An innovative method to enhance the Productivity of the casting produced by a Man-Machine System using a Field Data Base Model

Rahul P Bachute and Akshay N Surade

[1] *Associate Professor Department of Automobile Engineering, Ajeenkya D Y Patil school of Engineering, Lohgaon, Pune*

[2] *Assistant Professor, Department of Mechanical Engineering, Walchand Institute of Technology, Solapur*

Abstract

A Man-Machine System means an activity occurring/occurred with the involvement of a human being with the help of some tools used to interact with the material. In small foundries the moulding process is manual & labours have to work in different psychological moods, stress and strain, without training on ergonomic posture, in different environmental factors such as temperature, vibrations, noise dust which affects the productivity and also amount of human energy input to produce the component. This paper makes an attempt to develop a mathematical model to relate the productivity with various parameters and identify the most sensitive parameter to control the productivity.

Key words: Human Energy Input, Productivity, Mathematical Model, ANN Analysis, Optimization, Field database modeling, Sand Moulding, Cylinder Head

1 Introduction

India holds a prominent position among the top ten manufacturers of ferrous and non-ferrous castings globally. The foundry sector plays a significant role in the Indian economy, comprising over 7,000 foundries across small, medium, and large sectors. Employing approximately 550,000 people directly and 175,000 people indirectly, foundries are labor intensive, with varying degrees of automation based on their scale. The metal casting process encompasses multiple sub-processes, including pattern making, sand preparation, molding, melting, pouring, cleaning, and finishing. Among these, sand casting stands as the most widely used method for metal casting. The cylinder head of an air compressor is a critical component, and not all casting methods can achieve the desired geometry for it. The shape and positioning of the intake and exhaust ducts determine the overall geometry of the cylinder head, making sand casting a popular choice for its production. However, working conditions in foundries present challenges to laborers' well-being. They have to work under various psychological moods, stress, and strain, often without proper ergonomic posture training. Environmental factors such as temperature, vibrations, noise, and dust further impact productivity and human energy input for component production. Improper work postures in foundries lead to decreased productivity, increased work compensation, elevated stress levels, higher medical expenditures, and shortened work life [1].

In particular, the workload in foundries is associated with poor working postures and unfavourable work space arrangements, coupled with suboptimal workplace environments, notably with regards to dust and noise. Activities like forward bending and squatting positions account for a significant portion (70-90%) of the actual working time, especially when handling large-sized casts. However, work done using a table allows workers to adopt more frequent erect standing postures [2].

The performance of workers can be influenced by temperature and humidity in several ways. In everyday work settings, the temperature of the workroom can impact the efficiency and safety of the workers. Laboratory and on-site studies have revealed that skilled performance declines rapidly when the effective temperature exceeds the range of 27° to 30°C. For example, the time taken for loading coal tubs gradually increases with the rise in effective temperature from 19°C to 28°C. The impact of temperature increase is more significant for workers aged 30 years and above, particularly those over 50 years old. In warm and humid environments, the absence of sweat evaporation can lead to a reduction in worker efficiency [3].

The performance of any human-machine system is governed by various parameters, including anthropometric data of the worker, the posture adopted during activities, attitude, aptitude, skill, experience, health status, habits, and tool specifications. Additionally, external factors such as atmospheric temperature, humidity, noise level, dust, and air circulation also play a role in influencing performance.

The process of molding is a complex physical phenomenon, making it challenging to formulate logic-based models that establish direct cause-and-response relationships. In such cases, field data-based models are a suitable choice for understanding and predicting performance patterns.

2. Philosophy of a Field Data Based Model

2.1 Man-Machine System

A man-machine system refers to any activity involving human beings, whether male or female, interacting with materials using tools. In daily life, certain activities such as inventory operations, inspections, and raw material processing are planned to a certain extent, but not fully perfected. Each of these activities represents a man-machine system [4].

