Formulation of Field Data Based Model for Productivity Improvement of an Enterprise Manufacturing Tractor Axle Assembly:an Ergonomic Approach

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***Abstract*— The paper describes an approach for formulation of generalized field data based model for the process of tractor axle assembly of an enterprise. The theory of experimentation as suggested by Hilbert Schenck Jr. is applied. It suggests an approach of representing the response of any phenomenon in terms of proper interaction of various inputs of the phenomenon. The Tractor axle assembly process is considered for study which is a complex phenomenon. The aim of field data based modeling for axle assembly process is to improve the performance of system by correcting or modifying the inputs for improving output. The reduction of human energy expenditure while performing axle assembly is main objective behind study. Reduced human energy consumption will increase overall productivity of assembly process. The work identifies major ergonomics parameters and other workstation related parameters which will affect the productivity of axle assembly process. The identified parameters are raw material dimensions, workstation dimensions, energy expenditure of workers, anthropometric data of the workers and working conditions. Working conditions include humidity of air, atmospheric temperature, noise level, intensity of light etc. at workstation which influence the productivity of assembly operation. Out of all the variables identified, dependant and independent variables of the axle manufacturing system are identified. The no of variables involved were large so they are reduced using dimensional analysis into few dimensionless pi terms. Buckingham pi theorem is used to establish dimensional equations to exhibit relationships between dependent terms and independent terms. A mathematical relationship is established between output parameters and input. The mathematical relationship exhibit that which input variables is to be maximized or minimized to optimize output variables. Once model is formulated it can be optimized using the optimization technique. Sensitivity analysis is a tool which can be used to find out the effect of input variables on output variables. Simultaneously it would be interesting to know influence of one parameter over the other. The model will be useful for an entrepreneur of an industry to select optimized inputs so as to get targeted responses.**

Keywords— FDBM; Ergonomics; Dimensional analysis; Optimization; sensitivity analysis

I. INTRODUCTION

Field data based modelling is applicable for any type of man-machine system [1].Field data based model form the relationship between input and output variables. This type of modeling is used for improving the performance of system by suggesting or modifying the inputs for improving output. The process of fabrication of axle assembly is a man-machine system. The workers are involved in all the operations. The human energy consumption during the process is a major concern. Workers are involved in manual handling of material and most of operations are carried out manually. This cause stress and fatigue among workers which reduces their productivity. The mathematical model formed is useful in selecting optimized input variables so as to reduce human energy consumption to improve the worker productivity as well as system productivity.

II. SELECTION OF INDUSTRY

Enterprise selected for study is a medium scale industry in Hingna MIDC at Nagpur in Maharashtra. The industry is involved in fabrication and assembly of axle for various types of tractors. Fabrication process of axle is targeted for Mahindra tractor as it is having the highest production rate as its requirement is more.

III. METHODOLOGY TO FORMULATE THE FIELD DATA BASED MODEL

A. Experimental Approach

For Man Machine system for some of the activities, it is only partially possible to plan experimentation. However, in many of such systems, test planning part of experimentation approach is not feasible to be adopted. One has to allow the activity i.e. phenomenon to take place either the way it takes place or else allow it to take place as planned by others. This happens when one wishes to formulate model for any industrial activity. Here the

activity is processing of raw material for fabrication of finished parts. Formulating the quantitative relationship based on the logic is not possible in the case of complex phenomenon. Because of no possibility of formulation of theoretical model (logic based), one is left with the only alternative of formulating experimental data based model. Hence, it is proposed to formulate such a model for the process of fabrication of axle. The approach adopted for formulating generalized experimental model is suggested by Hilbert Schenck Jr. [2].
It is stepwise detailed below

- Identification of independent, dependent and Independent and extraneous variables.
- Reduction of independent variables adopting dimensional analysis.
- Data collection from existing process of fabrication.
- Purification of data collected from man-machine system.
- Formulation of the field data based model.
- Model optimization.
- Sensitivity analysis.
- Artificial Neural Network simulation.

