NEURAL VALIDATION OF FDBM SIMULATION FOR A MANUAL ACTIVITY IN RCC CONSTRUCTION

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Abstract

The India and other developing countries utilize intensive manual labour in building and infrastructure development. The methods used in these activities are either traditional or designed in a limited way. The present paper aimed to propose improvements in methods of performing these activities by developing a mathematical simulation of data collected while the work was actually being executed in the field. Once the generalized model using all possible parameters developed, the weaknesses of the present method identified and improvement is possible. The main contribution of this paper is to develop the mathematical simulation of formworks placing sub activities in reinforced concrete construction and validate it with the Neural Network prediction. Validation of the Field Data Based Mathematical (FDBM) model is achieved by comparing with the Artificial Neural Network Prediction and found satisfactory.

Key words: FDBM simulation, manual construction, reinforced concrete construction, Reliability, sensitivity, ANN simulation.

Introduction: Formworks are temporary structures, which are removed after concrete attains enough strength of a R.C.C. member. Construction activities (Gunnar Lucko et al., 2009) though appear simpler in execution but the relation between inputs and outputs shows a very complex pattern (H.Schenck, Jr, 1961). All framed structures constitutes Reinforced Concrete work (Suhad M. Abd et al. 2008; Kwangseog Ahn et al.2000) as a major activity and the cost of formwork(E. Sarah Slaughter et al.,1997) found to be 30-60 % of cost of a framed structure.

This paper explains the mathematical simulation (Anu Maria 1997) of manual formwork fixing sub activity. The purpose of developing a model was to overcome the deficiencies in the current method, for process improvement, process management and to reduce fatigue in the workers and musculoskeletal injuries (John Rasmussen et al.2003; Kwangseog et al. 2000, Rwamamara et al, 1988). The approach has been motivated from principles of construction management and Method study in industrial engineering (S. Dalela 1991; K.H.F.Marrel 1967).

1. Formulation of FDBM Model

(a) Study of the present method of manual Formwork fixing: The formworks are built on site using timber planks and props for lateral supports at suitable intervals. The traditional timber formwork is preferred at a common construction site and this is developed according to size and type of building components. Such as ground beam, beams supported from three sides, footings of columns, columns and slab forms.

(b) Identification of Independent and Dependent variables: Causes or dependent variables: The activity of formwork includes the workers' data as input like anthropometric data, height, age and weight .The tools used in formwork are small hammer with one end as nail remover, Hacksaw for cutting timber planks and props there geometric dimensions are recorded as inputs as the each dimension on varying influences the outputs. The workstation data such as size and numbers of planks and props with their dimensions and weight, size, diameter and numbers of nails required to fix a formwork and time required to complete a given size of form recorded. The material properties such as hardness in Rockwell hardness no. and shear strength of wood used .The environmental data such as ambient temperature, wind speed and humidity influences the output of workers so they are also recorded.

Dependent variables: For the formwork operations, the dependent variables would be:
(i) The extent of work done,
(ii) The human energy consumed and
(iii) The performance error in % of the required work.

Extraneous Variables: These are other parameters, which could not identified, as inputs would be considered as extraneous variables such as loss of human energy by other means, effect of enthusiasm and motivations in workers performing the activity.

