Evaluation of Dust-control Reliability in Coal Mine Tunneling Face

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Abstract

Dust in coal mines,which imposes severe influence on workers' health, mainly derives from the tunneling face. This paper establishes the evaluation system of dust-control reliability in coal mine tunneling face, employs AHP method to divide factors impacting on dust concentration in work face into 4 aspects and carries out weight calculation on the index of each aspect. Based on the on-site experience in digging face and real producing conditions, the reliability factors of machines and equipment are set as an example to construct membership function of 4 single factor affiliated to those factors. Finally, the summary is made in accordance with the scores of each factor which are also utilized to carry out classified statistics on the evaluation results. According to the results of the classified statistics, correction opinions that are relevant to the dust-control outcomes in tunneling face are proposed for assuring better practicability of the evaluation system.

Keywords

Tunneling face; Dust-control reliability; AHP method; Membership function; Fuzzy comprehensive evaluation.

1. Introduction

The dust-control reliability in coal mine digging face is defined for pledging that the dust concentration in excavation roadway meets the requirements in The Coal Mine Safety Rules and each working unit can cooperate smoothly together.

The process of mining, excavating and producing in coal mine can generate a mass of dust which mainly derives from the tunneling face where the dustiness is between 30% and 70% [1]. And 80% of the overall dust is composed of respirable dust containing chemical elements like SiO_2 which can tremendously increase workers' risk of developing pneumoconiosis and impose a grave threat to workers' safety. On the basis of the regulations in The Coal Mine Safety Rules, the dust concentration in the working place should never reach to 10mg/m^3 which is the maximum permissible concentration, with the respirable dust concentration below 3.5mg/m^3.

The dust movement in tunneling face is an ever-changing process. According to the dust origin analysis, the dust in digging face primarily roots in the blasting, loading, transportation, reshipment, anchoring, shotcreting and other working units of the coal-rock roadway. The dust contribution and movement conditions in excavation roadway are relevant to the methods of roadway excavation and ventilation and the property of dedusting equipment.

As a kind of comprehensive attributes, reliability [2] contains stability character, continuity character and easy-rehabilitation character. When determining the evaluation indexes of dust-control reliability, it is necessary to determine the ones which can illustrate reliability at the most extent and make most contribution to the research system [3]. On the basis of the working characteristic requirements in the tunneling face, the stability character which refers to the system capability of successive and stable work is set as the most important index.

2. Establishment of Evaluation System of Ventilation Reliability

2.1 Establishment of Evaluation Principles

In the real production process, dust-control reliability in roadway excavation face should satisfy the principles as follows:

(1) Scientific principles

The establishment of evaluation system should conform to objective reality. The evaluation system in this paper is combined with the actual demand parameters to assure scientificity and veracity of the system.

(2) Feasibility principles

The establishment of evaluation system is to ultimately satisfy the requirements of reducing the dust concentration in tunneling face and in the meanwhile it should be convenient for collecting materials and taking on-site tests to cut down some procedures that are unnecessary and irrelevant [4].

(3) Specificity and universality principles of evaluation indexes

When determining evaluation indexes, it is necessary to seek common factors so that the representativeness of indexes can be guaranteed.

2.2 Evaluation System of Dust-control Reliability

Depending on the methods and theories that are mentioned in the former passage and conforming to the principles above, the human-machine-environment analysis method is employed to establish the evaluation system of dust-control reliability which is shown in Fig.1.

