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MATHEMATICAL MODELLING AND OPTIMIZATION OF PRODUCTIVITY OF ROOF BOLTING OPERATION

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Abstract

In the underground coal mine the Roof is supported by bolt so that coal can be easily extracted from the mine. Presented Research work is to formulate the mathematical model and optimization of productivity of roof bolting operation. The various parameters like dependent and independent has been identified. In this research work dependent and independent pi (π) terms are formed. The correlation of various parameters and pie terms is a mathematical model. From the studies on the model of productivity it has been observed that the influence of specification of bolt and humidity is predominant over the specification of drill rod, operator, and illumination.2D graphical analysis of the mathematical models shown the influence of the operator on productivity is significant. The optimum values of the independent pi (π) terms can be found by optimization of these models for maximum productivity. Optimum values of independent pi terms for maximum productivity are found to be $\Pi 1 = 8.398$, $\Pi 2 = 1.548e-08$, $\Pi 3 = 1.778e29$, $\Pi 4 = 331.1311$, $\Pi 5 = 457.088$ and $\Pi 6 = 96$.

1. Introduction

In the underground coal mine the Roof is supported by bolt so that coal can be easily extracted from the mine. At the time of their introduction, roof

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bolts were acclaimed as “one of the great social breakthroughs of our time” because they promised to significantly reduce the incidence of roof fall accidents, which were then responsible for hundreds of deaths each year. The complete process of operation of the underground mine comprises of the following operations.

(i) Deciding the location of blasting. (ii) Preparing the drilling layout (iii) Drilling of the holes (iv) Filling of the explosive in the holes. (v) Assembly of the components of the ignition system. (vi) Firing of the explosives using the ignition system (vii) Planning of the collection of coal. (viii) Roof supporting operation (Roof Bolting) (ix) Executing the manual coal collection by shoveling. (x) Transferring the collected coal in the trolleys of the haulage system. (xi) Pulling the complete haulage system out of the mine.

All the above operations are falling under the class of the man machine systems. In this article Roof supporting operation (Roof Bolting) is selected for the best performance efficiency.

In this Research work Roof supporting operation (Roof Bolting) in Underground mine is selected for the best performance efficiency. Roof bolting makes up 50-60% of the time of the miner. A repetitive task that requires uncomfortable postures and can be physically demanding on the neck, shoulder, back, and forearms, as well as using a significant amount of Human Energy, this job is not recommended.

An attempt is made in this research work to create a mathematical model for the productivity of roof supporting (bolting) operations. The information on the various parameters (both independent and dependent) has been acquired during the course of the observational study. There are pi terms that are both dependent and independent in this context. When performing roof bolting operations, it is necessary to statistically correlate the many independent and dependent pi factors that are involved. This correlation can be represented as a mathematical model. The best values of the independent pi terms can be discovered by optimizing the mathematical model in order to achieve the highest possible productivity.

2. Literature Review: Mechanization of Mining Operations

According to P. Fraser (2001) Underground mining and particularly dipping narrow tabular ore bodies are difficult to mechanize appropriately, given the low gold price and other external factors. Particularly in the deep level mines, there is little choice left but to mechanize if the industry is to remain competitive and significant.

According to P. C. Schutte and J. R. Smith (2001), mine mechanisation has had an effect on the prevalence of injury, mostly due to the use of human physical effort as a source of power. While mechanisation has reduced the operator's role to primarily that of a controller rather than an energy source. However, the risk of damage has not decreased.

According to the research of W.M. Keyserling, M. Brouwer, and B. A. Silverstein it is possible to develop an awkward working posture at the trunk, neck, and shoulders due to a variety of reasons, including workstation layout, visual demands of the task, design of equipment and tools, as well as work practises, among others. The elimination or reduction of awkward work posture is a critical objective of many workplace ergonomic programmers due to the fact that it is a recognised risk factor for the development of fatigue, pain, and possibly impairment.

3. Formulation of Problem

The proposed research work attempts to establish the co-relation between independent variables and Dependent variables and their influence on the entire roof bolting operation.

Table 1. Independent Variables and Dependent Variables.

