An AHP Based Study Of Coal-Mine Zero Harm Safety Culture Evaluation

Hongxia Li[1,2,3,4],Hongxi Di[1,2,3,4],Xu An Wang[5]
*[1]School of Management, Xi'an University of Science and Technology, Xi'an 710054,China;
[2]School of Energy Engineering, Xi'an University of Science and Technology, Xi'an 710054, China;
[3]Key Laboratory of Western Mine Exploitation and Hazard Prevention, Ministry of Education, Xi'an University of Science and Technology, Xi'an 710054,China;
[4]Shanxi Provincial Audit Office, Xi'an 710054,China;
[5]Engineering University of CAPF, Xi'an 710054,China
Email:416139865@qq.com

ABSTRACT. At present, the Coal-mine industry calls for a reliable method for evaluating "zero harm" safety cultural construction performance. On the basis of an analysis of various factors affecting "zero harm" safety cultural construction performance, a comprehensive index system for evaluating safety cultural construction performance is built. The analytical hierarchy process (AHP) and the theory of Fuzzy Comprehensive Evaluation (FCE) are employed to build an AHP-FCE Model for coal-mine zero harm safety culture, thus providing a scientific and practical quantitative method for systematic analyses and comprehensive evaluations of coal-mine zero harm safety culture.

This model is used to analyze the "zero harm" safety cultural construction performance of BLA. Analytical results show that the AHP-based "zero harm" safety culture evaluation index system has a great practical applicability. It can be applied to provide a solid foundation for enterprises to improve their strategic goals of "zero harm" safety culture construction", so it should be popularized and widely applied.

Keywords: safety culture, zero harm, AHP, FCE

1 Introduction

Coal-mine safety culture [1] is a new concept of safety management which deepens cognition of safety problems in coal-mine safety production by extending from the natural science to the human science. Coal-mine safety culture puts people first. It is a culture about management and survival, reflecting enterprise workers' pursuit of personal safety and health [2] - [6].

"Zero harm" safety culture with distinct features is proposed based on long-term production practice of coal-mine enterprises in China." 100-1 = 0" is the core concept

F. Xhafa et al. (eds.), *Advances on P2P, Parallel, Grid, Cloud and Internet Computing*, Lecture Notes on Data Engineering and Communications Technologies 1, DOI 10.1007/978-3-319-49109-7_6

in its safety value construction. The “zero harm” safety culture advocates safety cognitions that “production safety should be placed first”, “one industrial incident will deny all achievements”, and “absolute safety means zero accident rate” [7] - [10].

Zero harm safety culture has rich connotations. The goal of zero harm safety culture is “zero harm”. Safety culture works for safety production and guarantees safety. However, in the daily safety production, the weakness safety consciousness and poor safety quality are greatest hidden troubles for achieving coal-mine safety production. Therefore, in safety cultural construction, it is an important link to cultivate safety awareness of employees, improve their safety quality and implement the “zero harm” safety culture idea concept.

In this paper, a zero harm safety culture model is proposed. On this basis, the AHP is chosen to make a scientific and complete evaluation of zero harm safety culture construction effects, in order to reflect strengths and weaknesses of the coal-mine enterprise in safety culture construction, thereby improving safety culture construction effects and maintaining sustainable development of safety culture of the enterprise.

2. Establishment Of Safety Cultury Evaluation Model For Enterprise

2.1 Establishment Of Evaluation Factors

On the basis of investigating existing research results, considering the actual national condition that China is still in the exploratory stage of zero harm safety culture construction and following the principle of establishing the index system, the author presents four 1st level indictors for the zero harm evaluation index system, including zero harm safety concept culture, safety institution culture, safety behavior culture and safety material culture. Four 1st level indicators get three 2nd level indicators, respectively and a total of 12 2nd level indicators. Zero harm safety concept culture, as one 1st level indicator, covers three 2nd level indicators including zero harm safety values, enterprise zero harm safety concept and enterprise zero harm safety thinking mode. Zero harm safety institution culture includes enterprise safety leadership system, enterprise safety institutional system and enterprise safety organizational structure. Zero harm safety behavior culture gets three 2nd level indicators including enterprise safety production style, safety production decision-making and field operation. Zero harm safety material culture includes enterprise safety material products, enterprise safety material technology and enterprise safety material environment. Each 2nd level indicator gets several evaluation factors and forms some 3rd level indicators. The AHP is employed to build an enterprise zero harm safety culture evaluation model, as shown in Figure 1.