TABLE 1. Name of Variables, Symbols and Dimensional Equation of Variables

Name of Variables	Symbols	Type of parameter	Units of measurement	Dimensional formula
Height of Worker 1	h_1	Independent	cm	L
Anthropometric data of Worker 1	A_1	Independent	cm	-
Age of Worker 1	ag_1	Independent	years	T
Weight of Worker 1	wt_1	Independent	kg	M
Height of Worker 2	h_2	Independent	cm	L
Anthropometric data of Worker 2	A_2	Independent	cm	-
Age of Worker 2	ag_2	Independent	years	T
Weight of Worker 2	wt_2	Independent	kg	M
length of Hacksaw	lhs	Independent	cm	L
average width of Hacksaw	avwhs	Independent	mm	L
thickness of Hacksaw blade	thohsb mm	Independent	mm	L
weight of wooden handle of Hacksaw	wtowhhs	Independent	kg	M
length of wooden handle of hacksaw	lowhhs	Independent	cm	L
Hardness of Hacksaw blade	hrhsb	Independent	No.	-
No. of teeth in hacksaw blade	noths	Independent	No.	-
weight of hacksaw	wths	Independent	kg	M
length of hammer head	hhl	Independent	cm	L
dia of hammer head	hhd	Independent	cm	L
weight of hammer head	hwt	Independent	kg	M
length of wooden handle of hammer	hwhl	Independent	cm	L
weight of wooden handle of hammer	hwhwt	Independent	kg	M
nail remover length	nrl	Independent	cm	L
nail remover width	nrb	Independent	cm	L
nail remover thickness	nrt	Independent	mm	L
hardness of wooden handle	hrhw	Independent	No.	-
hardness of hammer	hrh	Independent	No.	-
Wind Speed	vs	Independent	meter/seconds	LT-1
Temperature	T	Independent	degree centigrade	-

Name of Variables	Symbols	Type of parameter	Units of measurement	Dimensional formula
Humidity	hu	Independent	%	
Acceleration due to gravity	g	Independent	m/sec 2	LT-2
length of wooden props	lopp	Independent	meter	L
Number of wooden props	nopp	Independent	nos.	-
Dia. of wooden props	diaopp	Independent	meter	L
weight of wooden props	wtopp	Independent	kg	M
hardness of wooden props	hrppw	Independent	No.	-
weight of wooden plank	hrplw	Independent	No.	-
Number of wooden plank	nopl	Independent	no.	-
length of wooden plank	lopl	Independent	m	L
width of wooden plank	bopl	Independent	m	L
thickness of wooden plank	thopl	Independent	m	L
weight of wooden plank	wtpl	Independent	kg	M
No. of nails	non	Independent	nos.	-
Hardness of nail	hrn	Independent	No.	-
diameter of nails	don	Independent	m	L
length of nails	ln	Independent	m	L
Initial Pulse Rate Of Worker1	Pi_1	Dependent	pulse/minute	T -1
Final Pulse Rate Of Worker1	Pf_1	Dependent	pulse/minute	T -1
Initial Pulse Rate Of Worker2	Pi_2	Dependent	pulse/minute	T -1
Final Pulse Rate Of Worker2	Pf_2	Dependent	pulse/minute	T -1
Duration	t	dependent	minutes	T
Extent Of Work done	Af	Dependent	Meter2	L2
Actual area of formwork	Afa	Dependent	Meter2	L2

(c) Mathematical approach selected and development of the model: The mathematical relation between inputs and outputs could be of any form may be polynomial, exponential or log linear. The Buckingham theorem (S.P. Mishra et al. 2011 (2); Piotr D. Moncari et al, 1981) 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 eqn. (1)

$$Y = k \times A^a \times B^b \times C^c \times D^d \times E^e \quad \ldots(1)$$

Moreover, the controls over the variables are not affected.

Combining of variables in pie terms: The obtained independent variables can be utilized only after modifying or converting into standard dimensionless form. The various dimensions recorded in Table were converted into desired form i.e. the pie terms.

Pie terms:

TABLE 2. Combining of independent variables in Pie terms

Pie Terms	Dimensionless equations
π_1	$\frac{A_2 \times W_2 \times Ag_2 \times ht_2}{A_1 \times W_1 \times Ag_1 \times ht_1}$
π_2	$\frac{hhl \times hhd \times hwhl \times wthh \times wtowh \times nrl \times nrt}{lhs \times avwhs \times lowhhs \times thob \times wths \times wtwh \times nrb}$
π_3	$\frac{vs \times Hu}{g \times t \times 60}$
π_4	$\frac{hrhsb \times hrh \times hrhw}{hrn \times hrplw \times hrppw}$
π_5	$Noths$
π_6	$\frac{lopp \times lopl \times lon \times thopl \times wtopp}{dopp \times dopp \times bopl \times diaon \times wtpl}$

TABLE 3. Combining Independent Pie Terms: Above pie terms were further reduced in following A, B, C, D and E dimensionless pie terms –