S. N.	Variables	Nature of Variable	Symbol	Dimension
1	Diameter of Hole	Independent	Dh	L
2	Length of Hole	Independent	Lh	L
3	Diameter of Bolt	Independent	Db	L
4	Length of Bolt	Independent	Lb	L
5	Length of spanner	Independent	Ls	L
6	Weight of Spanner	Independent	Ws	MLT-2

7	Diameter of Spanner	Independent	Ds	L
8	Weight of Bolt	Independent	Wb	MLT-2
9	Weight of Resin Tube	Independent	Wt	L MLT-2
10	Length of Resin Tube	Independent	Lt	L
11	Diameter of resin tube	Independent	Dt	L
12	Length of push rod	Independent	Lr	L
13	Weight of push rod	Independent	Wr	MLT-2
14	Diameter of Push Rod	Independent	Dr	L
15	Air velocity	Independent	Av	LT-1
16	Relative Humidity	Independent	Rh	
17	Illumination	Independent	I	MT-3
18	Anthropometric data of Roof Bolter	Independent	Ad	
19	Time of Bolting operation	Dependent	Tm	T-1

Table 2. Dependent Pi Term.

SN	Description of Pi terms	Equations of Pi terms
1	Pi term relating response variable Productivity of bolting operation	$\Pi = \{(Pb * Lc)/Ar\}$

3.1 Development of model for productivity of bolting operation Our main results can be stated as the following theorem.

3.1.1 Development of model for dependent pi term

The mathematical modelling is done by using Curve fitting technique and multiple regression analysis. The model for π term of response variable productivity of bolting operation is as under

$$\Pi = 1.000^{*}(\Pi 1)^{-0.3995*}(\Pi 2)^{-0.0596*}(\Pi 3)^{1.8431*}(\Pi 4)^{0.1259*}(\Pi 5)^{-0.5100}$$

4. Analysis of Data

The model for the dependent pi (π) term of response variable productivity of bolting operation is examined as follows.

It has been observed the equation that, the model of a pi (π) term containing Productivity P as response variable. The following primary conclusions appear to be justified from the above model.

(i) The absolute index of $\Pi 3$ is 1.8431, which is the highest. As a result, in this model, the pi term with the greatest influence is $\Pi 3$, which refers to the bolt specification. This index has a positive value, showing that $\Pi 7$ varies directly in relation to $\Pi 3$.

(ii) In terms of absolute index, -0.0596 is the lowest. As a result, $\Pi 2$ term is related to the specification of drill rod/bit. This index's value is negative, suggesting that the relationship between $\Pi 7$ and $\Pi 2$ is inverse.

(iii) As a result, the remaining independent pi variables in this model have an impact on the model's output in the following order: -0.3995, 0.5129 for $\Pi 1$, $\Pi 5$ and $\Pi 4$ respectively. The value of index $\Pi 1$, $\Pi 5$ are negatives. demonstrating that the value of $\Pi 7$ fluctuates inversely of the values of $\Pi 1$ and $\Pi 5$.

4.1 Graphical representation of models for bolting operation (3D)

In this study five independent pi terms are identified. viz. pi terms related to anthropometry of operator, specification of drill rod/bit, specification of roof bolt, Illumination, and relative humidity. It is decided to study the effect of pi term related to Illumination viz. $\Pi 4$ along with other pi terms (combined together) on the response variables. To achieve this, five independent pi terms are reduced to two terms called as prime pi terms viz. $\Pi 4$ and a pi term $\Pi 1, 2, 3, 5$ formed by taking the product of $\Pi 1$, $\Pi 2$, $\Pi 3$, $\Pi 5$.

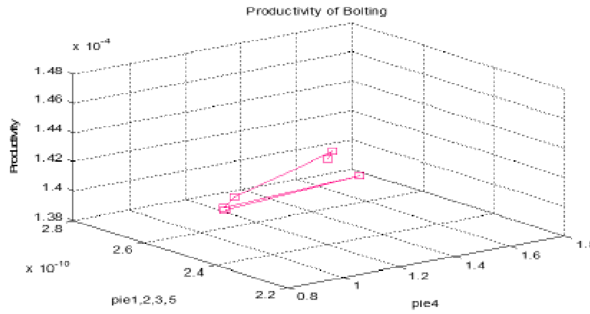

Figure 4.1. 3D plot showing variation of productivity of bolting operation with prime pi terms.