However, not all activities within the man-machine system can be fully planned for experimental purposes, and it may not be feasible to adopt test planning as a part of experimentation. In such cases, the activity is allowed to be executed either as it naturally occurs or as planned by others. This is often the case when formulating models for various industrial activities, underground or open cast mining operations, or processes like molding.

2.2 System, Causes, Effects, and Extraneous Variables

In any activity, including tree plantation as an example, four essential parameters come into play: system, causes, effects, and extraneous variables. Let's take the example of a worker engaged in digging during tree plantation:

- System: The specific location on the land with natural atmospheric conditions, such as surrounding temperature, relative humidity, and air circulation.

- Causes: The factors responsible for initiating the activity, in this case, tree plantation.

- Effects: The reactions of the system after the execution of the activity, such as the growth of trees.

- Extraneous Variables: These are additional factors or parameters that influence the performance of the activity but may not be directly measurable or controlled.

Establishing relationships between causes and effects (inputs and outputs) is crucial. This analysis helps identify the strengths and weaknesses of the activity based on its existing method of execution. By understanding the weaknesses, it becomes possible to improve the current method of carrying out the activity. Therefore, establishing a conceptualized field data-based model that represents the relationship between cause and effect is essential for enhancing the activity's performance.

A1=f1[(W1,W2,W3,W4,W5,W6) (X1,X2,X3,X4,X5),(Y1,Y2,Y3,Y4),(Z1,Z2,Z3,Z4)]------ (4.1.1)

A2=f2[(W1,W2,W3,W4,W5,W6) (X1,X2,X3,X4,X5),(Y1,Y2,Y3,Y4),(Z1,Z2,Z3,Z4)]------ (4.1.2)

A3=f3[(W1,W2,W3,W4,W5,W6) (X1,X2,X3,X4,X5),(Y1,Y2,Y3,Y4),(Z1,Z2,Z3,Z4)]------(4.1.3)

Improving the method of working becomes feasible once the relationships between different factors are established. To assess the strength and weaknesses of the current moulding process, a mathematical simulation model is developed. The primary aim of this model is to enhance the process, manage it effectively, and reduce fatigue and musculoskeletal injuries experienced by the workers.

3. Mathematical Model

Traditionally, equipment design often overlooks human characteristics and ergonomics. However, incorporating ergonomics into the design process can significantly improve productivity by optimizing methods and modifying workstations and layouts. To establish a relationship between productivity, human energy input, and the influencing variables in the complex moulding process, mathematical simulation is employed.

For instance, in the case of a worker performing the moulding operation, causes may include anthropometric information about the operator, such as dimensions from foot fingers to knee, knee to waist, waist to chest, knee to chest, from shoulder to elbow, elbow to fingers, and so on.

.

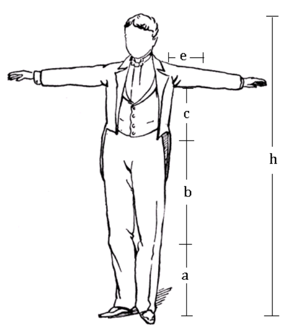

Figure 2 Anthropometric Dimensions of Labour

Dimensions of tools used for the activity- Weight of Pattern, Ram and Moulding box

Responses (i.e. effects) (Z) would be: Productivity (Z1), Human Energy input (Z2).

3.1 Formulation of Model in Exponential Form

In this task, a total of 176 observations have been made, and there are 7 unknowns, as previously mentioned. The process variables, represented by their respective symbols and dimensions, are provided in Table (5.1), along with the nomenclature of various parameters involved in this activity, categorized as independent and dependent physical quantities/parameters. Dimensional analysis using Buckingham's method has been performed, resulting in the derivation of dimensionless Pi terms.

