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A fuzzy logic model to predict the out-of-seam dilution in longwall mining

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A B S T R A C T

The longwall mining method is often affected by the out-of-seam dilution (OSD). Therefore, predicting and controlling of dilution are important factors for reducing mining costs. In this study, the fuzzy set theory and multiple regression models with parameters, including variation in seam thickness, dip of seam, seam thickness, depth of seam, and hydraulic radius as inputs to the models were applied to predict the OSD in the longwall coal panels. Field data obtained from Kerman and Tabas coal mines, Iran were used to develop and validate the models. Three indices including coefficient of determination (R^2), root mean square error (RMSE) and variance account for (VAF) were used to evaluate the performance of the models. With 10 randomly selected datasets, for the linear, polynomial, power, exponential, and fuzzy logic models, R^2, RSME and VAF are equal to (0.85, 4.4, 84.4), (0.61, 7.5, 59.6), (0.84, 4.5, 72.7), (0.80, 4.1, 79.6), and (0.97, 2.1, 95.7), respectively. The obtained results indicate that the fuzzy logic model predictor with $R^2 = 0.97$, RMSE = 2.1, and VAF = 95.7 performs better than the other models.

1. Introduction

In mining, mixing ore with waste rock is described as dilution. It significantly reduces the grade of ore, increases the total costs of mining and may endanger the financial achievements of a project [1]. Hence, in order to reduce mining costs, controlling dilution is an important issue in mining operations.

Many investigators have devoted a part of their studies to mining dilution. Planeta et al. evaluated the impact of rock dilution on underground mining [1]. Annels estimated the dilution on basis of the field data at Stillwater mine in Montana [2]. Further, Clark studied minimizing dilution in open stope mining with focus on stope design and narrow vein longhole blasting [3]. Moreover, Suorineni et al. applied the equivalent liner overbreak-slough (ELOS) concept to quantify the dilution [4]. Also, a research work on the measurement and control of dilution in an underground coal operation was carried out by Noppe [5]. Further, Wang studied the influence of stress, undercutting, blasting, and time on the open stope stability and dilution [6]. At the same time, Chugh et al. evaluated the effect of out-of-seam dilution on coal utilization [7]. Further, a study on the dilution in an underground coal mine in the USA was carried out by Chugh et al. to understand the impacts on production, processing and waste disposal [8]. Also, Henning and Mitri carried out numerical modeling of the ore dilution in blasthole stoping [9]. Further, the level of out-of-seam dilution (OSD) for the longwall mining method in the Tabas coal mine was quantified by Saeedi et al. [10]. In another attempt, numerical modeling of the OSD in longwall retreat mining was carried out by Saeedi et al. [11].

The objective of this paper is to develop a fuzzy logic model to predict the OSD in longwall mining. The field data from Tabas and Kerman coal mines, Iran are used to evaluate the performance of the proposed fuzzy model. Also, multiple regression models are developed based on the field data from the same mines.

2. Out-of-seam dilution in longwall coal mining

In general, any waste material within the mining block is referred as the term “dilution” [9]. The sources of OSD in the longwall mining method may be divided into three main classes: primary, secondary, and tertiary dilution [5]. Primary dilution includes cutting of the rock floor or roof by the longwall shearer machine. Secondary dilution is slabbing or break-up of the roof or floor during mining and trimming. Tertiary dilution includes waste material loaded with the coal during section-cleaning operations.

The most important contributing parameters affecting the OSD, excluding the human element, are including the variation in seam thickness ((variation in seam thickness/seam thickness) × 100)

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Fig. 1. Location of Kerman and Tabas coal mines.

Table 1
Descriptive statistics for 35 sets of data from Kerman and Tabas coal mines.

Parameter	Symbol	Range	Mean	Standard deviation
Variation in seam thickness (%)	VST	3.8–80	39.83	23.63
Seam thickness (m)	t	0.4–2.6	1.36	0.58
Dip of seam (°)	α	5–43	26.42	9.29
Cutting method	CM			
Roof quality (RMR)	RQ	15–70	42.43	21.73
Floor quality (RMR)	FQ	15–80	62.16	26.36
Depth of seam (m)	H	146–900	348	209.47
Hydraulic radius (m)	HR	0.1–2.7	0.75	0.55
Out-of-seam dilution (%)	OSD	7.8–44.2	17.9	9.82

Table 2
Samples of data from Kerman and Tabas coal mines.