A	Workers pie term	π_1	$\frac{A_2 \times W_2 \times Ag_2 \times ht_2}{A_1 \times W_1 \times Ag_1 \times ht_1}$
B	Environmental pie term	π_3	$\frac{vs \times Hu}{g \times t \times 60}$
C	Tools pie term	$\pi_2 \times \pi_5$	$\frac{hhl \times hhd \times hwhl \times wthh \times wtowh \times nrl \times nrt \times Noths}{lhs \times avwhs \times lowhhs \times thob \times wths \times wtwh \times nrb}$
D	Work station pie term	π_6	$\frac{lopp \times lopl \times lon \times thopl \times wtopp}{dopp \times dopp \times bopl \times diaon \times wtpl}$
E	Materials pie term	π_4	$\frac{hrhsb \times hrh \times hrhw}{hrn \times hrplw \times hrppw}$

TABLE 4. Conversion of output data: Similarly the Dependent variables into Y_1, Y_2 and Y_3 Pie Terms –

Extent of Work done Pie Term	Y_1	$\frac{Af}{lhs \times hhl}$
Human Energy Pie Term	Y_2	$\left[\frac{(Pf_1 + Pf_2)}{2} - \frac{(Pi_1 + Pi_2)}{2}\right] \times t$
Performance Error (% Error in work done)	Y_3	$\frac{Af_a - Af}{Af} \times 100$

A, B, C, D, E are the final independent pie terms representing workers data, environmental data, tools data, workstation data and materials data and the response variable Y can be stated for all Y_1,Y_2 and Y_3.

This dimensionless statement (1), transformed into linear relationship using log operation. The log linear relationship so obtained is easy to understand and does not damage any facets of original relationship.

For determining the indices of the relation between output and inputs, we use multiple regressions and Matlab software, thus the models for Y_1, Y_2 & Y_3 obtained as under.

$$Y_1 = 1.057547 A^{-0.0259}.B^{-1.0456}.C^{0.0815}.D^{-0.4836}.E^{0.0047} \quad \ldots (2)$$

$$Y_2 = 1.000023 A^{0.0066}.B^{-1.1617}.C^{0.3225}.D^{-0.455}.E^{0.0017} \quad \ldots (3)$$

$$Y_3 = 1.000011 A^{0.436}.B^{0.1844}.C^{0.0394}.D^{0.383}.E^{0.0024} \quad \ldots (4)$$

2. Results and Analysis

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. To check the sensitivity of each model the set of output and input parameters are selected in which has minimum error in from Y observed. 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.

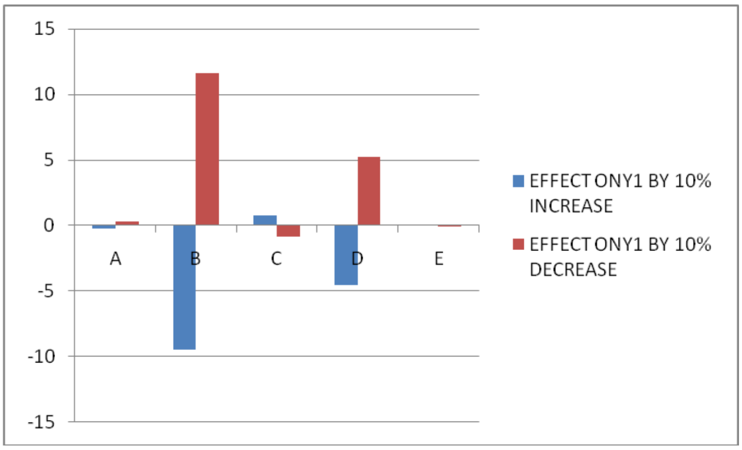

Figure 2. Influence of individual input variable in % of Y_1

Figure 2 shows the comparative degree of influence by input variables in percentage on Y1 (Extent of work done).The figure represents that environmental data(B) and work station data(D) has significant influence but B is most influencing but effect is inversely proportional to variations. Extent by which it influences Y1 i.e. productivity indicated by the graph.

