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Mathematical Model for Manual Loading Activity in Underground mines

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***ABSTRACT*: The paper details the approach to improve the productivity and conserving human energy in Manual loading activity. Manual loading is one of the primary activities and consumes a good amount of time for the mining crew in the underground mines. With formulation of the mathematical model, improvements in the present method of Manual loading which can conserve human energy besides increasing the productivity and reducing the time required. This mathematical model predicts the optimization of Manual loading activity. Some of the variables used to formulate this model are (1) Environment of working area, which include the ergonomic aspects; i.e. various postures of the worker, anthropometric data of the miners and environmental aspects such as illumination, ambient temperature, relative humidity and air circulation facility around the work station (2)Tools used by miner which include geometric dimensions of tools, (3) Loading of the Ore per unit time, human energy consumption etc., based on the data collected of these variables, mathematical model is formulated.**

Keywords: Mathematical Modeling, Manual Loading, Human energy, Underground mines.

1.0 An overview of manual loading activity in underground mines

In the Indian mining industry, most of the work is done manually because of the limitations for mechanization such as technological, environmental and cost oriented. Considering this fact, many activities are manual in underground mines. Mine workers are exposed to all kinds of environmental hazards. Ergonomics tries to achieve human comfort while accomplishing the work efficiently. Disregard for ergonomic principles and practices lead to low man-machine system efficiency, poor health and increased number of accidents.

Manual loading is one of the primary operations and consumes about 35-40% of the total time for a five member mining crew in the underground mine. The tools and equipments required for manual loading are Metal baskets & Shovels. In this manual loading operation, a five member crew (Miners) performs the task for the duration of about 3 hours except when they are relieved for a small break for refreshments in a shift of 8 hours. Normally, two miners load the ore into Metal baskets with shovels and three miners carry these baskets and dump into the nearby chute. In a three hours time, about 12-15 tons of Manganese ore is manually loaded into the chute.

In the present method, the productivity is less and requirement of human energy is substantial. Therefore, the factors influencing the manual loading activity have been identified, so as to optimize the productivity and conserving human energy in this activity. The generalized mathematical model has been formulated using theories of experimentation for the manual loading of ore 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.

2.0 Problems associated with Manual loading activity in Underground mines

Space limitations, varied nature of the activity, and the reluctance to make substantial investment in mechanised/automated equipment are some of the reasons for not avoiding or reducing manual handling (Mital 1997).

Invariably, the abilities of individuals to perform these activities, either frequently or occasionally are exceeded, resulting in severe chronic or acute injuries. The most common work related health problem reported was back pain, which was reported by 33% of workers. It is also reported that exposure to poorly designed work environments which involves carrying heavy loads and working in awkward, painful positions remains prevalent.

The Regulations set no specific requirements such as weight limits; the ergonomic approach shows clearly that such requirements are based on too simple a view of the problem. However, regulations have to take into account weight, repetition and location of lift as a means of identifying handling activities, which involve risk. Manual loading is a repetitive task that involves awkward posture with physically demanding on the neck, shoulder, back and forearms of the miners for more time and consumes more human energy. Further, they have to work in humid, less airy, poor illumination & noisy environments. So, due to the present manual loading method, the productivity is less & requirement of human energy and time required is substantial. Hence, it is required to identify the factors influencing the Manual loading necessitate to formulate the FDBM for this activity. With the help of this model, we get the control on dependent and independent variables which helps to increase the productivity & to reduce the required time and human energy.

3.0 Need for formulation of mathematical model for identifying optimum

Indeed, a question arises before the production in-charge that in spite of the hard work done by the miner, why he fails to give the adequate productivity which reduces the efficiency of activity. Hence, this aspect in general incites to investigate a mathematical model, which can predict the manual loading activity performance which involves man- machine system. Indeed, the model will be useful for both miners as well as for the production in-charge to work on prominent variables by which they can improve the performance of miner by deciding the strength and weakness of present method. Once weaknesses are known corrective action can be decided.

