



Research Paper

# MATHEMATICAL MODEL FOR FACE DRILLING IN UNDERGROUND MINING OPERATION

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The paper details the improvement in productivity and conserving human energy in face drilling activity in underground mines. Face drilling is one of the primary activities consumes a good amount of time and human energy for the mining crew in the underground mines. With formulation of the mathematical model, improvements in the present method of face drilling which can conserve human energy besides increasing the productivity and reducing the time required. This mathematical model predicts the optimization of face drilling activity.

**Keywords:** Mathematical Modeling, Face drilling, Ore productivity, Human energy

## INTRODUCTION

Face drilling is one of the primary operations and consumes about 50-60% of the total time for a three member mining crew in the underground mine. The tools and equipments required for face drilling operation are pneumatically (compressed air) operated Jack hammer mounted on air-leg, drill rods in lengths of 0.8m, 1.2m & 1.6 m. and flexible tube water connection for removing debris from the hole. In this face drilling operation, a three member crew (Miners) performs the task for the duration of 3 hours in a shift of 8 hours except for the small occasional breaks. Jack hammer is a machine, (rests on two legs in an inclined position on the ground) utilizes 5-7 kgf/cm<sup>2</sup> compressed air and consumes 140-150 c.f.m. air per hole. In this operation, a 32mm dia., 1.2m drill rod is placed into the holder of a Jack hammer to drill into the face of the mine of about 1m depth. The drill rod's sharp edges chisel

the mine face by rotating through 360° and the hole is formed. The drill rod is having a central longitudinal capillary, through which water is fed for the debris removal from drilling point, also for cooling the chisel like edges of drill rod. The compressed air in Air leg along with force applied by the miners provides the necessary feed to the drill rod for obtaining progressive depth in the hole. In this process, drilling a hole takes about 6 to 15 minutes time. An approx. 1m<sup>2</sup> grid will have 9 holes of about 1 m depth which takes about 2.5 to 3 hours time to drill these holes. Explosive sticks are inserted (explosive charging) into these holes and are remotely blasted to obtain one cubic meter of Ore production.

In the present method, the productivity is less and requirement of human energy is substantial. Therefore, the factors influencing the face drilling have been identified, so as to optimize the productivity and conserving human energy in this activity. The generalized mathematical model has

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been formulated using theories of experimentation for the face drilling activity in underground mines. Therefore, present approach could be replaced with optimized techniques based on field data based modeling in which dependent and independent variables of an activity can be compared and the one most effective method for improving the present method can be evolved.

## FACE DRILLING IN UNDERGROUND MINES

Strength characteristics of the underground miners including back, shoulder, arm, sitting leg strength and standing leg strength are poor when compared with other industrial workers. Most studies agree that underground miners are inclined to have lower than average aerobic capacity compared with the population norms and with the comparison groups. Occasionally, miners perform physical work in vertical space restrictions such that crawling is not even possible. While this represents an extreme case, it is not at all uncommon in the mine to be not higher than 1.5 meters. The physiological and biomechanical demands of doing manual work in such an environment are much greater, with the above constraint. Further, they have to work in humid, less airy, poor illumination & noisy environment along with vibrations. So, due to the present face drilling method the productivity is less & requirement of human energy and time required is substantial. Hence, it is required to identify the factors influencing the face drilling necessitate to formulate the Field data based model (FDBM) for this activity for increasing the productivity besides reducing the time required for face drilling and conserving human energy.

## AN APPROACH TO FORMULATE THE MATHEMATICAL MODEL

Normally, the approach adopted for formulating generalized experimental data based model in the present investigation which involves following steps:

- Identification of variables or parameters affecting the phenomenon
- Reduction of variables through Dimensional analysis

- Direct data collection for the activity from work station(Test data)
- Rejection of absurd data
- Formulation of the model

### Identification of Variables

First step in this process is the identification of variables. Identification of dependent and independent variables of the phenomenon is to be done based on known qualitative physics of the phenomenon.

