacity （U3）	Environmental adaptability（U4）
Compliance with safety regulations, operating rules and operating procedures（U11） Strong sense of responsibility for security and timely actions to stop rule-violating fellow workers（U12） master working skills, identify potential safety problems and solve timely（U13）Be familiar with and master the safe operation knowledge of specific working types（U14） Self-awareness of prevention, drawing lessons timely from accidents（U15）。	Sedate character, unlikely to get agitated（U21）; adjust one's attitude and constrain one's behavior consciously(U22); Not easily infuriated（U23); not flaunting, discreet（U24); Few negative emotions at work（U25)。	Flexibility, quick response（U31）; Cool-headed to handle emergencies（U32）; Excellent knowledge of safe operation, and extensive knowledge（U33）; Good observation, sensitivity to abnormal conditions（U34）; Energetic, vigorous and physically fit （U35）。	Considering the impact of one's actions on the security environment（U41）; keeping a clear head to work properly under great pressure（U42); Strong adaptability（U43）; Continuous learning and innovation, improving one's own capacity（U44）; Adversity Quotient（U45）。

B. Establishment of evaluation Index System and calculation of weight index

TABLE Ⅱ
THE POST SAFETY COMPETENCY INDEX SYSTEM AND FUZZY MEMBERSHIP OF STATE-OWNED COAL MINE BLASTER X1

Primary grade index	Weight	Secondary grade index	Weight	grade				
				Strongly conform	Relatively conform	Basically conform	Less conform	Not conform
Knowledge and skills of safe operation (U1)	0.25	U11	0.39	0.2	0.5	0.1	0.2	0
		U12	0.25	0.2	0.4	0.3	0	0.1
		U13	0.14	0.3	0.3	0.3	0.1	0
		U14	0.17	0.2	0.4	0.2	0.1	0.1
		U15	0.05	0.1	0.3	0.4	0.2	0
Emotional Stability (U2)	0.25	U21	0.28	0.2	0.2	0.3	0.2	0.1
		U22	0.12	0.3	0.3	0.3	0.1	0
		U23	0.28	0.2	0.3	0.4	0	0.1
		U24	0.22	0.1	0.3	0.2	0.1	0.3
		U25	0.10	0.2	0.2	0.3	0.1	0.2
Emergency response capacity (U3)	0.28	U31	0.24	0.3	0.4	0.2	0.1	0
		U32	0.15	0.2	0.5	0.2	0	0.1
		U33	0.12	0.3	0.5	0.1	0.1	0
		U34	0.30	0.4	0.4	0.1	0.1	0
		U35	0.19	0.3	0.4	0.2	0.1	0
Environmental adaptability (U4)	0.22	U41	0.27	0.1	0.2	0.4	0.2	0.1
		U42	0.37	0.3	0.4	0.2	0.1	0
		U43	0.11	0.2	0.2	0.5	0.1	0
		U44	0.17	0.2	0.2	0.4	0.1	0.1
		U45	0.08	0.2	0.1	0.4	0	0.3

The subjects participated in the evaluation is that whether a state-owned coal mine blasting worker x1 is competence or not. We will investigate specifically in four aspects: the knowledge and skills of safe operation, emotional stability, emergency response ability and environmental adaptability. The object being evaluated will give their own assessment in accordance with the primary and secondary indexes, applying "strongly conform, relatively conform, basically conform, less conform, not conform" five grades.

Firstly we list the primary and secondary index system, and then get the weighting results by expert scoring, and then establish the membership set under the evaluation grade as given. As the indicators have divergences, we calculate them according to the principle of entropy, and finally obtain the weight of the index system as shown in tableⅡ, and then establish the membership set based on the assessment rating.

IV. FUZZY COMPREHENSIVE EVALUATION

First, we carry out fuzzy comprehensive evaluation according to table1 and formula (6) , $S_1 = W_1 \bullet R_1 =$ （ 0.237,0.451,0.154,0.133,0.025 ） , Similarly, $S_2 = W_2 \bullet R_2 =$ (0.2, 0.272, 0.306, 0.1, 0.123), $S_3 = W_3 \bullet R_3 =$ (0.331, 0.427, 0.157, 0.085, 0), $S_4 = W_4 \bullet R_4 =$ (0.211, 0.238, 0.435, 0.108, 0.008).

Then we use formula (7) to carry out secondary fuzzy comprehensive evaluation, and get the final evaluation results:

A= (0.248 0.345 0.263 0.117 0.027)

In accordance with the principle of maximum degree, the results show that the underground blasting worker's post security competency is good. For comparison purposes, we will translate the results of the comprehensive evaluation into component values. As shown in tableⅢ，take the median score obtained for the evaluation level:

V= {Excellent Good Fair poor very poor}
= {95 80 65 50 20}

TABLE Ⅲ
SCORE CLASSIFICATION OF SECURITY COMPETENT LEVEL

security competency scores	90—100	70—90	60—70	40—60	0—40
Competent level	Excellent	Good	Fair	poor	very poor

Therefore, in the comprehensive security competency evaluation of this underground blaster, the scores of the results of the two level evaluations are:

$F_1 = S_1 \bullet V$ =75.73, Similarly， $F_2 = S_2 \bullet V$ =68.19； $F_3 = S_3 \bullet V$ =80.26； $F_4 = S_4 \bullet V$ =72.94.