Π	Variables	Symbol	Type of Variable
01	Productivity	P	Dependent
02	Human Energy	HE	Dependent
1	Sand Compression Strength	Ss	Independent
2	Gravitational acceleration	ga	Independent
3	Weight of the Ram	MR	Independent
4	Weight of Moulding Box	Mb	Independent
5	Weight of Pattern	Mp	Independent
6	Casting cooing time	Tc	Independent
7	Groud to Knee	a	Independent
8	Knee to Waist	b	Independent
9	Waist to Chest	c	Independent
10	Knee to Chest	d	Independent
11	Shoulder to elbow	e	Independent
12	Knee To Shoulder + Knee to Waist	f	Independent
13	Buttocks	g	Independent
14	Ground to head	h	Independent
15	Sand grain size – AFS Number	Sg	Independent
16	Sand Compactibility	Sc	Independent
17	Relative Humidity	RH	Independent
18	Temp. of molten metal	Tm	Independent
19	Ambient air Temp	Ta	Independent

Table 1 Process variables, their symbols

It means

$$P = f\left(HE, S_S, g_a, M_R, M_{b,} M_{p,} T_{c,} \rightleftarrows\rightleftarrows\rightleftarrows\ a, b, c, d, e, f, g, h, j, k, S_g, S_c, RH, T_m, T_a\right)$$

Upon the application of Buckingham's Pi theorem and the grouping of relevant terms, the following mathematical model is derived. Consequently, the final equation for the dependent Pi term is as follows:

1. For Productivity

$$\pi_{02} = f\left(\frac{M_R M_b M_p}{S_S^3 x g_a^6 x T_c^{12}} \frac{abcdefghjk}{g_a^{10} x T_c^{20}} S_g S_c RH \left(\frac{T_m}{T_a}\right)\right)$$

$$P = Kf\left(\frac{M_R M_b M_p}{S_S^3 x g_a^6 x T_c^{12}} \frac{abcdefghjk}{g_a^{10} x T_c^{20}} S_g S_c RH \left(\frac{T_m}{T_a}\right)\right) \text{..........(1)}$$

Dimensional analysis serves primarily as an experimental tool to consolidate multiple experimental variables into a single entity. The main objective of employing this technique is to streamline experimentation while maintaining precise control over the process, ensuring efficiency and accuracy. [5]

π	Ratio	Dimension less π term
1	Weight of Ram/Pattern/Moulding box	$\pi 1 = \left(\frac{M_R M_b M_p}{S_g^3 x g_a^6 x T_c^{12}} \right)$
2	Anthropometric data of workers	$\pi 2 = \left(\frac{a\, b\, c\, d\, e\, f\, g\, h}{g_a^8 x T_c^{16}} \right)$
3	Sand grain size – AFS Number	$\pi 3 = (S_g)$
4	Sand Compactibility	$\pi 4 = (S_c)$
5	Relative Humidity	$\pi 5 = (RH)$
6	Temp. Of molten metal	$\pi 6 = \left(\frac{T_m}{T_a} \right)$

Table 2 Grouping of pi terms

The above equation is stated in alternative simplified form as under -

$\pi_{01} = K_1^{'}(\pi_1)^{a1}(\pi_2)^{b1}(\pi_3)^{c1}(\pi_4)^{d1}(\pi_5)^{e1}(\pi_6)^{f1}$

Where K1' is Curve Fitting Constant and a1, b1, c1, ……. f1 are exponents of π terms.

3.2 Results

In this particular activity, there are a total of 176 observations and 7 unknowns, resulting in $176^7 = 5.23105^{15}$ combinations, or values, which would be a laborious task to solve individually. To tackle this challenge efficiently, Multiple Regression Analysis is employed, allowing the regression equation to be expressed in the form:

Z = K + a*A + b*B + c*C...