The face drilling phenomenon is influenced by following variables:

### Establishment of Dimensionless $\pi$ Terms

These independent variables have been reduced into group of terms. The Equation (1) ahead shows the relationship of Dimensionless terms of the phenomenon.

List of the Independent & Dependent terms of the face drilling activities are presented in Tables 1, 2 and 3.

### Formulation of Field Data Based Model

Seven independent  $\pi$  terms ( $\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6$  and  $\pi_7$ ) and three dependent terms ( $Z_1, Z_2$ , and  $Z_3$ ) have been identified for field study model formulation.

Each dependent  $\pi$  term is a function of the available independent  $\pi$  terms,

$$Z_1 = f(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7)$$

$$Z_2 = f(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7)$$

$$Z_3 = f(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7)$$

Where,

$$Z_1, \text{ First dependent } \pi \text{ term} = Td \cdot R / Dr$$

$$Z_2 = \pi_{D2}, \text{ Second dependent term} = Pd \cdot Dr / R$$

$$Z_3 = \pi_{D3}, \text{ Third dependent term} = He / (Dr^3 \cdot Pa)$$

$$(Z) = K \{ [(N \cdot A_2 \cdot A_4 \cdot A_6 \cdot A_1) / (Am \cdot A_3 \cdot A_5 \cdot A_7)]^a,$$

$$[Lr \cdot D_c \cdot Lc] / [Dr^3]^b,$$

$$[(Wr \cdot Wc \cdot Wj) / Dr^2 \cdot Pa] \cdot [ (So \cdot Ss \cdot Hr) / (Pa) ] \cdot \{ (Do \cdot R^2) / Pa \} \cdot \{ (Ds \cdot R^2) / (Pa) \} \cdot (Qw / Dr^2 \cdot R)]^c,$$

$$[(N \cdot Dr \cdot Ar) / (R)]^d,$$

$$[\theta / 100]^e,$$

$$[\emptyset]^f,$$

$$[I / (Pa \cdot R)]^g \}$$

... (1)