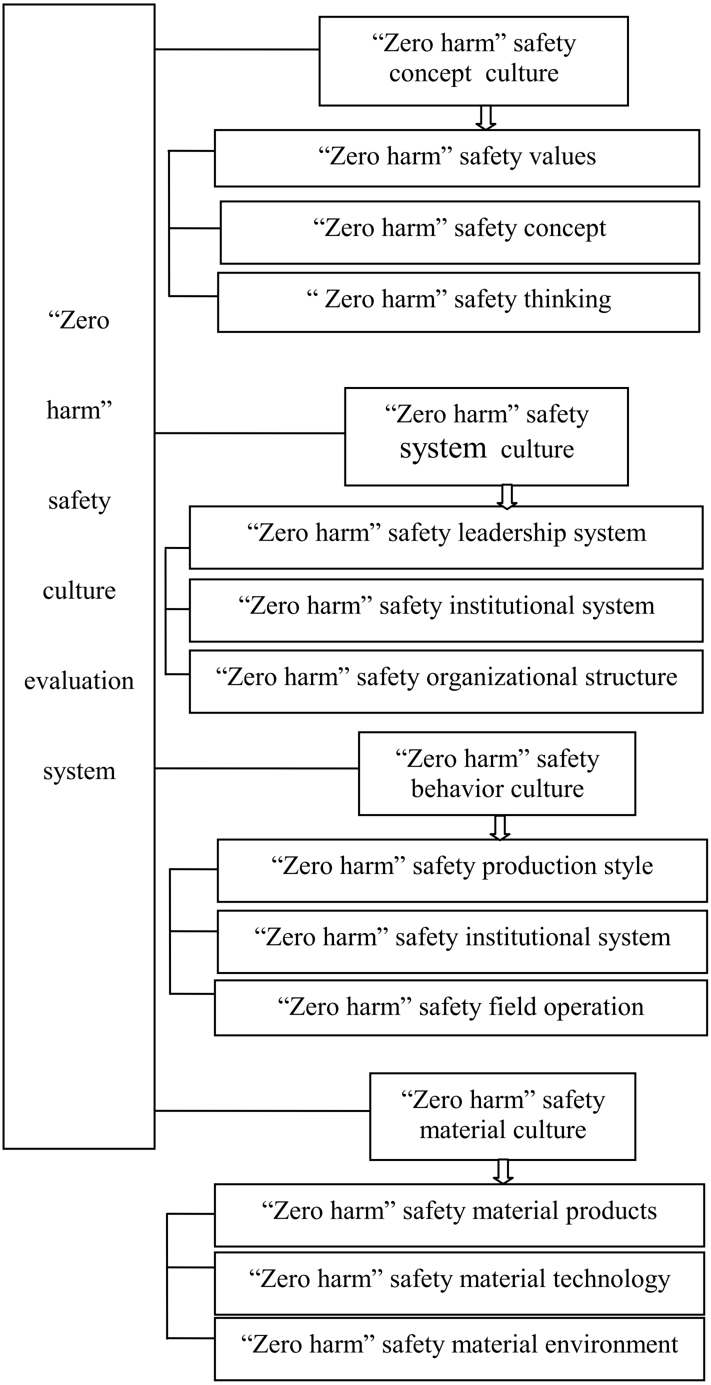

Figure. 1. "Zero harm" safety cultural evaluation index.

