OPTIMIZATION OF BLASTING COST IN LIMESTONE MINES BY PSO METAHEURISTIC ALGORITHM

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Abstract: In this research, a model is presented to predict the blasting cost by collecting blasting data from six limestone mines in Iran using a nonlinear multivariate regression. This model has a higher correlation coefficient (0.913) and lower root mean square error (1089) than the linear multivariate regression model, thus indicated a better compliance with the actual blasting costs. In this study, in addition to achieving the blasting cost function using a nonlinear multivariate regression method, a model was proposed for blasting limiting functions including fragmentation, fly rock, and back break. These functions were used as constraints to the particle swarm optimization (PSO) metaheuristic algorithm in order to optimize the blasting cost. Results showed that the spacing, borehole number, and length of holes were 3.6 m, 462 loops, and 13 m as blasting design parameters, respectively. The mean grading, fly rock, and back break 44 cm, 84.5 m and 3.6 m, respectively, were the blasting constraints, and also the blasting cost was calculated to be 6235 Rials per ton. These results showed a 12.9% reduction in blasting costs, and an optimal control of the adverse consequences of blasting in comparison to the conventional blasting patterns.
Keywords: Blasting cost, limestone mines, nonlinear multivariate regression, particle swarm optimization algorithm.

1- INTRODUCTION

The calculation of the blasting cost without considering the adverse consequences of blasting is meaningless. Regarding the importance of blasting and its impact on the extraction costs of minerals, the provision of a model to predict the blasting cost seems necessary.

Some studies have focused on the blasting cost and its related issues (e.g., Nielsen, Jimeno et al., Eloranta, Kanchibotla, Rajpot, Usman and Muhammed, Afum and Temeng, Adebayo and Mutandwa, Jackson, Ghanizadeh et al.). Most of these studies have been carried out to calculate the drilling cost, relation between blasting cost and transportation cost, impact of fragmentation properties on blasting cost, reduction of drilling and blasting cost, and presenting a blasting cost model in a particular mine and adverse consequences of blasting.

Based on the literature review, no researches were intended to study the prediction and optimization of the blasting cost in limestone mines, making it necessary to present a model accordingly. In this research, the nonlinear multivariate regression was applied to predict the blasting cost of limestone mines. Results of this study were compared with real collected data and linear multivariate regression, then the blasting cost and optimal design parameters were calculated using particle swarm optimization (PSO) algorithm and consideration of constraints.

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2. Prediction and optimization model of blasting cost

2.1. Modeling with multivariate regression

Among the 146 recorded blasting in six limestone mines, 80% of the data were used for modeling and 20% were used for testing the model, randomly. The SPSS24 software and Forward method were used to predict the blasting cost regarding the fragmentation, fly rock, and back break constraints; the linear multivariate regression (LMR) models were formulated as equations (1)-(4):

$$BC = 22148.722 - 6624.528S - 0.597AN + 217.96D - 1711.786T \quad (1)$$

$$Fr = -26.776 + 0.529D + 4.901S + 0.001AN \quad (2)$$

$$FL = 85.95 - 41.097T + 12.176S + 0.62D \quad (3)$$

$$BB = -2.912 + 0.000186AN - 2.465T + 0.086D + 0.756S \quad (4)$$

Furthermore, the nonlinear polynomial, power, exponential and logarithmic models were processed using the data.Considering a higher R^2 value, the logarithmic model was selected for predicting blasting cost among other models, and other constraints were used as equations (5)-(8).

$$BC = \frac{10^{5.648}}{S^{1.627} \times N^{0.28} \times H^{0.176}} \quad (5)$$

$$Fr = 10^{1.089} \times H^{0.313} \times S^{0.362} \quad (6)$$

$$FL = \frac{10^{2.262}}{H^{0.3}} \quad (7)$$

$$BB = \frac{N^{0.23}}{10^{0.056}} \quad (8)$$

In the above equations, BC indicates the blasting cost (Rials per ton), Fr means fragmentation (Cm), FL shows fly rock (m), and BB is considered as back break (m). In addition, S, AN, D,T, N, and H represent spacing, amount of ANFO, hole diameter, stemming, borehole number, and hole length, respectively. Figure 1 shows the consistency of results obtained from the two models with real data.

2.2. Optimization with Particle Swarm Algorithm (PSO) metaheuristic algorithm

After coding the model with PSO algorithm in MATLAB, and applying the blasting cost function and constraints of fragmentation, fly rock, back break, spacing-to-burden ratio (S≥B) and hole length-to-burden (H = (3-4) B) in the relevant model, different results were obtained by changing the inertia coefficient and its adjustment factor, personal learning rate, collective learning rate at the output of the model. The optimal results were obtained when these parameters were selected based on Table 1. The proposed model was executed with different repetition numbers including 200, 500, 1000, 2000 and even higher. It was observed that the value of the objective function remained constant after the 130th repetition.

