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Modeling and Prediction on Productivity Performance of Sewing Machine Operation Using Dimensional Analysis and Artificial Neural Network

Swapna Ghatole[1], Yashpal [2], Mahesh Bundele[3], J.P. Modak [4]

Research Scholar[1], Associate Professor[2]
Poornima University Jaipur, (Rajasthan), India

Principal & Director[3]
Poornima College of Engineering, Jaipur (Rajasthan), India

Advisor Technical, Prof. Emeritus[4]
J D College of Engineering, Nagpur (MS), India
swapnaghatole72@gmail.com

Abstract:

The productivity performance of standalone sewing machine operation is analyzed in the present work by using dimensional analysis approach & artificial neural network (ANN). The models are formulated to correlate the input parameters such as Anthropometric data, personal data, environmental data at workstation, workstation specification, specifications of parts of pedal sewing machine and their condition with the dependent parameter productivity through design of experiments (DOE) plan. From the field data based study findings, it has been observed that the anthropometric parameters of operator, his environmental conditions, sewing machine parameters are the most influencing parameters. In order to find outthe accuracy of the formulated dimensional analysis approach and ANN models, correlation coefficient (R^2) was calculated. From theR^2 values, it was clear that both dimensional analysis and ANN approaches are competent to predict the productivity performance of the sewing machine operator. In addition, the models formulated by using ANN approach were found tobe more perfect than the dimensional analysis approach. The higher values of R^2 (87.89%) and lower value of variouserror based parameters shows the adequacy and reliability of the dimensional analysis and ANN models. Comparativestudy of dimensional analysis and ANN models disclosed the accuracy of ANN models hence recommended.

Keywords: artificial neural network,dimensional analysis, input parameters, output parameters

1.0 INTRODUCTION

The sewing machine operation involves various activities for execution of final workingoutput in sewing. During sewing machine operation the operators perform each type ofactivity which forms a man–machine system[1]. This man–machine systemis influencedby the operator's anthropometric data, posture, their skills, motivation, workstation environmentand design as per the requirement of the working season. Field databasemodeling can be applied to any type of man–machine system. It is the relationship betweeninput and

output parameter. The comparative study of operator's productivity for dimensional analysis and ANN approach is studied in thispaper[22]. Stress and fatigue is felt by operator in manual sewing machine operation hence the need was felt to study their productivity.

2.0 METHOD and PROCEDURE

The formulation of Field Database modeling method is used to analyze the impact of differentfield parameters in sewing machine operation.There are many day to day totally physical phenomena which cannot be represented by application ofbasic balances of mechanics, so such complex man–machine operated phenomena can bearrived at mathematical model by adopting the theory of experimentation suggested byHilbert Shank Junior[24]. The model formulation is done by using the following steps:

1. Identification of inputand output parameters.
2. Identification of extraneous variables.
3. Reduction of input parameters into dimensionless terms by adopting dimensional analysis method.
4. Data collection of sewing machine operators on existing process.
5. Formulation of model using dimensional analysis approach and artificial neural network approach of model in field database management.

2.1 Procedureof Work for Productivity:

Initially data from thirty operators was collected by interview technique for obtaining the anthropometric data of operator consisting parameters such as age, experience, height with sitting , sitting eye height, sitting height from elbow, knee height, buttock knee height, popliteal height, span between elbow, length of leg, arm reach, inclination of head, inclination of eyeball, inclination of back w.r.t to working machine table, personal information of operator regarding health related issues, machine specifications, and measurement of environmental conditions[1-2].In this work 38input parameters are identified[1,2,8]. Their Mass, Length, and Time units are identified and studied, then dimensionally similar homogeneous groups of 38input terms are formed [1,2,8]. All the input parameters are converted into dimensionless termsas required by dimensionally homogeneous groups and input and output Pi terms are defined[11]. Total five Input Pi terms such as Π_1, Π_2, Π_3, Π_4, Π_5 and one output Pi term for productivity (Z3) as Π_6 [12,14,22] isdefinedas detailed in Table1.

