



A derivative method to calculate resistance sensitivity for mine ventilation networks

Lihong Zhou* and Davood Bahrami

National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Mining Research Division, Pittsburgh, PA, USA

*Corresponding author email: lzhou2@cdc.gov

Full-text paper:

Mining, Metallurgy & Exploration (2022) 39:1833–1839, <https://doi.org/10.1007/s42461-022-00630-z>

Keywords: Mine ventilation, Ventilation network, Ventilation stability, Resistance sensitivity

A reliable and stable ventilation system is essential to the safe operation of underground mines. The stability of a mine ventilation system becomes extremely critical when responding to a fire incident, as an unstable ventilation system will pose a risk of airflow reversal. The reversed airflow could bring fire contaminants, such as toxic gases and smoke, unexpectedly to working areas. In the past few years, there has been a growing interest in the study of ventilation network stability using the concept of resistance sensitivity, which is described as an indicator of how the airflow in an airway is reacting to a resistance change of other airways. Several methods of calculating the resistance sensitivity in a mine ventilation network have been developed by researchers and scholars around the world. However, those proposed methods rely heavily on a vast number of mine ventilation simulations, which is time-consuming and computer-resource intensive, especially for a large-scale mine ventilation network. In this study, a derivative method calculating the resistance sensitivities with a single mine ventilation simulation is developed and implemented into the MFIRE mine fire simulation software. The results from the derivative method were verified against the results from a traditional method. The derivative method is proved to be reliable and accurate.

Background

Derivative method. The resistance sensitivity of an airway is an indicator of how much the airflow in the airway is affected by the change of resistance in a certain airway. It is mathematically defined as [1,2]:

$$s_{ij} = \lim_{\Delta R_j \rightarrow 0} \frac{\Delta Q_i}{\Delta R_j} = \frac{\partial Q_i}{\partial R_j} \tag{1}$$

where s_{ij} is the sensitivity of airway i to the change of resistance in airway j , R_j is the resistance in airway j , and Q_i is the volumetric airflow rate in airway i .

Given a ventilation network with N airways, each airway can have N sensitivities to the rest of the airways and itself. Therefore, an $N \times N$ sensitivity matrix, S , can be formed for the ventilation network:

$$S = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1N} \\ s_{21} & s_{22} & \cdots & s_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ s_{N1} & s_{N2} & \cdots & s_{NN} \end{bmatrix} \tag{2}$$

For a given airway k with resistance R_k , the sensitivity of any airway i to the resistance change in airway k , denoted as $\partial Q_i / \partial R_k$, can be obtained using:

$$\sum_{j=1}^N 2b_{ij}R_jQ_j \left(\sum_{i=1}^M c_{ij} \frac{\partial Q_i}{\partial R_k} \right) - \frac{\partial H_{Fi}}{\partial R_k} - \frac{\partial H_{Ni}}{\partial R_k} = 0 \tag{3}$$

($i = 1, 2, \dots, M$) ($k \neq j$)

$$\sum_{j=1}^N 2b_{ij}R_jQ_j \left(\sum_{i=1}^M c_{ij} \frac{\partial Q_i}{\partial R_k} \right) + \sum_{j=1}^N b_{ij}Q_j^2 - \frac{\partial H_{Fi}}{\partial R_k} - \frac{\partial H_{Ni}}{\partial R_k} = 0$$

($i = 1, 2, \dots, M$) ($k = j$)

The derivation of Eq. (3) is the result of the application of Kirchhoff’s first and second laws with differentiation operation. Details can be found in the full-text paper.

Method and results

Verification of the derivative method. The above mathematical model of resistance sensitivity is implemented into the National Institute for Occupational Safety and Health’s (NIOSH) MFIRE, an open-source mine fire simulation software, to calculate the resistance sensitivities of a mine ventilation network. Furthermore, the resistance sensitivities obtained from the derivative method are compared with those calculated by changing the resistance of each branch one at a time by “Delta R” and running the ventilation simulation for each. Taking an example of a target branch from a 49-branch ventilation network, we calculated the airflow changes in each branch while the absolute resistance changes of the target branch are 0.1, 0.2 and 0.8 ($10^{-10} * \text{in.w.g./cfm}^2$), respectively. To better understand the correlation of the results, the normalized scatterplot by Delta R is used to display the relationship between the sensitivity from the derivative method and the results from the fixed resistance changes. It can be seen from Fig. 1 that the resistance sensitivity of the target branch calculated from the derivative method is linearly related to the results obtained from the various resistance changes with a Pearson coefficient of 0.999.