B. Study of Process of Fabrication of Axle

Fig.1 indicates the flow process diagram for axle assembly process.
Various machines like bending machine, linear welding machine, drilling machine and different facilities for welding processes are arranged in a sequence. The raw material is transferred manually by workers for processing at different workstations. Initially raw material which is in the form of plate is fed to the bending machine where it is converted in square box. After this box shaped axle moves through different processing facilities where other operation like center hole drilling and bow shaped bending of is carried out. The other parts as center sleeve, support bracket, bow weld nuts, two side sleeves are welded to bow type axle by welding operation. Finally all the welds are cleaned for removing burrs and the bow type square cross section axle is ready for other assembly operation in other cells.

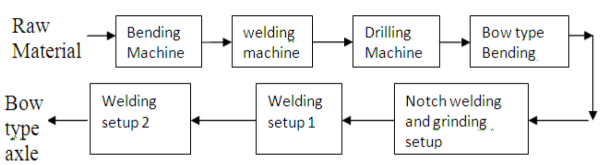

Fig.1.Flow process diagram

C. Identification of Independent and Dependent Variables

Any physical quantity that undergoes a change can be said to be a variable in general sense. If particular variable can be changed without affecting other variables then it is independent variable. Similarly if a particular variable changes in response to variation of one or more variable, it is called as dependent or response variable. If the physical quantity changes in random or uncontrolled manner then it is termed as extraneous variable.

1) Causes or independent variables

There are many independent variables in axle assembly process which are grouped as under.

- Anthropometric features of workers
- Dimensions of workstation and machines
- Environmental factor
- Geometry of the workpiece and tools used

2) Response or dependant variables Selection

Dependent variables identified in case of assembly of axle are as under

- Human energy input

3) Process variables

Table 1 shows list of process variables which include dependant and independent variables

TABLE I. LIST OF PROCESS VARIABLES

Sr.no.	Name of variable	Symbol	Dimensions
1	Anthropometric dimensions ratio of worker	A	$M^0 L^0 T^0$
2	Height of Worker	h	$M^0 L^1 T^0$
3	Age of worker	Ag	$M^0 L^0 T^1$
4	Weight of worker	w	$M^1 L^0 T^0$
5	Shoulder height o worker	Sh	$M^0 L^1 T^0$
6	Elbow height of worker	Eh	$M^0 L^1 T^0$
7	Forward reach of worker	Fr	$M^0 L^1 T^0$
8	Upper reach of worker	Ur	$M^0 L^1 T^0$
9	Hip height of worker	Hh	$M^0 L^1 T^0$
10	Height of worksurface	Hw	$M^0 L^1 T^0$
11	Width of work surface	Ww	$M^0 L^1 T^0$
12	Depth of worksurface	Dw	$M^0 L^1 T^0$
13	Height of stack	Hs	$M^0 L^1 T^0$
14	Width of stack	Ws	$M^0 L^1 T^0$
15	Depth of stack	Ds	$M^0 L^1 T^0$
16	Length of raw workpiece	Lr	$M^0 L^1 T^0$
17	Width of raw workpiece	Wr	$M^0 L^1 T^0$
18	Thickness of raw workpiece	Tr	$M^0 L^1 T^0$
19	Hardness of workpiece	BHN	$M^0 L^0 T^0$
20	Compressive strength of the workpiece material	Sc	$M^1 L^{-1} T^{-2}$
21	Weight of raw workpiece	WR	$M^1 L^0 T^0$
22	Weight of tool	WT	$M^0 L^0 T^0$
23	Force applied by tool	FT	$M^1 L^1 T^{-2}$
24	Length of tool	Lt	$M^0 L^1 T^0$
25	Width of tool	Wt	$M^0 L^1 T^0$
26	Thickness of tool	Tt	$M^0 L^1 T^0$
27	Atmospheric temperature	Tatm	$M^0 L^0 T^0$
28	Humidity	Ø	$M^0 L^0 T^0$
29	Wind speed	Vf	$M^0 L^1 T^{-1}$
30	Light intensity	LUX	$M^0 L^0 T^0$
31	Sound intensity	DB	$M^0 L^0 T^0$
32	Initial pulse rate of worker	Pi	$M^0 L^0 T^0$
33	Final pulse rate of worker	Pf	$M^0 L^0 T^0$
34	Human energy input	Y	$M^1 L^2 T^{-2}$
35	Duration	t	$M^0 L^0 T^1$

D. Reduction of Variables

1) Selection of primary dimensions

According to Theories of engineering experimentation by H. Schenck Jr. "The choice of Primary Dimensions", most systems require at least three primaries, but the analyst is free to choose any reasonable set he wishes, the only requirement being that his variables must be expressible in his system [3]. In axle assembly process all the variables are expressed in mass (M), length (L), time (T) hence M, L, and T are chosen as primary dimensions for the dimensional analysis.