Table 1 : Details of Pi terms defined as Input and Output parameters

Sr. No	Type of parameter	Symbol	Detail of parameters	Dimensional analysis
1	Input	Π_1	Anthropometric data	P1 = (A1,A3,A4,A5,A9)/(A6,A7,A8, A10,L,L)
2	Input	Π_2	Personal data	P2 = (P1,P3,P4)/(P2,P5,P6)
3	Input	Π_3	Environmental conditions	P3 = (TW1,NW1)/(IW1,NW2)

4	Input	Π_4	WorkStation Specification	P4 = [(h1,h5/h4), (h2,h3/h6)]/[(so/h7, LL), (A11,A12,A13)]
5	Input	Π_5	Specifications of parts of pedal sewing machine and their condition.	P5 = [(Lbelt), (Pmc),(H3)]/[(Td), (Psrd), (Ax), (Fwh)]
6	**Output**	**Z3**	**Productivity**	Stl / SSTDl

Productivity parameter Z3 is calculated as shown in Table 2

Z3 = Stl / SSTDl ~~Equation 1~~ →

where

Stl = Stitching length per day or (work done/day)

SSTDl = standard Stitching length / day

Probably exact mathematical form for the dimensional analysis equation of the phenomenon could be the relationships assumed as the form of exponential form. So, the model representing the behavior of output pi term Pi6 with respect to various input pi terms can be obtained. The model representing the behavior of output Pi term with respect to various input piterms can be obtained with regression analysis method as shown in equation 2:

$\Pi 6\ (Z3) = K\ \Pi_1^{a1} * \Pi_2^{a2} * \Pi_3^{a3} * \Pi_4^{a4} * \Pi_5^{a5}$ Equation 2 →

All the values of input parameters and output Pi terms as regards regression analysis and dimensional analysis are calculated as shown in Table 2.

Table 2 : Dimensional Analysis of Pi terms and Productivity(Z3)

Π1 = (A1, A3, A4, A5, A9) / (A6,A7,A8, A10,LL)	**Π2 = (P1,P3,P4)/(P 2,P5,P6)**	**Π3 = [(TW1,Nw1)/ (Iw1,Nw2)]**	**Π4 = [((H1,H2)/H4) , (H2,H3)/H6, (A11/H2))] / [(H7,LL)/ H6), A13]**	**Π5 = (Bd,Pmc,H3) / (Td, Psrd, Ax, Fwh)**	**Z3 = Stl /SSTDl (length)**
Π1	**Π2**	**Π3**	**Π4**	**Π5**	**Z3**
0.03	0.31	-1.68	-0.27	0.82	1.88
0.04	0.34	-1.66	-0.46	0.82	1.88
0.01	0.82	-1.65	-0.45	0.82	1.70
-0.09	1.37	-1.71	-0.49	0.82	1.70
0.05	1.02	-1.68	-0.42	0.82	1.70
0.09	0.60	-1.62	-0.40	0.82	1.88
0.23	0.59	-1.67	-0.42	0.82	1.88
-0.10	0.98	-1.58	-0.45	0.96	1.88
-0.04	0.55	-1.61	-0.41	0.99	1.70
-0.05	0.40	-1.67	-0.49	0.99	1.88
-0.10	0.49	-1.64	-0.56	1.06	1.88

0.02	0.65	-1.66	-0.57	1.06	1.70
-0.02	0.95	-1.63	-0.60	1.06	1.88
-0.17	0.72	-1.73	-0.57	0.90	1.88
-0.15	0.25	-1.64	-0.64	0.90	1.70
-0.05	0.33	-1.75	-0.51	0.90	1.70
0.02	0.31	-1.61	-0.49	0.83	1.70
-0.04	0.25	-1.64	-0.56	0.93	1.70
0.04	0.85	-1.65	-0.39	0.93	1.70
-0.07	0.77	-1.65	-0.43	0.93	1.70
-0.02	0.48	-1.61	-0.45	0.93	1.70
0.04	0.50	-1.68	-0.39	0.70	1.88
0.03	0.06	-1.62	-0.47	0.70	1.70

A mathematical model based on dimensional analysis approach for Z3 has been developed with parameters shown in Table1. After calculations on regression analysis equation the model is developed for Z3 as shown in equation3.

$$Z3 = 40.1975\ \Pi1^{0.0035} * \Pi2^{-0.0042} * \Pi3^{-0.1138} * \Pi4^{0.2104} * \Pi5^{0.1031}$$ Equation 3

2.2 Discussion on Productivity(Z3) model:

Equation 3 for Z3 indicates that Z3 is output Π term related to productivity indicates that it has a curve fitting constant quantified as 40.1975. This collectively represents influence of all extraneous variables. These are influence of posture, influence of enthusiasm, attitude of the operator during the execution of the activity. This is so because these factors although influence the activity they cannot be individually quantified.