4.0 An approach to formulate the mathematical model

A theoretical approach can be adopted in a case; if a known logic can be applied correlating the various dependent and independent parameters of the system. Though qualitatively, the relationships between the dependent and independent parameters are known based on the available literature references, the generalized quantitative relationships are not known sometimes. Whatever quantitative relationships are known, those pertaining to a specific anthropometric data for a specific task. This data is not available for mine workers, engaged in manual loading activity. Hence, formulating the quantitative relationship based on the logic is not possible. Due to non-availability of theoretical model (logic based) one is left with the only alternative of formulating experimental data based or to be more specific in this case field-data based model. Hence, it is proposed to formulate such a model in the present investigation.

Normally, the approach adopted for formulating generalized experimental data based model suggested by Schenck H. Jr., [1], to be more specific field- data based model suggested by Modak.J.P.et al[2] has been proposed 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
- Rejection of absurd data
- Formulation of the model

Identification of dependent & independent variables of the phenomenon is to be done based on known qualitative physics of the phenomenon. If the system involves a large number of independent variables, the experimentation becomes tedious, time consuming and costly. By deducing dimensional equation for the phenomenon, we can reduce the number of independent variables. The exact mathematical form of this equation will be the targeted model. Upon getting the experimental results, adopting the appropriate method for test data checking and rejection, the erroneous data be identified and removed from the gathered data. Based on the purified data as mentioned above, one has to formulate quantitative relationship between the dependent and independent π terms of the dimensional equation, i.e. the “Model formulation”.

4.1 Identification of Variables or quantities:

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. These variables are of three types:

(1) Independent variables,
(2) Dependent variables &
(3) Extraneous variables.

The independent variables are those which can be changed without changing other variables of the phenomenon, whereas, the dependent variables are those, which can only change with any change in the independent variables. The extraneous variables change in a random and uncontrolled manner in the phenomenon. If the system involves a large number of independent variables, the experimentation becomes tedious, time consuming and costly. By deducing dimensional equation for the phenomenon, we can reduce the number of independent variables. The exact mathematical form of this equation will be targeted model. Upon getting the experimental results, adopting the appropriate method for test data checking and rejection, the erroneous data be identified and removed from the gathered data. Based on the purified data as mentioned above one has to formulate quantitative relationship between the dependant and independent π terms of the dimensional equation.

The manual loading phenomenon is influenced by following variables:

Sr. No.	**Description**	**Type of variable**	**Symbol**	**Dimension**
1	Stature	Ind	a	$[M^0 L T^0]$
2	Shoulder Height	Ind	b	$[M^0 L T^0]$
3	Elbow Height	Ind	c	$[M^0 L T^0]$
4	Eye Height	Ind	d	$[M^0 L T^0]$
5	Finger tip Height	Ind	e	$[M^0 LT^0]$
6	Shoulder Breadth	Ind	f	$[M^0 L T^0]$
7	Hip Breadth	Ind	g	$[M^0 LT^0]$
8	Hand Breadth across thumb	Ind	h	$[M^0 LT^0]$
9	Walking Length	Ind	W_L	$[M^0 LT^0]$
10	Walking Breadth	Ind	W_W	$[M^0 LT^0]$
11	Anthropometric data(A_1)	Ind	A_1	$[M^0L^0T^0]$
12	Number of Miners(N)	Ind	N	$[M^0L^0T^0]$
13	Age of the Miner(Am)	Ind	A_m	$[M^0L^0T^0]$
14	Experience in performing work(A_2)	Ind	A_2	$[M^0L^0T^0]$
15	Skills in performing work(A_3)	Ind	A_3	$[M^0L^0T^0]$
16	Posture adopted by Worker(A_4)	Ind	A_4	$[M^0L^0T^0]$
17	Enthusiasm of performing the activity(A_5)	Ind	A_5	$[M^0L^0T^0]$
18	Habits(A_6)	Ind	A_6	$[M^0L^0T^0]$
19	General health status(A_7)	Ind	A_7	$[M^0L^0T^0]$
20	Ambient temperature(θ)	Ind	θ	$[M^0L^0T^0]$
21	Relative Humidity(ø)	Ind	ø	$[M^0L^0T^0]$
22*	Ambient Air Velocity(Ar)	Ind	Ar	$[M^0LT^{-1}]$
23	Illumination(I)	Ind	I	$[M^1L^0T^3]$

