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Field Data Based Mathematical Modeling (FDMM): State of the Art and Literature Review

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Abstract: The term model is to refer to the ensemble of equations which describe and interrelate the variables and parameters of a physical system or process. The term field data based mathematical modeling in turn refers to the derivation of appropriate equations that are solved for a set or system of process variables and parameters. These solutions are often referred to as simulations, i.e., they simulate or reproduce the behavior of physical systems and processes. This paper is organized to summarize a number of field data based mathematical modeling case studies and revises state of the art and its literature review.

Key words: Field data based mathematical modeling (FDMM), optimization, and validation.

1. Introduction

Mathematical model is nothing but the algebraic relationship amongst the response variable and independent variable. Here, response variable is called dependant variable. Any phenomena can be presented mathematically by knowing the physics involve in it. These mathematical models are of three types (1) Logic based (2) Field data based (3) Experimental data based. Some phenomena can be presented by application of basic balances. In certain situations, it is not possible to formulate a mathematical model for complex phenomena on the basis of application of the basic balances of mechanics. In such situations, it becomes inevitable to collect experimental data for the process and to utilize the generated experimental data to formulate the generalized algebraic relationship amongst the various physical quantities involved in the process which may be called as experimental data based modeling. Field data based modeling 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 [2]. Data sets contain information and the behavior of the process variables, often much more than can be learned from just looking at plots of those observed data. Mathematical models based on observed input and output data from real life situation help us to gain new information and understanding from these data. Thus, it is not possible to plan such activities on the lines of design of experimentation 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]. Hence the approach of formulating a field data based model is utilized to make analysis of any process. 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 [4] [5].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 method and finally to establish the relationship between outputs (effects) and inputs (causes) using various graph papers called field data based mathematical model.

1. Formulation of FDBM Model

1.1 Study of the present method

Study the present method or process and enumerate problems with an existing system. Collect data on system specifications, input variables, as well as performance of the existing system. Identify sources of randomness in the system, i.e., the stochastic input variables. Select an appropriate input probability distribution for each stochastic input variable and estimate corresponding parameters.

1.2 Identification of Independent and Dependent variables:

This step involves identification of the Causes and Effects by performing qualitative analysis of physics of such a phenomenon. Causes or independent variables and 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.

1.3 Reduction of independent variables adopting dimensional analysis: T

This step involves establishing dimensional equation for such a phenomenon. Once a dimensional equation is formed, it is a confirmatory face that all involved physical quantities are considered. Getting dimensionless input quantities through physical quantities, these are the causes (or Inputs). According to Theories of Engineering experimentation by H. Schenck Jr., Chapter 4 [10], "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 the variables must be expressible in his system. In this research all the variables are expressed in mass (M), length (L), time(T) hence M, L, and T are chosen for the dimensional analysis. The process variables, their symbols and dimensions are listed in M, L and T form are the symbols for the mass, length and time respectively.

1.4 Selection of 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 theorem [8] 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.

1.5 Combining of variables in pie terms

The obtained independent variables can be utilized only after modifying or converting into standard dimensionless form. The various parameters recorded were converted into desired form i.e. the dimensionless pie terms. 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. 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 obtained.

2. Literature review

The work done in the area of field data based mathematical modeling is as under.

2.1 Field data based model Scheffler reflector

Rupesh Patil, Gajanan K. Awari and Mahendra P. Singh [7], discussed about work carried out on the Scheffler reflector. It has been focused about having scope for experimental data based modeling to establish relationship in different variables of Scheffler reflector. Scheffler reflector is studied with a typical experimental plan of simultaneous variation of independent variables. Experimental response data is analysed by formulating dimensional equations and validated by using neural network analysis.

2.2 Optimization of passenger car's scheduled service process.

K.S. Dixit, J.P. Modak, M. P. Singh [6], explained an approach to formulate Field Data Based Model (FDBM) for optimization of passenger car's scheduled service process. In view of the sustainably increasing competition in the automobile sector, different automobile companies are taking great efforts to improve their after sales service. One of the most important aspects of after sales service is the scheduled servicing of a vehicle. The scheduled servicing offers certain advantages, such as preplanning (ordering spares, costs are distributed more evenly, no initial costs for instruments for supervision of equipment) and avoiding inconvenience. However, often the delays during these scheduled servicing negates the advantages offered. Hence, generated a reliable and valid approach such as Field data based mathematical modeling and its optimization of Scheduled Servicing Functions of automobiles in general and Passenger Cars in particular.