In addition Z3 is influenced highest in forward sense by Π4 whose index is 0.2104 followed by Π5whose index is 0.1031 and Π1 whose index is 0.0035. This also indicates the relative influence of Π4respect to Π5 is 0.2104/0.1031 = 2.041times and also the relative influence of Π4respect to Π1 is 0.2104/0.0035= 60.11times. Similarly, it is observed that the reverse influence is of Π terms with negative indices i.e. those of Π2,Π3. Amongst this the highest influence is of Π3 followed by Π2. The relative inverse influence of Π3 with respect to Π2 is of the order of 0.1138/0.0042= 27.095times. Hence it shows thatindices for anthropometric parameters, workstation parameter and sewing machine parameter are having positive impact on productivity but personal factors and environmental factors are giving adverse impact which can affect the productivity. The reliability for Productivity model by calculations is found to be 80.62%.

3.0 Procedure for formulation of ANN Process:

For ANN process the gathered information from the field is divided into two sections i.e. input information data of independent pi terms as shown in Table 1 and the output data of output pi (Z3) term[14,15,20]. The input and output data is read by preset function and appropriately sized. In preprocessing step the input and output data is normalized using mean and standard deviation. The input and output data is then categorized in three classifications

of testing, validation, and training from 30 observations. In this paper Levenberg- Marquardt back propagation (trainlm)training algorithm was used with 10 neurons in the hiddenlayers. TheANN computation algorithm is divided into three parts. Training ofthe algorithm is the first step in ANN. An input data along with theoutput data is send to the ANN algorithm. The training step in the ANN algorithm is terminatedwhen the minimum gradient level is reached. The weights obtained in thefirst stage are utilized to obtain the ANN response. The second stepis the testing phase and the last step is the validation phase. The ANN with the help of neural fitting tool (nftool) divided the samples as 70% data samples for training, 15% for Validation and 15% for Testing. The ANN topology in a conventional manner is decided for the case with 1 neuron in output layer corresponding to one output quantity and 5 neurons in input layer corresponding five inputΠ terms[9,10,11] .The number of hidden Neurons are 10 as shown in figure 1.

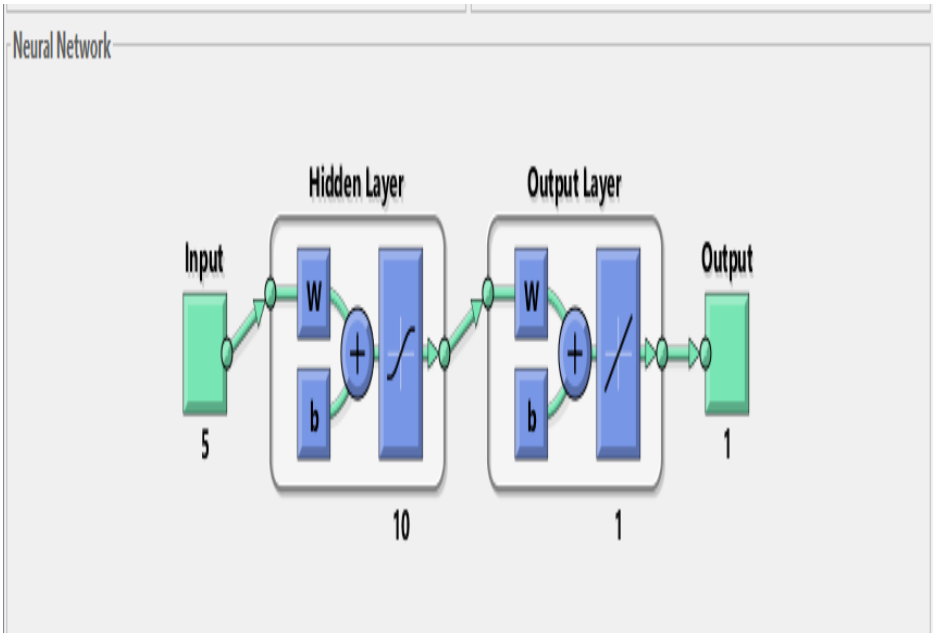

Figure 1: Hidden Neurons and input output layer

In order to examine what factors influence the Dimensional analysis modelingand ANN accuracy, the comparison between both output parameters have been carried out as shown in**Figure 2.** The data comparisons between dimensional analysis data and ANN data for productivity are in close nearness with each other

