Mathematical Modeling AndSimulation of Field Data BasedModel for Civil Activity

O. S. Bihade, S.S.Kulkarni,J. P. Modak, K.. S. Zakiuddin

Abstract— This paper discuss the approach to formulate Field Data Based Model (FDBM) for any Man Machine System. The presently observed civil construction activities are Man Machine Systems. 'Man-Machine System' means an activity occurring with the involvement of a human operator either a male and/or a female with the help of some tools used to interact with the material. The common building materials used in various activities are bricks, cement, coarse aggregate, fine aggregate, water, mild steel bars, timber, marble, granite, glass etc. The construction methods are being practiced over several decades. No investigation has been made as regards appropriate use of the posture, parameters of tools and construction materials for every construction activity. It is therefore felt necessary to ascertain the scope of improvement in the method of performing a construction activity.It is necessary to form such a Field Data Based Model for deciding strengths and weaknesses of the traditional method of performing any construction activity. Once the weaknesses are known, the corrective action can be decided. Specific application of Civil Engineering activities is treated. The present investigation reports "Field Data Based Modelling" of some of the construction activities. The scope of these activities is restricted to either exclusively for a single storied residential building or maximum up to the building with G+1 floor.

Index Terms— Man Machine Systems, Field Data Based Model, Ergonomics, Human Energy, Productivity, Mathematical Modeling, Site Clearance.

1 Philosophy of a Field Data BasedModel

1.1 Man Machine Systems

In our daily life either in a situation related to (1) Domestic (2) Social (3) Political (4) Industrial (5) Service Sector or (6) Education Field, many activities do take place which are planned in a limited way. The situation where activity takes place i.e. the workstation [1] is designed with only partial perfection. Every such activity is a Man-Machine system [2]

2 System, Causes, Effects AndExtraneous Variables

It is well known that any activity occurs because of four essential parameters namely System, Causes, Effects and Extraneous Variables. To make it clear, this is illustrated by an activity of gardening. For example a gardener is performing a digging operation in a garden. This activity is realized by arranging

System:- This is a specific spot in a garden with naturally available environment conditions of humidity, air circulation, ambient temperature etc.

Causes:- These are the issues which are actuating the system (which sets the system in action)

Effects:- These are the responses of the execution of an activity.

Extraneous Variables:- These are the Factors / Parameters / Causes which do influence the performance of the activity but which cannot be measured.

As regards the gardener performing digging operation causes would be viz. information about the operator i.e. his anthropometric data (A), his attitude towards the work (A1), aptitude towards the work (A2), skills of doing this work (A3), Experience of doing this work (A4), his enthusiasm at the specific event of performing the activity i.e. if it is being performed on Independence day at 11.00 a.m. what is the level of his enthusiasm (A5), general health status (A6), habits (A7) so on and so fourth.

Specifications of the tools used (B), In this case the material of the Gamela/Pawarah/Pick axe (B1), Dimensions of the Gamela/Pawarah/Pick axe (B2), Dimensions of wooden handle (B3), Sharpness and hardness of the digging edge (B4 and B5), Posture adopted by an operator (B6),

Specifications of the soil being excavated (C), Hardness / Cohesiveness of the soil (C1), Extent of vegetation embedded in the soil (C2), Amount of moisture in the soil (C3), Type of the soil i.e. whether black cotton soil or any other (C4),

Extraneous variables (D) would be: Atmospheric Temperature (D1), Humidity (D2), Air Circulation i.e. Air velocity (D3), Surrounding Noise Level (D4). Some are measurable, some are not measurable.

Responses (i.e. effects) (Y) would be (i) Human Energy Input (Y1), (ii) Amount of perspiration (Y2), (iii) Amount of soil dug (Y3), (iv) Rest-Pause needed (Y4) etc.

3 Brief Approach to Experimental Data Based Models

It is not possible to plan such activities on the lines of design of experimentation [11] when one is studying any completely physical phenomenon but the phenomenon is very complex to the extent that it is not possible to formulate a logic based model correlating causes and effects of such a phenomenon then one is required to go in for the field data based models [3].