24	Diameter of Metal Basket (Db)	Ind	Db	$[M^0 LT^0]$
25	Depth of Metal Basket (Lb)	Ind	Lb	$[M^0 LT^0]$
26*	Weight of Metal Basket with Ore (Wbo)	Ind	Wbo	$[M L T^{-2}]$
27	Length of Shovel Handle(Ls)	Ind	Ls	$[M^0 LT^0]$
28	Weight of Shovel with Ore(Ws)	Ind	Ws	$[M LT^{-2}]$
29*	Distance from W.S to Chute (D)	Ind	D	$[M^0 LT^0]$
30	Time for manual loading(T_l)	Dep	T_l	$[M^0L^0T^1]$
31	Productivity of manual loading(P_l)	Dep	P_l	$[M^0L^0T^1]$
32	Human energy consumption for manual loading(H_l)	Dep	H_l	$[ML^2T^{-2}]$

Note: Ind:Independent and Dep:Dependent

M, L and T are the symbols for mass, length and time respectively.

4.2 Establishment of Dimensionless π terms:
These independent variables have been reduced into group of π terms. The Equation (1) shows the Dimensionless π terms of the phenomenon. List of the Independent & Dependent π terms of the Manual loading activity are:

Independent dimensionless π terms

Sr. No.	Independent Dimensionless ratios or π terms	Nature of basic Physical Quantities
01	$\pi1=[(N*A_1*A_2*A_4*A_6)/(A_m*A_3*A_5*A_7)]$ Where $A_1=[a*c*e*g*W_L]/[b*d*f*h*W_W]$	Anthropometric dimensions of the Miners
02	$\pi2=(D_b/D)*(L_b/D)*(L_s/D)$	Specifications of Metal Basket & Shovel
03	$\pi3=[(\theta/100)]$	Ambient temperature at work station
04	$\pi4=[\varnothing]$	Relative Humidity in Work station
05	$\pi5=[(I*D^2/(Ar*Wbo)\}]$	Air velocity, Illumination in work station
06	$\pi=(Ws/Wbo)$	Specifications of Weight of Shovel & Basket with Ore

Dependent dimensionless π terms

Sr. No.	Dependent Dimensionless ratios or π terms	Nature of basic Physical Quantities
01	$\pi D_1 = T_l*(Ar/D)$	Time for Manual loading
02	$\pi D_2 = P_l*(Ar/D)$	Productivity of Manual loading
03	$\pi D_3 = H_l*(D^3/Wbo)$	Human energy consumption for Manual loading

4.3 Formulation of Field Data Based Model
Six independent π terms ($\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6$) and three dependent π terms ($\pi_{D1}, \pi_{D2}, \pi_{D3}$) have been identified for model formulation. Each dependent π term is a function of the available independent π terms,

$T_l = f(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6)$
$P_l = f(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6)$
$H_l = f(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6)$

Where,
$T_l = \pi_{D1}$, First dependent π term= $T_l*(Ar/D)$
$P_l = \pi_{D2}$, Second dependent π term= $P_l*(Ar/D)$
$H_l = \pi_{D3}$, Third dependent π term= $H_l*(D^3/Wbo)$

f stands for "function of " . The probable exact mathematical form for the dimensional equations of the phenomenon could be relationships assumed to be of exponential form.

$(Z)=K\{[(N*A_2*A_4*A_6 * A_1)/ (A_m A_3*A_5*A_7)]^a$,
$[(D_b/D)*(L_b/D)*(L_s/D)]^b$,
$[(\theta/100)]^c$,
$[(\o)]^d$,
$[(I*D^2/(Ar*Wbo)]^e$,
$[(Ws/Wbo)]^f\}$------------------------------(1)

4.4 Model formulation by identifying the constant and various indices of π terms:

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

$(Z_1)=K1*[(\pi_1)^{a1}*(\pi_2)^{b1}*(\pi_3)^{c1}*(\pi_4)^{d1}*(\pi_5)^{e1}*(\pi_6)^{f1}]$ (2)