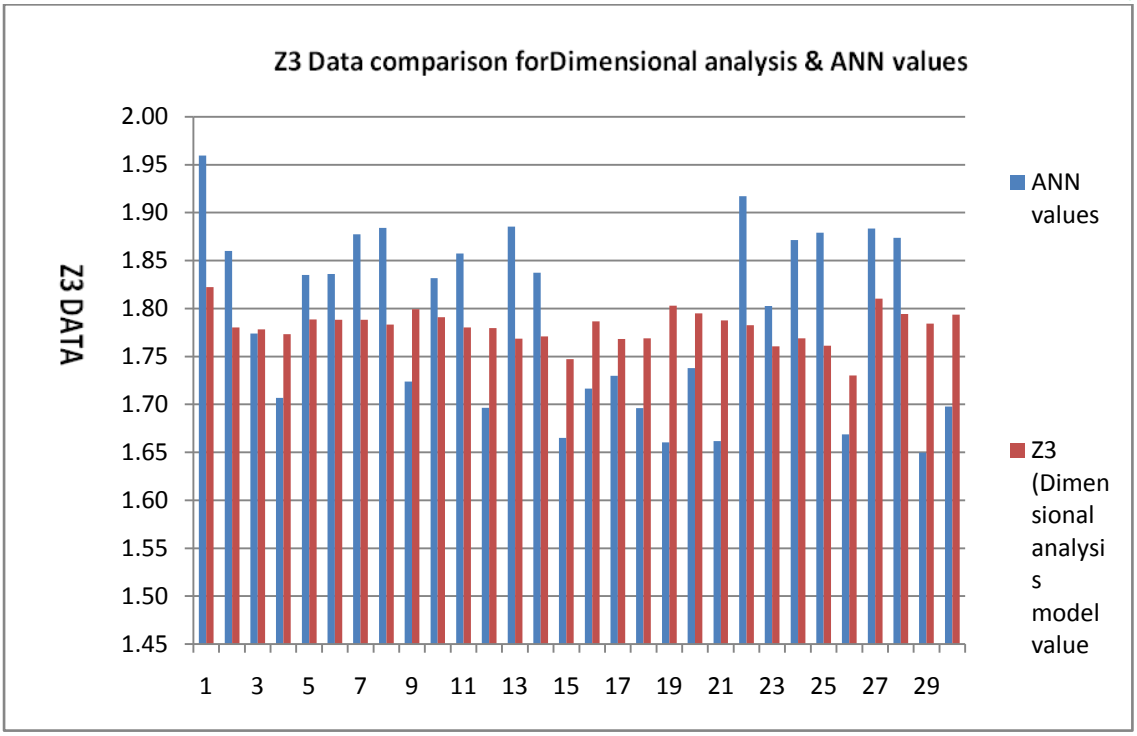

Figure 2:Data comparison forDimensional analysis &ANN for Z3

The reliability or the fitting accuracy of the formulatedDimensional analysis based models is reflected by the error analysis and thecorrelation obtain. The statistical analysis for the Dimensional analysis model hasbeen shown in Table 3.

Table 3 Details of the statistical parameters for Dimensional Analysis and ANN model.

S.N	Statistical Parameters	Dimensional Analysis	ANN
1	Mean square error MSE	-0.00402	0.0041
2	Root mean square error	1.27594	0.7641
3	Correlation coefficient R^2	0.94895	0.87895

The correlation coefficient(R^2)by Dimensional analysis based 0.94895 and by ANN is 0.87895. It is also seen from the above table 2 that the average prediction error is less than 10%.The network is trained for training the data by using feed forward back propagation method. The computation errors in the actual and target data are computed and then the network is simulated. The study shows that regression plots nearing to 1 i.e. 0.88 as shown in Figure 3.