In such a situation the various steps involved in formulating model for such a complex phenomenon is same as follows [4]

Identify the Causes and Effects performing qualitative analysis of physics of such a phenomenon. Establish dimensional equation for such a phenomenon. Once a dimensional equation is formed, it is a confirmation that all involved physical quantities are considered.

Then perform Test Planning which involves deciding Test Envelope, Test Points, Test Sequence

Test Envelop: - To decide range of variation of an individual independent term.

Test Points:- To decide and specify values of independent π terms at which experimental setup be set during experimentation.

Test Sequence: - To decide the sequence in which the test points be set during experimentation.

Plan of Experimentation:- Whether to adopt Classical Plan or Factorial Plan.

Physical Design of an Experimental Setup:- Here it is necessary to work out physical design of an experimental setup including deciding specifications and procuring instrumentation, subsequently it is necessary to fabricate the set up.

Next step would be to execute experimentation as per test planning and gather data regarding causes (Inputs) and effects (Responses)

Next step is to purify the gathered data using statistical methods

Finally to establish the relationship between outputs (effects) and inputs (causes) using various graph papers.

4 LIMITATION OF ADOPTING EXPERIMENTATION DATA BASED MODEL FORMULATION APPROACH FOR FORMULATING A MODEL FOR MAN MACHINE SYSTEM.

For Man Machine Systems enumerated earlier 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 whishes to formulate model for

a. Any industrial activity such as Inventory Operation, Raw Material Processing, Inspection, and Human Assembly.

b. Any activity in underground / open cast mining: Drilling, Manual Shoveling, Roof Bolting etc.

c. Any Civil Construction Activity :

Formulation of relationships amongst causes and effects (In other words inputs and outputs) however is essential. This is so because it is only after formulation of such relationships, that short comings or strengths of present method of execution of that activity becomes known.

Once the short comings are known, improvement in the method of performing such an activity becomes possible. Hence, from the point of view of improving system or performance of activity it is absolutely essential to form such analytical cause – effect relationships conceptualized in this chapter as "FIELD DATA BASED MODELS". It is necessary to formulate relationships such as

Y1=f1[(A1,A2,A3,A4,A5,A6,A7,A8),(B1,B2,B3,B4,B5),(C1,C2,C3,C4),(D1,D2,D3,D4)]------ (4.1.1)

Y2=f2[(A1,A2,A3,A4,A5,A6,A7,A8),(B1,B2,B3,B4,B5),(C1,C2,C3,C4),(D1,D2,D3,D4)]------ (4.1.2)

Y3=f3[(A1,A2,A3,A4,A5,A6,A7,A8),(B1,B2,B3,B4,B5),(C1,C2,C3,C4), (D1,D2,D3,D4)]------(4.1.3)

It is because, once such relationships are formed then only it is possible to improve the method of working. This statement becomes clear through one hypothetical application which is illustrated in the article 4.5 of this paper.

4.1 Application

One can find many activities which are man machine systems inspite of considerable automation is introduced in industries and / or in service sector. There are some industries which are still considerably labour intensive or which have not yet introduced automated mechanization. For example (a) Construction Industry. (b) Operations in mining industries either underground / open cast mines (c) i) Turbo Alternator Set in Thermal Station ii) Drag lines in Mining iii) Air Traffic Control (d) Train derailment [5,6](e) Road Accidents (f) Delay in Train Scheduling (g) Deciding policy of Total Quality Management (h) Ascertaining possibility of getting services in entrepreneurial activities. (i) To develop a tool for deciding improvement of productivity, quality and reduction of human energy input at any work station in industry.

4.2 Brief Specifications of the Scope of paper

In fact, complete demonstration of application of procedure to formulate a FIELD DATA BASED MODEL for each one of the above stated activities would result in separate several papers.

Hence, it is proposed to detail the procedure for getting such a model for one Civil Construction activity in this paper. What follows are the details of this scope.