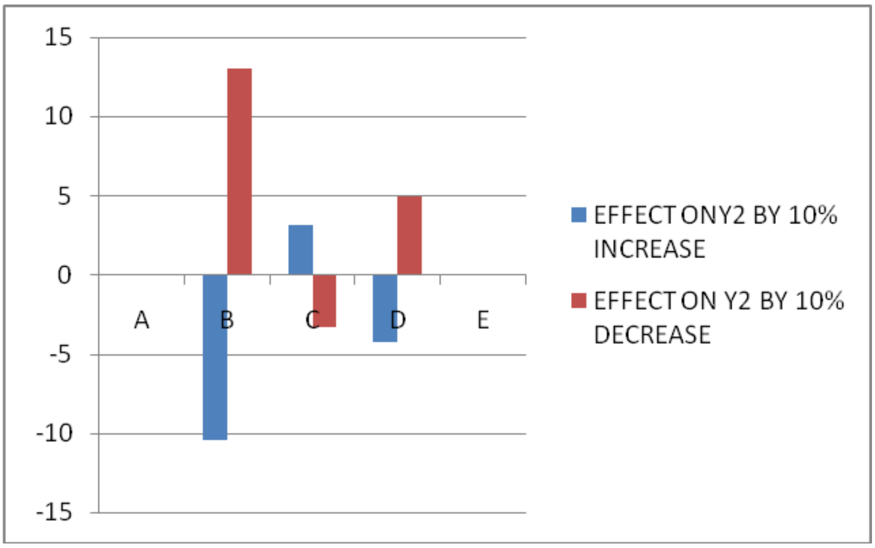

Figure 3. Influence of individual input variable in % of Y_2

Figure 3 shows the influence of variations in inputs on Y_2, which represents the Human energy consumption. The above figures imply that the input variable A is most influential and C is is least influential. The A indicates the ratio of workers data i.e., $\frac{W_2}{W_1}$ and as A is influencing inversely, by a positive increment in A the Y_2 is reduced, so to reduce the Y_2 worker 2 should be so selected that its anthropometric data be higher than worker 1.

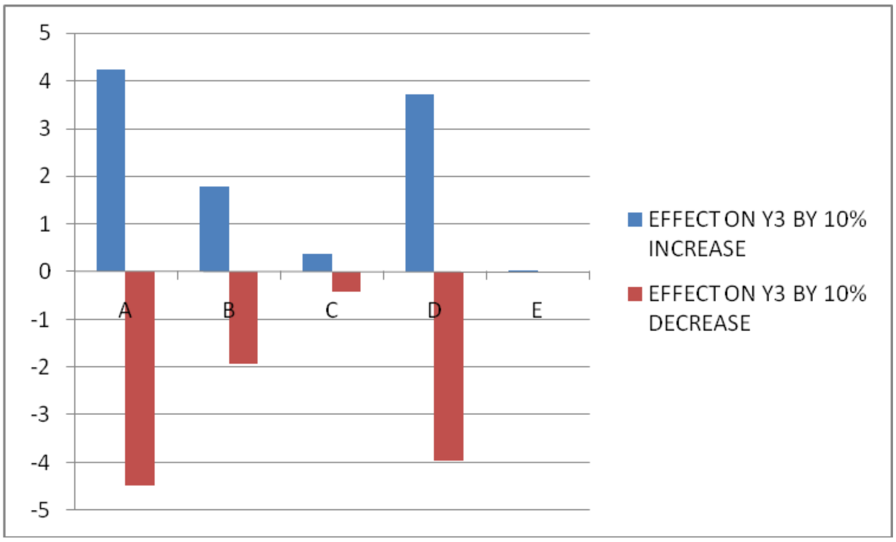

Figure 4. Influence of individual input variable in % of Y_3

Figure 4 shows the degree of influence by individual input variables on Y_3 Performance Error. The above figure clearly indicate that input variables A and D are highly influential to Y_3, so to reduce the Y_3 we should reduce A and D.

3. Validation of Model using Neural Network

Validation of FDBM models achieved by:

1. Comparing the ANN simulation results with Field observed (Vahid K. Alilou, 2009; Tapir S.H. et Al, 2005).
2. By performing Reliability analysis of (S.P. Mishra et al., 2011-1)

ANN Simulation: ANN Simulation of the gathered field data using Matlab softwre have been performed. Which results into simulation based model and quantify appropriate non-linear behaviour of effect (responses) as influenced by causes (Inputs).