After simulating the ANN, it is found that experimentally observed values are very close and in good agreement with the ANN predicted values. The regression plots are shown in figure 3

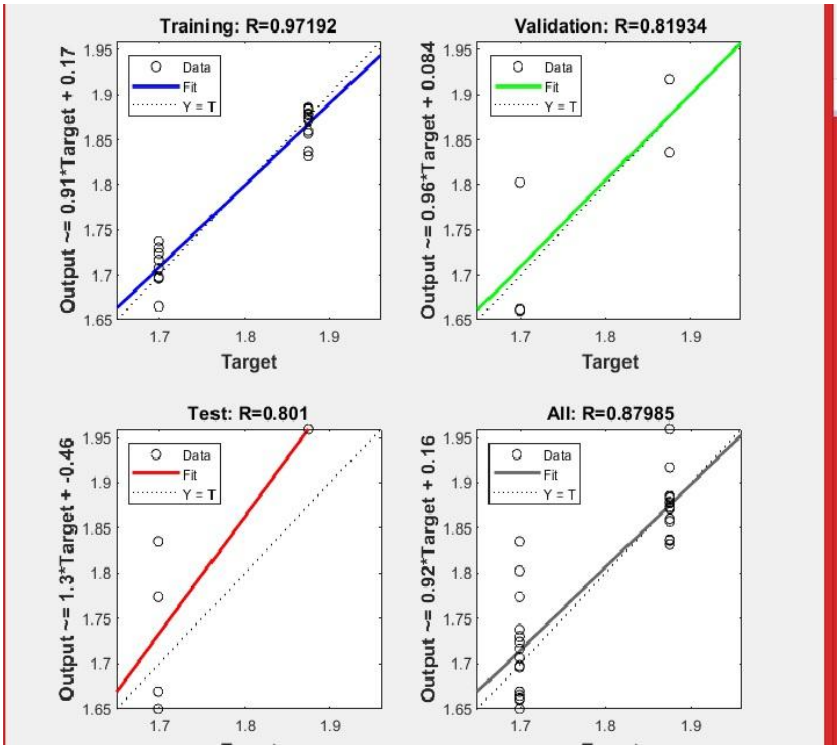

Figure 3: Regression plots of the ANN

The comparative performance analysis of **Dimensional analysis** data and ANN data and errors between the ANN along with its percentage of errors are depicted in table 4 . This table 4 explains the nearness of the data which helps us to decide that **Dimensional analysis** and ANN model data can be utilized for further workstation design with ergonomic intervention to reduce the fatigue in operators with improvement in productivity of sewing machine operator.

Table 4. Performance analysis of ANN and Comparison of dimensional analysis of productivity (the (Mathematical Model), THE (ANN Simulation)

Sr. No	Z3 dimensional analysis data	Z3ANN data	Error (dimensional analysis –ANN)	Error (dimensional analysis –ANN)
1	1.82	1.96	-0.14	-14%
2	1.78	1.86	-0.08	-8%
3	1.78	1.77	0.00	0%
4	1.77	1.71	0.07	7%
5	1.79	1.84	-0.05	-5%
6	1.79	1.84	-0.05	-5%
7	1.79	1.88	-0.09	-9%
8	1.78	1.88	-0.10	-10%
9	1.80	1.72	0.08	8%
10	1.79	1.83	-0.04	-4%
11	1.78	1.86	-0.08	-8%
12	1.78	1.70	0.08	8%
13	1.77	1.89	-0.12	-12%
14	1.77	1.84	-0.07	-7%

15	**1.75**	**1.66**	**0.08**	**8%**
16	**1.79**	**1.72**	**0.07**	**7%**
17	**1.77**	**1.73**	**0.04**	**4%**
18	**1.77**	**1.70**	**0.07**	**7%**
19	**1.80**	**1.66**	**0.14**	**14%**
20	**1.80**	**1.74**	**0.06**	**6%**
21	**1.79**	**1.66**	**0.13**	**13%**
22	**1.78**	**1.92**	**-0.13**	**-13%**
23	**1.76**	**1.80**	**-0.04**	**-4%**
24	**1.77**	**1.87**	**-0.10**	**-10%**
25	**1.76**	**1.88**	**-0.12**	**-12%**
26	**1.73**	**1.67**	**0.06**	**6%**
27	**1.81**	**1.88**	**-0.07**	**-7%**
28	**1.79**	**1.87**	**-0.08**	**-8%**
29	**1.78**	**1.65**	**0.13**	**13%**
30	**1.79**	**1.70**	**0.10**	**10%**

Also the Validation performance for output Z3 plotform against the mean squared error shown by ANN helps us to show the nearness in the data as shown by figure 4.