$(Z_2)=K2*[(\pi_1)^{a2}*(\pi_2)^{b2}*(\pi_3)^{c2}*(\pi_4)^{d2}*(\pi_5)^{e2}*(\pi_6)^{f2}]$ (3)

$(Z_3)=K3*[(\pi_1)^{a3}*(\pi_2)^{b3}*(\pi_3)^{c3}*(\pi_4)^{d3}*(\pi_5)^{e3}*(\pi_6)^{f3}]$ (4)

To determine the values of a1, b1, c1, d1, e1and f1 and to arrive at the regression hyper plane, the above equations are presented as follows:

$\Sigma Z_1 = nK_1 + a_1*\Sigma A + b_1*\Sigma B + c_1*\Sigma C + d_1*\Sigma D + e_1*\Sigma E + f_1*\Sigma F$

$\Sigma Z_1*A = K_1*\Sigma A +a_1*\Sigma A*A + b_1*\Sigma B*A + c_1*\Sigma C*A + d_1* \Sigma D*A + e_1*\Sigma E*A+f_1*\Sigma F*A$

$\Sigma Z_1*B = K_1*\Sigma B +a_1*\Sigma A*B + b_1*\Sigma B*B + c_1*\Sigma C*B + d_1* \Sigma D*B + e_1*\Sigma E*B+f_1*\Sigma F*B$

$\Sigma Z_1*C = K_1*\Sigma C +a_1*\Sigma A*C+ b_1*\Sigma B*C + c_1*\Sigma C*C + d_1* \Sigma D*C + e_1*\Sigma E*C+f_1*\Sigma F*C$

$\Sigma Z_1*D = K_1*\Sigma D +a_1*\Sigma A*D + b_1*\Sigma B*D + c_1*\Sigma C*D + d_1* \Sigma D*D + e_1*\Sigma E*D+f_1*\Sigma F*D$

$\Sigma Z_1*E = K_1*\Sigma E +a_1*\Sigma A*E + b_1*\Sigma B*E + c_1*\Sigma C*E + d_1* \Sigma D*E + e_1*\Sigma E*E+f_1*\Sigma F*E$

$\Sigma Z_1*F = K_1*\Sigma F +a_1*\Sigma A*F + b_1*\Sigma B*F + c_1*\Sigma C*F + d_1* \Sigma D*F + e_1*\Sigma E*F+f_1*\Sigma F*F$

In the above set of equations, the values of the multipliers K_1, a_1, b_1, c_1, d_1, e_1 and f1 are substituted to compute the values of the unknowns (viz. K_1, a_1, b_1, c_1, d_1, e_1 and f1). The values of the terms on L.H.S and the multipliers of K_1, a_1, b_1, c_1, d_1, e_1 and f1 in the set of equations are calculated and tabulated in the Table. After substituting these values in the equations, one will get a set of 7 equations, which are to be solved simultaneously to get the values of K_1, a_1, b_1, c_1, d_1, e_1 and f_1.The above equations can be verified in the matrix form and further values of K_1, a_1, b_1, c_1, d_1, e_1 and f1 can be obtained by using matrix analysis.

$$X_1 = \mathrm{inv}(W) \times P_1$$

The matrix method of solving these equations using 'MATLAB' is given below.
W = 7 x 7 matrix of the multipliers of K_1, a_1, b_1, c_1, d_1, e_1 and f_1
P_1 = 7 x 1 matrix of the terms on L H S and
X_1 = 7 x 1 matrix of solutions of values of K_1, a_1, b_1, c_1, d_1, e_1 and f1
Then, the matrix obtained is given by,

Matrix

$$Z_1 \; x \begin{bmatrix} 1 \\ A \\ B \\ C \\ D \\ E \\ F \end{bmatrix} = \begin{bmatrix} n & A & B & C & D & E & F \\ A & A^2 & BA & CA & DA & EA & FA \\ B & AB & B^2 & CB & DB & EB & FB \\ C & AC & BC & C^2 & DC & EC & FC \\ D & AD & BD & CD & D^2 & ED & FD \\ E & AE & BE & CE & DE & E^2 & FE \\ F & AF & BF & CF & DF & EF & F^2 \end{bmatrix} x \begin{bmatrix} K_1 \\ a_1 \\ b_1 \\ c_1 \\ d_1 \\ e_1 \\ f_1 \end{bmatrix}$$

X_1 matrix with K_1 and indices a_1, b_1, c_1, d_1, e_1 and f1 evaluated:
In the above equations, n is the number of sets of readings. A,B,C,D,E and F represent the independent π terms such as π_1, π_2, π_3, π_4, π_5 and π_6 while, Z represents, dependent π term. Next, calculate the values of Independent π term for corresponding dependent π 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.