4.2 Optimization of the models of bolting operation

The purpose and objective of this investigation is not only to construct models, but also to identify the optimal set of independent variables that will maximise or minimise the objective function. Specifically, our model corresponds to the Productivity of the bolting procedure in this scenario. The objective function that corresponds to the model is a single one. It is necessary to optimise the bolting model in order to increase production. Because the models are in non-linear form, it is necessary to convert them into linear form for the function of optimization. This can be performed by taking the log of both sides of the model. It is possible to optimise linear function by employing the linear programming technique, as illustrated below.

When we solve this linear programming problem, we may obtain the maximum value of the Z and a list of possible values for the variables that will allow us to obtain this maximum value. Finding the values of the independent pi terms is then taking the antilog of the values of Z, $X1$, $X2$, $X3$, $X4$, and $X5$. Using the preceding equations, the actual values of the multipliers and variables are discovered and swapped in, and the resulting problem can be expressed as follows: This is now a problem that can be solved using the MS solver.

$$X1 = 0.7375,\ X2 = 10.0362,\ X3 = -2.31995,\ X4 = 0.404,\ X5 = 1.96$$
$$Z = 3.817698.$$

To optimize the models for $\Pi 7$ value of $\Pi 7$ min the values of independent pi terms are obtained by taking antilog of $X1$, $X2$, $X3$, $X4$, and $X5$. These values are 8.3984,9.200e-11,0.004800,2.535 and 92.

5. Conclusions

(1) Roof bolter experience postural discomfort while performing the task. They are not aware as to, to what extent ergonomic intervention can elevate their drudgery. Secondly the relationship between various inputs (anthropometry of operator, specification of drill rod, specification of bolt, illumination, and environment) and the outputs (time of bolting operation, productivity, human energy) of the system is not known to them quantitatively.

(2) From the quantitative studies on roof bolting operation the following conclusions appear to be justified.

The data in the present work is collected by performing actual field observation Due to this the findings of the present study are seemed to be reliable. The influence of the operator on productivity is significant.

From the studies on the model of productivity it is found that the influence of specification of bolt and humidity is predominant over the specification of drill rod, operator, and illumination.

Optimum values of independent pi terms for maximum productivity are found to be $\Pi 1 = 8.4638$, $\Pi 2 = 9.200e - 11$, $\Pi 3 = 0.004788$, $\Pi 4 = 2.535$, $\Pi 5 = 92$.

References

[1] Rakesh Himte, S. R. Ghatole, M. S. Dhande and P. P. Bajpai, Mathematical modeling and analysis of time of roof bolting operation in an underground coal mine, sustainable engineering, Energy and the Environment Challenges and opportunities, Apple Academic Press, (2022), 11.

[2] Biman Das and Robert M. Grady, Industrial workplace layout design an application of engineering anthropometry, Ergonomic 26(5) (1983), 433-447.

[3] Biman Das and Arajit K. Sengupta, Industrial workstation design: A systematic ergonomics approach, Applied Ergonomic 27(3) (1991), 157-163.

[4] Janet Torma-Krajewski, Implementation of an ergonomics process at US surface coal mine, International Journal of Industrial Ergonomic 37 (2007), 157-167.

[5] S. Mason, Improving the ergonomics of British coal's mining machinery, Applied Ergonomic 23 (4) (1992) 233-242.

[6] R. J. Robbins, Mechanization of underground mining: a quick look backward and forward, International Journal of Rock Mechanics and Mining Sciences 37(1-2) (2000), 413-421.

[7] Francis J. Winn Jr, Exposure probabilities to ergonomics hazards among miners, International Journal of Industrial Ergonomic 18(1996), 417-422.

[8] Ashaf A. Shikdar and Mohamed A. Al- Hadhrami, Smart workstation design: ergonomics and methods engineering approach, International Journal of Industrial and System Engineering 2(4) (2007), 67-79.

[9] Robin burgess-Limerick and Leon Straker, Implementation of the Participative Ergonomics for Manual Task (Perform) programme at four Australian underground coal mines, International Journal of Industrial Ergonomics 37 (2007), 145-155.

[10] P. Fraser, Appropriate mechanization for underground mining in southern Africa, 6th International Symposium on Mine Mechanization and Automation, South African Institute of Mining and Metallurgy, 2001.