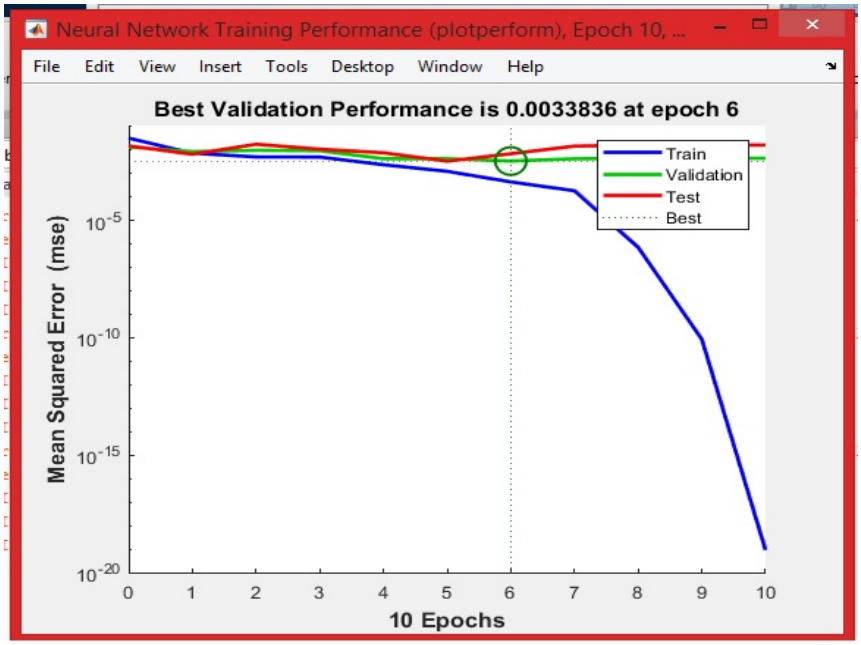

Figure 4Validation performance for output Z3

4.0. Conclusion

For Z3 indicates that Z3 is dependant Π term related to productivity indicates that it has a curve fitting constant quantified as 40.1975. This collectively represents influence of all extraneous variables. These are influence of posture, influence of enthusiasm , attitude of the operator during the execution of the activity. This is so because these factors although

influence the activity they cannot be individually quantified. In addition Z3 is influenced highest in forward sense by Π4 whose index is 0.2104 followed by Π5whose index is 0.1031 and Π1 whose index is 0.0035. This also indicates the relative influence of Π4respect to Π5 is 0.2104/0.1031 = 2.041times and also the relative influence of Π4respect to Π1 is 0.2104/0.0035= 60.11times. Similarly, it is observed that the reverse influence is of Π terms with negative indices i.e. those of Π2,Π3. Amongst this the highest influence is of Π3 followed by Π2. The relative inverse influence of Π3 with respect to Π2 is of the order of 0.1138/0.0042= 27.095times.

Z3 is influenced highest in forward sense by Π4, Π5 and Π1 .This also indicates the relative influence of Π4respect to Π5 2.041times and also the relative influence of Π4respect to Π1 60.11times i.e .influence of anthropometric data w.r.t workstation is more than machine elements. Similarly, it is observed that the reverse influence is of Π2,Π3. Amongst this the highest influence is of Π3 followed by Π2.

Further ANN Simulation model was developed for analysis of prediction of productivity of sewing machine operators considering Anthropometric data, Personal data, Environmental data, machine variables and machine workstation data as input parameter.

The comparison of statistical values of output pi term i.e. Productivity (Z3) obtained by dimensional analysis model, and ANN model are shown in Table 3[17,20]. All these values shows nearness very well with each other. From the values, it seems that the dimensional analysis models and ANN developed can be effectively used for calculation of output terms for a related set of the input pi terms. The Figure 2 depicts that the comparison made by dimensional analysis model values and ANN gives the response data which is overlapping[12,15,17,22]. The overlapping curves are due to less percentage error amongst the Models. This proves the authenticity of the responses for improvement in productivity of sewing machine operator by implementation of few ergonomic interventions with proper knowledge about musculoskeletal risk.

5.0 Result:

The significance of this model can very well be seen from the data presented in dimensional analysis values and the predicted ANN simulation strength in Table 4 and hence the values from dimensional analysis model method and ANN model can be utilized for improvement of future workstation design by intervention of proper knowledge of ergonomics as per OSHA data.

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