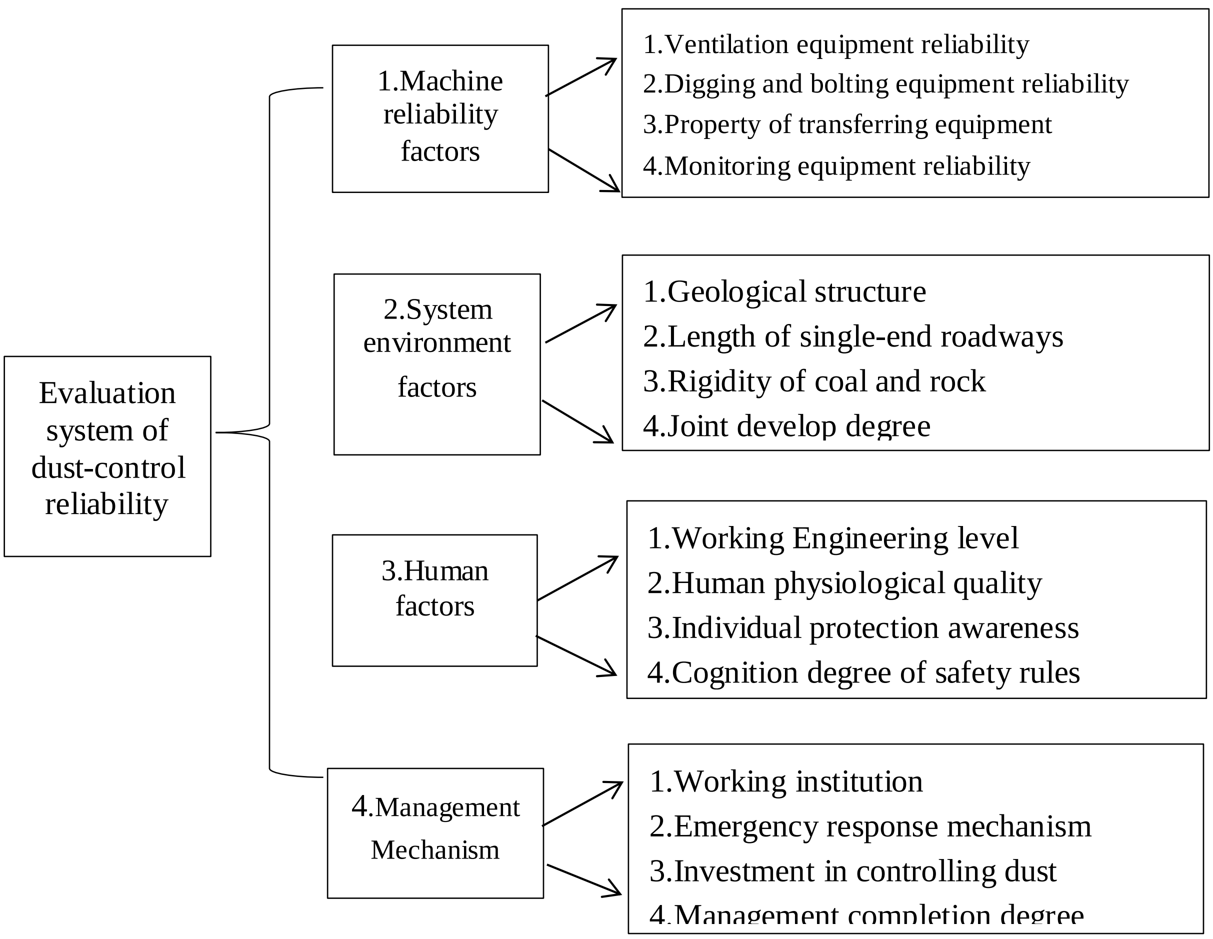

Fig.1. Evaluation system of dust-control reliability in tunneling face Elements of subsystem

Machine reliability factors: they refer to that all of the machines and equipment that are relevant to tunneling face have the property for keep working, containing that gadder, bolt miner, local fan and other machines remain a good condition.

System environment factors: they refer to the working circumstances and related factors that can impact the dust concentration during roadway excavation.

Human factors: they are variable in the working process. Thus, it is important to guarantee that the workers follow the rules in The Coal Mine Safety Rules and other related laws.

Management mechanism: some nonstandard problems commonly exist in management mechanism of tunneling face. Improving management efficiency effectively and perfecting management system are necessary guarantees for working environment to reach to the standard.

Through the analysis of dust-control reliability, machine reliability factors, environment system factors, human factors and management mechanism are determined as the first grade indexes. According to the detailed analysis of them, 16 second grade indexes are set under the four first grade indexes.

3. Weight Calculation of Ventilation Reliability Factors in Tunneling Face

Weight stands for the relative importance of each factor in evaluation system and the validity of its establishment determines the validity of evaluation results. According to the hierarchical structure of the dust-control reliability evaluation system, the first four grade indexes are set as an example and their names are abbreviated based on Chinese as follows: JQ (equipment reliability factors), HJ (environment system factors), RY(human factors), and GL(management mechanism). And then AHP method is adopted to get weight calculation results of each index.