Each evaluation factor gets following meanings.

① “Zero harm” safety concept culture

“Zero harm” safety values, “zero harm” safety concept and “zero harm” safety thinking mode constitute “zero harm” safety concept culture.

② “Zero harm” safety institution culture

“Zero harm” safety institution culture mainly discusses the “zero harm” safety leadership system, “zero harm” safety institutional system and “zero harm” safety organizational structure.

③ “Zero harm” safety behavior culture

“Zero harm” safety behavior culture mainly explores the “zero harm” safety production style, “zero harm” safety production decision-making and “zero harm” safety field operation.

④ “Zero harm” safety material culture

“Zero harm” safety material culture mainly investigates the “zero harm” safety material products, “zero harm” safety material technology and “zero harm” safety material environment.

2.2 Determining Weights Of Evaluation Factors

2) Calculation steps of the AHP

① Build a hierarchical model .

② Construct judgment matrixes.

Judgment matrixes are constructed based on comparisons between a factor in the higher layer and factors in its upper layer. The relative importance of each pair of factors in the same layer is compared to determine the corresponding weight. Results of relative importance comparisons are shown through the 1-9 scale method. Each scale gets its corresponding meaning, as shown in Table 1.

Table 1. Meaning of Scale 1 to 9.

Scale	Meaning
1	Indicating that the two factors are equally important
3	Indicating that one factor is slightly more important than the other
5	Indicating that one factor is obviously more important than the other
7	Indicating that one factor is greatly more important than the other
9	Indicating that one factor is extremely more important than the other
2，4，6，8	Between values of two neighboring judgments
Reciprocal	The relative importance scale of the latter to the former when two factors are compared.

The relative importance of each pair of factors is compared to get following results, as shown in Table 2.

Table 2 . Comparative results of relative importance.

	A_1	A_2	…	A_n
A_1	a_{11}	a_{12}	…	a_{1n}
A_2	a_{21}	a_{22}	…	a_{2n}
…	…	…	…	…
A_n	a_{n1}	a_{n2}	…	a_{nn}

Results obtained through comparisons of the relative importance can be used to get a comparison matrix A:A{ a_{ij} }.

Corresponding values in judgment matrixes should meet conditions: $a_{ij}>0$，

$$a_{ij}=\frac{1}{a_{ji}}, \quad a_{ii}=1.$$

③ Ranking of factors in the same layer and consistency test .

Judgment matrixes are used to calculate weight vectors of various factors in one layer to factors in the upper layer. In addition, consistency tests are made.

The summation process is chosen to calculate weight vectors, by following steps.

Calculate the weight vector using "Mediation Method" procedure is as follows:

Step 1: Normalize the vectors in each row of A to get $\overline{\omega}_{ij}=\frac{a_{ij}}{\sum_{i=1}^{n}a_{ij}}$ $(j=1,2,...n)$;

Step 2: add weight vectors $\overline{\omega}_{ij}$ of all rows of A to get a summation $\overline{\omega}_i=\sum_{j=1}^{n}\overline{\omega}_{ij}$ $(i=1,2,...n)$;

Step 3: normalize $\overline{\omega}_{ij}$ to get $\omega_i=\frac{\overline{\omega}_i}{\sum_{i=1}^{n}\overline{\omega}_i}$ and $w=(\omega_1,\omega_1,...,\omega_n)^T$ is approximate eigenfunction;

Step 4: calculate the maximum eigenvalue $\lambda_{\max}=\frac{1}{n}\sum_{i=1}^{n}\frac{(Aw)_i}{\omega_i}$.

When CR <0.1, the pairwise comparison matrix A is considered to show a good consistency. The normalized eigenvector of $\lambda_{\max}$ as the maximum eigenvalue of A is taken as a weight vector for the comparison matrix. When CR≥0.1, the wise comparison matrix must be adjusted, until a good consistency is obtained.