We have Equation for Productivity

π01 = K1' (π1)a1 * (π2) b1 * (π3)c1 * (π4) d1 * (π5) e1 * (π6) f1

Taking logs of both sides of equation to convert it in-to a linear form,

Log π_{01} = log K1' + a1 (logπ1) + b1 (logπ2) + c1 (logπ3) + d1 (logπ4) + e1 (logπ5) + f1 (logπ6)

6

Let

$\log \pi_{01} = Z1$, $\log K1' = K1$, $\log \pi1 = A$, $\log \pi2 = B$,
$\log \pi3 = C$, $\log \pi4 = D$, $\log \pi5 = E$, $\log \pi6 = F$,
Substituting these values in the equation, regression equation will be as

$Z1 = K1 + a1*A + b1*B + c1*C + d1*D + e1*E + f1*F$

Log π01 is calculated from H.E.Input. Means Z1 is known.

To determine the regression hyper plane, it is necessary to solve 7x7 matrix to determine the indices a1, b1, c1, d1, e1 and f1

$$\sum Z1*1= nK1 + a1*\sum A + b1*\sum B + c1*\sum C + d1*\sum D + e1*\sum E + f1*\sum F$$
$$\sum Z1*\sum A = K1*\sum A + a1*\sum A*A + b1*\sum B*A + c1*\sum C*A + d1*\sum D*A + e1*\sum E*A + f1*\sum F*A$$
$$\sum Z1*\sum B = K1*\sum B + a1*\sum A*B + b1*\sum B*B + c1*\sum C*B + d1*\sum D*B + e1*\sum E*B + f1*\sum F*B$$
$$\sum Z1*\sum C = K1*\sum C + a1*\sum A*C + b1*\sum B*C + c1*\sum C*C + d1*\sum D*C + e1*\sum E*C + f1*\sum F*C$$
$$\sum Z1*\sum D = K1*\sum D + a1*\sum A*D + b1*\sum B*D + c1*\sum C*D + d1*\sum D*D + e1*\sum E*D + f1*\sum F*D$$
$$\sum Z1*\sum E = K1*\sum E + a1*\sum A*E + b1*\sum B*E + c1*\sum C*E + d1*\sum D*E + e1*\sum E*E + f1*\sum F*E$$
$$\sum Z1*\sum F = K1*\sum F + a1*\sum A*F + b1*\sum B*F + c1*\sum C*F + d1*\sum D*F + e1*\sum E*F + f1*\sum F*F$$

The values of the terms on the left-hand side (L.H.S.), such as ∑Z1*1, ∑Z1*∑A, ∑Z1*∑B, ∑Z1*∑C, and so on, are already known. Similarly, the values of the multipliers of K1, a1, b1, c1, and so on, represented by N, ∑A, ∑B, ∑C, ∑D, ∑E, and so on, are also known. Substituting these known values into the 7 equations, which involve the unknown variables K1, a1, b1, c1, and so on, the values of these unknown variables are calculated. By solving these equations simultaneously, the values of K1, a1, b1, c1, d1, and so forth, have been obtained as presented below. The matrix analysis was performed using MATLAB software for this purpose.

1. Results obtained from MATLAB
2. Solution for matrix to establish relation for π_{02}

K1	a	b	c	d	e	f
3.45245	0.17854	0.04572	0.45847	0.35648	0.079642	0.87546

Substituting the values obtained from MATLAB for second set of readings,

π_{02} (Productivity) $= K_2'(\pi_1)^{a2} *(\pi_2)^{b2} *(\pi_3)^{c2} *(\pi_4)^{d2} *(\pi_5)^{e2} *(\pi_6)^{f2}$

Substituting known values it becomes ….

π_{02} (Productivity) $= 3.45245 * (\pi_1)^{0.17854} *(\pi_2)^{0.04572} *(\pi_3)^{0.45847} * (\pi_4)^{0.35648} *(\pi_5)^{0.079642} *(\pi_6)^{0.87546}$

4. Conclusions

The arrangement in descending order of indices is as follows:
(π6) 0.87546, (π3) 0.45847, (π4) 0.34648, (π1) 0.17854, (π5) 0.079642, (π2) 0.04572

The exponential form highlights the impact of individual independent π terms on the dependent π terms.