4.5 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:

$(Z_1) = 1.5289 * (\pi_1)^{2.8252} * (\pi_2)^{0.4425} * (\pi_3)^{1.1764} * (\pi_4)^{0.5332} * (\pi_5)^{-0.1189} * (\pi_6)^{0.6364}$ -- (5)

$(Z_2) = 1.1158 * (\pi_1)^{0.0234} * (\pi_2)^{0.4015} * (\pi_3)^{-2.6957} * (\pi_4)^{-1.1342} * (\pi_5)^{0.2303} * (\pi_6)^{0.7893}$ -- (6)

$(Z_3) = 1.4674 * (\pi_1)^{0.8397} * (\pi_2)^{-0.8444} * (\pi_3)^{0.0639} * (\pi_4)^{-0.2151} * (\pi_5)^{-0.1636} * (\pi_6)^{0.3514}$ -- (7)

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

4.6 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.

4.6.1 Interpretation of curve fitting constant (K_1) for Z_1: The value of curve fitting constant in this model for (Z_1) is 1.5289. 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 heat stress & less oxygen uptake etc.. Further, as it is positive, this indicates that these causes have influence on the time of manual loading activity (Z_1).

Analysis of the model for dependent π term Z_1:
1. The absolute index of π_1 is the highest Viz. 2.8252. Thus, the term related to Anthropometric data of miner is the most influencing π term in this model. The value of this index is positive (2.8252) indicating that the time of manual loading activity (Z_1) is directly proportional to term related to the Anthropometric data of Miner i.e. π_1.

2. The absolute index of π_5 is the lowest Viz. 0.1189. Thus, the term related to Illumination [I] is the least influencing π term in this model. The value of this index is negative(-0.1189) indicating that the time of manual loading activity (Z_1) is inversely proportional to the term related to Illumination [I] at the work station $[\pi_5]$.

3. The sequence of influence of other independent π terms present on this model is π_3, π_4, π_6 & π_2 having absolute indices as 1.1764, 0.6364, 0.5332 & 0.4425 respectively.

The time of manual loading activity (Z_1) is directly proportional to the term related to the Ambient temperature at the work station $[\pi_3]$ with the index as 1.1764. Similarly, the time of manual loading activity (Z_1) is directly proportional to the term related to the Specifications of Weight of Shovel & Basket with Ore $[\pi_6]$ with the index as 0.6364. The time of manual loading activity (Z_1) is directly proportional to the term related to the Relative Humidity in Work station $[\pi_4]$ with the index as 0.5332. The time of manual loading activity (Z_1) is directly proportional to the term related to the Specifications of Metal Basket & Shovel $[\pi_2]$ with the index as 0.4425.

4.6.2 Interpretation of curve fitting constant (K_2) for Z_2: The value of curve fitting constant in this model for (Z_2) is 1.1158. 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 heat stress & less oxygen uptake etc. Further, as it is positive, this indicates that these causes have influence on the productivity of manual loading activity (Z_2).

Analysis of the model for dependent π term Z_2:
1. The absolute index of π_3 is the highest viz. 2.6957. Thus, the term related to Ambient Temperature [θ] is the most influencing π term

in this model. The value of this index is negative (-2.6957) indicating that the productivity of manual loading activity (Z_2) is inversely proportional to term related to the Ambient Temperature [θ] i.e. π_3.

2. The absolute index of π_1 is the lowest viz. 0.0234. Thus, the term related to Anthropometric dimensions of the Miners is the least influencing π term in this model. The value of this index is positive (0.0234) indicating that the productivity of manual loading activity (Z_2) is directly proportional to the term related Anthropometric dimensions of the Miners [π_1].

