Original Article

Development of mathematical model and artificial neural network simulation to predict the performance of manual loading operation of underground mines

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ARTICLE INFO

Article history:
Received 20 August 2018
Accepted 10 April 2019
Available online 10 May 2019

Keywords:
Manual loading
Mines
Ergonomic
Human energy
Productivity

ABSTRACT

The paper illustrates the formulation of mathematical model for manual work such as loading operations at underground mines of manganese ore. The recent manual loading operation is having less production with large amount of human energy consumption. The variable responsible for the performance of manual loading operation has been identified to formulate the mathematical model. The indices of mathematical model indicate variables responsible for increasing the production and minimize human energy consumption. The field data based modeling has been achieved based on the field data for the three dependent π terms time, human energy and productivity. The validation of field data base model is not in close proximity due to the complex phenomenon involving non-linear kinematics, therefore it becomes necessary to formulate artificial neural network simulation of the observed data.

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1. Introduction

Manual loading operations in many of the mines are practicing manual loading for the excavated ore. Worker loads the ore into baskets with shovel and the other carries this to the chute and dumps into it. The ore is dumped into trolleys through chute which is hauled by battery operated locomotives else dumped into a dump truck [1]. The parameters related to the manual loading operation have been known to increase the production and save the human energy in the present method. Mathematical model is formed for manual loading operation for increasing the productivity and optimizes human energy. This mathematical model based on dependent and independent variables can be studied for enhancing the productivity and human energy conservation.

E-mail: pramodb@rediffmail.com
https://doi.org/10.1016/j.jmrt.2019.04.015
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2. Manual loading activities in underground mines

Comparative study details that the health status of the miners working in the underground mine is poorer as compared to the industrial workers with respect to the strength. Mine workers are having lesser aerobic capacity. Workers in mines have to work in less airy, poor lighting and loud surroundings together with sensations. This results in the less production with large requirement of human energy and considerable time requirement. Hence it is necessary to identify the controlling factors of mathematical model of manual loading operation [2]. Mathematical model predicts the performance of mine workers for improving the routine of miner by fixing the strength and weakness of current technique, accordingly corrective measures can be taken.

Anthropometry is the branch of ergonomics, which deals with the different human body dimensions of workers [3]. The anthropometric data of miner has been collected. Postural discomfort is experienced by the miner because of muscular discomfort required to maintain the body posture during work. Most limbs of human body have a particular neutral position in which muscular activity is at minimum. Maintenance of the body at this position is the least fatiguing and most comfortable [4].

The theory of experimentation is a good approach of presenting the respond of different entries of the event. This approach has been adopted for the formulation of model correlating various inputs to the phenomenon of manual loading activity in underground mine. The various inputs in the manual loading activity are (a) body specifications of the operator (viz. the anthropometric measurements) and (b) specifications of environmental factors such as ambient temperature, humidity, air circulation, etc., at the work place. The response variables of the phenomenon are time for manual loading operation, productivity of manual loading and human energy consumed during manual loading operation. A quantitative relationship is established among the responses and inputs. The inputs are observed and the corresponding responses are measured. Relationships between inputs and responses are known as models. The interest of the miner lies in arranging inputs so as to obtain targeted responses. It is possible only by formulation of such models. The intensity of influence of various independent variables on the dependent variables is determined so that some important conclusions are drawn based on the analysis of models [5].

3. Formulation of the mathematical model

The correlation between inputs and outputs variables based on the known logic is not possible hence suggested to form the mathematical model in this investigation [6]. It is intended to study the interactive influence of manual loading operation such as (a) anthropometric dimensions of the miner which include the attitude and aptitude to do manual loading, (b) specifications of basket and shovel, (c) air temperature, (d) humidity, (e) air velocity and illumination at the work station, and (f) specifications of weight of shovel and basket with ore [7]. The quantitative relationship of the interaction of these inputs mentioned above on the time of manual loading, productivity of manual loading and human energy consumption during manual loading operation [8]. Table 1 shows the list of the independent and dependent variables.