2) Dimensional analysis

As the number of independent variables is too large, they are reduced to few using dimensional analysis by applying Buckingham's pi theorem [3] .When this theorem is applied to a system having "n" independent variables and "m" primary dimensions,(n-m) number of pi terms is formed. Three primary dimensions used are L, M, T. If the product of these pi terms is taken then it will yield dimensionless pi term. This approach is used to reduce the number of variables and following pi terms are formed logically for axle assembly process. Table II shows Pi terms for independent variables and Table III shows Pi terms for dependant variable

TABLE II. PI TERMS FOR INDEPENDENT VARIABLES

Pi terms related to Anthropometric data	Π_1	((A1×W1×Ag1)/(A2×W2×Ag2)) × ((A1×W1×Ag1)/(A3×W3×Ag3)) × ((A2×W2×Ag2)/(A3×W3×Ag3))
Pi terms of Workstation	Π_2	(Hw×Ww×Dw)/(Hs×Ws×Ds)
Pi terms of workpiece material	Π_3	(HN×Lr×Wr×Tr×Sy)/(FT×Wt)
Pi terms of tool used	Π_4	(Lt×Wt)/(Tt×Wr)
Pi terms of environmental factors	Π_5	(Ø×T_{atm}×Vf×DB)/(LUX×g×t)

TABLE III. PI TERMS FOR DEPENDANT VARIABLES

Human Energy Pi term	Π_6	((Pi+Pf)/2)× t

E. Mathematical Approach and Development of Model

The mathematical relation between inputs and outputs could be of any form may be polynomial, exponential or log linear. The Buckingham Pi theorem found suitable for developing the model. As it states that if the inputs and outputs represented in dimensionless pie terms by dimensional analysis then they can be represented

By equation (1)

$$\Pi_6 = k \times \Pi_1^a \times \Pi_2^b \times \Pi_3^c \times \Pi_4^d \times \Pi_5^e \qquad (1)$$

The model has various indices as K, a, b, c, d, e whose values are unknown.

This model represents the field data base model for one workstation for axle assembly process. This model and the Pi terms formed in this model will be used for developing model for different workstation in the process. The Pi terms will be different for other workstations. Human energy input at every workstation is represented by independent Pi term Π_6.

1)Simplification of model

Model contains various indices as K, a, b, c, d, e whose values are unknown. The values for dependant and independent Pi terms can be easily find out by observation and recording of workstation parameters, tool parameters, atmospheric parameters, anthropometric data of workers involved at different workstations and measurement of there pulse rate while performing their work to estimate human energy consumption.

2) Determination of indices

For determining the indices of the relation between output and inputs multiple regressions and Matlab software can be used

Model is represented by equation (1)

$$\Pi_6 = k \times \Pi_1^a \times \Pi_2^b \times \Pi_3^c \times \Pi_4^d \times \Pi_5^e$$

There are six unknown terms in the equation (1) curve fitting constant K and indices a, b, c, d, e. To get the values of these unknowns we need minimum a set of five set of all unknown dimensionless pi terms.

Consider the following relation

$$Z = A + bX + CY \qquad (2)$$

Equation (2) represents equation of a curve fitting technique.

Equation (1) can be brought in the form of equation (2) as follows.

Taking log on both side of equation (1)

$$\text{Log}\Pi_6 = \text{Log } k \times a\text{Log}\Pi_1 \times b\text{Log } \Pi_2 \times c\text{Log}\Pi_3 \times d\text{Log } \Pi_4 \times e\text{Log } \Pi_5 \qquad (3)$$

Let, Z = log π_6, K = log k, A = log π_1, B = log π_2, C =log π_3, D = log π_4, E = log π_5,

Equation (3) become

$$Z=K+a\times A+b\times B+c\times C+d\times D+e\times E \qquad (4)$$

Equation (4) is a regression equation of Z on A, B, C, D and E in a dimensional co-ordinate system