**Table 1: Independent Variables**

Sl. No.	Description	Types of variables	Symbol	Dimension
1	Stature(a)	Independent	a	$[M^0 L T^0]$
2	Shoulder Height(b)	Independent	b	$[M^0 L T^0]$
3	Elbow Height(c)	Independent	c	$[M^0 L T^0]$
4	Eye Height(d)	Independent	d	$[M^0 L T^0]$
5	Finger tip Height(e)	Independent	e	$[M^0 L T^0]$
6	Shoulder Breadth(f)	Independent	f	$[M^0 L T^0]$
7	Hip Breadth(g)	Independent	g	$[M^0 L T^0]$
8	Hand Breadth across thumb(h)	Independent	h	$[M^0 L T^0]$
9	Walking Length( $W_L$ )	Independent	$W_L$	$[M^0 L T^0]$
10	Walking Breadth( $W_w$ )	Independent	$W_w$	$[M^0 L T^0]$
11	Anthropometric data( $A_1$ )	Independent	$A_1$	$[M^0 L^0 T^0]$
12	Number of Miners(N)	Independent	N	$[M^0 L^0 T^0]$
13	Age of the Miner( $A_m$ )	Independent	$A_m$	$[M^0 L^0 T^0]$
14	Experience in performing work( $A_2$ )	Independent	$A_2$	$[M^0 L^0 T^0]$
15	Skills in performing work( $A_3$ )	Independent	$A_3$	$[M^0 L^0 T^0]$
16	Posture adopted by Worker( $A_4$ )	Independent	$A_4$	$[M^0 L^0 T^0]$
17	Enthusiasm of performing the activity( $A_5$ )	Independent	$A_5$	$[M^0 L^0 T^0]$
18	Habits( $A_6$ )	Independent	$A_6$	$[M^0 L^0 T^0]$
19	General health status( $A_7$ )	Independent	$A_7$	$[M^0 L^0 T^0]$
20	Diameter of Drill rod (Dr)	Independent	Dr	$[M^0 L T^0]$
21	Length of Drill rod(Lr)	Independent	Lr	$[M^0 L T^0]$
22	Weight of Drill rod(Wr)	Independent	Wr	$[M L T^{-2}]$
23	Hardness of Drill rod(Hr)	Independent	Hr	$[M L^{-1} T^{-2}]$
24	Diameter of Comp. air Hose(Dc)	Independent	Dc	$[M^0 L T^0]$
25	Air Velocity (Ar)	Independent	Ar	$[M^0 L T^{-1}]$
26	Length of Comp. air Hose(Lc)	Independent	Lc	$[M^0 L T^0]$
27	Weight of Comp. air hose(Wc)	Independent	Wc	$[M L T^{-2}]$
28	Rate of Water flow through hose(Qw)	Independent	Qw	$[M^0 L^3 T^{-1}]$
29	Weight of Jack hammer(Wj)	Independent	Wj	$[M L T^{-2}]$
30	Illumination(I)	Independent	I	$[M^1 L^0 T^{-3}]$
31	Speed of Machine(N)	Independent	N	$[M^0 L^0 T^{-1}]$
32	Penetration rate(R)	Independent	R	$[M^0 L^1 T^{-1}]$
33	Comp. Air Pressure(Pa)	Independent	Pa	$[M L^{-1} T^{-2}]$
34	Ambient temperature( $\theta$ )	Independent	$\theta$	$[M L^2 T^{-2}]$
35	Relative Humidity( $\phi$ )	Independent	$\phi$	$[M^0 L^0 T^0]$
36	Shear strength of Ore( $S_o$ )	Independent	$S_o$	$[M L^{-1} T^{-2}]$
37	Shear strength of Mica Schist( $S_s$ )	Independent	$S_s$	$[M L^{-1} T^{-2}]$
40	Density of Ore( $D_o$ )	Independent	$D_o$	$[M L^{-3} T^0]$
41	Density of Mica Schist( $D_s$ )	Independent	$D_s$	$[M L^{-3} T^0]$
42	Time of drilling (Td)	Dependent	Td	$[M^0 L^0 T^1]$
43	Productivity of drilling(Pd)	Dependent	Pd	$[M^0 L^0 T^{-1}]$
44	Human energy(He)	Dependent	He	$[M L^2 T^{-2}]$

**Table 2: Independent Dimensionless  $\pi$  Terms**

Sl. No	Independent Dimensionless ratios	Nature of basic Physical Quantities
01	$\pi_1 = [(N \cdot A_2 \cdot A_4 \cdot A_6 \cdot A_1) / (A_m \cdot A_3 \cdot A_5 \cdot A_7)]$ Where $A_1 = [a \cdot c \cdot e \cdot g \cdot W_L] / [b \cdot d \cdot f \cdot h \cdot W_W]$	Anthropometric dimensions of the Miner
02	$\pi_2 = [Lr \cdot D_c \cdot L_c] / [Dr^3]$	Specifications of Drill Rod
03	$\pi_3 = [(Wr \cdot Wc \cdot Wj) / (Dr^2 \cdot Pa)] \cdot [(So \cdot Ss \cdot Hr) / (Pa)] \cdot [(Do \cdot R^2) / (Pa)] \cdot [(Ds \cdot R^2) / (Pa)] \cdot (Qw / Dr^2 \cdot R)$	Specifications of Drilling Machine/ process parameters
04	$\pi_4 = [(N \cdot Dr \cdot Ar) / (R)]$	Speed & Penetration rate of Drill Machine
05	$\pi_5 = [\theta / 100]$	Ambient temperature
06	$\pi_6 = \phi \%$	Relative Humidity
07	$\pi_7 = I / [Pa \cdot R]$	Illumination