- π6 represents the ratio of Temperature of Molten metal to Ambient Temperature.
- π3 corresponds to the Sand grain size
- π4 corresponds to the sand compactibility

Among these π terms, the highest influence on Productivity of the casting is (π02) is from π6, followed by π3, π4, π1, π5, and π2. All the terms have a positive influence on the Productivity,

References

1. Sadao HORINO "Environmental Factors And Work Performance Of Foundry Workers", J. Human Ergo!., 6: 159-166, 1977
2. Ling Lei, Youxin Liang, P.R, "Ergonomic problems among foundry workers in China – A field survey and simulation study in the laboratory"
3. C.H.Wyndham, "The Relationship between Energy Expenditure and performance Index" in the Task of Shovelling Sand, Ergonomics 1966, Vol. 9, No. 5, 371-378.
4. J.P. Modak, S.P. Mishra, O.S. Bihade and B.K. Parabat, An approach to simulation of a Complex Field Activity by a Mathematical Model. Indian Institution of Industrial Engineering, PP-IT-IJ, Vol. II No. 20, February 2011.
5. V.H.Tatwawadi and J.P.Modak, "Measurement of Productivity of a Small Scale industry. Manufacturing Electric Motor Remaining Within the Domain of time study, Method Study and Ergonomics" UDYOG Pragati (The Journal of Practicing Manager) Pub. By N.I.T.E Mumbai (India) Vol. 29 No.4,Oct-Dec 2005.
6. Rahul P. Bachute and Dr. K S Zakiuddin "A Novel approach for Productivity Improvement of a Man Machine System – A Field Data Based Model Way", International Journal of Mechanical Engineering and Technology, Volume 9, Issue 8, August 2018, pp. 948–954
7. J.P. Modak, S.P. Mishra, O.S. Bihade and B.K. Parabat. An approach to simulation of a Complex Field Activity by a Mathematical Model. Indian Institution of Industrial Engineering, PP-IT-IJ, Vol. II No. 20, February 2011.
8. Sadao HORINO "Environmental Factors And Work Performance of Foundry Workers", J. Human Ergo, 6: 159-166, 1977.
9. J.P.Modak and A.R.Bapat, "Formation of Generalised Experimental Model for a manually driven flywheel motor and it's Optimisation" Applied ergonomics 1994, Vol 25, No 2, pp 119-122.
10. Mathematical Modeling and Simulation of Field Data Based Model for Civil Activity O. S. Bihade, S.S.Kulkarni,J. P. Modak, K.. S. Zakiuddin, International Journal of Scientific & Engineering Research, Volume 3, Issue 3, March-2012.
11. K.H.F.Murrell, "Nature of Ergonomics" Ergonomics (Man in his Working Environment), Chapman and Hall London, New York, 1956.
12. Manish Bhadke, "Formulation of Field Data Based Model for Productivity Improvement of an Enterprise Manufacturing Tractor Axle Assembly:an Ergonomic Approach,Proceedings of the 1st International and 16th National Conference on Machines and Mechanisms (iNaCoMM2013), IIT Roorkee, India, Dec 18-20 2013.
13. Zakiuddin K.S., Singh M.P., Modak J.P. (2019) Mathematical Modeling & Simulation of Chaff Cutter Energized by Human Powered Flywheel Motar. In: Uhl T. (eds) Advances in Mechanism and Machine Science. IFToMM WC 2019. Mechanisms and Machine Science, vol 73. Springer, Cham.

8

14. P.N. Belkhode,Development of mathematical model and artificial neural network simulation to predict the performance of manual loading operation of underground mines,Journal of Materials Research and Technology,Volume 8, Issue 2, April 2019, Pages 2309-2315.
15. Sadok Rezig, Wajih Ezzeddine, Mathematical Model for Production Plan Optimization—A Case Study of Discrete Event Systems,11 June 2020.
16. Yakovlev, V.V., Kalugin, Y.I., Kalugin, A.Y. et al. Mathematical modelling of enhanced gas production. J Petrol Explorer Prod Technology 9, 561–571 (2019).