No	VST (%)	t (m)	a (°)	CM	RQ	FQ	H (m)	HR (m)	OSD (%)
1	9.09	2.2	20	1	22.5	45	350	0.52	23.1
2	16.67	1.8	18	2	30	65	345	0.35	17.4
3	38.46	1.3	30	2	30	30	300	0.7	15.5
4	11.11	1.8	20	1	22	65	220	0.5	22.3
5	26.67	1.5	33	2	30	30	600	0.6	29.5

(VST), seam thickness (t), dip of seam (α), cutting method (CM), roof quality (RQ), floor quality (FQ), depth of seam (H), and hydraulic radius (ratio of the area of exposed roof of longwall face to the perimeter of exposed roof of longwall face) (HR) [7].

Different definitions for the OSD are used here. Eqs. (1) and (2) are used worldwide to determine dilution [12].

$$\mathrm{OSD}(\%) = (W/O) \times 100 \tag{1}$$

$$\mathrm{OSD}(\%) = (W/(O+W)) \times 100 \tag{2}$$

where, W is the tons waste mined; and O the tons ore mined.

3. Data collection

The field data (35 datasets), from Kerman and Tabas longwall coal mines, Iran (Fig. 1), were obtained to establish a database for model development. These data are including variation in seam thickness, seam thickness, dip of seam, cutting method (e.g., pick, machine, and blasting), roof quality, floor quality, depth of seam, hydraulic radius, and the OSD.

Variation in seam thickness, seam thickness, dip of seam, depth of seam and hydraulic radius were obtained through the geological survey and field observations. The roof and floor quality were determined based on the rock mass rating (RMR) classification. Furthermore, the OSDs for 35 datasets were calculated by using Eq. (2). Descriptive statistics of the data are shown in Table 1. Also, samples of data can be seen in Table 2.

4. Regression and fuzzy logic modeling

4.1. Input and output parameters

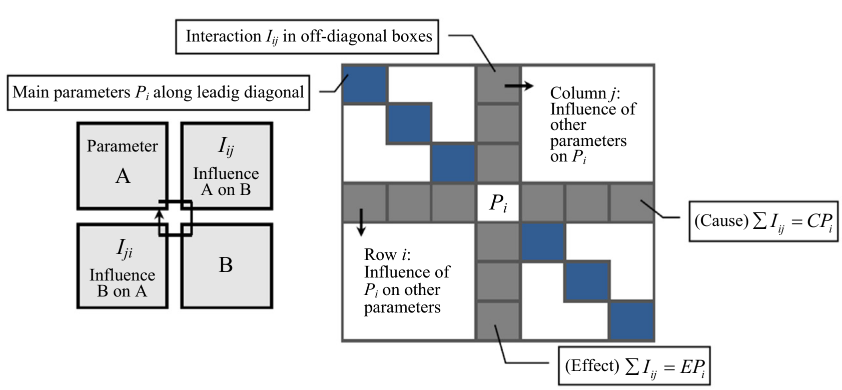
Based on the existing reviewed literature [7], eight parameters given in Table 1 represent the most effective parameters on the occurrence of OSD. Among these parameters, parameter cutting method was excluded as it is a descriptive parameter and cannot be considered as input in the regression and fuzzy modeling. Also, in order to have a simpler modeling and in particular to reduce the number of rules in the fuzzy modeling, a number of effective parameters were removed based on their weight on the OSD. For this purpose, the rock engineering systems (RES) was used.

4.2. Rock engineering systems

The RES methodology, first introduced by Hudson [13], was used to address and quantify the interactions among the parameters that affect to different degrees the outcome of a rock engineering system. In this methodology, the "interaction" matrix constitutes the foundation of the methodology.

In the interaction matrix, all parameters affecting the system are located along the leading diagonal of the matrix, and the off-diagonal positions are assigned with values, which describe the degree of the influence of one parameter on the other parameters (Fig. 2).

Assigning numerical values to the interaction boxes (i, j) and (j, i) is referred to as coding the matrix. There are three procedures:



(a) Interaction matrix of two parameters (b) General illustration of the coding of interaction matrix

Fig. 2. Interaction matrix in rock engineering systems [13].