**Table 3: Independent Dimensionless  $\pi$  Terms**

Sl. No.	Dependent Dimensionless ratios or $\pi$ terms	Nature of basic Physical Quantities
01	$Z_1 = [Td \cdot R / Dr]$	Time of drilling
02	$Z_2 = [Pd \cdot Dr / R]$	Productivity of drilling
03	$Z_3 = [He / (Dr^3 \cdot Pa)]$	Human Energy Consumed in Drilling

$$Z_1 \times \begin{bmatrix} 1 \\ A \\ B \\ C \\ D \\ E \\ F \\ G \end{bmatrix} = \begin{bmatrix} n & A & B & C & D & E & F & G \\ A & A^2 & BA & CA & DA & EA & FA & GA \\ B & AB & B^2 & CB & DB & EB & FB & GB \\ C & AC & BC & C^2 & DC & EC & FC & GC \\ D & AD & BD & CD & D^2 & ED & FD & GD \\ E & AE & BE & CE & DE & E^2 & FE & GE \\ F & AF & BF & CF & DF & EF & F^2 & GF \\ G & AG & BG & CG & DG & EG & FG & G^2 \end{bmatrix} \times \begin{bmatrix} K_1 \\ a_1 \\ b_1 \\ c_1 \\ d_1 \\ e_1 \\ f_1 \\ g_1 \end{bmatrix}$$

**Model Formulation by Identifying the Curve Fitting Constant & Various Indices of  $\pi$  Terms**

The multiple regression analysis helps to identify the indices of the different terms in the model aimed at, by considering seven independent terms and one dependent term. Let model aimed at be of the form:

$$(Z_1) = K_1 \cdot [(\pi_1) a_1 \cdot (\pi_2) b_1 \cdot (\pi_3) c_1 \cdot (\pi_4) d_1 \cdot (\pi_5) e_1 \cdot (\pi_6) f_1 \cdot (\pi_7) g_1] \dots(2)$$

$$(Z_2) = K_2 \cdot [(\pi_1) a_2 \cdot (\pi_2) b_2 \cdot (\pi_3) c_2 \cdot (\pi_4) d_2 \cdot (\pi_5) e_2 \cdot (\pi_6) f_2 \cdot (\pi_7) g_2] \dots(3)$$

$$(Z_3) = K_3 \cdot [(\pi_1) a_3 \cdot (\pi_2) b_3 \cdot (\pi_3) c_3 \cdot (\pi_4) d_3 \cdot (\pi_5) e_3 \cdot (\pi_6) f_3 \cdot (\pi_7) g_3] \dots(4)$$

To determine the values of a1, b1, c1, d1, e1, f1 and g1 and to arrive at the regression hyper plane, the above equations are presented as follows:

Then, the matrix obtained is given by

**$X_1$  matrix with  $K_1$  and indices  $a_1, b_1, c_1, d_1, e_1, f_1$  and  $g_1$  evaluated**

In the above equations, n is the number of sets of readings, A,B,C,D,E,F and G represent the

independent terms  $\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6,$  and  $\pi_7$  while, Z represents, dependent  $\pi$  term. Next, calculate the values of Independent  $\pi$  term for corresponding dependent term, which helps to form the equation in matrix form. It is recommended to use MATLAB software for this purpose for making this process of model formulation quickest and least cumbersome.

**Models Developed for the Dependent Variables**

The Field data has been collected from M/s Manganese Ore (India) Limited, Nagpur's Underground Mines at Gumgaon & Khandri Mines. The Readings have been collected from 100', 200' & 300' levels at 6 work stations with a team of 5 miners at each location at different timings.

**The Exact Forms of Models Obtained are as Under**

$$(Z_1) = 1.32 \cdot (\pi_1)^{0.5708} \cdot (\pi_2)^{0.3598} \cdot (\pi_3)^{-0.5058} \cdot (\pi_4)^{-0.0994} \cdot (\pi_5)^{-0.0937} \cdot (\pi_6)^{0.3325} \cdot (\pi_7)^{-0.5959} \dots(5)$$

$$(Z_2) = 1.2409 \cdot (\pi_1)^{0.4023} \cdot (\pi_2)^{0.1577} \cdot (\pi_3)^{-0.5025} \cdot (\pi_4)^{0.0496} \cdot (\pi_5)^{-0.0174} \cdot (\pi_6)^{-0.0116} \cdot (\pi_7)^{0.2012} \dots(6)$$

$$(Z_3) = 1.3457^*(\pi_1)^{0.051^*}(\pi_2)^{0.0536^*}(\pi_3)^{0.6947^*}(\pi_4)^{0.215^*}(\pi_5)^{2.4812^*}(\pi_6)^{0.5452^*}(\pi_7)^{-2.632} \dots(7)$$

