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Grey Correlation Model of influence factors analysis of ventilation time in single-way tunnel

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ABSTRACT
Ventilation time is an important parameter in the process of heading face ventilation. Shortening ventilation time has great significance in improving the efficiency of tunneling work. This paper analyzes the influence factors affecting the heading face ventilation time and establishes the grey correlation model based on the ventilation time data of a -118m single-way tunnel in a golden mine. Calculations of the correlation degree between the four influence factors are as follows: blasting fume throwing length (X_0), distance of air duct to tunneling face (X_2), length of tunnel (X_3), initial concentration of CO (X_4), and evaluation of the sensitivity. Results show that tunnel length and blasting fume throwing length are more sensitive to ventilation time of the four influence factors, the distance from the duct to the diving face is less sensitive to ventilation time, and the influence factor of initial concentration is the least sensitive of all. The analysis results can help create practical and instructive effects on ventilation work in single-way tunnels.
KEYWORDS: Single-way tunnel; ventilation time; influence factors analysis; Grey correlation; correlation degree

INTRODUCTION

Driving takes place extensively in mining, tunnels, and underground excavation. As a way of digging tunnels, blasting plays a major role in underground engineering (JI Hong-guang, 2014). Hazardous gases and dust, collectively called blasting fumes, are produced during the explosions. After blasting, it is necessary to ventilate in the one-way tunneling in order to disperse the blasting fumes for preparation of slag removal. Ventilation time is defined as duration time from blasting to when the toxic gas concentration is lower than the state standards to ensure the health and safety of workers. Ventilation time not only marks the efficiency of ventilation, but also provides a reference for the arrangement of the tunneling cycle. Shortening the ventilation time can enhance the work efficiency of tunneling and eliminate toxic gas poisoning accidents (YANG Zan-cheng, 2011).

Theoretically, the nature of ventilation in one-way tunnels is mixture and dilution between fresh air and blasting fumes and drainage with a method of turbulent flow deformation. For a given blasting fume volume and regulated standard concentration of toxic gases, fresh air volume ($Q \cdot t$) is needed to satisfy the requirement of ventilation (Q means volume of ventilator, t means ventilation time). Practically, there are a number of influence factors and complicated interactions which cause the extension of ventilation. Several scholars found that volume of air, length of blasting fume throwing, distance of duct to tunnel face, length of tunnel, and original concentration of blasting fume have an influence on ventilation time (WU Li-zhong, 1959; WANG Yin-min, 1993; WU Chao, 2008). In practical engineering, carrying out weight evaluation through introducing proper methods in order to analyze the sensitive degree between the influence factors and ventilation time has a vitally instructive effect on ventilation in one-way tunnels.

In the past, researchers have focused on the mathematical model of removal of blasting fumes in tunnels (SU Li-jun, 2000; YANG Li-xin, 2000). Accurate mathematical models have been established that depict the movement of blasting fumes and the volume of air. The authors have paid less attention to the weight influence factors analysis of ventilation. Although statistical methods show priority on sensitive analysis, these methods need abundant data (WANG Yang, 2004). Applying the grey correlation model to the analysis of

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sensitive influence factors of ventilation time can obtain better advantages. The grey correlation model not only can fit with less data, but it also avoids the problem of the difference of parameter units and magnitude (WU Ai-you, 2005). Therefore, in this article the grey correlation model is built to carry out weight analysis on the influence factors.

1. INTRODUCTION OF GREY CORRELATION MODEL

The grey correlation model is established via three steps as follows: Firstly, confirm the system feature sequence and influence factors sequence; Secondly, obtain the correlation degree by calculating the influence factors sequence; Thirdly, perform a correlation analysis according to correlation degree (LIU Si-feng, 2013).