4. Formation of Pie terms

The total quantity of independent variables is reduced to set of six × terms [9]. Eq. (1) shows the different Pie terms of the phenomenon. Lists of the independent and dependent × terms of the manual loading activity are shown in Tables 2 and 3.

5. Approach to mathematical model

Independent dimensionless Pie terms (P₁, P₂, P₃, P₄, P₅, P₆) and dependent Pie terms (P₀D₁, P₀D₂, P₀D₃) of Tables 2 and 3 are correlated as given below:

\[ Z₁ = f(P₁, P₂, P₃, P₄, P₅, P₆) \]
\[ Z₂ = f(P₁, P₂, P₃, P₄, P₅, P₆) \]
\[ Z₃ = f(P₁, P₂, P₃, P₄, P₅, P₆) \]

where

\[ Z₁ = P₀D₁ = T₁*(Ar/D); \]
\[ Z₂ = P₀D₂ = P₁*(Ar/D); \]
\[ Z₃ = P₀D₃ = H₁*(D²/Wbo). \]

The probable exact mathematical form to be of exponential form

\[ (Z) = K \left\{ \left[ \frac{N * A₂ * A₄ * A₆ * A₁}{A₄ * A₃ * A₅ * A₇} \right]^a \left[ \frac{\left( \frac{D₉}{D} \right) * \left( \frac{L₉}{D} \right) + \left( \frac{L₉}{D} \right)}{\left( \frac{D₉}{D} \right) * \left( \frac{L₉}{D} \right)} \right]^b \right\} \left[ \left( \frac{I + D²}{\frac{Ar}{Wbo}} \right)^e \left[ \left( \frac{Ws}{Wbo} \right) \right]^f \right] \]  \tag{1} \]

6. Evaluation of identifying the constant and various indices of Pie terms

The regression analysis is used to know the indices of the each Pie terms in the model. Let model aimed at be of the form,

\[ (Z₁) = K₁ * (P₁) * (P₂) * (P₃) * (P₄) * (P₅) * (P₆) \]
\[ (Z₂) = K₂ * (P₁) * (P₂) * (P₃) * (P₄) * (P₅) * (P₆) \]
\[ (Z₃) = K₃ * (P₁) * (P₂) * (P₃) * (P₄) * (P₅) * (P₆) \]

To find out the values of \( a₁, b₁, c₁, d₁, e₁ \) and \( f₁ \), the above equations are presented as follows:

\[ \Sigma Z₁ = nK₁ + a₁*ΣA₁ + b₁*ΣB₁ + c₁*ΣC₁ + d₁*ΣD₁ + e₁*ΣE₁ + f₁*ΣF₁ \]

\[ \Sigma Z₂ = K₂ + a₂*ΣA₂ + b₂*ΣB₂ + c₂*ΣC₂ + d₂*ΣD₂ + e₂*ΣE₂ + f₂*ΣF₂ \]