In the above equations ( $Z_1$ ) is relating to response variable for time of face drilling activity, ( $Z_2$ ) is relating to response variable for productivity of face drilling and ( $Z_3$ ) is relating to response variable for human energy consumed in the activity.

### Interpretation of Model

Interpretation of model is being reported in terms of several aspects viz. (1) Order of influence of various inputs (causes) on outputs (effects) (2) Relative influence of causes on effect (3) Interpretation of curve fitting constant K.

### Interpretation of Curve Fitting Constant (K1) for $Z_1$

The value of curve fitting constant in this model for ( $Z_1$ ) is 1.32. This collectively represents the combined effect of all extraneous variables such as lower aerobic capacity of miners, physiological and biomechanical demands of doing manual work in vertical space restrictions, working in noisy environment along with vibrations etc.. Further, as it is positive, this indicates that these causes have influence on the time of face drilling activity ( $Z_1$ ).

### Analysis of the Model for Dependent $\pi$ Term Z1

1. The absolute index of  $\pi_7$  is the highest Viz. 0.5959. Thus, the term related to Illumination is the most influencing  $\pi$  term in this model. The value of this index is negative (-0.5959) indicating that the time of face drilling activity ( $Z_1$ ) is inversely proportional to term related to the Illumination, i.e.  $\pi_7$ , indicates that in the poor illuminated work station, more time is required for face drilling suggesting that artificial lighting (Through Petromax Lights/ Battery operated lights/LED in place of conventional bulbs) will reduce the time required for the face drilling.

2. The absolute index of  $\pi_5$  is the lowest Viz. 0.0937. Thus, the term related to Ambient Temperature [ $\theta$ ] is the least influencing  $\pi$  term in this model. The value of this index is negative(-0.0937) indicating that the time of face drilling

activity ( $Z_1$ ) is inversely proportional to the term related to Ambient Temperature [ $\theta$ ] at the work station [ $\pi_5$ ]. As the index is very low, we may ignore or in cooler climates, some physically comforting measures for the miners would reduce the time required for the face drilling.

3. The sequence of influence of other independent  $\pi$  terms present on this model is  $\pi_1$ ,  $\pi_3$ ,  $\pi_2$ ,  $\pi_6$  &  $\pi_4$  having absolute indices as 0.5708, -0.5058, 0.3598, 0.3325 & -0.0994 respectively.

The time of face drilling activity ( $Z_1$ ) is directly proportional to the term related to the Anthropometric Data of the miner [ $\pi_1$ ] with the index as 0.5708. With the Age, Enthusiasm, General Health status of Miner deteriorates making the time for face drilling increases as [ $\pi_1$ ] increases.

Similarly, the time of face drilling activity ( $Z_1$ ) is directly proportional to the term related to the Specifications of Drill Rod [ $\pi_2$ ] with parameters as [Lr/ Dr], [DC/ Dr], [Lc/Dr] esp. as the length of Drill rod {Lr} increases the time required for the face drilling increases with the index as 0.3598.

The time of face drilling activity ( $Z_1$ ) is directly proportional to the term related to the Relative Humidity at the work station [ $\pi_6$ ] with the index as 0.3325, increasing the time required for face drilling as the miner gets exhausted quickly with the increase in Relative humidity at the work station.

The time of face drilling activity ( $Z_1$ ) is inversely proportional to the term related to Specifications of Drill machine/Process parameters [ $\pi_3$ ] with the index as (-0.5058). Hence, as the Penetration rate increases the time required for face drilling reduces.