(1) A comparison matrix A is established:

$$A=\begin{bmatrix}1 & 3 & 5 & 5\\ 1/3 & 1 & 2 & 2\\ 1/5 & 1/2 & 1 & 1\\ 1/5 & 1/2 & 1 & 1\end{bmatrix} \quad (1)$$

(2) Transfer matrix B is obtained by taking the logarithm on matrix A:

$$B=\log A=\begin{bmatrix}0 & 0.4771 & 0.6990 & 0.6990\\ -0.4771 & 0 & 0.3010 & 0.3010\\ -0.6990 & -0.3010 & 0 & 0\\ -0.6990 & -0.3010 & 0 & 0\end{bmatrix} \quad (2)$$

(3) On basis of $C_{ij}=\frac{1}{n}\sum_{k=1}^{n}(b_{ik}-b_{jk})$ the optimal transfer matrix C is obtained:

$$C=\begin{bmatrix}0 & 0.4375 & 0.7188 & 0.7188\\ -0.4375 & 0 & 0.2812 & 0.2812\\ -0.7188 & -0.2812 & 0 & 0\\ -0.7188 & -0.2812 & 0 & 0\end{bmatrix} \quad (3)$$

(4) On basis of $a_{ij}^{*}=10^{c_{ij}}$ the quasi-optimal consistent matrix A* of matrix A is obtained:

$$A^{*}=\begin{bmatrix}1 & 2.7384 & 5.2336 & 5.2336\\ 0.3652 & 1 & 1.911 & 1.911\\ 0.1911 & 0.5234 & 1 & 1\\ 0.1911 & 0.5234 & 1 & 1\end{bmatrix} \quad (4)$$

(5) Normalized matrix $A^{\&}$ of A^{*} is obtained:

$$A^{\&}=\begin{bmatrix}0.572 & 0.572 & 0.572 & 0.572\\ 0.209 & 0.209 & 0.209 & 0.209\\ 0.109 & 0.109 & 0.109 & 0.109\\ 0.109 & 0.109 & 0.109 & 0.109\end{bmatrix} \quad (5)$$

Then the eigenvector is obtained:

$$W = \begin{bmatrix} 0.57 \\ 0.21 \\ 0.11 \\ 0.11 \end{bmatrix} \quad (6)$$

Therefore, the weighted value of each index of the first grade factors is: $W_1 = 0.57, W_2 = 0.21$, $W_3 = 0.11, W_4 = 0.11$.

Implementing the standards of the indexes in the first gradation on their counterparts in the second gradation, AHP method is employed to construct comparison matrix. And simultaneously, according to the real conditions in tunneling face, the weighted results are modified properly to obtain the weighted results of each factor which is shown in Table.1.

Table 1. Evaluation index weight of dust-control reliability in tunneling face

	Evaluation indexes	Weight
Machine reliability factors 0.57	Ventilation equipment reliability	0.38
	Digging and bolting equipment reliability	0.32
	Property of transferring equipment	0.18
	Monitoring equipment reliability	0.12
System environment factors 0.21	Geological structure	0.25
	Length of single-end roadways	0.35
	Rigidity of coal and rock	0.25
	Joint develop degree	0.15
human factors 0.11	Working engineering level	0.35
	Human physiological quality	0.22
	Individual protection awareness	0.22
	Cognition degree of safety rules	0.21
Management mechanism 0.11	Working institution	0.24
	Emergency response mechanism	0.32
	Investment in controlling dust	0.30
	Management completion degree	0.14

4. Establishment of Membership Function of Evaluation Indexes

During the actual production in tunneling face, the dust concentration has time-varying characteristics and the dust distribution condition is a non-linear, non-static, ambiguous and changing process. There are a host of problems existing in dust-control outcomes of tunneling face which are difficult to be coped with using traditional mathematics. However, the fuzzy mathematics is able to offer suitable means for it [3]. According to the related regulations in The Coal Mine Safety Rules, this paper combines the on-site experience and adopts standard simple construction methods of fuzzy set membership function [5, 6].

According to the previous experience and field data, the classification membership function of the second grade indexes is established, with relevant materials and construction method of standard fuzzy sets referenced as well. Based on what is mentioned above, this paper sets the machine reliability having the biggest weight as an example to establish its indexes.

(1) Ventilation equipment reliability

Ventilation equipment reliability, which is the ventilation foundation of reliable working in tunneling face, refers to the ratio between the effective air quantity offered by local fans in single-end roadways (the effective part of overall air quantity) and the air quantity required by working face. This coefficient must be greater than 1 and a greater value of it means more effective air quantity and a better outcome of controlling dust. And when it is less than 1, the working face will lack effective air quantity. Thus, in order to ensure certain adjustable allowance, this paper deems it relatively appropriate to set this coefficient greater than 1.1, which is shown in Table 2.