\[ \Sigma Z₃ = K₃ + a₃*ΣA₃ + b₃*ΣB₃ + c₃*ΣC₃ + d₃*ΣD₃ + e₃*ΣE₃ + f₃*ΣF₃ \]
Table 1 – The manual loading phenomenon is influenced by the following variables.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Description</th>
<th>Type of variables</th>
<th>Symbol</th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stature</td>
<td>Independent</td>
<td>a</td>
<td>[M²LT⁻¹]</td>
</tr>
<tr>
<td>2</td>
<td>Shoulder height</td>
<td>Independent</td>
<td>b</td>
<td>[M²LT⁻¹]</td>
</tr>
<tr>
<td>3</td>
<td>Elbow height</td>
<td>Independent</td>
<td>c</td>
<td>[M²LT⁻¹]</td>
</tr>
<tr>
<td>4</td>
<td>Eye height</td>
<td>Independent</td>
<td>d</td>
<td>[M²LT⁻¹]</td>
</tr>
<tr>
<td>5</td>
<td>Finger tip height</td>
<td>Independent</td>
<td>e</td>
<td>[M²LT⁻¹]</td>
</tr>
<tr>
<td>6</td>
<td>Shoulder breadth</td>
<td>Independent</td>
<td>f</td>
<td>[M²LT⁻¹]</td>
</tr>
<tr>
<td>7</td>
<td>Hip breadth</td>
<td>Independent</td>
<td>g</td>
<td>[M²LT⁻¹]</td>
</tr>
<tr>
<td>8</td>
<td>Hand breadth across thumb</td>
<td>Independent</td>
<td>h</td>
<td>[M²LT⁻¹]</td>
</tr>
<tr>
<td>9</td>
<td>Walking length</td>
<td>Independent</td>
<td>WL</td>
<td>[M²LT⁻¹]</td>
</tr>
<tr>
<td>10</td>
<td>Walking breadth</td>
<td>Independent</td>
<td>Ww</td>
<td>[M²LT⁻¹]</td>
</tr>
<tr>
<td>11</td>
<td>Anthropometric data (A₁)</td>
<td>Independent</td>
<td>A₁</td>
<td>[M²⁹T⁻⁸]</td>
</tr>
<tr>
<td>12</td>
<td>Number of miners (N)</td>
<td>Independent</td>
<td>N</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>13</td>
<td>Age of the miner (Am)</td>
<td>Independent</td>
<td>Am</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>14</td>
<td>Experience in performing work (A₂)</td>
<td>Independent</td>
<td>A₂</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>15</td>
<td>Skills in performing work (A₃)</td>
<td>Independent</td>
<td>A₃</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>16</td>
<td>Posture adopted by worker (A₄)</td>
<td>Independent</td>
<td>A₄</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>17</td>
<td>Enthusiasm of performing the activity (A₅)</td>
<td>Independent</td>
<td>A₅</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>18</td>
<td>Habits (A₆)</td>
<td>Independent</td>
<td>A₆</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>19</td>
<td>General health status (A₇)</td>
<td>Independent</td>
<td>A₇</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>20</td>
<td>Ambient temperature (ϑ)</td>
<td>Independent</td>
<td>ϑ</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>21</td>
<td>Relative humidity (ϑ)</td>
<td>Independent</td>
<td>ϑ</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>22</td>
<td>Ambient air velocity (Ar)</td>
<td>Independent</td>
<td>Ar</td>
<td>[M²²T⁻¹]</td>
</tr>
<tr>
<td>23</td>
<td>Illumination (I)</td>
<td>Independent</td>
<td>I</td>
<td>[M²²T⁻¹]</td>
</tr>
<tr>
<td>24</td>
<td>Diameter of metal basket (Db)</td>
<td>Independent</td>
<td>Db</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>25</td>
<td>Depth of metal basket (Lb)</td>
<td>Independent</td>
<td>Lb</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>26</td>
<td>Weight of metal basket with ore (Wbo)</td>
<td>Independent</td>
<td>Wbo</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>27</td>
<td>Length of shovel handle (Ls)</td>
<td>Independent</td>
<td>Ls</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>28</td>
<td>Weight of shovel with ore (Ws)</td>
<td>Independent</td>
<td>Ws</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>29</td>
<td>Distance from Ws to chute (D)</td>
<td>Independent</td>
<td>D</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>30</td>
<td>Time for manual loading (Tₖ)</td>
<td>Dependent</td>
<td>Tₖ</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>31</td>
<td>Productivity of manual loading (Pₖ)</td>
<td>Dependent</td>
<td>Pₖ</td>
<td>[M²¹T⁻¹]</td>
</tr>
<tr>
<td>32</td>
<td>Human energy consumption for manual loading (Hₖ)</td>
<td>Dependent</td>
<td>Hₖ</td>
<td>[M²²T⁻¹]</td>
</tr>
</tbody>
</table>