Similarly, the time of face drilling activity ( $Z_1$ ) is inversely proportional to the term related to the Speed & Penetration rate of Drill Machine [ $\pi_4$ ] with the index as (-0.0994), as the Speed of Drilling machine {N} increases the time required for face drilling reduces.

The repeating variables are Dr & R appear in three different terms having final indices as 0.0316 and -0.4203 respectively. The time for face drilling ( $Z_1$ ) increases directly proportional to the



diameter of Drill Rod [Dr] as index is 0.0316. Similarly, the time for face drilling ( $Z_1$ ) is inversely proportional to the penetration rate [R] as its index is (-0.4203) reducing the time required for face drilling.

### Interpretation of Curve Fitting Constant ( $K_2$ ) for $Z_2$

The value of curve fitting constant in this model for ( $Z_2$ ) is 1.2409. This collectively represents the combined effect of all extraneous variables such as lower aerobic capacity of miners, physiological and biomechanical demands of doing manual work in vertical space restrictions, working in noisy environment along with vibrations. Further, as it is positive, this indicates that these causes have influence on the productivity of face drilling ( $Z_2$ ).

### Analysis of the Model for Dependent $\pi$ Term $Z_2$

1. The absolute index of  $\pi_3$  is the highest Viz. 0.5025. Thus, the productivity of face drilling ( $Z_2$ ) is inversely proportional to the term related to Specifications of Drill machine/Process parameters [ $\pi_3$ ] is the most influencing  $\pi$  term in this model. The value of this index is negative indicating that the productivity of face drilling ( $Z_2$ ) is inversely proportional to the term related to Specifications of Drill machine/Process parameters [ $\pi_3$ ] with the index as (-0.5025). As Compressed Air Pressure [Pa] reduces & the values of Wj, So, Ss, Hr, Do, Ds increase productivity of face drilling falls.

2. The absolute index of  $\pi_6$  is the lowest Viz. 0.0116. Thus the term related to Relative Humidity at the work station [ $\pi_6$ ] is the least influencing  $\pi$  term in this model. The value of this index is negative indicating that the productivity of face drilling ( $Z_2$ ) is inversely proportional to the term related to Relative Humidity at the work station [ $\pi_6$ ] with the index as (-0.0116), as the Relative Humidity at work station increases, the miner gets exhausted quickly, hence, the productivity of face drilling falls.

3. The sequence of influence of other independent terms present on this model is  $\pi_1$ ,

$\pi_7$ ,  $\pi_2$ ,  $\pi_4$  &  $\pi_5$  having absolute indices as 0.4023, 0.2012, 0.1577, 0.0496 and 0.0174 respectively.

The productivity of face drilling ( $Z_2$ ) is directly proportional to the term related to the Anthropometric data of the Miner [ $\pi_1$ ] with the index as 0.4023. With the Age & the experience/habits, the miner makes use of his anthropometric dimensions to the advantage of increasing productivity of face drilling.

Similarly, the productivity of face drilling ( $Z_2$ ) is directly proportional to the term related to the Illumination [ $\pi_7$ ] with the index as 0.2012. With the increase in Illumination [I], the productivity of face drilling increases.

The productivity of face drilling activity ( $Z_2$ ) is directly proportional to the term related to the Specifications of Drill Rod [ $\pi_2$ ] with parameters as [Lr/ Dr], [DC/ Dr], [Lc/Dr] esp. as the length of Drill rod [Lr] increases the productivity of face drilling increases with the index as 0.1577.

Similarly, the Productivity of face drilling activity ( $Z_2$ ) is directly proportional to the term related to the Speed & Penetration rate of Drill Machine [ $\pi_4$ ] with the index as 0.0496, as the Speed of Drilling machine [N] increases the Productivity of Face drilling.

The index of  $\pi_3$  is negative indicating that the productivity of face drilling ( $Z_2$ ) varies inversely proportional to the term related to Ambient Temperature [ $\theta$ ] at the work station [ $\pi_5$ ] with the index as (-0.0174), indicating that with the raise in Ambient temperature [ $\theta$ ], the productivity of drilling reduces.