4.3 Choice of Activity within the Broad Scope

Various constructional operations have been enlisted chronologically in paper under article 3. However, only four activities have been selected for research as under.

Site Clearance i.e. Cleaning of plot

Excavation for foundation trenches (Wall footings or Column footings)

Removing excavated stuff from foundation trenches

Laying Plain Cement Concrete (PCC) in foundation beds.

4.4 Procedure for Getting FDBM For Activity of M.S. Bars Cutting within the Broad Scope

In this paper, it is decided to detail out the procedure for getting FILED DATA BASED MODEL for one such activity of centering i.e. mild steel bars cutting. Description of the Work Station and Activity of Work Station

- *O.S.Bihade is currently pursuingPhD degree program in Civil Engineering in RTM,NagpurUniversity,Nagpur, E-mail:osbihade @hotmail.com*
- *Dr. J.P.Modak is currently Dean (R&D),Priyadarshini College of Engineering in RTM,NagpurUniversity, Nagpur, E-mail:jpmodak@gmail.com*
- *Dr.K.S.Zakiuddin is currently Dean Academics,Prof & Priyadarshini College of Engineering in RTM,NagpurUniversity, Nagpur,*
- *qszaki1@rediffmail.com*

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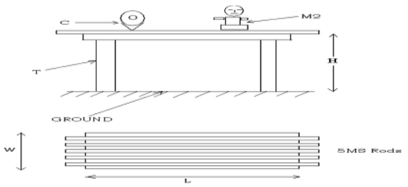
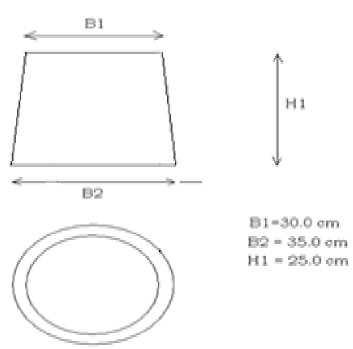


Figure 4.1 Work Station for cutting of Mild Steel bars.

Figure 4.1 describes the work station for cutting of Mild Steel bars for reinforcement. T is a wooden table on the top of which the mild steel bars (in the range of 6 mm to 10 mm diameter) are placed in a row containing 2 to 5 bars at a time. Height of the table top from the ground is H, L, and W are the length and width of the table T respectively. There are two operators of this work station M1 and M2. M1 is having standing posture whereas M2 is having sitting posture. Posture means the geometry of outline of the body adopted by the operator / worker [7]. M1 is assigned the task of cutting the bars with Chisel C. This Chisel is made from the cast iron with a sharp hardened edge which is made to strike the bunch of bars (2/3/4/5) with severe impact. This impact is created by raising the Chisel through about 3 meters above the top of the table T and swing in the air with the help of the wooden handle about 0.8 to 1.1 meter long, 3 to 4 cm in diameter. M1 is required to give several blows (5 to 10) on the bunch of bars for shearing them off. This operation may take time t around 5 to 7 minutes. This time t may vary from batch of bars to another batch of bars. During this cutting procedure the operator M1 is using his stored Human Energy (HE) which can be estimated in pulse .



Operator M2 adopts a seating posture [8]. However, his seat is not properly designed [9]. It may just be a portion of the trunk of the dead tree as shown in Figure 4.2.

4.5 Causes or Inputs to the Activity

In this case complete anthropometric data of both the operators M1 and M2, parameters defining the work station such as H, W, L, H1, B1, B2, the M.S. bar diameter d, yield point of material of the bars being cut, Geometric dimensions of chisel C and its wooden handle, height through which chisel is raised by M1 (say H2), the weight of chisel C and its wooden bar, sharpness of edge S, hardness of edge He, number of bars being cut at a time (n), number of blows given to the bunch of bars being cut, (N), would be the causes or inputs.

Effects or Outputs or Responses of the Activity

For this operation, the effects / outputs / responses would be time (t) needed to cut the specific bunch of bars (ρ), shearing accuracy of the bars, (HE) human energy input.