3)Weight calculations of safety culture evaluation indictors

Experienced leaders, safety management experts and on-site safety supervision personnel are invited to grade weights of indicators in different layers, combined with actual on-site situation.

(1)Weight calculation of Level 1 “zero harm” safe culture indicators and consistency test

1st level indicator set, $U_n = \{U_1, U_2, U_3, U_4\}$ = {“Zero harm” safety concept culture, “Zero harm” safety institution culture, “Zero harm” safety behavior culture, “Zero harm” safety material culture}. Calculations are shown in Table 3.

Table 3. Weight calculation of Level 1 “zero harm” safe culture indicators and consistency test.

U	U_1	U_2	U_3	U_4	Weight W_i	W_i^0	λ_{mi}
U_1	1	4	3	2	2.213	0.476	4.178
U_2	1/4	1	2	1	0.841	0.181	4.128
U_3	1/3	1/2	1	1/3	0.485	0.105	4.149
U_4	1/2	1	3	1	1.107	0.238	4.074

$$\lambda_{max} = \frac{1}{4}(4.178 + 4.128 + 4.149 + 4.074) = 4.132$$

$$C.I. = \frac{\lambda_{max} - n}{n-1} = \frac{4.132 - 4}{4-1} = 0.044 < 0.1$$

$$C.R. = \frac{C.I.}{R.I.} = \frac{0.044}{0.89} = 0.049 < 0.1$$

Because CR=0.049<0.1, the judgment matrix has a good consistency. Therefore, calculated values of weights can be used.

(2) Weight calculation of Level 2 “zero harm” safe concept culture indicators and consistency test

Level 2 indicator set: “Zero harm” safety concept culture $U_1 = \{U_{11}, U_{12}, U_{13}\}$ = {Enterprise “zero harm” safety values, “zero harm” safety concept, “zero harm” thinking modes}. Calculation results are listed in the following Table 4.

Table 4. Weight calculation of Level 2 “zero harm” safe concept culture indicators and consistency test.

U_2	U_{21}	U_{22}	U_{23}	Weight W_i	W_i^0	λ_{mi}
U_{21}	1	4	1/2	1.260	0.359	3.108
U_{22}	1/4	1	1/3	0.437	0.124	2.953
U_{23}	2	3	1	1.817	0.517	3.108

$$\lambda_{max} = \frac{1}{3}(3.108 + 2.953 + 3.108) = 3.056$$

$$C.I.=\frac{\lambda_{max}-n}{n-1}=\frac{3.056-3}{3-1}=0.028<0.1$$

$$C.R.=\frac{C.I.}{R.I.}=\frac{0.028}{0.52}=0.054<0.1$$

CR=0.0087<0.1 indicates that the judgment matrix passes the consistency test, so calculations of weights can be used.

(3) Weight calculation of Level 2 "zero harm" safe institution culture indicators and consistency test

Level 2 indicator set: "Zero harm" safety institution culture $U_2=\{U_{21},U_{22},U_{23}\}=$ {enterprise "zero harm" safety leadership system, "zero harm" safety institutional system, "zero harm" safety organizational structure}. Calculations are shown in Table 5.

Table 5. Weight calculation of Level 2 "zero harm" safe institution culture indicators and consistency test.

U_1	U_{11}	U_{12}	U_{13}	Weight W_i	W_i^0	λ_{mi}
U_{11}	1	3	2	1.817	0.545	3.018
U_{12}	1/3	1	1	0.693	0.210	3.020
U_{13}	1/2	1	1	0.794	0.240	3.017

$$\lambda_{max}=\frac{1}{3}(3.018+3.020+3.017)=3.018$$

$$C.I.=\frac{\lambda_{max}-n}{n-1}=\frac{3.018-3}{3-1}=0.009<0.1$$

$$C.R.=\frac{C.I.}{R.I.}=\frac{0.009}{0.52}=0.017<0.1$$

CR=0.0087<0.1 indicates that the judgment matrix passes the consistency test, so calculations of weights can be used.