Conclusions

Resistance sensitivity of a ventilation network is a valuable tool to understand the degree of the interdependency of each branch and the overall stability of the network. This paper presents a derivative method to calculate the sensitivity in a ventilation network without the need for numer-

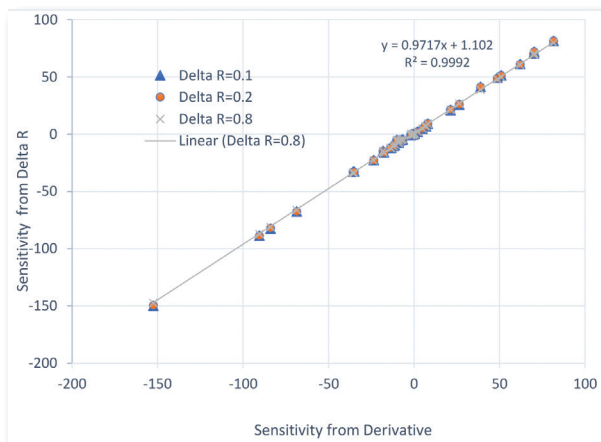


Fig. 1 Correlation between the sensitivity from the derivative method and normalized resistance changes.

ous simulations of the ventilation network as used in other methods. As compared to other methods, the advantage of the derivative method is savings in time and computer resources, as the derivative method only requires running the ventilation network simulation one time. The proposed

method has been implemented into NIOSH's MFIRE mine fire simulation program and has proven to provide a useful addition to the software features. The verification study of the derivative method has shown that the calculated sensitivity results from the derivative method are in excellent agreement with the airflow rate changes from the example cases using a manual resistance change, Delta R. The sensitivity matrix of a ventilation network provides a good picture of how the airways correlate with each other. It can help mine operators to perform ventilation control and diagnose ventilation problems such as abnormal airflow. ■

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute an endorsement by NIOSH.

Selected references

1. Jia J, Jia P, Li Z (2020) Theoretical study on stability of mine ventilation network based on sensitivity analysis. *Energy Sci Eng* 00:1–8
2. Zhou L, Luo Y, Wu F (2007) Identification of abnormal airflow quantity in underground coal mines. *Int J Min Resour Eng* 12(4):257–265

Determining the benefit of air receivers in South African deep-level mines using a genetic algorithm

Michael David Harmse*, **Jean Herman van Laar**, **Wiehan Adriaan Pelser** and **Cornelius Stephanus Lodewyk Schutte**

Department of Industrial Engineering, Stellenbosch University, Stellenbosch, South Africa

*Corresponding author email: mdharmse@gmail.com

Full-text paper:

Mining, Metallurgy & Exploration (2022) 39:2083–2093, <https://doi.org/10.1007/s42461-022-00640-x>

Keywords: Air receiver, Deep-level mining, Compressed air, Optimization, Modeling, Genetic algorithms, Economic dispatch, Artificial intelligence

Rising electricity costs in South Africa have resulted in a need for optimized compressed-air networks in the mining environment. As a result, the financial benefit of air receivers needs to be reconsidered along with the economic dispatch strategy. This study investigates the use of an evolutionary algorithm in the mining industry to determine the potential financial benefit for various-sized air receivers, as well as their dispatch strategy. A genetic algorithm was selected due to the improved solution reliability and accuracy compared to other optimization techniques. This study indicates that a genetic algorithm can be used to determine the optimal dispatch of compressed air in the deep-level mining industry. Further, this study indicates that air receivers are financially viable in the mining industry and can be used to reduce operating costs, improving profitability.

Background

In the deep-level gold mining industry, compressed air is required for underground rock drilling. It forms part of

the blasting process, which is required for the production process in mining operations. Various alternatives to compressed air have been developed and tested, including water and electric drilling. The alternatives proved to be both financially viable and more efficient in terms of operation. However, capital expenditure and life of mine have limited the viability of implementing these alternatives. The most cost-effective solution is therefore to optimize the existing compressed-air infrastructure and operating strategies by addressing the wastage of compressed air and improving its supply and management by introducing alternative technological solutions.

The deep-level mining industry presently uses dams to implement economic dispatch for optimization in systems such as dewatering and cooling systems. However, compressed-air systems in the mining industry do not use storage facilities. Compressed-air storage facilities, known as air receivers, were previously used in deep-level mining but are no longer present as air receivers became unfeasible due to the

Reproduced with permission of copyright owner. Further reproduction prohibited without permission.