2.3 Field data based model for turning process

Mangesh R. Phate, Chetan K.Mahajan, Mangesh L.Mote, Bharat V.Patil, Harshal G.Patil [3], shown the clear idea about the detailed methodology of mathematical model formulation for the surface roughness, tool temperature, and machine vibration and operator pulse rate during the turning process. It helps to develop an accurate and reliable model

for predicting and optimizing the critical process parameters which affects the quality, productivity and the safety of the operator during a step turning process. This work represents the detailed about the formulation of field data based model to analyze the impact of various machining field parameters on the machining of Aluminum 6063, S.S304, BRASS, EN1A, EN8.In Indian scenario where majority of total machining operation are still executed manually which needs to be focused and develop a mathematical relation which simulate the real input and output data directly from the machining field where the work is actually being executed. The findings indicate that the topic understudy is of great importance as no such approach of field data based mathematical simulation is adopted for the formulation of mathematical model.

2.4 Framework of reinforced concrete structure using field data based mathematical modeling

Satya Prakash Mishra, Parbat D.K [8], carried out the sensitivity analysis of manual formwork activity of Reinforced concrete structures and applied field data based mathematical approach (FDMM). They demonstrated sensitivity analysis is used to analyze how sensitive a system response with respect to change in key input parameters of construction phenomenon.

2.5 Field data based model foe manual stirrup making activity

S.R.Ikhar, Dr.A.V.Vanalkar, Dr.J.P.Modak [9], made the detailed study of present manual stirrup making activity which indicates that the process suffers from various draw back like lack of accuracy, low production rate and resulting in to severe fatigue in the operator. Stirrup or lateral tie is one of the essential element of reinforce cement concrete in civil construction. These stirrups are used for strengthening columns and beams, avoiding buckling of long slender column and avoiding sagging of horizontal beam. The construction operator not only subjects his hands to hours of repetitive motion but also some times suffers internal injury to his body organ that is disorder carpel tunnel syndrome. In order to remove above draw backs authors have determine an appropriate sample size for the activity and formulated various field data based mathematical models (FDMM) such as multivariable linear model, polynomial model, exponential model, logarithmic model, on the basis of gathered field data by applying theories of experimentation. The formulated model can use to optimize the human energy of worker, production rates and inaccuracy of stirrups.

2.6 Formulation of generalized field data based model for the process of tractor axle assembly of an enterprise

Manish Bhadke, Dr.K.S.Zakiuddin [2], described an approach for formulation of generalized field data based model for the process of tractor axle assembly of an enterprise. 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 is 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.

2.7 Prediction of unbalance effect of on journal bearing through field data based mathematical model.

Vijaykumar.S.Shende, Prerna.S.Borkar [16], presented works on a possible approach which provides the prediction of unbalance through mathematical model and the effect of unbalance on journal bearing. Now a day's vibration based condition monitoring technique is widely used in several core companies. These companies are like - Cement Companies, Thermal Power Stations, Rolling Mills etc. This technique prevents excessive failure of the machine component. Hence in such a company's special departments are there, which handles the problem related to the health of machine. Sometimes, maintenance department of the company has this responsibility. There are so many process machines used in the industries. Amongst such a machine some machines have rotor system. Even in some machine the journal bearings bear the load of different rotor.

2.8 Formulation of Field Data Based Model (FDBM) for any Man Machine System

O.S.Bihade, S.S.Kulkarni, J.P.Modak, K.S.Zakiuddin [5], discussed the approach to formulate Field Data Based Model (FDBM) for any Man Machine System of construction activity. 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 investigation reports "Field Data Based Modeling" of some of the construction activities.

2.9 Fall in liquor revenue in terms of various causes by applying field data based mathematical modeling

Satish Chaturvedi, Shubha Johri, J.P. Modak [10], described that before getting independence of INDIA from British regime, large number of Leaders of India was required to take strong agitation against British Government for getting freedom. One of the prominent leaders was Mr. M. K. Gandhi. During the period 1920 to 1942 in Central Provinces and Berar specifically pertaining to the period June 1930 to September 1930, strong agitations took place towards reducing income to Government by way of reducing liquor consumption. Several events took place towards this objective. Based on the facts, the attempt is made in this paper to present the entire agitation as one social phenomenon in

the form of a Field data based Mathematical Model correlating the fall in liquor revenue in terms of various causes responsible for this fall in revenue. It is only through the Mathematical Model that it is possible to get quantitative idea of intensity of interaction of causes on effects of any phenomena may be it be scientific or socio-economic or of any other type. Particularly the approach of Field Data Based Model [11] is applicable in such a situation as this is a Field Phenomena. Such models serve as most reliable tools to plan future such activities. This could be known as a process of PROGNOSIS.