Extraneous VariablesThese would be

1.Vibrations generated in the work table T. (Energy contained in these vibrations is one cause for energy loss which one cannot estimate)

2.The influence of environmental conditions on working of M1 and M2

Observations

Supposing about 50 bundles of bars of 6 mm diameter are cut

TABLE 4.1 OBSERVATION TABLE OF M.S. BARS CUTTING OPERATION

S.N.	INPUTS																Responses		
	A's for M1/M2			Geometric and other parameters of Work Station								Parameters of Chisel and hammer				$Y_1 = t$	$Y_2 = p$	$Y_3 = HE$
	A1	A2	A3 to A8	H	W	L	H1	B1	B2	D	SY	GD	H2	n	N			
1↓																		
25↓																		
50																		

in the required lengths. Let this length be L then one will have recorded 50 observations as symbolically denoted in Table 4.1 given below:

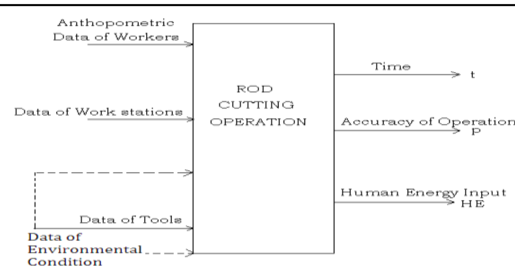


Figure 4.3 Block Representation of the Phenomenon Under Study.

Rejection of Erroneous Data

Out of these 50 observations, there are chances that some data may be erroneous either from inputs or from responses. Adopting techniques of rejecting the erroneous data [9], the observed data can be purified or in other words can be made more reliable for proceeding further with the step of formulation of Models.

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4.6 Approach for Formulation of Modes Based on Observed Data

In order to make this step very clear, it is assumed that let the activity under observation has less number of inputs say only four A, B, C, D and the responses Y1 and Y2. It is intended to establish the mathematical relationship in a much generalized form as under:

Y1 = K1 [(A)a1 * (B)b1*(C)c1*(D)d1] ---------------------------(4.1.4)

and

Y2 = K2 [(A)a2*(B)b2*(C)c2*(D)d2 (4.1.5)

This is known as exponential form of the model. Assuming such a form, it is convenient to decide precisely the degree of influence of one input relative to other inputs on the response variable. After having established this, one would be able to decide the inputs which have low influence on the response. Thus this aspect will crystallize the inputs which need attention from the point of view of IMPROVING THE METHODS OF PERFORMING THE ACTIVITY which is the main purpose of formulation of FIELD DATA BASED MODEL for an activity.

Recalling equation (4.1.4) what needs to be done is to decide 5 unknowns in this equation viz., K1, a1, b1, c1, d1. For this purpose one needs only 5 observations. Let us select observation number 1, 23, 35, 41 and 48 then all these observation values of Y1, A, B, C, and D are known. These may be denoted as Y1 (23), A23, B23, C23, and D23 respectively. Say for example for observation no. 23. Then if one substitutes these values in equation 4.1.4

Y1 (23) = K1 [(A23)a1 (B23)b1 (C23)c1 (D23)d1] --------------------------------- (4.1.4.1)

Taking log on both sides, following relation can be obtained,

Thus for observation number 1, 35, 41 & 48 similar equations can be formed. One will get set of 5 equations which can be put in a matrix form as under :

$$\begin{pmatrix} \text{Log } Y_1 (1) \\ \text{Log } Y_1 (23) \\ \text{Log } Y_1 (35) \\ \text{Log } Y_1 (41) \\ \text{Log } Y_1 (48) \end{pmatrix} = \begin{pmatrix} 1 & \log (A1) & \log (B1) & \log (C1) & \log (D1) \\ 1 & \log (A23) & \log (B23) & \log (C23) & \log (D23) \\ 1 & \log (A35) & \log (B35) & \log (C35) & \log (D35) \\ 1 & \log (A41) & \log (B41) & \log (C41) & \log (D41) \\ 1 & \log (A48) & \log (B48) & \log (C48) & \log (D48) \end{pmatrix} \begin{pmatrix} \text{Log } K1 \\ a_1 \\ b_1 \\ c_1 \\ d_1 \end{pmatrix} \text{ - (1.4.3)}$$