(4) Weight calculation of Level 2 "zero harm" safe behavior culture indicators and consistency test

Level 2 indicator set: "Zero harm" safety institution culture $U_3=\{U_{31},U_{32},U_{33}\}=${ Enterprise "zero harm" safety production style, "Zero harm" safety production decision-making, field operation}. Calculation results are listed in the following Table 6.

Table 6. Weight calculation of Level 2 "zero harm" safe behavior culture indicators and consistency test.

U_3	U_{31}	U_{32}	U_{33}	Weight	W_i^0	λ_{mi}

				W_i		
U_{31}	1	1/2	1/3	0.550	0.163	3.010
U_{32}	2	1	1/2	1	0.297	3.009
U_{33}	3	2	1	1.817	0.540	3.009

$$\lambda_{max}=\frac{1}{3}(3.010+3.009+3.009)=3.009$$

$$C.I.=\frac{\lambda_{max}-n}{n-1}=\frac{3.009-3}{3-1}=0.0045<0.1$$

$$C.R.=\frac{C.I.}{R.I.}=\frac{0.0045}{0.52}=0.0087<0.1$$

CR=0.0087<0.1 indicates that the judgment matrix passes the consistency test, so calculations of weights can be used.

(5) Weight calculation of Level 2 "zero harm" safe material culture indicators and consistency test

Level 2 indicator set: "Zero harm" safety material culture $U_4=\{U_{41},U_{42},U_{43}\}$ ={ Enterprise "zero harm" safety material products, Enterprise "zero harm" safety material technology, Enterprise "zero harm" safety material environment}. Calculation results are shown in the following Table 6.

Table 7. Weight calculation of Level 2 "zero harm" safe material culture indicators and consistency test.

U_4	U_{41}	U_{42}	U_{43}	Weight W_i	W_i^0	λ_{mi}
U_{41}	1	2	4	2	0.558	3.019
U_{42}	1/2	1	3	1.145	0.320	3.018
U_{43}	1/4	1/3	1	0.437	0.122	3.250

$$\lambda_{max}=\frac{1}{3}(3.019+3.018+3.250)=3.096$$

$$C.I.=\frac{\lambda_{max}-n}{n-1}=\frac{3.096-3}{3-1}=0.048<0.1$$

$$C.R.=\frac{C.I.}{R.I.}=\frac{0.048}{0.52}=0.092<0.1$$

As CR=0.0087<0.1, it indicates that the judgment matrix passes the consistency test, so calculations of weights can be used.

(2) Calculation of evaluation results

1) Calculation methods

On the basis of using the AHP to determine weights of various factors, the FCE is employed to grade "zero harm" safety culture of BLA as a coal-mine enterprise. The FCE is a method using the fuzzy set theory to evaluate systems or programs. It is hard to use traditional mathematical methods to solve problems with various evaluation factors and fuzzy evaluation standards or natural state. However, the FCE can well solve them. Before score assignment, work is done to set a total of six evaluation ranks. The evaluation set is V= $(v_1, v_2, v_3, v_4, v_5, V_6)$ =(quite important, important, general, somewhat important, less important, and quite unimportant). A corresponding score is assigned to each evaluation rank, as shown in Table 8.

Table 8. Score assignments of different evaluation ranks.

Evaluation ranks	**Quite high**	**High**	**General**	**A bit low**	**Low**	**Quite low**
Interval value in Hundre dmark system	90 100	80 90	70 80	60 70	60	Below 60
Class midvalue	95	85	75	65	60	30

The AHP is used to determine that weights of Level 2 indicators are W1 = (48, 18, 10, 24); W2 = (55, 21, 24); W3 = (16, 30, 54); W4 = (56, 32, 12). Meanwhile, a total of 10 professors, assistant professors and lecturers specialized in safety engineering from universities and relevant doctoral students and graduate students were gather o form an expert team to mark the zero harm safety culture effects. Concrete grading results are listed in Table 9-1、9-2.