Table 2 – Independent Pie terms.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Independent Pie terms</th>
<th>Physical quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>P₁ = π₁ = [(N * A₁ * A₂ * A₃ * A₄ * A₅ * A₆) / (A₁m * A₁ * A₅ * A₆)]</td>
<td>Anthropometric magnitude of the miners</td>
</tr>
<tr>
<td></td>
<td>where A₁ = [a * c * g * W₁ / (b * d * f * h * Ww)]</td>
<td>Specifications of metal basket and shovel</td>
</tr>
<tr>
<td>02</td>
<td>P₂ = π₂ = (Dₘ / D *) (Lₒ / Lₘ)</td>
<td>Ambient temperature at work station</td>
</tr>
<tr>
<td>03</td>
<td>P₃ = π₃ = [i (1000)]</td>
<td>Relative humidity in work station</td>
</tr>
<tr>
<td>04</td>
<td>P₄ = π₄ = [e]</td>
<td>Air velocity and illumination in work station</td>
</tr>
<tr>
<td>05</td>
<td>P₅ = π₅ = [1 / D² / (Ar * Wbo)]</td>
<td>Specifications of weight of shovel and basket with ore</td>
</tr>
<tr>
<td>06</td>
<td>P₆ = π₆ = (Ws / Wbo)</td>
<td></td>
</tr>
</tbody>
</table>

Thus the matrix form is given by,

\[
\Sigma Z = [ \Sigma 1 = B₃ + A₁ + \Sigma A₃ + B₁ + \Sigma B₃ + C₁ + \Sigma C₃ + B₁ + \Sigma D₃ + B₃ + \Sigma F₃ + B₃ + \Sigma E₃ + B₁ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Sigma F₃ + \Sigma D₃ + B₃ + \Sigma F₃ + C₁ + \Sigma E₃ + B₁ + \Σ

\[
\begin{bmatrix}
A \\
B \\
C \\
D \\
E \\
F
\end{bmatrix}
\begin{bmatrix}
1 \\
A \\
B \\
C \\
D \\
E \\
F
\end{bmatrix}
\begin{bmatrix}
B₁ \\
C₁ \\
D₁ \\
E₁ \\
F₁
\end{bmatrix}
\]

In the above equations, \( n \) is the number of sets of readings. \( A, B, C, D, E \) and \( F \) represent the independent Pie terms such as \( P₁, P₂, P₃, P₄, P₅ \) and \( P₆ \), while \( Z \) represents dependent \( π \) term. The field data has been obtained from underground mines.
The readings have been collected at different work stations. The miners have been enquired through questionnaire for data such as age of the miner (Am), experience in performing work (A2), general health status (A3) and Habits (A4) are rated on a 1–10 scale. The supervisors have been enquired through questionnaire for collecting data such as skills in performing work (A5), enthusiasm in performing the activity (A6) of the individual miner to rate them on 1–10 scale. Postures have been arrived at by observing the activity at the work station.

Weight of the individual miner has been measured through digital weighing balance. The measurements such as stature, shoulder height, elbow height, eye height, finger tip height, shoulder breadth, hip breadth, hand breadth across thumb, walking length and walking breadth have been measured with Harpenden Stadiometer, Holtain Bi-condylar Calliper and measuring tape for Body. The anthropometric data of miners Pi term has been calculated [10]. The ambient temperature and relative humidity have been measured with the thermometer and relative humidity measuring digital meter. The Illumination (I) at the work station has been measured with light meter to measure intensity of light. These parameters have been used for calculating $P_5$, $P_6$ and $P_7$ terms [11]. The human energy consumption measured by the heart rate/min with the polar heart rate monitor [12].