3. The sequence of influence of other independent π terms present on this model is π_4, π_6, π_2 & π_5 having absolute indices as 1.1342 ,0.7893, 0.4015& 0.2303 respectively.

The productivity of manual loading activity (Z_2) is inversely proportional to the term related to the Relative Humidity in Work station [π_4] with the index as (-1.1342). Similarly, the productivity of manual loading activity (Z_2) is directly proportional to the term related to the Specifications of Weight of Shovel & Basket with Ore [π_6] with the index as 0.7893. The productivity of manual loading activity (Z_2) is directly proportional to the term related to the Specifications of Metal Basket & Shovel [π_2] with the index as 0.4015. The productivity of manual loading activity (Z_2) is directly proportional to the term related to the Illumination in the work station [π_5] with the index as 0.2303.

4.6.3 Interpretation of curve fitting constant (K_3) for Z_3: The value of curve fitting constant in this model for (Z_3) is 1.4674. 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 heat stress & less oxygen uptake etc. Further, as it is positive, this indicates that these causes have influence on the Human energy consumed in manual loading activity (Z_3).

Analysis of the model for dependent π term Z_3:

1. The absolute index of π_3 is the highest viz. 0.8444. Thus, the term related to Specifications of Metal Basket & Shovel [π_2] is the most influencing π term in this model. The value of this index is negative (-0.8444) indicating that the human energy consumed in manual loading activity (Z_3) is inversely proportional to term related to the Specifications of Metal Basket & Shovel [π_2].

2. The absolute index of π_3 is the lowest viz. 0.0639. Thus, the term related to Ambient temperature at work station [θ] is the least influencing π term in this model. The value of this index is positive (0.0639) indicating that the human energy in manual loading activity (Z_3) is directly proportional to the term related Ambient temperature at work station [π_3].

3. The sequence of influence of other independent π terms present on this model is π_1, π_6, π_4 & π_5 having absolute indices as 0.8397 ,0.3514, 0.2151& 0.1636 respectively.

The human energy in manual loading activity (Z_3) is directly proportional to the term related to the Anthropometric dimensions of the Miners [π_1] with the index as 0.8397. Similarly, the human energy in manual loading activity (Z_3) is directly proportional to the term related to the Specifications of Weight of Shovel & Basket with Ore [π_6] with the index as 0.3514. The human energy in manual loading activity (Z_3) is inversely proportional to the term related to Relative Humidity in Work station [π_4] with the index as (-0.2151). The human energy in manual loading activity (Z_3) is inversely proportional to the term related to the Illumination in the work station [π_5] with the index as (-0.1636).

4.7 Optimization of the Model:

As far as the activity of manual loading is concerned any one will wish to maximize Z_2 (i.e. Productivity) whereas he would like to minimize Z_1 (i.e. Time to required for manual loading) & Z_3 (i.e. Human energy input).

Now, it is the time to apply the subject optimization technique for arriving at, at which values the inputs that Z_2 can be maximized and

Z_1 & Z_3 can be minimized. This has to be the sole objective of deciding *"How to improve the method of performance of Manual loading activity"***.** Thus this approach of formulation of FDBM for such a man-machine system should be looked upon as a new technique of method study. This was not possible in the absence of establishing such models. These models will help to predict the **"***Intensity of interaction of inputs on deciding Response*" of manual loading activity.

4.8 Reliability of Models:

Obviously, before taking up the step of sensitivity of inputs, it is necessary to decide the validity of the model. This is so because though, we have taken care to purify the observed data, there is a chance of some impure data entering in the mathematical processing of the data though even using MATLAB.

The approach to decide the validity would be to substitute in the model known inputs for every observation & decide the difference in response by model and actually observed response. This will give us pattern of distribution of error & frequency of its occurrence. Using this distribution & literature on reliability, we would establish the reliability of the model

5.0 Conclusions:

The postural discomfort experienced by miners while performing manual loading, 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, specification of tools, surrounding environmental conditions and their responses such as time to complete manual loading, human energy and productivity of manual loading 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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