2.10 Application of field data based modeling in corrugated box production process

Sachin G Mahakalkar, Dr.Vivek H Tatwawadi, Jayant P Giri, Dr. J. P. Modak [12], presented that Response surface methodology (RSM) is a statistical method useful in the modeling and analysis of problems in which the response variable receives the influence of several independent variables, in order to determine which are the conditions under which should operate these variables to optimize a corrugated box production process (similar to field data based mathematical modeling). The purpose of this research is to create response surface models through regression on experimental data which has been reduced using DA to obtain optimal processing conditions. Studies carried out for corrugated sheet box manufacturing industries having man machine system revealed the contribution of many independent parameters on cycle time. The independent parameters include anthropometric data of workers, personal data, machine specification, workplace parameters, product specification, environmental conditions and mechanical properties of corrugated sheet. Their effect on response parameter cycle time is totally unknown. The developed model was simulated and optimized with the aid of MATLAB R2011a and the computed value for cycle time is obtained and compared with experimental value.

2.11 Modeling and simulation of human powered flywheel motor by field data based modeling

As per geographical survey of India, A. R. Lende, J. P. Modak [13]**,** observed that about 65% of human population is living in rural areas where urban resources like electricity, employment accessibility, etc are very deprived. The country is still combating with fundamental needs of every individual. The country with immense population living in villages ought to have research in the areas which focuses and utilizes the available human power. Some Authors related to this work had already developed a pedal operated human powered flywheel motor (HPFM) as an energy source for process units. The various process units tried so far are mostly rural based such as brick making machine (both rectangular and keyed cross sectioned), Low head water lifting, Wood turning, Wood strips cutting, electricity generation etc. This machine system comprises three sub systems namely (i) HPFM (ii) Torsionally Flexible Clutch (TFC) (iii) A Process Unit. Because of utilization of human power as a source of energy, the process units have to face energy fluctuation during its supply. To evaporate this rise and fall effect of the energy, the concept of use of HPFM was introduced. During its operation it had been observed that the productivity has great affection toward the rider and producing enormous effect on quality and quantity of the product. This document takes a step ahead towards the development of a controller which will reduce system differences in the productivity. A. R. Lende, J. P. Modak contributes in development of optimal model through artificial neural network which enables to predict experimental results accurately for seen and unseen data. The paper evaluates ANN modeling technique on HPFM by alteration of various training parameters and selection of most

excellent value of that parameter. The field data based mathematical model developed which then could be utilized in design of a physical controller.

2. 12 Formulation of a Field Data Based Model for a Surface Roughness

Mangesh R.Phate, Dr. V.H.Tatwawadi [14], focused on new approach of model formulation using response surface methodology (RSM) in the convectional turning (CT) of ferrous and nonferrous material. The data was collected from the actual field where the actual work is carried out. Random plan of experimentation based on the industry interests were considered for the data collection. The various independent parameters considered in this research are operator data, tool data, work piece data, cutting process parameters, machine data and the environmental parameters while the dependent parameter is surface quality achieved during the convectional turning process. The surface quality is measured in terms of surface roughness of the finished product.

3. Summary of the work done in Field Data based Mathematical Modeling

Key findings of different authors in field data based mathematical modeling are summarized in the following table.

Sr.No	Authors and Years	Title of the research Work	Key Findings
1	Rupesh Patil, Gajanan K. Awari, Mahendra P. Singh. (2011).	Formulation of Mathematical Model and Neural Network Analysis of Scheffler Reflector	This study has developed dimensionless correlations for analyzing the performance of Scheffler reflector. Dimensional analysis shows that generated water temperature is determined primarily by ratio of product of wind speed and time of operation to Dish size. The models have been formulated mathematically for the local conditions. After training the Artificial Neural Network it is found that every case of experimental results are in good agreement with the predicted values obtained by ANN. From the results it is seen that the mathematical models can be successfully used for the computation of dependent terms for a given set of independent terms.
2	Satish Chaturvedi, Shubha Johri, J.P. Modak. (2013)	Formulation of Mathematical Model of Picketing of Liquor Shops and Warehouses	Based on the numerical data established and applying the methodology of model formulation, the mathematical model for falling liquor sell is formulated. The value