### 7. Models developed for the dependent variables in manual loading

The model formed for the different dependent variables are:

\[
(Z_1) = 1.5289 \ast (\pi 1)2.8252 \ast (\pi 2)0.4425 \ast (\pi 3)1.1764
\ast (\pi 4)0.5332 \ast (\pi 5)0.1189 \ast (\pi 6)0.6364
\]

\[
(Z_2) = 1.1158 \ast (\pi 1)0.0234 \ast (\pi 2)0.4015 \ast (\pi 3)2.6957
\ast (\pi 4)1.1342 \ast (\pi 5)0.2303 \ast (\pi 6)0.7893
\]

\[
(Z_3) = 1.4674 \ast (\pi 1)0.8697 \ast (\pi 2)0.8444 \ast (\pi 3)0.6039
\ast (\pi 4)0.2151 \ast (\pi 5)0.1636 \ast (\pi 6)0.3514
\]

8. **Analysis of mathematical model**

Analysis of model is being presented in numerous forms viz.

8.1. **Reading of curve fitting constants ($K_1$) for $Z_1$, ($K_2$) for $Z_2$ and ($K_3$) for $Z_3$**

The values of curve fitting constants in these models for ($Z_1$), ($Z_2$) and ($Z_3$) are 1.5289, 1.1158 and 1.4674 respectively. The values of curve fitting constants are positive indicating that inputs have influence on the time ($Z_1$), productivity ($Z_2$) and human energy consumed in the manual loading activity ($Z_3$).

8.2. **Investigation of the model for dependent term $Z_1$**

(i) The index of $P_1$ is maximum 2.8252 related to anthropometric data of worker is the most effective Pie term. The positive value indicating that the time of manual loading activity ($Z_1$) is directly related to data of worker, i.e. $P_1$.

(ii) The total index of $P_6$ is the minimum 0.1189 related to Illumination [I] is the least influencing Pie term in this model. The negative value shows the time of manual loading activity ($Z_1$) is inversely related to Illumination.

(iii) The series of power of other Pie terms present on this model is $P_3$, $P_4$, $P_5$ and $P_7$ having absolute indices as 1.1764, 0.6364, 0.5332 and 0.4425 respectively.

The time of manual loading activity ($Z_1$) is directly related to the term related to the air temperature at the work station $[P_4]$ with the index as 1.1764. Similarly the time of manual loading activity ($Z_1$) is directly related to the term related to the specifications of weight of shovel and basket with ore [P6] with the index as 0.6364. The time of manual loading activity ($Z_1$) is directly related to the term related to the humidity in work station $[P_5]$ with the index as 0.5332. The time of manual loading activity ($Z_1$) is directly related to the term related to the specifications of metal basket and shovel $[P_2]$ with the index as 0.4425.

8.3. **Investigation of the model for dependent term $Z_2$**

(i) The absolute index of $P_3$ is the maximum 2.6957 related to air temperature [I] is the most influencing Pie term in this model. The absolute index of $P_1$ is the minimum 0.0234 related to anthropometric dimensions of the miners is the less influencing Pie term in this model. The sequence of influence of other independent Pie terms present on this model is $P_4$, $P_5$, $P_6$ and $P_7$ having absolute indices as 1.1342, 0.7893, 0.4015 and 0.2303 respectively.
The productivity of manual loading activity ($Z_2$) is inversely related to the term related to the humidity in work station [$P_4$] with the index as (−1.1342). Similarly the productivity of manual loading activity ($Z_2$) is directly related to the term related to the specifications of weight of shovel and basket with ore [$P_6$] with the index as 0.7893. The productivity of manual loading activity ($Z_2$) is directly related to the term related to the specifications of metal basket and shovel.

[$P_2$] with the index as 0.4015. The productivity of manual loading activity ($Z_2$) is directly related to the term related to the illumination in the work station [$P_5$] with the index as 0.2303.