(a) Validation of Productivity model (Y1)

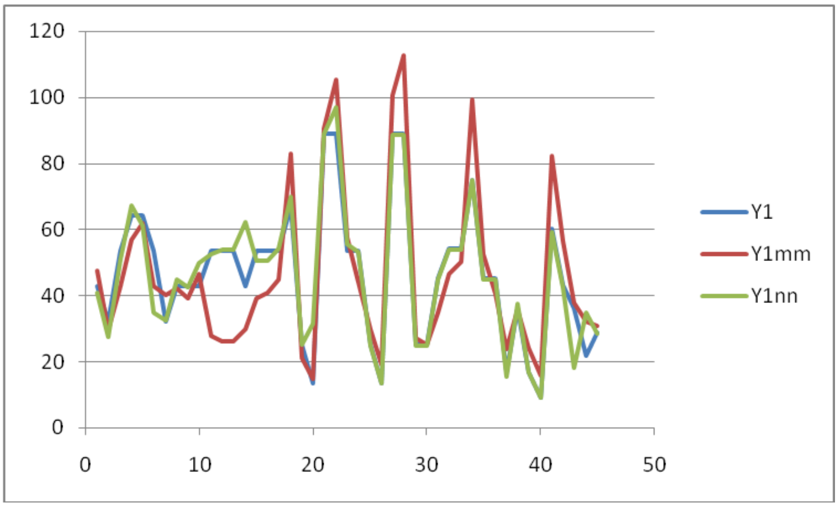

Figure 5. Comparative plot of Y_1, Y_1cal and Y_1nn (Neural Prediction)

In Figure 5 on ordinates productivity in dimensionless pie terms and on abscissa the number of observations have been plotted which indicates the proximity and variations in observed outputY1, model output Y1cal with ANN predictions Y1nn thus validates the developed model for Extent of Work Done i.e. Productivity in Manual formwork Operation.

(b) Validation of Human Energy model (Y2)

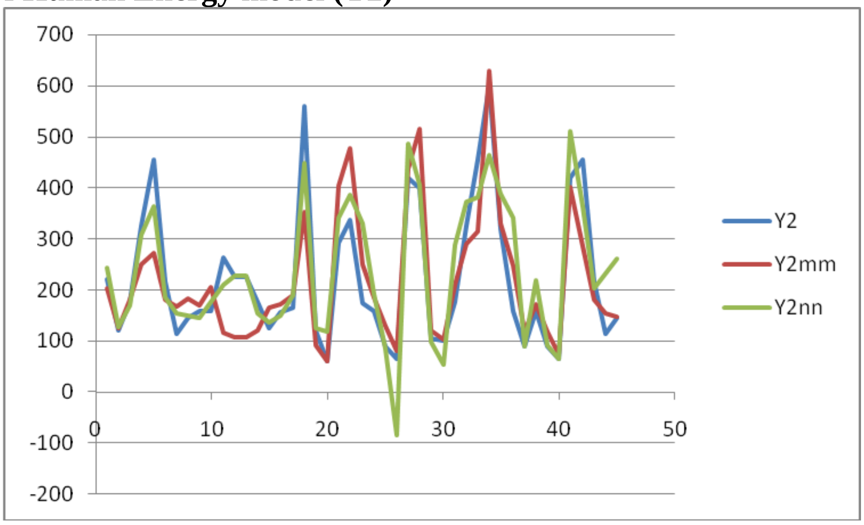

Figure 6. Comparative Plot between observed Human energy (Y_2), model output (Y_2m) and Neural Prediction (Y_2nn)

The proximity of observed values of human energy Y2, calculated values from mathematical model Y2cal and neural network simulation results are plotted in Figure 6 which validate the mathematical model.