Similarly， the score of the primary comprehensive evaluation is： $F = A \bullet V$ =74.79.

We have obtained by calculation that the total score of this underground blasting worker's evaluation is 74.79. Then we compare this result to the safety competency scale and conclude that the final result of this underground blasting worker's post safety competency evaluation is good, which is consistent with the result of maximum degree evaluation. But the situation is not ideal; the training and development of post safety competency should be strengthened and the safety culture construction should be promoted.

V. Conclusions

The index system of the Post Safety Competency Evaluation of Special Operation Personnel in Coal Enterprises is considered in four aspects, i.e. knowledge and skills of safe operation, emotional stability, emergency response capability, and environment adaptability. It can fully reflect the situation of special operator's post safety competency, laying a foundation for the objective evaluation. The entropy evaluation method, combining the subjective judgments with objective calculation, increases the credibility of the weight, and thus increases the scientificity and comparability of the evaluation.

Acknowledgment

This work is supported by the National Natural Science Foundation of China(71071003), the MOE Project of Youth Foundation of Humanities and Social Science（09YJC630004）, and the Natural Science Foundation key project of Anhui University (KJ2009A59)

References

[1] Ridder, A. (2005). Importance sampling simulations of Markovian reliability systems using cross-entropy, Annals of Operations Research ,134, 119-136.

[2] Peng, Z.Z. (2002). Fuzzy Mathematics etc Application. Wuhan university press, China: Wuhan.

[3] Jiang Z.J., Wang L.F., Gao H.B. (2004). Fuzzy Mathematics Tutorial, National defense industry press, China: Beijing.

[4] Zhang Y., Jia C.B., Wang J.J (2004) Evaluation of emergency plans Based on fuzzy comprehensive assessment, Chinese Journal of Management Science, 12, 153-156.

[5] Malin Song, Shuhong Wang, Jie Wu, Li Yang. (2011),"A New Space-Time Correlation Coefficient and its Comparison with Moran's Index on Evaluation"，Management Decision，Vol. 49 No. 9, pp. 1426-43.

[6] Liu J.F., Zhu J.J., Zhang P.J., Chen J. (2008) Study on evaluation method of natural disaster emergency plan in China (part II):responsibility matrix evaluation, China safety science journal,18(4):5-15.

[7] Xiaoliang Zhao. (2005). Assessment Approach To Coalmine Safety Based On Continental Distance Model With Varying Weight, Journal Of Safety And Environment , 5(5):9-11.

[8] Boer, P.T. de, and Nicola, V.F.（2002）. Adaptive state-dependent importance sampling simulation of Markovian queueing networks, European Transactionson Telecommunications 13, 303-315.

[9] Li Yang, Malin Song. Coal mine safety evaluation with V-fold cross-validation and bp neural network[J]. Journal of Computers, 2010,5(9):1364-1372.

[10] Boer, P.T. de, Nicola, V.F., and Rubinstein, R.Y. （2000）. Adaptive importance sampling simulation queueing networks, Proceedings of the 2000 Winter Simulation Conference J.A. Joines, R.R. Barton, K. Kang, and P.A. Fishwick (Eds.), IEEE Press, 646-655.

[11] Dupuis, P. andWang, H. （2007）. Subsolutions of an Isaacs equation and efficient schemes for importance sampling. Mathematics of Operations Research 32, 723-757.

[12] Xiaoliang Zhao,Ziling Song,Junshan Hu,（2005）.Foundation And Application Of Varying Weight Identify Model Of Mine Water Quality Evaluation. Open Mining Technology 2(1):32-34.

[13] Li Yang, Malin Song. Formation mechanism of green strategic alliances and its cooperative system for coal-mining eco-industrial parks based on synthetic decision support system[J]. Journal of Computers, 2009,4(11):1109-1117.

[14] Xiaoliang Zhao,Ziling Song,Yang Zhou,Guozhi Zhao.（2005）.Assessment Approach To Coalmine Safety Based On Continental Distance Model With Varying Weight.Journal Of Safety And Environment ,5(5):9-11.

[15] Juneja, S. and Shahabuddin, P. （2006）. Rare-event simulation techniques: an introduction and recent advances. In Handbooks in Operations Research and Management Science, Vol. 13: Simulation. S. Henderson and B. Nelson (Eds.), Elsevier, Amsterdam, 291-350.

[16] Rubinstein, R.Y. and Kroese, D.P. （2004）. The cross-entropy method: a unified approach to combinatorial optimization, Monte-Carlo simulation and machine learning, Springer.

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