2.1 System feature sequence and influence factors sequence matrix

Select system feature sequence as X_0, influence factors as X_1、X_2 …X_i showed in the formulas below.

$$X_0 = \left(x_0(1), x_0(2), \cdots, x_0(n),\right)$$
$$X_1 = \left(x_1(1), x_1(2), \cdots, x_1(n),\right)$$
$$\cdots\cdots$$
$$X_i = \left(x_i(1), x_i(2), \cdots, x_i(n),\right)$$

2.2 Calculation Process of Correlation Degree

(1) Sequence original image:

$$X_i' = X_i / x_i(1) = \left(x_i'(1),\ x_i'(2),\ \cdots,\ x_i'(n)\right),\quad i = 0, 1, 2, \cdots, m$$

(2) Difference value of sequence:

$$\Delta_i(k) = \left|x_0'(k) - x_i'(k)\right|,\quad \Delta_i = \left(\Delta_i(1),\ \Delta_i(2) \cdots\ \Delta_i(n)\right)\quad i = 1, 2, \cdots, m$$

(3) Maximum and minimum differences:

$$M = \max_i \max_k \Delta_i(k), \qquad m = \min_i \min_k \Delta_i(k)$$

(4) For $\xi \in (0,1)$

$$\gamma\left(x_0(k),\ x_i(k)\right) = \frac{\min\limits_i \min\limits_k \left|x_0(k) - x_i(k)\right| + \xi \max\limits_i \max\limits_k \left|x_0(k) - x_i(k)\right|}{\left|x_0(k) - x_i(k)\right| + \xi \max\limits_i \max\limits_k \left|x_0(k) - x_i(k)\right|}$$

When ξ=0.5, the formula can be transformed as follows:

$$\gamma_{0i}(k) = \frac{m + 0.5\mathrm{M}}{\Delta_i(k) + 0.5\mathrm{M}},\quad k = 1, 2, \cdots, n \quad i = 1, 2 \cdots m$$

(5) Correlation degree:

$$\gamma_{0i} = \frac{1}{n}\sum_{k=1}^{n} \gamma_{0i}(k),\quad i = 1, 2 \cdots m.$$

Correlation degree is the metric that weights the correlation extent between the influence factor and feature sequence. Its value ranging interval is [0,1]. The closer to 1 the correlation degree is, the higher the influence on the feature sequence the factors have; On the contrary, the closer to 0 the correlation degree is, the lower the influence on the feature sequence the factors have.

2. APPLICATION OF GREY CORRELATION MODEL

3.1 Calculation steps

Take forced auxiliary ventilation in a single-way tunnel at a golden mine as an example. Select X_1, X_2, X_3, X_4 as the influence factors sequence, and X_0 as the feature sequence. Ventilation monitoring tests were conducted to acquire relevant test data in single-way tunnel after blasting according to the practicality.

X_1 stands for length of blasting fume throwing, m;
X_2 stands for distance of duct to working face, m;
X_3 stands for length of tunnel, here is instead of the distance of test point to working face, m;
X_4 stands for original concentration of blasting fume, ppm;
X_0 stands for ventilation time, min.

Table 1: Original data of feature sequence and influence factors sequence.

Sample ID	X_0 (min)	X_1 (m)	X_2 (m)	X_3 (m)	X_4 (ppm)
1	82	21.4	20	48	3693779.3
2	70	20.6	23	53	859406.7
3	150	15.8	12	42	1648480.3
4	176	19.8	14	36	1443225.6
5	105	21	18	38	1629622.8
6	186	22.2	17	50	6289709.5
7	50	18.2	10	31	508339.4
8	54	20.6	19	35	491464.1
9	81	19.8	24	40	443655.8

(1) Calculation of sequence original image:

$$X_i^{'} = X_i / x_i(1) = \left(x_i^{'}(1),\ x_i^{'}(2),\ \ldots,\ x_i^{'}(n) \right) \quad i = 0,1,2 \quad n = \cdots, 9$$

$$X^{'} = \left(X_0^{'}, X_1^{'}, X_2^{'}, X_3^{'}, X_4^{'} \right)^T = \begin{pmatrix} 1 & 0.854 & 1.829 & 2.146 & 1.281 & 2.268 & 0.610 & 0.659 & 0.988 \\ 1 & 0.963 & 0.738 & 0.925 & 0.981 & 1.037 & 0.851 & 0.963 & 0.925 \\ 1 & 1.150 & 0.600 & 0.700 & 0.900 & 0.850 & 0.500 & 0.950 & 1.200 \\ 1 & 1.104 & 0.875 & 0.750 & 0.791 & 1.041 & 0.646 & 0.729 & 0.833 \\ 1 & 0.233 & 0.446 & 0.391 & 0.441 & 1.703 & 0.137 & 0.133 & 0.120 \end{pmatrix}$$