8.4. Investigation of the model for dependent term $Z_3$

(i) The absolute index of $P_3$ is the maximum 0.8444 related to specifications of metal basket and shovel [$P_2$] is the most influencing Pie 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 related to term related to the specifications of metal basket and shovel [$P_2$]. The index of $P_3$ is the minimum 0.0639. The term related to air temperature at work station [$θ_i$] is the less influencing Pie 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 related to the term related air temperature at work station [$P_3$]. The sequence of influence of other independent Pie terms present on this model is $P_1$, $P_6$, $P_4$ and $P_5$ having absolute indices as 0.8397, 0.3514, 0.2151 and 0.1636 respectively.

The human energy in manual loading activity ($Z_3$) is directly related to the term related to the anthropometric dimensions of the miners [$P_1$] with the index as 0.8397. Similarly, the human energy in manual loading activity ($Z_3$) is directly related to the term related to the specifications of
weight of shovel and basket with ore \([P_6]\) with the index as 0.3514. The human energy in manual loading activity \((Z_2)\) is inversely related to the term related to humidity in work station \([P_4]\) with the index as \((-0.2151)\). The human energy in manual loading activity \((Z_3)\) is inversely related to the term related to the Illumination in the work station \([P_5]\) with the index as \((-0.1636)\).

### 9. Artificial neural network for manual loading operation

The complex relationships between input and output data are solved by the powerful tool artificial neural network. The expert system ANN is efficient in simulating the complicated phenomena due to its non-linear structures. Simulation consists of three layers. First layer is known as input layer. Number of neurons in input layer is equal to the number of independent variables. Second layer is known as hidden layer. Number of neurons in hidden layer is equal to the number of independent variables. The third layer is the output layer. It contains one neuron as one of the dependent variable. Multilayer feed forward topology is decided for the network. Fig. 1 shows an artificial neural network structure used in the present investigation.

The various steps followed in developing the algorithm for ANN are given below.

1) The observed data from the field is separated into two parts viz. input data and the output data. The input data and the output data are imported to the program respectively.

2) The input and output data is read by the prestd function and appropriately sized. Function prestd is preprocesses the data so that the mean is 0 and the standard deviation is 1. Input and output data is normalized in preprocessing step.

3) The input and output data is then categorized in three categories viz. testing, validation and training. The data is then stored in structures for training, testing and validation.

4) Looking at the pattern of the data, feed forwards back propagation type neural network is chosen. Using the training data the network is trained. The network is simulated by using the computed errors between actual and target data.

Graphs show the comparison of output data recorded from the field, mathematical model and ANN for the three dependent variables of the manual loading operation. The values of the dependent variables plotted for number of recorded data obtained using ANN and field values. It was observed that the results obtained by the ANN simulations are in close agreement with the field values. These models proved to be successful in terms of agreement with actual field values. It can be concluded that ANN models perform accurately to determine the optimal values (Figs. 2–4).

### 10. Conclusions for manual loading

The data for conducting the present work has been collected by performing actual field observation. The findings of the present study seem to be reliable. The mathematical model and ANN developed for the phenomenon truly represents the degree of interaction of various independent variables. This is made possible only by the approach adopted in the investigation. The standard error of estimate of the predicted/computed values of the dependent variables is found to be very low. This gives authenticity to the developed mathematical models and ANN. The trends for the behavior of the models demonstrated by graphical analysis are found complementary to each other. These trends are found to be truly justified through some possible physics of phenomenon.

Mathematical models showed that the control of anthropometric data of the miner and air temperature on the time of manual loading is significant and increases with increase in
air temperature. The response variable time of manual loading decreases with improvement in illumination, ambient air velocity in the work station. The response variable productivity increases significantly with reduction in air temperature and humidity. The response variable human energy consumed in manual loading operation is significantly dependent upon anthropometric data of miner and distance of chute from mine face. Table 4 shows the significant of independent variables on the dependent variables. 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.

11. Conflicts of interest

The authors declare no conflicts of interest.

REFERENCES