Again equation (4) is written as

$$Z = n\times K + a\times\Sigma A+b\times\Sigma B+c\times\Sigma C+d\times\Sigma D+e\times\Sigma E \qquad (5)$$

$$\Sigma ZA = K\,\Sigma A + a\times\Sigma A\times A + b\times\Sigma B\times A + c\times\Sigma C\times A + d\times\Sigma D\times A + e\times\Sigma E\times A \quad (6)$$

$$\Sigma ZB = K\,\Sigma B + a\times\Sigma A\times B + b\times\Sigma B\times B + c\times\Sigma C\times B + d\times\Sigma D\times B + e\times\Sigma E\times B \quad (7)$$

$$\Sigma ZC = K\,\Sigma C + a\times\Sigma A\times C + b\times\Sigma B\times C + c\times\Sigma C\times C + d\times\Sigma D\times C + e\times\Sigma E\times C \quad (8)$$

$$\Sigma ZD = K\,\Sigma D + a\times\Sigma A\times D + b\times\Sigma B\times D + c\times\Sigma C\times D + d\times\Sigma D\times D + e\times\Sigma E\times D \quad (9)$$

$$\Sigma ZE = K\,\Sigma E + a\times\Sigma A\times E + b\times\Sigma B\times E\; c\times\Sigma C\times E + d\times\Sigma D\times E + e\times\Sigma E\times E \quad (10)$$

In the above set of equations the values of the multipliers K,A,B,C,D,E are substituted to compute the values of a, b, c, d and e. After substituting these values in the equations one will get a set of five equations, which are mutinously to get the values of k , a, b, c, d and e .The above equations can be verified in the matrix form and further values of k , a, b, c, d and e can be obtained by using matrix analysis.

$$[P1] = [W]\,[X1] \quad (11)$$

$$X1 = inv\,(W) \times P1 \quad (12)$$

Where
W = 5 × 5 matrix multipliers of k, a, b, c, d and e
P1 = 5 × 1 matrix of the terms on L H S and
X1 = 5 × 1 matrix of values of k, a, b, c, d and e
Solving these equations using 'MATLAB' software we get values of unknown indices K, a, b, c, d, e.
Hence the model can be written in complete format by knowing values of indices calculated using Matlab software.

F. Optimization of the Model

The ultimate objective of this work is not merely developing the model but to find out best set of independent variables which will result in minimization of the objective functions. After knowing the form of mathematical model it is required to optimize the model. Here response variable is human energy consumption which is to be minimized. Optimization of model indicates which input variables are to be minimized and which input variables to be maximized so as to minimize the human energy utilization. In any optimization technique there is an objective function and constraints or limitations. Here objective function is minimization of human energy input while the constraints are maximum and minimum values of variables. The model developed has non-linear form; hence, it is to be converted into a linear form for optimization purpose. This can be achieved by taking the log of both the sides of the model. The linear programming technique is to be applied which is detailed as below [4].

Taking log on both the sides of the equation (1), we get the objective function as under.

$$MinZ = Log(k) + aLog(\Pi_{1}) + bLog(\Pi_{2}) + Log(\Pi_{3}) + dLog(\Pi_{4}) + eLog(\Pi_{5}) \quad (13)$$

Subject to the following constraints

$$1X_1 + 0X_2 + 0X_3 + 0X_4 + 0X_5 \le LOG(Max\Pi_1)$$
$$1X_1 + 0X_2 + 0X_3 + 0X_4 + 0X_5 \ge LOG(Min\Pi_1)$$
$$0X_1 + 1X_2 + 0X_3 + 0X_4 + 0X_5 \le LOG(Max\Pi_2)$$
$$0X_1 + 1X_2 + 0X_3 + 0X_4 + 0X_5 \ge LOG(Min\Pi_2)$$
$$0X_1 + 0X_2 + 1X_3 + 0X_4 + 0X_5 \le LOG(Max\Pi_3)$$
$$0X_1 + 0X_2 + 1X_3 + 0X_4 + 0X_5 \ge LOG(Min\Pi_3)$$
$$0X_1 + 0X_2 + 0X_3 + 1X_4 + 0X_5 \le LOG(Max\Pi_4)$$
$$0X_1 + 0X_2 + 0X_3 + 1X_4 + 0X_5 \ge LOG(Min\Pi_4)$$
$$0X_1 + 0X_2 + 0X_3 + 0X_4 + 1X_5 \le LOG(Max\Pi_5)$$
$$0X_1 + 0X_2 + 0X_3 + 0X_4 + 1X_5 \ge LOG(Min\Pi_5)$$