(c) Validation of Performance Error Model

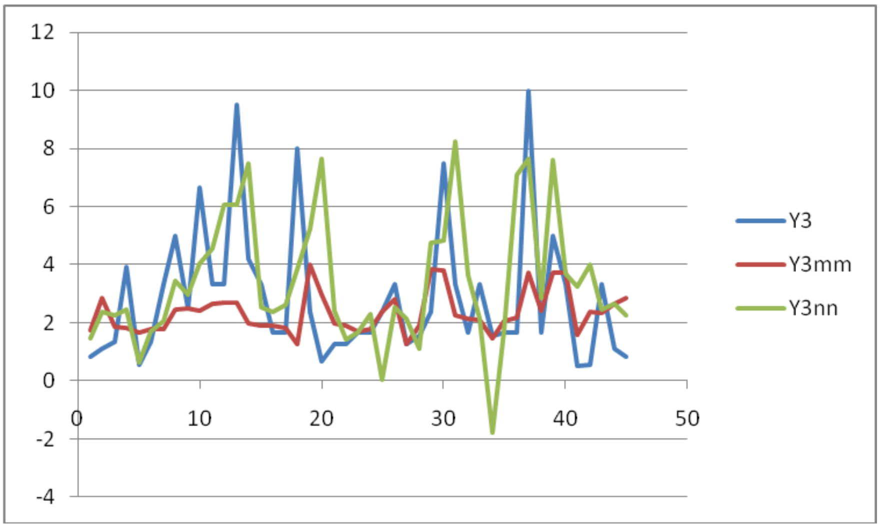

Figure 7. Comparative Plot between observed Human Energy (Y_3), Calculated (Y_3mm) and Neural Network Prediction (Y_3nn)

The Figure 7 shows comparison between the actual fields recorded performance error Y_3, Calculate value from model (4) Y3mm and Neural network prediction Y3nn. The graph indicates that Y3mm curve flatter than Y3nn and variations are small so the model Y_3 validated.

DISCUSSIONS:

1. The mathematical models obtained from FDBM approach are in polynomial form and complex as each independent major pie terms are multiple of various input parameters as described in Table 3.
2. Interpretation of models gave extent of influence on output of the model by any pie terms or any variables listed in Table 1.
3. By comparing the indices of equation(1), as to maximize the productivity Y_1 the absolute value of indices D found to be most influencing because it is highest whereas the negative sign indicates it should be minimized, further indices of E being positive and second highest it should be maximized. Thus, by analyzing the variables combined in developing D and E major pie terms one can easily suggest the method improvement to get required results.
4. Similarly in equation (2) Y_2 human energy should be minimum, the indices of A, workers data being highest and with negative sign, it is found most influencing and needs to be minimized.
5. In equation (3), the indices of B environmental conditions at work place found to be most influencing and positive so to reduce the error in shearing of rebars minimized.
6. Sensitivity analysis suggest the degree of influence of variables A, B, C, D, E on output Y1,Y2,Y3. Desired values of the output obtained by adjusting inputs according to this analysis.
7. Optimization analysis suggests the optimum output achieved, if the results of this analysis incorporated in present method of Formwork fixing.

8. ANN simulation validates the model for Productivity, Human Energy and model of Performance Error.
9. Study of mathematical model output and developed ANN predictions for the phenomenon truly represents the degree of interaction of various independent variables.

Conclusion:

1. Field data based modelling concept thus found very useful and can be applied to any complex construction activity as the observations for variables are obtained directly from the work place and include all kinds of data such as workers anthropometrics, environmental conditions, tools used and its geometry, layout of workstation and material properties.
2. Modelling and proper analysis can suggest a correct method of doing such activities and modifying the tool's geometry, materials for tools with changes in the layout of workstations will improve productivity, reduce losses of materials, losses due to error in construction work and ergonomic construction.
3. Before finding the sensitivity of inputs, it is necessary to decide the validity of the models. This is so because though we have taken care to purify the observed data there is a chance of any impure data entering in the mathematical processing of the data.
4. The approach to decide the validity would be to substitute in the model known inputs for every observation & decides the difference in response by model and actually observed response. This will give us a pattern of distribution of error & the frequency of its occurrence.
5. The formulated models in this study are as per working conditions and environmental conditions of selected building construction sites. This needs to be tested for other working and environmental conditions.
6. The FDBM approach can be applied for Ergonomic construction, mechanization and prioritization in mechanization all kind of infrastructure construction as it has been seen that the non availability of construction workers leads to delay the major projects so ergonomic construction is the need of present scenario.

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