Table 9-1. Marking table for experts.

Evaluation factors		**"Zero harm" safety culture U**				**"Zero harm" institution culture I**		
		U1	U2	U3	U4	U21	U22	U23
Evaluation scale	90	4	1	5	3	2	6	2
	80	3	5	2	4	3	2	5
	70	2	4	1	2	5	2	1
	60	1	0	2	1	0	0	1
	60	0	0	0	0	0	0	1
	30	0	0	0	0	0	0	0

Table 9-2. Marking table for experts.

"Zero harm" concept culture **C**			"Zero harm" material culture **M**			"Zero harm" behavior culture **B**		
U11	U12	U13	U41	U42	U43	U31	U32	U33
4	0	3	4	6	5	1	3	6
2	5	4	6	3	2	5	2	2
2	3	1	0	1	2	3	2	1
2	2	1	0	0	1	1	3	0
0	0	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1

For U1, 4 experts consider it to be quite important; 3 experts choose "important"; 2 experts choose "general"; and 1 expert choose "somewhat important". Following grading results can be obtained. U11 = 1/10 = 0.1; U12 = 4/10 = 0.4; U13 = 4/10 = 0.4; U14 = 1/10 = 0.1; U15 = 0, U16 = 0. These values are membership degrees of corresponding evaluation scales. In the same way, membership degrees of other factors can be calculated. Membership degree matrixes of other factors are as follows.

$$I=\begin{bmatrix} 0.2 & 0.3 & 0.5 & 0 & 0 & 0 \\ 0.6 & 0.2 & 0.2 & 0 & 0 & 0 \\ 0.2 & 0.5 & 0.1 & 0.1 & 0.1 & 0 \end{bmatrix} \quad C=\begin{bmatrix} 0.4 & 0.2 & 0.2 & 0.2 & 0 & 0 \\ 0 & 0.5 & 0.3 & 0.2 & 0 & 0 \\ 0.3 & 0.4 & 0.1 & 0.1 & 0.1 & 0 \end{bmatrix}$$

$$M=\begin{bmatrix} 0.4 & 0.6 & 0 & 0 & 0 & 0 \\ 0.6 & 0.3 & 0.1 & 0 & 0 & 0 \\ 0.5 & 0.2 & 0.2 & 0.1 & 0 & 0 \end{bmatrix} \quad B=\begin{bmatrix} 0.1 & 0.5 & 0.3 & 0.1 & 0 & 0 \\ 0.3 & 0.2 & 0.2 & 0.3 & 0 & 0 \\ 0.6 & 0.2 & 0.1 & 0 & 0 & 0.1 \end{bmatrix}$$

The same method can be employed to construct the membership degree matrix of the factor in the target layer

$$U=\begin{bmatrix} 0.4 & 0.3 & 0.2 & 0.1 & 0 & 0 \\ 0.1 & 0.5 & 0.4 & 0 & 0 & 0 \\ 0.5 & 0.2 & 0.1 & 0.2 & 0 & 0 \\ 0.3 & 0.4 & 0.2 & 0.1 & 0 & 0 \end{bmatrix}$$

In accordance with the above-mentioned evaluation steps, the comprehensive evaluation vector of the factor U in the target layer is:

$$T=W*R=(0.48\ \ 0.18\ \ 0.1\ \ 0.24\ \ 0\ \ 0)\begin{bmatrix}0.4 & 0.3 & 0.2 & 0.1 & 0 & 0\\ 0.1 & 0.5 & 0.4 & 0 & 0 & 0\\ 0.5 & 0.2 & 0.1 & 0.2 & 0 & 0\\ 0.3 & 0.4 & 0.2 & 0.1 & 0 & 0\end{bmatrix}=(0.4\ 0.35\ 0.23\ 0.092\ 0\ 0)$$

Normalize T to get the final evaluation result (0.37 0.33 0.21 0.09 00).