(2) Calculation of differences of sequence:

$$\Delta_i = \left(\Delta_1, \Delta_2, \Delta_3, \Delta_4 \right)^T = \begin{pmatrix} 0 & 0.109 & 1.091 & 1.221 & 0.299 & 1.231 & 0.241 & 0.304 & 0.626 \\ 0 & 0.296 & 1.229 & 1.446 & 0.381 & 1.418 & 0.110 & 0.291 & 0.212 \\ 0 & 0.251 & 0.954 & 1.396 & 0.489 & 1.227 & 0.036 & 0.071 & 0.155 \\ 0 & 0.621 & 1.383 & 1.756 & 0.839 & 0.566 & 0.472 & 0.526 & 0.868 \end{pmatrix}$$

(3) Calculation of maximum and minimum differences:

$$M = \max_i \max_k \Delta_i(k) = 1.756$$

$$m = \min_i \min_k \Delta_i(k) = 0$$

(4) Calculation of correlation coefficient:

$$\gamma_{0i}(k) = \frac{m + 0.5\text{M}}{\Delta_i(k) + 0.5\text{M}} = \frac{0.878}{\Delta_i(k) + 0.878} \quad k = 1, 2, \cdots 9 \quad i = 1, 2, 3, 4$$

Then the corresponding grey correlation matrix is:

$$R_{0i} = \begin{pmatrix} 1 & 0.890 & 0.446 & 0.418 & 0.746 & 0.416 & 0.785 & 0.743 & 0.935 \\ 1 & 0.748 & 0.417 & 0.378 & 0.698 & 0.382 & 0.889 & 0.751 & 0.805 \\ 1 & 0.778 & 0.479 & 0.386 & 0.642 & 0.417 & 0.961 & 0.926 & 0.850 \\ 1 & 0.586 & 0.388 & 0.333 & 0.511 & 0.608 & 0.650 & 0.626 & 0.503 \end{pmatrix}$$

(5) Calculation of grey correlation degrees:

$$\gamma_{0i} = \frac{1}{n} \sum_{k=1}^{n} \gamma_{0i}(k), \quad i = 1, 2, 3, 4 \quad k = 1, 2, \cdots, 9$$

$$\overline{R_{0i}} = \left(\gamma_{01}, \gamma_{02}, \gamma_{03}, \gamma_{04} \right) = \left(0.709, 0.674, 0.715, 0.578 \right)$$

3.2 Results analysis and practical application

Results were acquired through the grey correlation model. The correlation degrees of the four influence factors (X_1, X_2, X_3, X_4) are 0.709, 0.674, 0.715, and 0.578. The length of the tunnel (X_3) shows the maximum influence on ventilation; the second influence factor is the length of blasting fume throwing (X_1); the third influence factor is the distance from the duct to the working face (X_2); the original concentration of blasting fume (X_4) has the minimum influence on ventilation time.

In order to shorten the ventilation time in single-way tunnels, the most effective approach is to improve the influence factor which has the maximum influence on ventilation time. According to the results calculated through the grey correlation model, shortening the length of tunnel (X_3) should be the most effective. However, this is not practical. Therefore, lessening the length of blasting fume throwing (X_1) is another good way to shorten ventilation time. Limited explosives should be used in every explosion to decrease the original concentration of blasting fumes. Because the correlation degrees of these influence factors show big relativity to ventilation time, enhancing one or several factors can effectively shorten the ventilation time.

3. CONCLUSION

The grey correlation model has better effects on the weight analysis of influence factors to ventilation time. Through making use of the grey correlation model, the qualitative analysis can be expressed in quantitative results, clarifying the major and minor influence factors for ventilation time. This provides rewarding instruction and reference to ventilation management during the process of tunneling.

The grey correlation model was applied to analyze several independent influence factors. Therefore, the selection of influence factors and the use of data sequences has some influence on the accuracy and reasonability of the results of the model evaluation.

The ventilation system in the tunnel can be equal to forcing auxiliary ventilation with a constant air volume. As another influence factor, the extent of air volume to ventilation time has important value in research. For exhausted ventilation and combined ventilation, whether and how much the influence factors above are related to ventilation time remains to be researched and confirmed.

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