Table 2. Membership degree of ventilation equipment reliability

Index k	k≥1.1	1<k<1.1	k<1
Membership degree f	1	$f=\frac{k-1}{1.1-1}$	0

(2) Digging and bolting equipment reliability

Driving and bolting equipment reliability refers to the percentage between the dust quantity generated by digging equipment and shotcreting equipment in construction links and the overall dust quantity in tunneling face. Greater value of it means worse reliability. According to practical experience and related materials, its membership degree is shown in Figure.3.

Table 3. Membership degree of digging and bolting equipment reliability

Index k	k≤70%	70%<k≤90%	k>90%
Membership degree f	1	$f=\frac{k-70\%}{90\%-70\%}$	0

(3) Transferring equipment reliability

Transferring equipment reliability refers to the percentage between the raise dust generated by transferring and transportation equipment in construction links and the overall dust in tunneling roadways. A greater value of it means poorer outcomes of controlling dust by transferring equipment. According to the field materials and practical experience, its membership degree is shown in Table 4.

Table 4. Membership degree of transferring equipment reliability

Index k	k≤10%	10%<k≤20%	k>10%
Membership degree f	1	$f=\frac{k-10\%}{20\%-10\%}$	0

(4) Monitoring equipment reliability

Monitoring equipment reliability refers to the number of times when the data having relatively big error arise among the tested one-hundred data while monitoring equipment measures the dust concentration in tunneling face. The measurement is based on the standards in The Coal Mine Safety Rules and it shows that a less value of this index means higher monitoring equipment reliability. Its membership degree is shown in Table 5.

Table 5. Membership degree of monitoring equipment reliability

Index k	k≤10%	10%<k≤20%	k>10%
Membership degree f	1	$f=\frac{k-10\%}{20\%-10\%}$	0

5. Disposal of Comprehensive Evaluation Results

When the dust-control reliability in tunneling face is being evaluated, the membership degree of all the elements in the second grade factors should be calculated. According to the evaluation results of each index, the final comprehensive evaluation is carried out. The calculations of comprehensive scores of dust-control reliability in tunneling face adopts the formula as follows:

$$S=\sum_{i=1}^{4}N_i\times\sum_{i=1}^{j}N_{ij}\times f_{ij}$$

Where S is the comprehensive evaluation value of dust-control reliability, Ni is the weight of the first gradation (the principle gradation) index, Nij is the weight of the second gradation (the factor gradation) index, fij is the membership degree of the factor gradation index.

In the practical evaluation, the membership degree of each index in factor gradation is obtained according to the concrete parameters in tunneling face and then classification statistics are carried out on the comprehensive scores, which is shown in Table 6.

Table 6. Classification of dust-control reliability evaluation

S	S≥0.80	0.60≤S<0.80	0.40≤S<0.60	S<0.40
Evaluation	Reliable	Nearly reliable	Unreliable	Need Modification

When evaluation is reliable, it demonstrates the outcomes of controlling dust are good so that it only needs to make adjustment to partial links. When it is nearly reliable, it shows that the dust-control outcomes generally meet the requirements in The Coal Mine Safety Rules, but it is also necessary to make malfunction eliminations on some links. When it is unreliable or needs modification, it illustrates that the dust-control outcomes in tunneling face cannot reach to the standards and satisfy requirements of safety production, and furthermore it needs to be troubleshooter in all aspects and halts production to be rectified and reformed.

6. Conclusion

(1) This paper adopts AHP method to implement unified inspection on each elements of the tunneling face in coal mines, determines the weight of each index, utilizes simple standard construction methods of fuzzy-set function, proposes the final scores of dust-control reliability which are classified as well and puts forward relevant modification measures.

(2) The evaluation of dust-control reliability involved in this paper, which is supposed to combine the practical characteristics and construction requirements of excavation roadways to make further reformations, is a relatively fuzzy concept. The evaluation results are directly influenced by the determination of membership degree of each factors impacting dust-control outcomes and the establishment of comparison matrix. Implementing concrete evaluation is supposed to be objective and consider factors in all aspects.

(3) Evaluating the dust-control outcomes in tunneling face can utilize fuzzy comprehensive evaluation methods. In this way, the results can reflect the dust-control conditions in tunneling face more systematically and authentically, which has a high value of application.

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