### Interpretation of Curve Fitting Constant ( $K_3$ ) for $Z_3$

The value of curve fitting constant in this model for ( $Z_3$ ) is 1.3457. This collectively represents the combined effect of all extraneous variables such as lower aerobic capacity of miners, physiological and biomechanical demands of doing manual work in vertical space restrictions, working in noisy environment along with vibrations. Further, as it is positive indicates that these causes have influence on the human energy consumed [ $Z_3$ ].

### Analysis of the Model for Dependent $\pi$ Term $Z_3$

1. The absolute index of  $\pi_7$  is the highest Viz. 2.632. Thus, the term related to Illumination at the work station [ $\pi_7$ ] is the most influencing  $\pi$  term in this model. The value of this index is negative indicating that the Human energy consumed ( $Z_3$ ) is inversely proportional to the term related to Illumination at the work station [ $\pi_7$ ] at the work station with the index as (-2.632), as human energy is properly applied with Illumination at the work station.

2. The absolute index of  $\pi_1$  is the lowest Viz. 0.051. Thus the term related to Anthropometric data of miner [ $\pi_1$ ] is the least influencing term in this model. The value of this index is positive indicating Human energy consumed ( $Z_3$ ) is directly proportional to the related to Anthropometric data of miner [ $\pi_1$ ] with its index as 0.051, indicating that as the Bent Posture increases the human energy requirements.

3. The sequence of influence of other independent terms present in this model is  $\pi_5$ ,  $\pi_3$ ,  $\pi_6$ ,  $\pi_4$  &  $\pi_2$  having absolute indices as 2.4812, 0.6947, 0.5452, 0.215 & 0.0536 respectively.

The Human energy consumed ( $Z_3$ ) is directly proportional to the term related to the Ambient Temperature at the work station [ $\pi_5$ ] with the index as 2.4812 indicating that with the increase in Ambient temperature [ $\theta$ ], the human energy requirements increase in face drilling.

Similarly, the Human energy consumed ( $Z_3$ ) is directly proportional to the term related to the Specifications of Drilling Machine/ Process parameters [ $\pi_3$ ] with the index as 0.6947. As Compressed Air Pressure [Pa] reduces & the values of Wj, So, Ss, Hr, Do, Ds increase human energy requirements of face drilling increases.

The Human energy consumed ( $Z_3$ ) is directly proportional to the term related to the Relative Humidity at the work station [ $\pi_6$ ] with the index as 0.5452 indicating that the miner exhaustion with increase in Relative Humidity [ $\phi$ ] increases the human energy requirements of face drilling.

The Human energy consumed ( $Z_3$ ) is directly proportional to the term related to the Speed & Penetration rate of Drill Machine [ $\pi_4$ ] with the index as 0.215 indicating that with the increase in Speed [N] & decrease in Penetration Rate [R], the human energy requirements of face drilling increase.

The Human energy consumed ( $Z_3$ ) is directly proportional to the term related to the Specifications of Drill Rod [ $\pi_2$ ] with the index as 0.0536. Human energy requirements of face drilling activity ( $Z_1$ ) is directly proportional to the term related to the Specifications of Drill Rod [ $\pi_2$ ] with parameters as [Lr/ Dr], [DC/ Dr], [Lc/Dr] esp. as the length of Drill rod {Lr} increases the human energy required for the face drilling increases with the index as 0.0536.

### CONCLUSION

The postural discomfort experienced by miners while performing face drilling, became the cornerstone for this work. They are not aware as to what extent ergonomic intervention can alleviate their drudgery. Secondly, the relationship between various inputs such as anthropometry of miners, specifications of drill machine, specification of tools, surrounding environmental conditions and their responses such as time to complete drill, human energy and productivity of face drilling activity is not known to them quantitatively. Thus from these models "Intensity of interaction of inputs on deciding Response" can be predicted which will help to control the variable for the desired results.

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