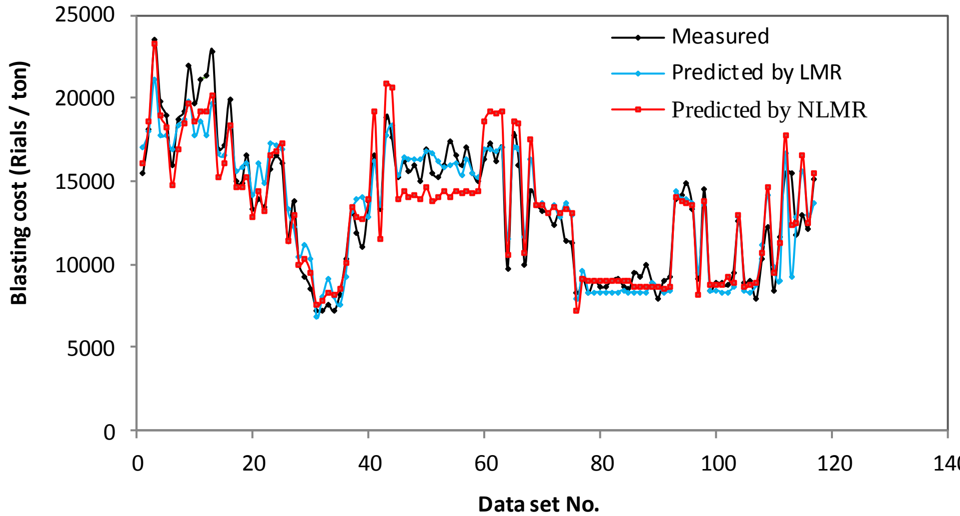

Figure 1. The comparison of the predicted cost of the two models with real cost

Table 1. The controllable parameters of the PSO algorithm

Parameter	Symbol	Value
Maximum number of Iteration	MaxIt	200
Number of particles	Npop	146
Number of input variables	Nvar	3
Inertia Coefficient	W	1
Inertia Coefficient adjustment factor	Wdamp	0.99
Personal learning rate	C_1	2
Collective learning rate	C_2	2

3. Discussion

Table 2 compares the obtained values by non-linear multivariate regression method - particle swarm optimization algorithm (NLMR-PSO), with the mean and minimum value of the data. Based on the table and the proposed PSO model with this algorithm, a 12.9% reduction is observed in blasting cost (a decrease from 7157 to 6235 Rials per ton). As a result of blasting, the size of fragmentation increased from 40 to 44 cm, due to the presence of a jaw crusher with an inlet opening of 110×90 cm, which did not cause problems for production process in the processing plant. The strength of this study is a 28% reduction in back break (from 5 to 3.6 m), and a 23.2% reduction in fly rock (from 110 to 84.5 m). Finally, the result of NLMR-PSO model is satisfactory, comparing the results in Table 2 for BC, BB, FL, and Fr.

Table 2. The comparison of the obtained values of NLMR-PSO with the mean and minimum values of real data

Model	BC		Fr		FL		BB	
	Value (Rials /Ton)	Difference with minimum data(%)	Value (Rials /Ton)	Difference with minimum data(%)	Value (Rials /Ton)	Difference with minimum data(%)	Value (Rials /Ton)	Difference with minimum data(%)
NLMR-PSO	6235	-12.9	44	+10	84.5	-23.2	3.6	-28
Average of data	13468	88.2	36	-10	97	-11.8	3.4	-32
Minimum of data	7157	0	40	0	110	0	5	0

4- CONCLUSIONS

The nonlinear multivariate regression was compared to the linear model, and a higher correlation coefficient, with a lower root mean square error were observed. Based on real data, comparing the results of the nonlinear multivariate regression model with the linear multivariate regression model indicated that the nonlinear model had a better consistency with the real blasting costs, than the linear model.

According to the sensitivity analysis, using relevancy factor (RF) method on the blasting cost model with nonlinear multivariate regression method showed that the spacing had the most significant effect on the target function, while the hole number had the smallest impact.. The number of holes was positively correlated with the blasting cost function, whereas the parameters of hole length and spacing were negatively correlated to the function.

Comparing the obtained results of blasting cost, fragmentation, fly rock, and back break using the NLMR-PSO model, with the values obtained from experiments indicated the capability of the model for prediction and optimization of blasting costs.

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