This above linear programming problem can be solved by using MS solver in MS Excel. We get values of X_1, X_2, X_3, X_4, X_5 and Z.
Thus Min value of Π_6 =Antilog of Z .Corresponding to this minimum value of the Π_6 the values of the independent π terms are obtained by taking the antilog of X_1,X_2,X_3,X_4,X_5 and Z. Thus we get optimized values of pi terms. It can be estimated from this that which pi term values to be maximized and which pi terms are to be minimized so as to minimize human energy input.

G. Sensitivity Analysis

When a model has multiple input parameters then it becomes important to know for a certain value of positive and negative variation which parameter is influencing maximum and output parameter is sensitive up to what extent. Sensitivity of a model is the percentage influence on Y, by 10% positive or negative variations keeping the other variable to its minimum error set. In sensitivity analysis the effect of input variables on response variable is known if they are decreased and increased by certain amount. We assume 10% increase and 10% decrease in pi terms. Thus, total range of the introduced change is ±20 %. The effect of this introduced change on the change in the value of the dependent π term is evaluated. The sensitivity analysis can be represented graphically by indicating % change in output on Y-axis because of % change in pi terms on represented on X-axis.

H. Artificial Neural Network Simulation

The maximum reliability of the model can be established by performing ANN simulation of the gathered field data using Matlab software.

ANN simulation will lead to simulation based model which will quantify appropriate non-linear behavior of output as influenced by Inputs.

REFERENCES

[1] J.P.Modak, K.S. Zakiuddin, "Mathematical modeling and simulation of field data based model for civil activity," International Journal of Scientific & Engineering Research, Volume 3, Issue 3, March-2012.

[2] H.Schenck Jr., Theories of Engineering Experimentation, McGraw Hill Book Co, New York.

[3] H.Schenck Jr, ' Reduction of variables dimensional analysis' , Theories of Engineering Experimentation, Mc Graw HillBook Co, New York,chapter4, p.p 60-81.

[4] M.R.Phate,V.H.Tatwawadi, J.P.Modak,"Formulation of a generalized field data based model for the surface roughness of aluminium 6063 in dry turning operation," New York Science Journal 2012;5(7).

[5] A. D. Dhale, J. P. Modak, "Formulation of experimental data based model for oil press using human powered flywheel motor as energy source,"Agric Eng Int: CIGR Journal, Vol. 14, No.3,218-229 September, 2012

[6] C.N. Sakhale, J.P.Modak, "Formulation of approximate generalized experimental data based model for machining properties of bamboo," 13th World Congress in Mechanism and Machine Science, Guanajuato, Mexico, 19-25 June, 2011

[7] H.L.Himate , J. P. Modak, " An approach to form field data based model for roof bolting operation in underground mine,"International J. of Engg. Research & Indu. Appls. (IJERIA), Vol.3, No. I (2010), pp 51-67

[8] J. P .Modak and A. R .Bapat, "Formulation of a generalized experimental model for a manually driven flywheel motor and its optimization," Applied Ergonomics 1994 25(2) 119—122.

[9] K.S. Zakiuddin , J. P. Modak, "Formulation of data based ANN model for the Human powered fodder chopper,"Journal of Theoretical and Applied Information Technology, 31st May 2010. Vol.15. No.2.

[10] M.R.Phate,V.H.Tatwawadi ,"Modeling of power consumption in turning of ferrous and nonferrous materials using artificial neural network," International Journal of Engineering Trends and Technology- Volume4Issue3- 2013.

[11] S. P. Mishra, D.K Parbat "Sensitivity analysis of multi parameter mathematical model in reinforced concrete construction," International journal of civil and structural engineering Volume 3, No 1, 2012

[12] V.N.Bhaisawar,J.P.Modak, "Dynamic analysis of lobe coupling by formulation of an approximate generalized experimental data based model,"International Journal of Scientific and ResearchPublication,Volume ,Issue1,December2011.