In equation (1.4.3) all quantities are known excepting log K1, a1, b1, c1, d1. For deciding these unknowns, decide M^{-1}. Here M is a 5 x 5 square matrix on R.H.S. Then, premultiplying all matrices of equation (1.4.3) by M^{-1} one would get the relation as under :

$$[M]^{-1} \begin{Bmatrix} \text{Log } Y_1 (1) \\ \text{Log } Y_1 (23) \\ \text{Log } Y_1 (35) \\ \text{Log } Y_1 (41) \\ \text{Log } Y_1 (48) \end{Bmatrix} = [M]^{-1} [M] \begin{Bmatrix} \text{Log } K1 \\ a_1 \\ b_1 \\ c_1 \\ d_1 \end{Bmatrix} \text{ ---------------- (1.4.4)}$$

Log Y1 (23) = Log K1 + a1.Log (A23) + b1.Log (B23) + c1.Log (C23)+ d1.Log(D23). ---- (4.1.4.2)

Thus, K1, a1, b1, c1, d1 can be found for one set of 5 observations from the observations taken. Thus if 50 observations are taken then one will arrive at NCR. Here NCR will be combinations of 50 observations taken any 5 at a time. This amounts to getting very large number of values each of K1, a1, b1, c1, d1. The arithmetic average of these would probably be the reliable values of K1, a1, b1, c1, and d1. Thus the exact form of model (4.1.1.4) can be deduced. It is recommended to use MATLAB software for this purpose for making this process of model formulation quickest and least cumbersome.

4.7. AN APPROACH TO DECIDE THE UTILITY OF THE MODEL

4.7.1. Sensitivity of Inputs

Supposing the exact form of model (4.1.4.1) is obtained as

Y1 = 6.1 [(A)0.3 * (B)4 * (C)-1.7 * (D)2.1] -- (4.1.4.5)

It is now the time to decide the effectiveness of the present method as regards the influence of inputs on response variable Y1. Equation 4.1.4.5 shows the influence of inputs on Y1 is the maximum of keeping B as high as possible as compared to C. This is so because, the index of B is highest and that of C is lowest. The influence of other inputs in the descending order is by the same logic is of D and A. 6.1 is the value of curve fitting constant which collectively represents all extraneous variables.

4.7.2 Optimization of the Models

As far as the activity of cutting of bars is concerned any one will wish to maximize Y2 (i.e. accuracy of operation) whereas he would like to minimize Y1 (i.e. the time to cut the bars) and Y3 (i.e. the human energy input).

Now it is the time to apply the subject optimization technique [30] for arriving at, at which values of the inputs that Y2 can be maximized and Y1 and Y3 can be minimized.

This has to be the sole objective of deciding "HOW TO IMPROVE THE METHOD OF PERFORMING ANY ACTIVITY". Thus this approach of formulation of FDBM for any man machine system should be looked upon as a new technique of method study of any Man Machine System. This was not possible in the absence of establishing such models. These models only enlighten us about the "INTENSITY OF INTERACTION OF INPUTS ON DECIDING RESPONSE" of any activity.

4.7.3 Reliability of any Model

Obviously before taking up the step 4.7.1 sensitivity of inputs, it is necessary to decide the validity of the model. Because though care has been taken to purify the observed data there is a chance of some impure data entering in the mathematical processing of the data though even after using MATLAB.

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

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4.7.4 ARTIFICIAL NEURAL NETWORK (ANN) SIMULATION

The maximum reliability of the model can be established provided ANN Simulation [10] of the gathered data is performed. ANN simulation will lead to simulation based model which will quantify appropriate non-linear behavior of effects (responses) as influenced by causes (Inputs). It is alternative to exponential form of Model..

5 CONCLUSION

Paper details the use of contemporary techniques for the purpose of study, compression and generalized approach for the FDBM of any Man Machine System.

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