Quantify evaluation ranks to calculate the overall score of the “zero harm” safety culture evaluation for BLT.

$$U=(0.37\ 0.33\ \ 0.21\ 0.09\ 0\ 0)\begin{bmatrix}90\\ 80\\ 70\\ 60\\ 60\\ 30\end{bmatrix}=79.8\ (\text{points})$$

On the basis of a calculation of the “zero harm” safety culture level of BLT as a coal-mine enterprise, the calculation result (79.8 points) can help to determine the development stage of “zero harm” safety culture of BLT, in order to provide useful references to BLT to make plans for developing its “zero harm” safety culture.

Table 10 shows the division of “zero harm” safety culture levels of a coal-mine enterprise

Table 10. Level division of “zero harm” safety culture a coal-mine enterprise.

Valuation	“Zero harm” safety culture levels	Development stage	Suggestions
[95,100]	Level 5	Most developed	“Zero harm” safety culture should be preserved;
[85,95]	Level 4	More developed	“Zero harm” safety culture should be perfected;
[75,85]	Level 3	Medium-developed	“Zero harm” safety culture should be further developed;
[60,75]	Level 2	Less developed	“Zero harm” safety culture should be constructed
[0,65]	Level 1	Least developed	“Zero harm” safety culture requires improvement;

4. Conclusion

The AHP is used to determine weights of “zero harm” safety culture of BLT, and the FCE is chosen to mark the safety culture development of BLT. The total points for “zero harm” safety culture of BLT are 79.8.

This score indicates that BLT is at the self-management stage, as an intermediate development stage of “zero harm” safety culture.

BLT does not complete get rid of the passive restrained state. Therefore, BLT should timely build a mechanism to make employees participate in discussion and decision-making of safety issues, so that employees can realize the great importance and value of safety for them, and individual employees and production groups can voluntarily make commitment to and compliance with safety culture. In this way, BLT can fully realize self-management, proceed in an orderly way, and finally move towards the advanced stage of “zero harm” safety culture.

Acknowledgment

The work was supported by National Natural Science Foundation of China (7127116 9, 71273208).

References

1. Kastenberg W E. Ethics, Risk and Safety Culture. Reflections on the Fukushima Daiichi Nuclear Accident, pp.165-187，2015.
2. MA Yue，FU Gui，ZANG Ya-li． Evaluation index system of enterprise safety culture construction level.China SafetyScience Journal，vol. 24(4) ，pp.124 — 129,2014.
3. Guldenmund F W. The nature of safety culture: a review of theory and research.Safety Science,vol. 34(1),pp:215–257,2000.
4. Liu C, Liu J, Wang J X. Fuzzy Comprehensive Evaluation of Safety Culture in Coal Mining Enterprises. Applied Mechanics & Materials, vol. 724, pp.373-377,2015.
5. QIAN Li-jun LI，Shu-quan． Study on assessment model for aviation safety culture based on rough sets and artificial neuralnetworks.China Safety Science Journal，19(10),pp. 132 — 138,2009.
6. LIU Fang． Study on safety culture evaluation of construction enterprise,Ph.D. thesis, Harbin: Harbin Institute ofTechnology，2010．
7. QIN Bo-tao，LI Zeng-hua． Application of improved AHP method in safety evaluation of mine． Xi′an University of Science & Technology Journal，22(2),pp. 126 — 129．2002.
8. Piyatumrong, et al. "A multi-objective approach for high quality tree-based backbones in mobile ad hoc networks." International Journal of Space-Based and Situated Computing 2.2(2012):83-103.
9. MLABao, Sarenna, and T. Fujii. "Learning-based p-persistent CSMA for secondary users of cognitive radio networks." International Journal of Space-Based and Situated Computing 3.2(2013):102-112.
10. Wen, Yean Fu, and C. L. Chang. "Load balancing consideration of both transmission and process responding time for multi-task assignment."International Journal of Space-Based and Situated Computing4.2(2014):100-113.