			of curve fitting constant in this model is 54.5. This collectively represents the combined effect of all extraneous variables.
3	K.S. Dixit, J.P. Modak, M. P. Singh. (2012)	Optimization of scheduled servicing functions of passenger cars using a mathematical modeling approach.	A generalized field data based model was developed to simulate the scheduled servicing process for passenger cars. They had found that vehicle design parameters like accessibility of air filter, fuel filter & oil filter have maximum influence on cycle time of scheduled servicing of the passenger cars. Also The difficulty in dismantling, changing seal & assembling seemed to have significant effect on cycle time of scheduled servicing of the passenger cars. Inspection for leakage becomes difficult & time consuming if accessibility is poor. Anthropometric factors seem to have impact on the cycle time in as much as the service operation is being performed in all three positions i.e. sitting on legs, bending & standing position. Other influencing factor include those parameters, which are workplace related.
4	Mangesh R. Phate, Chetan K.Mahajan, Mangesh.L.Mote, Bharat.V.Patil, Harshal G.Patil (2013)	Investigation of Turning Process Using Field Data Based Approach in Indian Small Scale Industries.	In this study, a generalized field data based model was developed to simulate the step turning process for aluminum and brass. The approach of generalized model formulation model provided an excellent and simple way to analyze the engineering complex process where the impact of field data is dominating the performance.
5	Satya Prakash Mishra, Parbat D.K. (2012)	Sensitivity analysis of multi parameter mathematical model	In this work, Field data based modelling concept found very useful and can be

		in reinforced concrete construction.	applied to any complex construction activity as the observations for variables are obtained directly from the work place and include all kind of data such as workers anthropometrics, environmental conditions, tools used and its geometry, layout of work station and materials properties. Modelling and proper analysis can suggest a correct method of doing such activities and modifying the tools geometry, materials for tools with changes in layout of workstation will improve productivity, reduce losses of materials, losses due to error in construction work and ergonomic construction.
6	S. R. Ikhar, Dr. A. V. Vanalkar, Dr. J. P. Modak. (2013)	Field Data Based Mathematical Model for Stirrup Making Activity in Civil Construction	Stirrup or lateral tie is one of the essential element of reinforce cement concrete in civil construction. The process suffers from various draw back like lack of accuracy, low production rate and resulting in to severe fatigue in the operator. The construction operator not only subjects his hands to hours of repetitive motion but also some times suffers internal injury to his body organ that is disorder carpel tunnel syndrome. In order to remove above draw backs authors have determine an appropriate sample size for the activity and formulated various field data based mathematical models (FDBM) such as multivariable linear model, polynomial model, exponential model, logarithmic model, on the basis of gathered field data by applying theories of experimentation

7	Manish Bhadke, Dr.K.S.Zakiuddin. (2013)	Formulation of Field Data Based Model for Productivity Improvement of an Enterprise Manufacturing Tractor Axle Assembly: an Ergonomic Approach	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. It is found that 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.
8	Prof. Girish D. Mehta, Prof.Vijaykumar.S.Shende, Prof.Prerna.S.Borkar. (2013)	A Mathematical Model For Vibration Based prognosis For Effect Of Unbalance On Journal Bearing	In this investigation following some important conclusion are made. 1) As there is increase in unbalance mass, amplitude at 1 x frequency gets increased of journal bearing. 2) For this phenomenon of unbalance the mathematical model for prognosis of amplitude at 1x frequency of rotor is established for the individual bearing. 3) As unbalance mass is increased, this will increases coefficient of friction between journal and oil film.
9.	O.S.Bihade, S.S.Kulkarni, J. P. Modak, K.S. Zakiuddin (2012)	Mathematical Modeling and Simulation of Field Data based Model for Civil Activity	Paper details the use of contemporary techniques for the purpose of study, compression and generalized approach for the FDMM of any Man Machine System. By this. 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.
10.	Sachin G Mahakalkar, Dr. Vivek H Tatwawadi, Jayant P Giri, Dr. J. P. Modak. (2013)	Corrugated box production process optimization using dimensional analysis and response surface methodology	The study presents an illustration of how dimensional analysis (DA) can be applied to significantly reduce the number of independent variables used to optimize the cycle time as response variable using response surface methodology (RSM) (like FDMM). Using DA 43 independent variables has been reduced to 07 dimensionless Pi terms. This can greatly help in constructing a response surface approximation function of fewer variables.
10.	A. R. Lende, J. P. Modak. (2013)	Modeling and simulation of human powered flywheel motor for field data in the course of artificial neural network- a step forward in the development of artificial intelligence.	The optimization methodology adopted is unique and rigorously derives the most optimum solution for field data available for Human Powered Flywheel Motor. The effect on prediction of network is observed very consciously with variation each ANN parameter.

4. Conclusion

This paper presents the overview of filed data based modeling and its formulation. Further it describes a detailed review of the various methods used for establishing field data based mathematical models. The performance characteristics and usefulness of the various models are critically examined. The existing methods of field data based models based on both long term data and short-term measured data are also presented.

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